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A decision-making model for remanufacturers: Considering both consumers' environmental preference and the government subsidy policy

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ABSTRACT

Remanufactured products have the significantly low environmental impact through their life cycles, but consumers' acceptance of remanufactured products is low and uncertain. To promote the use of remanufactured products, the governments in developing countries such as China have provided subsides for remanufacturers. However, how to understand consumers' preferences and effectively use the government subsidy is still difficult for remanufacturers. This paper develops a decision-making model considering both consumers' preference for remanufactured products and effect of the government subsidy. Using the price elasticity of demand (PED) of remanufactured products as an indicator to differentiate consumers' environmental preference, it examines a joint decision problem for price determination of a remanufactured product and share of the subsidy between the remanufacturer and consumers. It is found that the optimal price and the subsidy-sharing percentage are inversely proportional to the weighted-sum of the price elasticity of demand (PED). Based on data from a leading remanufacturer in China, this study finds that if a remanufacturer shares a percentage of the subsidy with consumers, it can get more profit due to the increased market. In order to balance the trade-off of price and share of the subsidy effectively, the sharing percentage of the subsidy and the optimal price of remanufactured products should follow the certain rules, and the sharing percentage of the subsidy relies on the proportion of green consumers. In addition, it is necessary for remanufacturers to have a complete understanding of consumers' environmental preference and its trends.

1. Introduction

Remanufacturing end-of-life products helps to conserve a remarkable amount of natural resources, energy and landfill space, and thus it has brought both environmental and economic gains (Kerr and Ryan, 2001; Sundin and Bras, 2005). However, due to low consumers' acceptance, especially in developing countries such as China, remanufacturers suffer from low profitability (Zhu et al., 2015). Previous studies identified that different clusters of consumers exist in terms of preference and purchase of remanufactured products. Some consumers would like to buy remanufactured products but they are sensitive to price while others prefer new products due to concern about quality of remanufactured products (Atasu et al., 2008). Remanufacturers need to understand consumers' potential preference to remanufactured products and then make the right decision for price determination. Based on surveys among 1600 households in Devon, Canada, Gilg et al. (2005) identified at least four different types of consumers in terms of environmental awareness. Consumers with the higher environmental awareness are more willing to buy remanufactured products. However, a reasonable marketing strategy for green products should understand that most consumers are not willing to compromise on traditional product attributes such as convenience, availability, price, quality and performance to buy remanufactured products (Ginsberg and Bloom, 2004). Thus, this study aims to develop a decision-making model for a remanufacturer to determine a right price to maximize its profit considering different segments of consumers for their potentials to buy remanufactured products.

In developing countries, government incentives such as providing subsidies to remanufacturers have been introduced to promote the remanufacturing industry. For example, the Chinese govern-

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ment has provided a subsidy to remanufacturers for each sold remanufactured truck engine (Y.X. Wang et al., 2014). To attract more consumers, some Chinese remanufacturers have transferred the whole subsidy to consumers. As a result, the government subsidy could not reduce any cost of remanufactures. Moreover, whether and how many more consumers really buy remanufactured products are not clear under such subsidy transfer. A reasonable sharing of the government subsidy between a remanufacturer and consumers can both reduce cost of the remanufacturer while attract consumers, especially for those with the high environmental awareness. Thus, beyond the price determination when considering consumers' environmental preference, the proposed decision-making model in a remanufacturing supply chain (RSC) for a remanufacturer also considers the utilization efficiency of government subsidies to maximize the remanufacturer' profit.

In order to understand how to achieve economic performance for a RSC, scholars have conducted many studies from various perspectives such as RSC coordination (Zhao and Zhu, 2015), RSC or closed-loop SC game-theoretic analysis (Li et al., 2014; Wei et al., 2015), hybrid new/remanufactured product pricing (Abbey et al., 2015; Ferrer and Swaminathan, 2006, 2010; Wu, 2012a; Yenipazarli, 2016), closed-loop or manufacturing-remanufacturing-hybrid supply chain design (Wei and Zhao, 2013), and case study on remanufacturing systems (Ginsberg and Bloom, 2004; Kerr and Ryan, 2001; Y.X. Wang et al., 2014). In addition to these studies, many researchers have also demonstrated that the subsidy incentive can be effective for the development of the remanufacturing industry. In the early stage of the remanufacturing industry, a low acceptable price of a remanufactured product is one of the two key barriers for remanufacturers, and thus the government subsidy is an important incentive to attract more consumers (Zhu et al., 2015). Ma et al. (2013) showed that the role of government consumption-subsidy is conducive to the expansion of a closed-loop supply chain, and the subsidy benefits remanufacturers and retailers, simultaneously. Considering a remanufacturer with two channels, i.e., selling remanufactured products through a manufacturer or directly to consumers, K.Z. Wang et al. (2014) found that the subsidy can incentivize remanufacturing efforts in both two channels, but too high or too low subsidy can bring competitiveness between the remanufacturer and the manufacturer, while an intermediate subsidy can bring cooperation between two firms. In addition, they showed that lower consumers' acceptance toward remanufactured products results in more likely competition between two firms. Some scholars studied the impact of the government subsidy on the production scale and pricing decision for a manufacturer that produces green products, and they found that the subsidy to consumers is a sufficient mechanism to coordinate the government and the manufacturer in terms of the price and quantities (Cohen et al., 2015). Shi and Min (2015) demonstrated that a product unit-based subsidy is more effective than a lump sum subsidy for remanufacturing implementation in the long run. Therefore, this paper considers product unit-based subsidy policy in the decision-making model, which is consistent with the subsidy for remanufactured products in China. Learning from Mitra and Webster (2008), this study assumes that a remanufacturer can share a part of the subsidies with consumers.

To our knowledge, questions regarding the decision to implement a remanufacturing system, in which both consider product pricing and government subsidies' utilization efficiency when this remanufacturing system faces consumer's environmental preference, have rarely (if any) been discussed in the extant literature. When remanufactures determine price for their products, price elasticity is an important factor to consider. Price elasticity of demand (PED) measures responsiveness or sensitivity of demand to changes in price (Samuelson, 1965; Tellis, 1988; Tsai et al., 2010), and it has been applied in various fields, such as food (Andreyeva et al., 2010), recycled water (Hurlimann, 2009), airport pricing (Zhang and Zhang, 2003), electricity markets (Thimmapuram and Kim, 2013), household appliances (Dale, 2008), business cycle behaviors (Field and Pagoulatos, 1997), as well as internationally short-run and long-run demand adjustment for crude oil (Cooper, 2003). In the process identifying consumers' segment, after observing that when the price of remanufactured products changes, non-green consumers have stronger substitution preference towards remanufactured products, i.e., higher price elasticity, than green consumers, this paper is the first attempt to define the price elasticity of demand (PED) as an indicator to differentiate consumers' environmental preference. The main contributions of this paper are as follows. With the help of the *Optimization method*, this paper develops a decision-making model for remanufacturers to develop processes to improve profit through pricing trade-off considering both consumers' environmental preference and the government subsidy policy. This paper finds that the optimal price and the subsidy-sharing percentage are inversely proportional to the weighted-sum of PED. Mathematical analysis also demonstrates that sharing a percentage of the subsidy as a discount to consumers benefits remanufacturer's profitability, and the percentage relies on the proportion of green consumers. In addition, the sharing percentage and the optimal selling price of a remanufactured product have an interrelationship. Results using an actual case of a truck engine remanufacturing company also provide managerial insights of this study.

To achieve the research goals, the remainder of the paper is organized as follows. The following section describes problems and Section 3 introduces model formulation. Section 4 analyzes the decision-making model for a remanufacturer on a one-echelon RSC and discusses the model properties with some findings. In Section 5, a leading truck engine remanufacturer in China is selected for case analysis. Theoretical and managerial implications are explored in Section 6. The last section provides conclusions followed by limitations and some suggestions for future research.

2. Problems description

Since an increasing number of consumers tend to be "green and eco-friendly" in today's business environment, market for remanufactured products is growing. However, researchers have shown that there are various types or segments of consumers according to their attitudes or preference for remanufactured products (Abbey et al., 2015; Atasu et al., 2008; Chen, 2001; do Paço and Raposo, 2009). Because consumers' environmental preference on remanufactured products varies greatly, remanufacturers must consider the customers' segments in order to improve profit for a RSC.

Decision of a remanufacturer includes two steps in practice. Firstly, a remanufacturer should consider consumers' environmental preference to understand the consumers' differentiated demand of remanufactured products. Secondly, since this study also considers a subsidy-sharing policy as an incentive for consumers to improve utilization efficiency of the subsidy, the remanufacturer should share a part of the subsidy with consumers to incentivize the consumers' demand. The decision problem considering two steps is difficult. Therefore, each step is described sequentially. Sub-section 2.1 introduces consumer segments on environmental preference, and in the following sub-section, a decision-making framework is provided to illustrate the trade-off problem that remanufacturers face.

2.1. Consumer segments

As indicated above, understanding consumers' preference is the first step to develop a decision-making model for a remanufac-

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