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Manufacturer-remanufacturing vs supplier-remanufacturing in a closed-loop supply chain

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ABSTRACT

Remanufacturing at the component level could be performed by either a manufacturer or a supplier. In this paper, we analyze the performance of manufacturer-remanufacturing and supplier-remanufacturing in a decentralized closed-loop supply chain, and examine their desirability from different stakeholder perspectives. We find that the manufacturer may engage in remanufacturing of used components even if remanufacturing is costlier than traditional manufacturing; given remanufacturing is costlier, the manufacturer may forgo remanufacturing due to a marginal increase in consumer willingness-to-pay for the remanufactured product. If the unit remanufacturing cost is high enough, the manufacturer and consumers prefer manufacturer-remanufacturing, while the supplier and the environment prefer supplier-remanufacturing; otherwise, the manufacturer, the supplier, and consumers prefer supplier-remanufacturing, while the environment's preference is contingent on the environmental impact discount for the remanufactured product. Finally, the key findings are distilled into a roadmap to guide the development of remanufacturing.

1. Introduction

In recent years, executives around the world are rallying behind sustainability, and have experienced a dramatic increase of interest in remanufacturing. Successful examples from many industries show that remanufacturing can be both faster-growing and more profitable than traditional manufacturing (Ayres et al., 1997, Guide and Wassenhove, 2003, Geyer et al., 2007). However, the remanufacturability of used products as a whole is restricted by increasing technical complexity, shorted product life cycle, rising costs and uncertainties.

Remanufacturing at the component level is an alternative that may help maximize the revenue generated from the return stream (Fleischmann et al., 2003), which has been a consensus between researchers and managers. In theory, remanufacturing is defined as "a production strategy whose goal is to recover the residual value of used products by reusing components that are still functioning well" (Debo et al., 2005). In practice, the remanufacturing process of Caterpillar (2010) can be briefly described as:

- First, used products collected from customers are disassembled into their constituent components.
- Next, the individual components are remanufactured to exact specifications to ensure they provide the same quality, reliability and durability as they did when they ware new.
- Last, remanufactured components are assembled, tested and made ready for sale as the remanufactured product.

In addition, nowadays, few manufacturers rely on only themselves to design and produce the whole product, which implies that most components are provided by their suppliers. Thus, remanufacturing at the component level can be performed by manufacturers such as Caterpillar, or by their key component suppliers. In 2008, Chinese National Development and Reform Commission launched a pilot program of auto part remanufacturing, and 14 firms were selected and supported to start up remanufacturing, seven of which are auto manufacturers (or their subsidiaries) and the other seven are part suppliers (Sina, 2008).

Thus, a research question is naturally emerging: what is the difference between manufacturer-remanufacturing and supplier-remanufacturing? Our primary objective in this paper is to develop a general understanding of the desirability of manufacturer-remanufacturing and supplier-remanufacturing from different stakeholder perspectives.

The literature on managing the closed-loop supply chain with remanufacturing is abundant, we refer the reader to Atasu et al. (2008a), Guide and Van Wassenhove (2009), and Souza (2013) for a thorough discussion. It has been demonstrated that remanufacturing

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can be an effective marketing strategy for manufacturers to defend their market share and render a higher profit (Heese et al., 2005, Atasu et al., 2008b, Chen and Chang, 2013, Wu, 2015). However, to the best of our knowledge, few papers consider the possibility of supplier-remanufacturing and identify the "right" remanufacturer, especially from the perspectives of the consumers and the environment. Xiong et al. (2013) make the first attempt to analyze how the interaction between the manufacturer and the supplier on new product production influences to the economic and environmental performance of remanufacturing. We extend Xiong et al. (2013)'s model to analyze and compare the implications of manufacturer-remanufacturing and supplier-remanufacturing.

More importantly, our model deviates from the literature by allowing remanufacturing a used component does not cost less than manufacturing a new one. On one hand, this deviation is greatly motivated by the industrial practice: although some pioneers have made a profit, most manufacturers have no infrastructure and expertize to remanufacture in a profitable manner (Ferguson, 2010). Specifically, in the globalized world today, remanufacturing is still largely a local business because many countries prohibit the international trade of used products. Huawei (2015), the world's third largest cell phone producer, capitalizes on recycling in Europe, but does not remanufacture. This may be driven by the possibility that producing a remanufactured cell phone in Europe costs more than producing a new one in China. On the other hand, this derivation leads us to some very interesting findings on firms' remanufacturing strategy. The prior literature on remanufacturing typically defaults that remanufacturing costs less than traditional manufacturing, e.g., in a seminal research, Ferrer and Swaminathan (2006) use the remanufacturing savings as the key parameter to define the strategy space. To the best of our knowledge, only one paper, Caner et al. (2013), considers the situation where remanufacturing is costlier for an integrated manufacturer. However, it finds remanufacturing is seldom profitable in this situation and suggests the manufacturer focus on situations where remanufacturing costs less. In contrast, our work demonstrates the manufacturer could be better off by engaging in remanufacturing even if it costs more than manufacturing in a decentralized supply chain. In addition, given remanufacturing is costlier, the analytical result shows that the manufacturer may decide to forgo remanufacturing as a result of a marginal increase in consumer willingness-to-pay for the remanufactured product. These findings make an excellent complement to the current literature on remanufacturing.

The rest of this paper is organized as follows. Section 2 delineates our modeling assumptions and notation. Section 3 presents the analysis and solutions of two models with manufacturer-remanufacturing and supplier-remanufacturing, respectively. Section 4 discusses firms' remanufacturing strategy and identifies the "right" remanufacturer from different stakeholder perspectives. Section 5 concludes this paper. Appendices contains the detailed proofs of all propositions. Hereinafter, for convenience, we use pronouns '*she*' and '*he*' to refer to the supplier and the manufacturer, respectively.

2. Assumptions and notation

We consider an industry with only one product but two versions: the new product and the remanufactured product. To focus our attention on the desirability of manufacturer-remanufacturing and supplier-remanufacturing from different stakeholder perspectives, we consider a simple bilateral monopoly, as depicted in Figs. 1 and 2. In this paper, we do not consider the reverse channel choice, which has been widely studied in the existing literature, e.g., Xiong et al. (2014), Hong et al. (2015), and Wei et al. (2015).

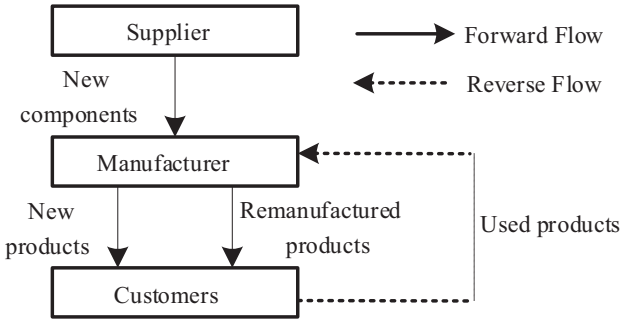

Fig. 1. The closed-loop supply chain model with manufacturer-remanufacturing.

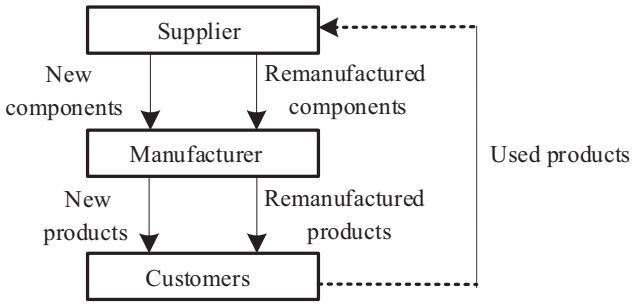

Fig. 2. The closed-loop supply chain model with supplier-remanufacturing.

Therefore, it is reasonable to assume that used products are collected (by the retailer, or the manufacturer, or the third-party operator) at a constant cost, which is normalized to 0.

To isolate the strategic issue of remanufacturing, our model rules out the distortion due to efficiency variance by assuming that either the manufacturer or the supplier costs c_r to remanufacture a used component. Similar assumptions have been widely used in the literature, e.g., Savaskan et al. (2004) assume a manufacturer and a retailer incur a same cost to collect used products, and demonstrate the retailer-managed collection is always preferred by the manufacturer; Zhou et al. (2013) assume centralization and decentralization within a manufacturer are equivalent in terms of the cost structure, and find decentralization outperforms centralization under certain conditions. For the sake of clarity, we assume that, except for the cost to obtain the new/remanufactured component, the manufacturer's other operating costs are constant and normalized to 0.

Other key assumptions concerning consumer preference, environmental performance, and decision-making rule are borrowed from the literature on closed-loop supply chain management, e.g., Galbreth et al. (2013), Xiong et al. (2013), Chang et al. (2015), and Gu et al. (2015). Here, we present the following set of assumptions, but skip the detailed discussion on their justification. For convenience, Table 1 summarizes the notation used in the model.

Assumption 1. The inverse demand functions for new and remanufactured products are

$$p_n = 1 - q_n - \delta q_r, \tag{1}$$

$$p_r = \delta(1 - q_n - q_r). \tag{2}$$

Assumption 1 implies that the consumer willingness-to-pay for the new product is heterogeneous and distributed over the interval $[0, 1]$ with the density of 1; each consumer's willingness-to-pay for the remanufactured product is a fraction $\delta \in (0, 1)$ of that for the new one; and each customer buys at most one product that offers the most utility, as long as the net utility is positive. Thus,