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Impact of product proliferation on the reverse supply chain

Shui-Mu Huang [a], Jack C.P. Su [b,*]

[a] Department of Industrial Engineering and Engineering Management, National Tsing Hua University, Hsinchu 30013, Taiwan
[b] Anderson School of Management, University of New Mexico, 1924 Las Lomas NE, Albuquerque, NM 87131, USA

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ABSTRACT

Product variety is one of the most important advantages in highly competitive markets. However, excessive product proliferation's reducing the profit margin has caused increased focus on developing a management method for maximal profit. In a closed-loop supply chain, product proliferation affects the reverse supply chain as well as the forward supply chain. Although increasing the number of product types can better satisfy diverse customer needs, complexity in the product recycling, remanufacturing, and resale processes may erode a firm's overall profits. In this study, we develop a mathematical model for analyzing a capacitated reverse supply chain consisting of a single manufacturer and multiple retailers. We reveal closed-form solutions for the optimal batch size and maximal profit, and discuss managerial insights into how the number of products and other factors can affect both batch size and profit. Finally, we investigate the relationship between product proliferation and the choice of logistics strategy.

1. Introduction

Rapidly evolving technologies, global competition, and changes in customer needs have contributed to an increase in product variety. According to Lee [1], product proliferation has been one of the most important market trends, and is very common in many industries [2,3,4,5]. For example, in 1992, over 2000 different PC models were available on the market, and between 1990 and 2004, the number of stock-keeping units in supermarkets increased from 16,500 to 25,153 [6].

Product variety can be defined in two ways: the breadth of products that a firm offers at any given time, and the rate at which a firm replaces existing products with new ones. Each of these parameters has steadily increased in many industries [7,8,9]. Firms regard product variety as an important tool of competition as it can better serve heterogeneous market segments and better satisfy diverse consumer preferences, enabling companies to increase or maintain their market share and enjoy higher profits. However, high product variety could also imply increased manufacturing complexity and cost [10,11]. In the past, firms relied solely on experience or intuition to determine the number of products to offer, and consequently tended to underestimate the operational inefficiencies and costs inherent in product variety. Kim and Chhajed [12] indicated that product proliferation may reduce manufacturing/logistics performance. Ramdas and Sawhney [13] claimed that simply increasing product variety does not guarantee an increase in long-term profits, and can, in fact, worsen competitiveness. Therefore, many firms have considered reducing the number of products they offer as a means of improving their supply chain performance. Raleigh [14] noted that Unilever uses its product logic framework to simplify its global home and personal care product portfolio. Yunes et al. [15] studied how the number of configurations for John Deere can be reduced to maximize profit. In both industry and academia, there is an ongoing debate about the cost–benefit tradeoff of product variety [9,16,17,18,19,20]. This uncertainty indicates the importance of carefully managing the number of products a company releases to maximize its profits.

Recent years have also seen increased research on the reverse supply chain due to the rising awareness of environmental protection issues. The reverse supply chain is defined as the series of activities required to retrieve a product from a customer in order to dispose of it or recover its remaining value [21]. The reverse supply chain process can be organized as five sequential key steps: collection of returned product or product acquisition, reverse logistics, inspection and disposition, remanufacturing or reconditioning, and selling and distribution [22]. Product return can be divided into two major types in a reverse supply chain: the return of a commercial product, and end of use (EOU) or end of life (EOL) product returns. In this paper, we focus on commercial product returns that Guide et al. [23] defined as products returned for any reason within 90 day of sale. The overall value of commercial product returns exceeds $100 billion annually in the United States [24], and therefore, management of the flow of

* Corresponding author. Tel.: +52 505 515 6921; fax: +52 505 277 7108.
E-mail addresses: willie.boy0717@msa.hinet.net (S.-M. Huang), jackcpsu@unm.edu, su@ie.nthu.edu.tw (J.C.P. Su).

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product returns to maximize profit is a significant concern for many manufacturers.

Product proliferation affects not only the forward supply chain but also the reverse chain. Although increasing the number of products will satisfy diverse customer demands, the increased complexity of product recycling, remanufacturing, and resale may reduce a firm's profitability. Therefore, we developed a mathematical model to analyze the effects of product proliferation on a capacitated reverse supply chain consisting of a single remanufacturer and multiple retailers. We find the closed form solution for the optimal batch size and profit, and discuss managerial insights derived from the closed form solutions. We also explore the relationship between the number of products that a system offers and the logistic strategies in the reverse supply chain.

The remainder of this paper is organized as follows. In Section 2, we review the relevant literature. In Section 3, we describe our research problem and assumptions in detail. In Section 4, we develop a mathematical model and derive the closed-form solutions. In Section 5, we present our managerial insights based on sensitivity analyses. The relationship between product variety and choice of logistics strategy is discussed in Section 6. Finally, in Section 7, we summarize our findings and discuss promising areas for future research.

2. Literature review

Three streams of literature are relevant to our research. The first examines the effects of batch size on manufacturing lead time. Several researchers have used queuing models to study the effects of batch size on manufacturing lead time and work-in-process costs for a system offering multiple products with setup times [25,26,27,28,29]. These models focus on determining batch sizes that minimize the manufacturing lead time and work-in-process costs. Tielemans and Kuik [30] investigated the relationship between batch size and the mean and variance of time in system. They found that the batch size that minimizes the average time in system will not minimize its variance when the utilization is high. Kuik and Tielemans [31] studied the relationship between batch size and lead time when the utilization is low. Koo et al. [32] explored the batch sizes of a bottleneck machine for maximal profit, and introduced a linear search algorithm for finding the optimal production rate and batch size. All the above-mentioned studies concentrated on batch size impact on the manufacturing lead time and work-in-process inventory in different manufacturing environments for a forward supply chain. In this paper, we focus on the relationship between batch size and reverse supply chain factors such as aggregate return rate, discount rate, number of products, and variance of unit remanufacturing time. Several distinct differences exist between forward and reverse supply chain models. First, in a forward supply chain, if the production line is automated, the process times required for the same product are relatively stable. In fact, many of the aforementioned papers have assumed a constant process time [33–35]. In a reverse supply chain, however, because the conditions of a return product tend to vary significantly, it is not reasonable to assume that the remanufacturing time is constant. Therefore, we assume that the remanufacturing time follows a general distribution. Second, because the conditions of returned products tend to vary greatly, remanufacturing is usually a more flexible process. Therefore, we ignore the setup times between product types.

The second stream studies the effects of product variety on inventory costs. Literature has demonstrated that product variety is an effective strategy for increasing market share because it enables a firm to serve heterogeneous market segments and satisfy various consumer needs. However, product proliferation induces certain operational challenges as well. For example, increasing the number of product types often results in higher inventory costs [9,20,36–38]. Eppen [36] and Zipkin [37] studied the effects of product variety on the performance of a two-level supply chain. Their model demonstrated that performance degrades in proportion to the square root of product variety. Fisher and Ittner [9] and Randall and Ulrich [20] used empirical data to examine the impact of product variety on the automobile and bicycle industries. Benjaafar et al. [38] introduced a multi-item production-inventory system model with finite capacity, and analyzed the effects of product variety on inventory-related costs. Su et al. [39] compared the time postponement (TP) strategy with the form postponement (FP) strategy using both time and cost as their performance matrices. They found that when the number of products increases above a certain threshold, TP is the preferable strategy in both performance matrices. Su et al. [40] compared two supply chain strategies, make-to-order (MTO) and configure-to-order (CTO), to address the challenges of product proliferation. They derived the conditions under which one is better than the other in terms of time and cost. All the above-mentioned papers explored the effects of product variety on forward supply chains using cost as their objective. In this paper, however, we explore the impact of product proliferation on the reverse supply chain. The average time in system for a return product is estimated using queuing theory and optimal batch size, and the best logistics strategy is determined as one that maximizes the time-discounted profit.

The last stream of research explores a closed-loop supply chain, especially for remanufacturing. In recent decades, various strategic and operational aspects of remanufacturing have been investigated, such as inventory control systems [41–43] and reverse channel/network design [44–46]. Several remanufacturing models focus on time value of product return [23] and limited durability and finite life cycles [47]. The primary objective of our study is to optimize the profit of the reverse supply chain by integrating two elements, reverse logistics and time value of product return. The literature most closely related to ours is reviewed as follows. Krumwiede and Sheu [48] developed a decision-making model for guiding an examination of reverse logistics feasibility and for determining whether to involve third-party logistics providers. Savaskan et al. [44] investigated a manufacturer's reverse channel choice in a single-manufacturer, single-retailer supply chain structure. Savaskan and Van Wassenhove [45] extended their own research by considering a competitive retailing environment. We explore the effects of product variety on the logistics strategies of returned products and the number of products as the logistics strategy switching point for determining whether to outsource. Guide et al. [23] claimed that a large proportion of the commercial product value erodes because of long processing delays in the reverse supply chain. They presented a network flow with delay models that includes the marginal value of time required to identify the drivers of a reverse supply chain design. They demonstrated that responsive decentralized return networks must be considered when the discount rate is high. In our model, we focus on commercial returns of multiple products and take into account the time value of the return product to maximize profit.

Two previous papers relate strongly with our study. First, Thonemann and Bradley [35] presented a mathematical model to analyze the effects of product variety on cycle time for a forward supply chain with a single manufacturer and multiple retailers. They demonstrated that the expected replenishment lead time and retailer costs are concave increasing in product variety. The present paper differs from that of Thonemann and Bradley [35] in three ways. First, we formulate our model to maximize profit, whereas Thonemann and Bradley's [35] objective was to minimize total cost. Second, we assume that the remanufacturing time