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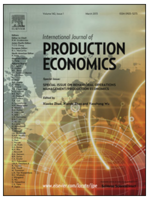

Capacity and production decisions under a remanufacturing strategy

Serra Caner Bulmuş*, Stuart X. Zhu, Ruud Teunter

University of Groningen, PO Box 800, 9700 AV, Groningen, The Netherlands

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ABSTRACT

In this paper, we investigate the effect of remanufacturing on capacity and production decisions. Inspired by the situation for a specific car company, we analyze a two-period model with manufacturing in both periods and the option in the second period to remanufacture products that are returned/collected at the end of the first period. We first and foremost focus on the case where remanufacturing is less costly and less capacity intensive than manufacturing. This setting is realistic and obviously the one where remanufacturing is most beneficial. Optimal manufacturing and remanufacturing quantities are derived and it is analyzed under what conditions (specified by costs, capacity restrictions and demand) remanufacturing leads to increased total production. We also consider the cases where remanufacturing is either more costly or more capacity intensive than manufacturing, and contrast the results the those of our main case. One particularly insightful find is that remanufacturing is seldom (very) profitable if it is more costly than manufacturing, and hence that companies should focus their attention on situations where remanufacturing lowers costs.

1. Introduction

Over the last 50 years, the level of consumption by growing population has been continuously increasing. As a result, the world now faces serious environmental problems such as waste with the presence of toxic materials and depletion of natural resources (Pochampally et al., 2009). Driven by legislation and societal pressure to mitigate these environmental problems, and also by economic incentives, more and more firms are starting remanufacturing operations next to the traditional manufacturing operations (Tang and Teunter, 2006).

Remanufacturing is the process of bringing used products to a "like-new" functional state with warranty to match. It has numerous benefits for original equipment manufacturers (OEMs), such as savings in labor, material and energy costs. By adopting remanufacturing firms can save between 40% and 60% of the cost of manufacturing a new product while using only 20% of the energy (Guide et al., 1997). In the 2008/2009 financial year, Fuji Xerox Australia remanufactured more than 230,000 equipment parts, equating to a $6 million cost-saving compared to sourcing new parts. Furthermore, remanufacturing leads to shorter production lead times; balanced production lines; new market development opportunities, and a positive, socially concerned image for firms (McConocha and Speh, 1991). Caterpillar created a new market among contractors who cannot afford to buy a Caterpillar product outright by adopting remanufacturing as a part of production strategy (Gutowski et al., 2001). In addition to these benefits, remanufacturing may offer a better alternative to capacity constraint on new product manufacturing (Atasu et al., 2008).

In this study, we consider remanufacturing in a two-period, capacitated production setting and our aim is to determine the effect of remanufacturing on capacity and production. More specifically, we address the following questions:

(1) Under what conditions is remanufacturing profitable? If remanufacturing is either more costly or more capacity intensive, can it still be profitable?
(2) What is the impact of remanufacturing on the optimal capacity and production decisions?
(3) How will market conditions and cost structures effect the profitability of remanufacturing?

We construct a model to optimize capacity, manufacturing and remanufacturing decisions. The model is motivated by a specific case company which manufactures and remanufactures car parts (Tang and Teunter, 2006). The details of the case and mathematical model are described in the next section.

Capacity management has been widely studied in the supply chain literature. The three main areas that have been addressed are production, inventory and demand management; real options; and risk sharing and vertical integration between suppliers and buyers through capacity reservation contracts. Wu et al. (2005)

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* Corresponding author. Tel.: +31 50 363 3252; fax: +31 50 363 2032.
E-mail addresses: s.caner@rug.nl (S.C. Bulmuş), x.zhu@rug.nl (S.X. Zhu), r.h.teunter@rug.nl (R. Teunter).

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provide an extensive review on capacity expansion tactics in the high-tech industry.

There are numerous studies on closed-loop supply chains and remanufacturing in the current literature. Fleischmann et al. (1997) provide an excellent review and Guide and Van Wassenhove (2009) describe the evolution of the research on closed-loop supply chains. A recent survey on production planning and control for remanufacturing is provided by Junior and Filho (2012). In the remanufacturing literature, there are relatively few studies that consider capacitated settings. In this literature stream some studies only focus on the planning remanufacturing activities capacities without considering production capacity of new products. For instance, Guide et al. (1997) consider remanufacturing capacity by taking into account material recovery rates and stochastic routings, and they evaluate the performance of several capacity planning techniques. Aksoy and Gupta (2001) analyze the trade-off between increasing the number of buffers and increasing the capacity at the remanufacturing stations with uncertainties in the operational environment. They use an open queuing network to model the remanufacturing system. Franke et al. (2006) consider remanufacturing capacity for the mobile phone industry. They introduce a linear programming model for the planning of remanufacturing capacities and production programs. Georgiadis et al. (2006) analyze capacity expansion/contraction of collection and remanufacturing activities considering product lifecyle and return patterns. They adopt system dynamics methodology to derive dynamic capacity planning policies. Another study that uses system dynamics methodology is conducted by Vlachos et al. (2007). They study the long-term behavior of reverse supply chains with remanufacturing, and propose efficient remanufacturing and collection expansion policies. They also include specific external factors such as obligations and penalties imposed by legislation that influence profits, costs and flows. Different from these studies, we consider production capacity for both new and remanufactured products.

Other studies that consider capacitated production setting for both new and remanufactured products do exist. Debo et al. (2006) analyze the introduction and management of remanufactured products considering life-cycles of products. They also focus on capacitated settings and try to understand the impact of the product diffusion rate on the capacity requirements for new and remanufactured products. Additionally, they investigate the relative value of flexible capacity which can be used to both manufacture and remanufacture products, compared to dedicated capacity for each activity. Bayindir et al. (2003) investigate the conditions on different system parameters, including capacity of the production facility, for which the remanufacturing option provides cost benefits. They model the production environment as a queuing network, where manufacturing and remanufacturing require both common and separated operations. They also assume that there is no difference between remanufactured and manufactured products. Bayindir et al. (2007) relax this assumption and investigate the profitability of having a remanufacturing option when the manufactured and remanufactured products are segmented to different markets and production capacity is finite. They consider a single period profit model where the retail price of the new and remanufactured products are fixed. Rubio and Corominas (2008) consider a lean production environment with known and constant demand, and propose a model where manufacturing and remanufacturing capacities can be adjusted. Different from these studies, we investigate the effect of remanufacturing on capacity and production (pricing) decisions in a two-period setting that consists of a growth phase and a maturity phase for a product. Two-period models have been used in the remanufacturing literature in several studies including these, by Majumder and Groenevelt (2001), Ferguson and Toktay (2006), Ferrer and Swaminathan (2006), and Webster and Mitra (2007). In these studies, it is assumed that there is infinite production capacity of new and remanufactured products whereas our study considers a capacitated setting.

The rest of the paper is organized as follows. The next section introduces the motivating case and describes the corresponding model in detail. We characterize the optimal policy for the case in which remanufacturing is less costly as well as less capacity intensive compared to manufacturing in Section 3. We further conduct a sensitivity analysis on the optimal solution in Section 4 to understand the effect of each parameter on the optimal solution. Also, by comparing to the case where the OEM only manufactures, we gain insights into the effect of remanufacturing on total production, capacity investment and retail prices. In Section 5, we relax the assumption that remanufacturing reduces both cost and capacity requirements. We again characterize optimal policies and also study numerically whether remanufacturing can still be profitable in such cases in Section 6. Section 7 ends with a brief summary of the findings, managerial insights, and avenues for further research.

2. Model

In this section, we first introduce the details of the motivating case then construct the mathematical model with related assumptions.

The motivating case for this study is a specific car company whose major products are diesel engines, petrol engines, water pumps, cylinder heads, crankshafts, and short blocks. For this study, we focus on a specific product, the water pumps for diesel engines. The remanufacturing processes are very similar to those for manufacturing except for the source of the materials, therefore both manufacturing and remanufacturing are performed on the same production line.

In the mathematical model we assume that the product lifecycle is split into two periods which we can interpret in the following way. In the first period (growth phase), the OEM builds its production capacity and introduces the new product to the market. The number of manufactured new products, q_{1n}, in that period is, of course, restricted by the production capacity Q, i.e., $q_{1n} \le Q$. In the second period (maturity phase) the product is already in the market and sales continue. Also, the returns from the first period's sales (where γ denotes the fraction that are returned) are received. In the second period, capacity is fixed (from the first period). We do allow the second period to have a different length than the first. Letting θ denote its relative length compared to that of the first period, this gives a capacity of manufacturing θQ new products in the second period. However, an OEM can use part of that capacity to remanufacture used products that are returned/collected at the end of period 1.

The relative capacity requirement for remanufacturing (per remanufactured product) is denoted by τ. So, letting q_{2n} and q_{2r} denote the manufactured and remanufactured products in period 2, we get the following capacity restriction for period 2:

$$q_{2n} + \tau q_{2r} \le \theta Q.$$

Remanufactured water pumps are sold with the same quality and warranty as the new product and OEM offers a (fixed) discount per remanufactured product. Newly manufactured and remanufactured water pump are used to fulfill the demand for spare parts for engines and demand for new engine assembly. The buyers are assumed to be indifferent between purchasing a newly manufactured product and a remanufactured product that is sold at a fixed discount. To avoid unnecessary notation, we include that “discount” for remanufactured products in our model by adding it