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Optimal pricing and production decisions in utilizing reusable containers

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A R T I C L E I N F O

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A B S T R A C T

In this study, we focus on pricing and production decisions in utilizing reusable containers with stochastic customer demand. We consider a manufacturer that sells a single product to the customers in reusable containers with two supply options: (i) brand-new containers and (ii) returned containers from customers. The return quantity depends on both customer demand and the acquisition fee determined by the manufacturer. The unit cost of production using brand-new containers is different than the unit cost of reusing returned containers. The customers are indifferent between brand-new and recovered products. We also consider resource restrictions on the production operations. In this setting, we investigate the optimal pricing and production decisions in order to maximize the manufacturer's profit. We characterize the optimal acquisition fee and the optimal order quantity of brand-new containers analytically and investigate the effect of parameters through an extensive computational study.

1. Introduction

Closed-loop supply chains (CLSC) focus on taking back products from customers and recovering added value by reusing the entire product, and/or some of its modules, components, and parts (Guide and Van Wassenhove, 2009). According to the classification of de Brito and Dekker (2004), two kinds of recovery operations are performed: process recovery and direct recovery. Reusing is a widely used recovery option within direct recovery operation alternatives. One of the earliest practices of reuse is reuse of containers. Reusable containers are durable packages that protect the main product during its transportation through different nodes of supply chain. Typical examples of reusable containers are glass bottles of beverages. Since reusable containers are purchased once and can be utilized several times, reusing containers is usually less costly.

Our goal in this study is to investigate the pricing and production decisions of a production system where reusable containers are utilized. Our model can be applied in a variety of settings where containers collected from customers can be reused, such as beverage and food manufacturing, packaging and transportation. Our research aim is to determine the optimal levels of acquisition fee and quantity of containers to be purchased in such environments. Although we use a "reusable container system" framework, our work applies to any hybrid manufacturing/remanufacturing systems where (i) the manufacturer collects and recovers his own products, (ii) the manufacturer supplies both brand-new and recovered products to his customers, and (iii) the customers are indifferent between brand-new and recovered products.

In hybrid manufacturing/remanufacturing systems, two main drivers of the production are customer demand and product returns, and modeling product returns is a critical aspect.

In modeling customer returns, first approach in the literature is to assume that the quantity of returns is an exogenous (deterministic or random) parameter, and totally independent of other dynamics of the system. This type of scheme is most suitable for return systems where the manufacturer collects and recovers products produced by not only himself but also by other manufacturers, hence the dependency of the return stream on the manufacturer's demand stream is weak. The focus of the studies following this approach is usually tactical or operational, and most of them are on production planning and inventory control for recovery systems (Teunter et al., 2006; Fleischmann and Kuik, 2003; Kiesmüller, 2003).

Second approach in modeling customer returns is to assume that the quantity of returns depends on customer demand. In this approach, returns are generally defined as a function of demand and a fraction indicating the proportion of returns to customer demand. This modeling approach is suitable for the systems where the manufacturer collects and recovers products supplied by only himself. There are a number of studies that extend the traditional EOQ problem to the recovery environment where the return rate is a fixed fraction of the demand rate.

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Teunter's (2001, 2004) studies are some examples for such studies. Tang and Grubbström (2005) extend these studies to the case where lead times are stochastic.

Kelle and Silver (1989a) introduce one of the most comprehensive studies on modeling and forecasting the returns of reusable containers. They develop four different forecasting methods to estimate returns and net demand during the lead time. Goh and Varaprasad (1986) also work on modeling and forecasting returns, and analyze the life-cycle of reusable containers in order to determine their expected service life. They develop an approach to analyze past data and model the return process.

One stream of research that considers demand dependent returns takes return rate as a parameter. Kelle and Silver (1989b) deal with the optimal purchasing policies for reusable containers under a service level constraint, where demand and return rates are stochastic. Kiesmüller and van der Laan (2001) investigate an inventory model for a single reusable product, and assume that the random returns depend on the demand stream with a time lag. The results show that using the information about the dependence between the demand and return processes generally decreases the average relevant costs.

Another stream of research that considers demand dependent returns takes return rate as a decision variable. Bayındır et al. (2003) investigate the benefits of utilizing returns in a hybrid manufacturing/remanufacturing system where customer demand is stochastic, and minimize average expected cost by determining the order-up to levels for the end item and the return ratio. Dobos and Richter (2003) investigate a production/recycling system where customer demand and return rates are deterministic and stationary. They consider the EOQ environment with recovery and define return rate as a fraction of the constant demand rate.

Third approach used in modeling customer returns defines returns as a function of sales price, acquisition fee or refund paid to customers by the manufacturer. Hess and Mayhew (1997) deal with modeling direct marketing returns. They assume that both time-to-return and return rate depend on sales prices. Guide et al. (2003) deal with product acquisition management problems in a remanufacturing environment to maximize the remanufacturer's profit by determining optimal acquisition and selling prices in a single period setting. In this environment, the profitability of remanufacturing operations depends on the quantity and quality of returned items and they assume that the quantity and quality of returns can be manipulated by quality-dependent acquisition prices. Mukhopadhyay and Setoputro (2004) investigate optimal price and return policies for reverse logistics in e-business and develop a model to determine optimal price and return policies to maximize e-tailer's profit. They formulate the demand for the products as a linear function of both sales price and refund paid to the customer; whereas they model the return function only dependent on refund.

In our study, we investigate the optimal pricing and production decisions in order to maximize the manufacturer's profit. Different than the rest of the existing literature, we define customer returns as a function of both the customer demand and the acquisition fee determined by the manufacturer. In this context, we consider two different environmental settings: (i) unrestricted resource capacity and (ii) restricted resource capacity.

The rest of the study is organized as follows: In Section 2, we define our problem, environmental setting and assumptions. In Section 3, we consider the uncapacitated and the capacitated models, and characterize the optimal acquisition fee and the optimal order quantity of brand-new containers. We also identify their sensitivity to the cost parameters analytically. An extensive computational study is conducted and results of this study are presented is Section 4. The study is concluded in Section 5.

2. Problem definition

Our main research objective is to investigate pricing and production decisions in a hybrid production environment where (i) the return stream depends on both the acquisition fee and the demand; (ii) both brand-new and returned containers use the same production facility. In order to address these critical issues properly, we consider a stylized model in a single period context. Below we discuss the environmental setting and the major assumptions of our model.

We consider a manufacturer that sells a single product with stochastic customer demand. The manufacturer has two supply options: (i) brand-new items and (ii) returns from customers. The manufacturer purchases brand-new reusable containers from an external supplier and he fills (manufactures) them. Returned containers are acquired from customers by paying an acquisition fee and they are refilled (remanufactured). We assume that all returned containers can be reused. Unit filling and refilling costs are non-identical. The end product is sold at a constant, exogenous sales price.

In our study, we define returns perfectly correlated with realized demand: a fraction of realized demand returns to the system. When decision period is defined to be long enough to supply reused containers from the current period's returns, it is reasonable to assume that returns of containers are positively correlated with the demand for the products; but, perfect correlation between these two streams is our further simplification. Fleischmann et al. (2002) and Kiesmüller and van der Laan (2001) also assume perfect correlation between stochastic return and demand streams; and define the mean of item returns as a fraction of the mean of demand.

The sequence of events in this setting is as follows (Table 1 summarizes the notation used):

(i) Order quantity of brand-new containers, Q, and the unit acquisition fee, f, are determined. Total purchasing cost of brand-new containers c_nQ is incurred.
(ii) Demand, D, and returns, $\gamma(f)D$, are realized. Total acquisition cost for returned containers $f\gamma(f)D$ is incurred.
(iii) The manufacturer determines the quantity of brand new containers used ($M \le Q$) and the quantity of returned containers reused ($R \le \gamma(f)D$) in order to satisfy the demand without exceeding the total capacity, i.e., $M+R \le C$. Note that since the demand has already been realized, the manufacturer never produces more than realized demand, i.e, $M+R \le D$.
(iv) Total cost of filling c_rM and refilling c_fR are incurred. A total revenue of $p(M+R)$ is received where $p > c_f$ and $p > c_n + c_r$.

Note that $\gamma(f)$ is the fraction of containers returned which is assumed to be an increasing, concave function of f. That is, $d\gamma(f)/df = \gamma'(f) \ge 0$ and $d^2\gamma(f)/df^2 = \gamma''(f) \le 0$. $\gamma(f)$ is equal to 0 only when f is equal to 0. When f takes a positive finite value, $0 < \gamma(f) < 1$. In the following steps of the analysis, we study with a closed form function $\gamma(f)$ and show it as γ for the sake of brevity. In this framework, the manufacturer's problem is to determine f and Q to maximize its expected profit. Our main research questions are as follows:

- What are the optimal levels of the acquisition fee and the order quantity of brand-new containers in order to maximize the manufacturer's profit?
- What are the effects of cost and demand parameters on the optimal levels of decision variables and the optimal expected profit?
- What are the effects of a restriction in production capacity on the optimal levels of decision variables and the optimal expected profit?