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The impact of information sharing, random yield, correlation, and lead times in closed loop supply chains

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ABSTRACT

We investigate the impact of advance notice of product returns on the performance of a decentralised closed loop supply chain. The market demands and the product returns are stochastic and are correlated with each other. The returned products are converted into “as-good-as-new” products and used, together with new products, to satisfy the market demand. The remanufacturing process takes time and is subject to a random yield. We investigate the benefit of the manufacturer obtaining advance notice of product returns from the remanufacturer. We demonstrate that lead times, random yields and the parameters describing the returns play a significant role in the benefit of the advance notice scheme. Our mathematical results offer insights into the benefits of lead time reduction and the adoption of information sharing schemes.

1. Introduction

Due to growing concerns with environmental issues, collection and recycling systems for post-consumer products have been developed in many countries. Return rates for polyethylene terephthalate (PET) bottles, for example, are increasing year by year in many countries. The 2012 rates in Europe, Japan and the USA are 52 percent (Petcore, 2013), 90.4 percent (CPBR, 2014) and 30.8 percent (Napcore, 2013), respectively. At the same time, many companies have been developing new remanufacturing processes. Suntory, one of the largest food and beverage companies in Japan, has developed bottle-to-bottle mechanical recycling technology that enables the company to produce PET bottles solely from reused resin (Suntory, 2013).

This world-wide environmental movement is mainly driven by the sustainability ethic (Welle, 2011), but the impact of the recycling system on the dynamics of the supply chain is not well understood.

Akçalı and Çetinkaya (2011) argue closed loop supply chains (CLSCs) are generally acknowledged to be more complex than traditional supply chains due to a number of factors: Both the demands and the product returns must be forecasted and incorporated into replenishment decisions. The demand and return may be correlated to each other. Two different lead times are present, the manufacturing lead time and the remanufacturing lead time. In many practical situations, the returned products will also be variable in quality, resulting in a remanufacturing process with a random yield.

It is often advocated that to improve supply chain performance, information should be shared between players. The value of such information sharing in traditional supply chains is well recognized (see Gavirneni, Kapuscinski & Tayur, 1999; Lee, So & Tang, 2000). However, there is little research that addresses information sharing in CLSCs.

This research investigates the impact of the remanufacturer providing advance notice of the product returns on the performance of the manufacturer in a decentralised CLSC. We focus on the stochastic and dynamic performance of the supply chain. The lead times, the degree of correlation between the demand and the product returns, and the random yield of the remanufacturing process are all incorporated into a mathematical model to investigate the benefit of advance notice via a variance analysis. With a constant lead time, the returns are converted into “as-good-as-new” products that are used alongside newly manufactured items to satisfy market demand. To cope with the uncertainty in demand and returns the manufacturer must forecast them both. However, the returns are already known to the external remanufacturer and this information could be shared in an advance notice scheme. We demonstrate that both the remanufacturing and the manufacturing lead times, the remanufacturing yield, the parameters of the return process, and the advanced notice scheme can have a significant impact on the manufacturer’s performance.

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As we progressed through our study we became aware that certain knowledge from our understanding of traditional supply chains does not hold true for CLSC. For example, the rule-of-thumb that "reducing lead time improves the dynamic performance of a traditional supply chain" does not always hold true in our CLSC. We were also surprised to learn that higher returns can sometimes reduce supply chain performance.

This paper is organized as follows. Section 2 provides a literature review. Section 3 defines our CLSC model. Section 4 deduces managerial properties from an analysis of the production quantities and inventory levels. Section 5 presents insights from a numerical exploration. Section 6 concludes. Some proofs are provided in the appendices, and summarises some numerical experiments for verification.

2. Literature review

Using some approximations when necessary, Ketzenberg, van der Laan and Teunter (2006) presented two analytical models for quantifying the value of information in the CLSC: a one-period model and a multi-period model. Information on the market demand, the returns and the remanufacturing yield was shared and its impact investigated. Assuming a capacitated CLSC, Ketzenberg (2009) investigated the value of sharing demand, returns, yields and capacity utilization information. Costs were quantified using a simulation study. It was shown that information regarding capacity utilization leads to the largest average benefit, though no type of information is dominant.

De Brito and van der Laan (2009) investigated the impact of imperfect information on the forecast of lead time demand in a remanufacturing setting. Inventory cost was used to quantify the consequences of imperfect information. Based on an analysis of four different forecasting methods, they concluded that the most informed forecasting method does not always result in the least cost. Flapper, Gayon and Vercraene (2012) considered imperfect advance return information and inventory cost using a Markov decision formulation. A random return lead time was assumed in a model with finite capacity but no correlation existed between demand and returns. They concluded that advance return information can reduce inventory cost by up to 5 percent, and this was affected by the expected return lead time.

The importance of considering delays in a system is well recognized (Forrester, 1961). Flapper et al. (2012) and Ferrer and Ketzenberg (2004) suggested that it might be reasonable to assume that lead times affect the value of information sharing. Assuming that both lead times were stochastic, van der Laan, Salomon and Dekker (1999) numerically investigated the impact of lead times. Poisson distributions were used to represent demand and return processes. It was found that a longer remanufacturing lead time resulted in a cost reduction, though longer manufacturing lead times always resulted in a cost increase. Inderfurth and van der Laan (2001) also supported this finding. Despite this theoretical support, Guide (2000) found that 60 percent of remanufacturing executives were under pressure to reduce remanufacturing lead times.

It is widely recognised, that demand and product returns are correlated with each other (Akçalı & Çetinkaya, 2011). This correlation assumption is intuitively understandable, as part of the demand eventually becomes the input into the remanufacturing process (Akçalı & Çetinkaya, 2011). van der Laan, Salomon, Dekker and van Wassenhove (1999) and Ketzenberg et al. (2006) modelled correlation between demand and the product returns with product returns that were a random function of the demand. Mitra (2012) assumed that product returns were a fraction of the demand plus a random term.

Practically it is common to have a random yield in the remanufacturing process as the quality of the return products is understandably varied (Guide, 2000). Ferrer and Ketzenberg (2004), Ketzenberg et al. (2006) and Ketzenberg (2009) used a Bernoulli process to represent a remanufacturing process with random yields. Yano and Lee (1995) suggested that one advantage of using the Bernoulli process was its simplicity, but this approach forbids the specification of yield variability. Akçalı and Çetinkaya (2011) suggested that only a few studies incorporate a random yield assumption. This rarity is probably due to the analytical complexity introduced by this feature.

Our research considers the impact of the value of advance notice on the dynamic and stochastic performance of a decentralised CLSC. The demand and the returns are stochastic and cross-correlated. In our model, the lead times of the manufacturer and the remanufacturer and the random yields in the remanufacturing process are considered. We characterize the variances of the serviceable products, the net stock levels and the production orders without specifying their probability distribution functions (PDFs). To the best of our knowledge, there are no previous studies that simultaneously consider the value of information, the impact of lead times and the random yield in a CLSC setting with correlated demands and returns in such a way. Interested readers can find a comprehensive review of recent CLSC literature in Akçalı and Çetinkaya (2011) and Govindan, Soleimani and Kannan (2015).

3. Model

Fig. 1 shows a schematic of our decentralised CLSC model. It is a periodic review system where both the manufacturer and the remanufacturer employ the same review period. The manufacturer uses an order-up-to policy (Hosoda & Disney, 2006) to determine its production quantity. Both the manufacturing and the remanufacturing processes have unlimited capacity. We assume that there is no difference between remanufactured and new products in terms of quality. This

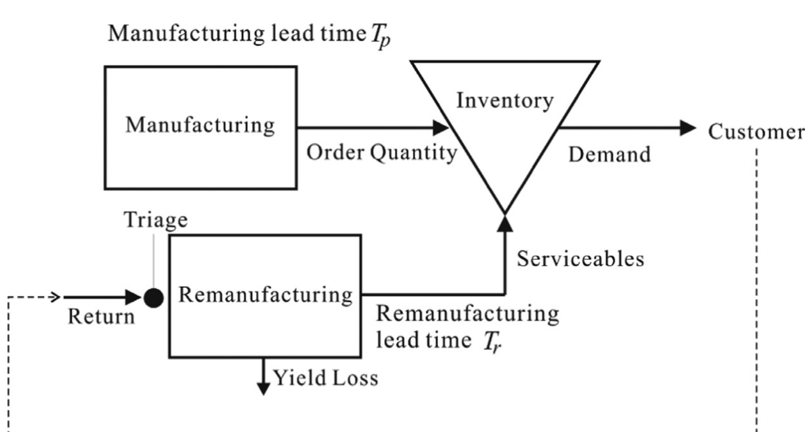

Fig. 1. Schematic of material flow.