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Optimal lot-sizing integration policy under learning and rework effects in a manufacturer–retailer chain

Tsung-Hui Chen [a], Yu-Chung Tsao [b,*]

[a] Department of Marketing and Distribution Management, National Pingtung Institute of Commerce, Pingtung, Taiwan, ROC

[b] Department of Industrial Management, National Taiwan University of Science and Technology, Taipei, Taiwan, ROC

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ABSTRACT

Most research in economic manufacturing/order quantity management assumes that all products are of perfect quality and are produced at a constant production rate. One result of this assumption is that the number of units produced in a given period is constant, which is not the case in real life. Most production systems produce items which are of perfect quality along with some that are of imperfect quality. Defective items, as well as the learning effect, affect production and inventory costs, thereby shaping the performance of the manufacturer–retailer chain. The present study uses the Nash, Stackelberg, and cooperation games to model an imperfect production system to investigate the combined effects of lot-sizing size integration, the learning effect, imperfect production, and the rework process on a manufacturer–retailer channel. This study also demonstrates the optimal properties of the proposed models, develops a search algorithm for obtaining optimal solutions, and conducts a numerical study to seek structural and quantitative insights into the structure of the proposed models. In addition it analyzes the sensitivity of the solutions in relation to the major parameters.

1. Introduction

A basic assumption of the classic economic manufacturing quantity model is that all items being manufactured are of perfect quality and are produced at a constant production rate. One result of this assumption is that the number of units produced in a given period is constant, which is not the case in real life. Most production systems produce both acceptable and defective items. Production and inventory costs are influenced by the defective items, thereby shaping the performance of the manufacturer–retailer chain. Further, the firm must rework imperfect products, thus incurring repair and holding costs, leading to an increased total cost. It is therefore essential that defective products are taken into consideration when formulating a realistic production model (Tsao et al., 2011).

In the early stages of a product's evolution, when a product's functionality does not yet meet the needs of key customers, companies compete on the basis of product performance. Later, when the underlying technology improves and the needs of the mainstream customers are met, companies compete on the basis of customization, flexibility, pricing, channel-wide performance, and ability to determine the best manufacturing/order quantity (Christensen et al., 2001; Harris, 1913).

Researchers have used the insights of game theory to generate numerous analyses of the manufacturer–retailer supply chain. Monahan (1984) and Lal and Staelin (1984) first investigated the one-vendor one-buyer supply chain with constant demand and price discounts based on an order quantity. The authors used a Stackelberg game to determine the optimal quantity discount schedule from the vendor's point of view for achieving an optimal solution for both the vendor and the buyer. In order to improve system-wide cost effectiveness, Kohli and Park (1994) proposed joint ordering policies as a method to reduce the transaction costs between a single seller and a homogeneous group of retailers. The results of their study showed that the efficiency of joint lot-sizes is independent of price, and is supported by a range of average-unit prices that permit every possible allocation of transaction cost saving between the buyer and the seller. Oczkowski (1999) illustrated the usefulness of employing limited dependent variable techniques to analyze bargaining in bilateral monopoly markets, and found that the technique's strength is that only the data on price and the number of transactions are needed to empirically measure the influence of the determinants that govern bargaining limits, bargaining strengths, and the resulting profits. To understand the effects of coordination between the marketing and production departments in two competing firms and a common

* Corresponding author.
E-mail address: yctsao@mail.ntust.edu.tw (Y.-C. Tsao).

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retailer, Parlar and Weng (2006) established game-theoretic models that show that coordinating the pricing and production quantity decisions in a firm may place that firm in a stronger position to increase its expected profits. Hsu et al. (2006) extended the lot-sizing problem by developing an inventory model of season pattern demand with expiration date. They compared the price discount model with the non-price discount model, and proposed an effective algorithm to determine the optimal replenishment cycle, shortage period, and order quantity for maximizing the total profit. In a three-echelon supply chain, Hsu et al. (2009) investigated an optimal lot-sizing policy for deteriorating items. They considered a seasonal demand pattern and an uncertain lead time for the items to provide a reference model for practical application. They also found that higher demand at the beginning of the replenishment period and variable ordering time increase the profit of the retailer. Lu et al. (2011) applied a game-theoretic framework to investigate the importance of service from manufacturers in the interaction between two competing manufacturers and their common retailer, when facing end consumers who are sensitive to retail price and service by the manufacturer. Their research found that consumers receive a higher level of service when the channel members have equal bargaining power. In that case the retailer separates the market segments by selling products with different levels of service and retail price when one of the manufacturers has an economic advantage in providing a service.

The aforementioned literature makes the unrealistic assumption that the items are perfect in both the production cycle and the selling period. In practice, systems that produce only perfect-quality items are largely non-existent. Liu and Yang (1996) investigated the problem of determining the optimal lot size in a single-stage imperfect production system under a higher than normal failure rate setting. They classified the defects produced as either re-workable defects or non-reworkable defects. Based on extending the EPQ/EOQ inventory formulation, Salameh and Jaber (2000) found that each lot received contains a percentage of defective items, with a known probability density function. The results of their research showed that the average percentage of imperfect quality items tends to increase as the economic lot size increases. However, Salameh and Jaber's (2000) study contained the errors in an equation and in a numerical example. Cárdenas-Barrón (2000) corrected the errors of the equation and the numerical example, and shown that the errors does not affect the main idea and the remainder of the article. Jamal et al. (2004) developed a production lot size model for determining the optimal batch quantity in a single-stage system in which the rework is completed within the same cycle, or after n cycles. It is evident from their numerical examples that the carrying and penalty costs for reworking defective items increases as the number of production cycles before the defective items are reworked rises. Cárdenas-Barrón (2009) extended Jamal et al. (2004) by developing an inventory model with planned backorders for determining the economic production quantity in an imperfect manufacturing system. The authors also used numerical examples to illustrate the optimal solution, and a closed form for the total cost of the inventory system. Their study involved the effect of backorders on the rework system. Ojha et al. (2007) proposed three different policies to show that the cost of the single-purchase-single-delivery case merges asymptotically with that of the lot-for-lot case which has a higher ratio of setup cost and ordering cost, and which increases at a much higher rate than in the single-purchase-multiple-delivery case. Chiu (2008) took into consideration the production of defective items and the inevitable random breakdown of production equipment. He incorporated the stochastic breakdown of production equipment and the reworking of defective items into the economic production quantity model for optimizing the production run time. Abdul-Kader et al. (2010) developed a model for optimizing the cost of reworking the off-specification items as well as the cost of adjusting manufacturing processes for eliminating rejects. The major contribution of their study is that their model is a reference model for production managers making investment decisions to correct defective processes.

The development of a traditional production model usually assumes that unit production costs are constant, which is far from reality while learning is in progress. Jaber et al. (2008) assumed that the percentage of defective products per lot declines according to a learning curve, which was empirically validated by data from the automotive industry. The results of their study demonstrated that by increasing the learning effect they could reduce the number of defective units, the shipment size, and the cost, all following a form similar to the logistics curve. Learning and job deterioration co-exist in many real life scheduling situations. Wahab and Jaber (2010) extended the work of Jaber et al. (2008) by considering different holding costs for good and defective items. They showed that the lot size with different holding costs for the items is larger than if the holding cost was the same for all items. They found that the difference between the lot sizes with and without different holding costs disappears with the amount of learning in the system. Chen (2011) proposed the Nash and the cooperation inventory models for a manufacturer and retailer supply chain, which considers the combined effects of the cooperative advertising mechanism, returns policy, and vendor–buyer coordination. His study revealed that the cooperative decision policy is always found to be superior to the non-cooperative decision policy in terms of profit improvement. Yin and Xu (2011) introduced a general scheduling model by simultaneously considering the effects of learning and deterioration. They used a polynomial method to solve single-machine scheduling problems to minimize the makespan, total lateness, and sum of earliness penalties. They showed that the problems of minimizing the total weighted completion time, discounted total weighted completion time, maximum lateness, maximum tardiness, total tardiness, and total weighted earliness penalties are polynomial solvable. Tsao et al. (2011) extended the traditional production model by considering rework of defective items and trade credits to reflect real life situations. Unlike previous models, their model calculated the interest earned based on the retail price. The authors developed an easy-to-use algorithm for solving the above described problem, and provided numerical examples to illustrate the influence of interest charged, interest earned, and the impact of the percentage of defective items on both production and total cost. Most imperfect quality inventory studies do not consider the imperfect inspection process and the related defect sales returns issue despite their practical significance. Taheri-Tolgari et al. (2012) presented a profit maximizing inventory model that incorporated both imperfect production quality and two-way imperfect inspection. They also provided a solution procedure for finding the optimal production policy, and they discussed the concavity conditions. Their numerical results showed that the total profit is sensitive to both the production and inspection rate, as well as the production and rework costs. Soni and Patel (2012) examined the effect of defective items on an integrated inventory system with variable production rate and price-sensitive demand. The authors considered a two-level trade credit policy in which the retailer receives a full trade credit from the supplier, and offers a partial trade credit to its customers. The settings of Soni and Patel's (2012) model are seldom studied in the literature. This study differs from the previous work in several ways. First, we consider the supplier as a make-to-stock producer who purchases raw materials from outside vendors periodically and stocks intermediate inventory stockpiles that will be used for the final assembly or production