Int. J. Production Economics 139 (2012) 127–134

Contents lists available at ScienceDirect

Int. J. Production Economics

journal homepage: www.elsevier.com/locate/ijpe

Dynamic pricing in the newsvendor problem with yield risks

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ARTICLE INFO

Article history:
Received 31 October 2009
Accepted 20 January 2011
Available online 4 February 2011

Keywords:
Yield risk
Dynamic pricing
Supply chain risk management
Newsvendor problem

ABSTRACT

Nowadays supply chains are facing challenges in managing risk issues. Supply of raw materials may exhibit a random yield due to technical failure of production resources or supply disruption after a natural disaster. In case supply has a random yield, one way to reduce supply chain loss is by introducing a dynamic pricing policy, with the aim of manipulating demand in the market while inducing the customer to buy substitute products temporarily. This paper investigates newsvendor problem with random demand and random yields, in which the price decision will be postponed and determined upon recognition of random yield and prior to realising demand uncertainties. With the objective of maximising expected profits, we develop the optimal price and ordering decisions in the system, while comparing the system's performances with dynamic and fixed pricing policies. Further, we investigate the conditions of adapting dynamic pricing policy. An interesting finding shows that such a policy brings increase in benefit when demand uncertainty is small. The outcome of this research provides alternative solutions in designing a robust supply chain.

1. Introduction

1.1. Background

Today's supply chains are facing a changing production environment due to various factors: short product life cycle, physically extended supply networks, and high dependency on internet and information systems, among other scenarios. Along with the technological and economic advancements in the above changes, we have also observed a growth in supply chain vulnerabilities. These vulnerabilities impact supply chains heavily, as any risk event occurring at any point of the supply chain could further lead to disruption of the whole system. Thus, handling supply chain risks and evaluating different mitigation policies have become important in today's supply chain management.

In the case of Taiwan earthquake in 1999, Dell's supply channel was affected when one of their second tier suppliers, TSMC, was involved in the incident. In order to minimise the impact of supply shortage from TSMC, Dell was forced to manipulate customer demand. As an on-line-sales practitioner, Dell had the advantage in influencing customers demand by offering lower prices on the products that consume alternative electronic components from other suppliers. This pricing strategy by Dell in response to the event was indeed impressive and helped them reduce losses from supply shortage.

On the other hand, despite the efforts in improving supply reliability and quality in industry, the supply yield is far from perfect. When an order is placed, there is always a risk of mismatch between the releasing and receiving of order quantities. In the semiconductor manufacturing industry, such yield loss can reach as high as 80% (Nahmias, 2008). Similarly, yield risk exists in retailing industry (due to information disorder) and remanufacturing (due to quality uncertainty of returns). However, the mechanism of pricing policy (such as the one in Dell's) and its impact on other operational decisions have not been thoroughly investigated. Even though there are studies investigating the pricing and random yield issues, these two streams of study often appear independently in literature.

The above background inspires our current research. In this paper, we aim to investigate the possibility of using pricing policy as a mitigation tool for yield risk. Specifically, we develop a detailed model in order to identify when and where a postponed and dynamic pricing policy could improve the economic consequences in case supply has random yields. We also focus on a system with relatively long replenishment lead time, so that the deficiency due to yield cannot be made up by emergency orders. In the meantime, the pricing decision needs to be made in order to tentatively reduce the inventory shortage and surplus during the selling season. Based on these problem settings, we investigate the above issues by adopting the newsvendor model, which

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doi:10.1016/j.ijpe.2011.01.018

is widely applied in literature in studying the pricing policy (Petruzzi and Dada, 1999) and random yield (Inderfurth, 2009). Furthermore, demand is treated in both deterministic and stochastic cases.

1.2. Literatures review

As mentioned before, the literature relevant to current study in production and inventory systems can be divided into two main streams, namely pricing policy and random yields. We provide a brief review of the literature in these two areas.

1.2.1. Pricing policy

There is a body of literature discussing pricing policy and its influence on production and inventory decisions. Studies aim at either finding the optimal price value or introducing dynamic pricing policy. Early research dealing with dynamic pricing was conducted by Gallego and van Ryzin (1994). With such a policy, price level varies with time or with the realisation of events, such as demand. Dynamic pricing is also widely investigated in revenue management (Bitran and Mondschein, 1997).

Petruzzi and Dada (1999) presented a well-cited paper on pricing policies of newsvendor models. They investigated price-dependant demand models for both multiplicative and additive cases, and further developed a unified framework for solving the optimal price in both cases. Their study demonstrates how optimal price level varies with different uncertainties introduced to the demand function. The unimodality of the objective function has also been discussed. Emmons and Gilbert (1998) studied pricing policy with a focus on return issues in a single period setting. They analysed the problem from both manufacturer and retailer perspectives. In the case of demand uncertainty, they demonstrated that retail price increases with uncertainty. Furthermore, contract issue and its influence on price have been discussed.

When introducing new products, companies nowadays often have to make decisions on capacity investment with regard to demand uncertainty. This issue has been discussed by Van Mieghem and Dada (1999) and Biller et al. (2006). In the study by Van Mieghem and Dada (1999), profit values were analysed and compared when price and/or production quantity decisions can be postponed after the realisation of demand. Biller et al. (2006) also considered the price-dependant demand functions.

During the last few years, we also observe increasing interests in the joint fields of pricing and learning (Petruzzi and Dada, 2002; Bisi and Dada, 2007; Levina et al., 2009), pricing issues with regards to perishable or non-perishable products (Karakul, 2008; Biller et al., 2005; Hamister and Suresh, 2008), product variety (Villas-Boas, 2009), stochastic demand (Zhang et al., 2008), and stochastic redemption rate (Arcelus et al., 2007). Research in pricing policy can also be categorised into various demand methods (Yin and Rajaram, 2007).

Another extension of pricing policy is toward multiple-period problems. Biller et al. (2005), for example, presented dynamic pricing with the consideration of production scheduling and inventory control. They demonstrated that dynamic pricing promotes market share, and its improvement level depends on demand variability.

For recent reviews of the literature on dynamic pricing, we refer to Bitran and Caldentey (2003) and Elmaghraby and Keskinocak (2003). Particularly, Elmaghraby and Keskinocak (2003) noted that a promising direction for future research is in applying customers' specific information to make customised offers. However, we have to note that in the above mentioned studies, one common assumption is that supplies are considered reliable without any uncertainty.

1.2.2. Random yield

As illustrated earlier, with the expansion of supply chains, networks have become more vulnerable with uncertainties. Therefore, it is no surprise to see rising number of studies dealing with supply yield issues, particularly in the last decade (Bollapragada and Morton, 1999; Hsu and Bassok, 1999; Grosfeld-Nir et al., 2000; Inderfurth, 2004, 2009; Inderfurth and Transchel, 2007; Li and Zheng, 2006).

Various approaches and policies have been investigated to handle the supply yields. Bollapragada and Morton (1999) presented myopic heuristics for the random yield problem with linear control rules. Their studies were further investigated by Inderfurth and Transchel (2007) by introducing production lead time in the heuristics. Inderfurth (2009) investigates demand uncertainty and supply yield in the material requirements planning (MRP) systems. Incorporating both supply and demand risks and using stochastic inventory theory, Inderfurth states that the safety stock level no longer increases linearly with respect to the uncertainty.

Li and Zheng (2006) also attempted to solve the optimal pricing and inventory replenishment problem by analysing a single-item, periodic-review inventory system. They applied Markov decision programming to show that high initial inventory decreases optimal price and quantity. They also compared the certain and uncertain yield cases and illustrated that certain yield situation brings better system performance. Liu et al. (2010) present another related study in which demand is manipulated and determined as a result of marketing effort, whereas product price is fixed. Not surprisingly, when marketing effort is high, demand increases and it further increases the profit. However, in case of high supply reliability, there is no pressure for marketing effort.

From the above mentioned literature, we see in many cases, the two issues, pricing policy and supply yield, are often treated separately. In other cases, even though random yield and price issue have been both investigated (Li and Zheng, 2006), it is in fact a static price policy, i.e. price and order quantity decisions are optimised simultaneously. The only exception we found is the research by Tang and Yin (2007), in which the authors considered a newsvendor problem facing a price-dependant demand with random supply yields. A responsive pricing policy is analysed and it is the most relevant work to current research. However, the major difference is in the demand assumption, where in Tang and Yin (2007) it is presumed to be deterministic.

Based on the above literature, we notice a research gap in dealing with both random yield and pricing policy issues in stochastic demand environments. In particular, it is unclear how a dynamic and postponed pricing policy could influence the supply yield problem. Thus, in this paper we study a production and inventory system with single selling season with random demand and random yields. Our aim is to investigate a postponed and dynamic pricing policy and its influence on the economic consequences in the system. Furthermore, we attempt to identify under which circumstances such a policy should bring more benefits to the system. Current research thus differs from early studies, and its result should fill the research gap in the area. The outcome of this study should also provide an alternative in designing a robust supply chain.

As mentioned before, current research is based on a single period with certain/uncertain demand. Model development is based on the framework of newsvendor problem. Despite its strict assumption of a single selling season, this model brings convenience in analysing stochastic inventory systems. It has