European Journal of Operational Research 218 (2012) 113–123

Contents lists available at SciVerse ScienceDirect

European Journal of Operational Research

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

Production, Manufacturing and Logistics

Ship-to-order supplies: Contract breachability and the impact of a manufacturer-owned direct channel

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ARTICLE INFO

Article history:
Received 3 May 2011
Accepted 13 October 2011
Available online 4 November 2011

Keywords:
Supply chain management
Gaming
Uncertainty modeling
Inventory

ABSTRACT

We address the issue of contract breachability in a supply chain involving a retailer and a manufacturer operating under ship-to-order contract terms and stochastic demands. The manufacturer is required to fulfill the retailer's demands on a continuous basis with little or no advance notice. The issue in such an environment is whether the retailer can "naively" assume that she will get a very high fill rate from the manufacturer and therefore has no need for contract penalties in case the manufacturer's inventory falls short. We suggest a stochastic calculus framework to study the problem and derive a condition when the retailer's naïve assumption is justified since the probability of stock-outs of the manufacturer is negligible. That is, the ship-to-order contract will not be breached and the fill rate will be more than a predetermined threshold. Furthermore we find that although the manufacturer-owned direct channel generates more revenue and may reduce the volatility of both inventory and production orders, the ratio between expected direct channel and retail sales affects the benefits.

1. Introduction

A primary consideration of supply chain management is the flow of goods from the source of raw materials to the ultimate end consumer. The focus on speed and the costs associated with the flow of goods in supply chains has given rise to such management strategies as *Continuous Replenishment Program, Efficient Consumer Response, Ship-to-Order* and *Demand Driven Supply* (see, for example, Raghunathan and Yeh, 2001; Harris et al., 1999; Barnes et al., 2000; Ayers, 2001). These strategies are based on the high visibility of customer demand and inventory flow throughout the supply chain along with the capability to respond rapidly to order requests. For example, large contract manufacturers (CMs) in the electronics industry are often contractually obliged by original equipment manufacturers (OEMs) to meet their demands on a continuous basis in a just-in-time mode with little or no advance notice (Barnes et al., 2000). The distribution system at Wal-Mart, (the world's largest public corporation by revenue) is based on a real-time response as well. Individual Wal-Mart stores transmit point-of-sale (POS) data from the cash register back to corporate headquarters. This demand along with the store's inventory information is used for continuous review and to setup shipments from the supplier to the Wal-Mart distribution center and the stores. Similarly, Hewlett-Packard Manufacturing Industries has long been guided by its understanding of the need for agility especially as the company moves closer to a ship-to-order or ship-to-demand environment.

Prompt response to customer demands has long been especially important in the health industry. For example, the Victoria Healthcare Association (VHA) set up a \$2.2 billion distribution program in contract purchases for a group of hundreds of hospitals and suppliers. Yet in 1997, the group established standards for its manufacturing partners as well as its authorized distributors (Business Word Inc., 1997). Currently, VHA has 77 so-called aligned manufacturers that were brought into a program that rates each company's behavior in the supply chain. The criteria include notifications of 45- to 60-day price and contract changes and a minimum fill rate. The fill rate starts at 85% with more points awarded for higher fill rates.

In this paper we consider a two-echelon supply chain with a supplier (manufacturer) who is required to fulfill demand in a ship-to-order mode from a downstream firm (who may also be a manufacturer, but whom we refer to below as a retailer). The demand that the retailer faces is stochastic. The parties are transparent in terms of information, interdependent in terms of decision-making and continuously monitor their inventories. Accordingly, the basic model in this study is the classic channel system of a manufacturer and a retailer. In such a system the manufacturer typically offers a wholesale price first. The retailer then orders products with respect to the wholesale price and her inventory level. Consequently, the supplier is able to predict the retailer's response when choosing his production and inventory policy to maximize profits from sales through the retailer and, possibly, through his own factory outlet – a store in which he sells

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doi:10.1016/j.ejor.2011.10.022

directly to the public. The latter approach has become especially popular among clothing, electronics, furniture and healthcare industry manufacturers. Consequently, this setting fits a broad category of models referred to in the literature as supply chain inventory (SCI) games, where the supplier is the Stackelberg leader. Special attention in these games has been paid to reorder point policies. These policies are typically employed in continuous-review inventory systems to unveil the effects of SCI competition when the supplier is not always able to immediately meet the retailer's orders (see, for example, Graves, 1985; Svoronos and Zipkin, 1988; Axsäter, 1990; Cachon, 2001). Specifically, Cachon (2001) analyzes equilibria in a SCI game in which it is assumed that the parties utilize reorder point policies; each firm continuously monitors its inventory position; and the supplier does not necessarily provide immediate shipments. If inventory is available, the supplier immediately ships a retailer's order. Otherwise, the supplier's backorders consist of the retailer's unshipped orders. Cachon shows that the game belongs to a special class of games, called *supermodular games*, which implies that when one party increases its reorder point the other may decrease it.

Unlike this supply chain interaction, another stream of research involves differential games, i.e., it is based on a hundred percent fill rate of the retailer's orders and decisions that have to be made continuously. Supply chain management literature has been primarily concerned only with applying deterministic differential games under quadratic cost functions. Jorgenson (1986) derives an open-loop Nash equilibrium under a channel setting and static deterministic demand. Eliashberg and Steinberg (1987) use the open-loop Stackelberg solution concept in a game with a manufacturer and a distributor involving gradually changing demand potential. To address deterministic seasonal demands, Desai suggests a numerical analysis for a general case of the open-loop Stackelberg equilibrium (Desai, 1996).

While the above papers adopt either a static setting, or a dynamic but deterministic perspective, in this paper we employ a stochastic and dynamic setting thereby extending the dynamic models formulated by Jorgenson (1986), Eliashberg and Steinberg (1987), and Desai (1996). This is accomplished within a stochastic calculus framework by modeling underlying inventory processes with stochastic differential equations. Specifically, as with deterministic differential models, we assume that the terms of contract between the parties require the manufacturer to guarantee immediate supplies at the retailer's request without either advance notice or unshipped orders. As a result, the retailer fully relies on timely supplies and may not consider the manufacturer's inventory level when making a decision. The manufacturer, on the other hand, accounts for his stocks as well as for those of the retailer since this is critical for satisfying the terms of the contract. As distinct from the deterministic differential models, we account for stochastic replenishment orders from the retailer and for the manufacturer-owned direct channel sales, which are stochastic as well. Under these conditions, the retailer could be assured of immediate supplies by imposing a so-called chance constraint, i.e., the requirement that the probability of stock-outs at the manufacturer's site be lower than some predetermined threshold. Since such a constraint, however, is difficult to meet for arbitrary system parameters, the retailer's assumption that the manufacturer will always (or almost always) fill the terms of the ship-to-order contract may not be justified. Therefore, our approach is to find a solution without the chance constraint and then determine the conditions for the system parameters when this solution does not violate the chance constraint. The fact that the constraint is not binding then implies that the retailer can indeed rely on timely supplies.

Similar to the differential inventory games, we utilize convex costs, which imply that the optimal behavior of the parties is not a reorder point policy. Specifically, we follow the classical quadratic-linear inventory model which assumes that the associated inventory and order costs are convex (Heyman and Sobel, 2003; Aviv, 2007). As a result, an optimal replenishment order as well as the equilibrium production rate is proportional to the difference between the current inventory and the corresponding set point (the target value). Furthermore, the relationship between the set points of the two parties can be either synchronous (when one set point increases the other increases as well) as in submodular games or inverse (substitutive) as in supermodular games, which depends on the source of change of the set point. We demonstrate that with the aid of stochastic calculus it is possible to assess the inventory distributions of the parties over time and at a steady state. Consequently, we derive the conditions when the probability of stock-outs is less than a predetermined threshold and, thus, the manufacturer is able to fulfill the contract terms. In general, the threshold varies depending on the specific industry, managerial policy, cost structure and so on. For expository simplicity, we employ throughout the paper the three-standard-deviation rule to justify the approximation with the threshold, as is extensively used in statistical process control. Thus, in terms of contract breachability, this rule implies that a 99.86% fill rate is sufficient for regarding all stochastic operations as under control and thereby the contract not violated.

Special attention is paid to the impact of the manufacturer-owned direct channel on contract breachability and thus supply chain sustainability. For conciseness, we henceforth refer to the manufacturer-owned direct channel as the "outlet". Specifically, we show that the manufacturer always attenuates the variance of demand when there are no outlet sales. The outcome is quite expected since the supply chain features sharing information and smoothing the flow of products (see, for example, Lee et al., 1997; Mason-Jones et al., 2000; Chen et al., 2000).This outcome also agrees with the conclusions of the investigation conducted by Cachon et al. (2007), who documented the strength of the bullwhip effect derived from industry-level US data. Moreover, one would also expect that outlet sales could further decrease the variance (i.e., the manufacturer imposes less volatility on his suppliers than is imposed by the retailer) when the correlation between the retail demand and the outlet demand is negative. Such a reduction in the variance would be attributed to the pooling effect since inventories intended for the retailer's orders and outlet sales are consolidated. Risk pooling typically yields a lower cost and the effect is increasing in the variance of demands and negative correlation between the demands (see, for example, Alfaro and Corbett, 2003; Gerchak and He, 2003; Zipkin, 2000). We show that the variance of the manufacturer's inventories is not necessarily pooled even when the correlation is negative and derive a condition which ensures the pooling effect. In particular, this condition holds if the variance of the outlet sales is lower than that of the retail sales. Otherwise, the outlet sales may have a negative impact on the supply chain since the volatility of the production orders may increase relative to the volatility of the demand for supplies. This will pass on higher demand variability to upstream suppliers thereby generating the bullwhip effect in the supply chain as well as increase the volatility of the manufacturer's inventories. The higher volatility will, in turn, lead to an increase in the probability of stock-outs at the manufacturer's site thereby affecting the sustainability of the supply chain.

2. Problem formulation

Consider a manufacturer, *A*, whose factory manufactures products and sells them at the manufacturer's own factory outlet as well as supplies the products to a retailer, *B*. The products are