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Streamlining inventory flows with time discounts to improve the profits of a decentralized supply chain

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ABSTRACT

We consider a decentralized supply chain, whereby a supplier sells a product to a group of independent buyers, and develop a strategy for the supplier to offer an all-units price discount or cash rebate for orders that are synchronized with its replenishments. As synchronized orders can be met with inventory directly from receiving to shipping without warehousing, the proposed strategy streamlines system inventory flows to minimize inventory and, hence, the related costs. On the other hand, by increasing the replenishment interval of the supplier, the proposed strategy is able to induce buyers to order in large quantities and hence achieve the objectives of quantity discounts. We show that the proposed strategy can achieve nearly optimal (minimum) system cost, and is much more effective than the existing coordination strategies for decentralized supply chains in the literature.

1. Introduction

Supply chain coordination has attracted considerable interest from both academics and practitioners. Many firms have realized that collaborating with their supply chain members can substantially improve their profits and enhance their strategic positioning. However, supply chain members are often separate economic entities that act independently and opportunistically to optimize their individual profits. The challenge, then, is to create useful and effective coordination mechanisms that are able to improve performance not only for the party that takes the initiative, but also for the entire supply chain (Li and Wang, 2007; Arshinder et al., 2008).

Previous research into this problem has focused on using quantity discount policies for suppliers to induce independent buyers to increase their order quantities so as to reduce ordering and order processing costs. Crowther (1964) first demonstrated that quantity discounts could substantially improve channel efficiency. Subsequently, various quantity discount policies were developed under different channel conditions (see, e.g. Dolan, 1978; Monahan, 1984; Lal and Staelin, 1984; Joglekar and Tharthare, 1990; Parlar and Wang, 1994; Weng, 1995; Wang and Wu, 2000; Munson and Rosenblatt, 2001; Wang, 2002; Altintas et al., 2008; Bellantuono et al., 2009). These studies showed that quantity discounts are able to produce significant benefits for independent suppliers and buyers.

However, the benefits from quantity discounts usually represent only a small portion of the maximum potential benefits of supply chain coordination (Wang, 2002). Consider a two-echelon supply chain whereby a supplier sells a product to a group of independent retailers. In addition to the benefits of quantity discounts, there are at least two other important benefits that the supplier can exploit. First, the supplier can induce buyers to synchronize their orders with its replenishments so that such orders can be met directly with inventory from receiving to shipping without warehousing, hence reducing its inventory and inventory holding cost. Secondly, the supplier can consolidate orders at common points in time so that such orders can be delivered and/or processed more efficiently, hence reducing its delivery and/or order processing costs.

Recent studies have addressed this issue by combining quantity discounts and a power-of-two or integer-ratio policy (Wang, 2001, 2004). A power-of-two or integer-ratio policy requires buyers to order in intervals that are power-of-two or integer-ratio multiples of the supplier's constant replenishment interval, and is able to achieve at least 98% of optimality for a centralized supply chain (Roundy, 1985, 1986). These studies advance the understanding of supply chain coordination by showing that the combination of quantity discounts and time coordination that synchronizes supply chain inventory decisions and activities can produce significant benefits over traditional quantity discounts. However, there is still a significant benefit that cannot be obtained by these mechanisms.

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This study develops the following new strategy: the supplier takes the initiative to set up a constant replenishment interval and provides an all-units price discount or cash rebate for orders that can be delivered at the arrival points of its replenishments. As an example, let the supplier order once a week and receive deliveries on Monday. The supplier then offers a price discount or cash rebate for every unit that can be delivered on Monday. Buyers remain independent economic agents and act rationally to minimize their relevant costs. The supplier offers a sufficiently large benefit to induce buyers to comply with the coordination mechanism and imposes no other conditions on their ordering decisions. Following previous quantity discount studies, we develop the supplier's optimal strategy and the buyers' optimal ordering decisions as (equilibrium) solutions to a Stackelberg game, in which the supplier acts as the leader and the buyers act as followers (Tirole, 1988).

The proposed strategy differs from a coordination strategy that combines quantity discounts and time coordination in several aspects. First, the supplier offers a quantity discount for any order at any point in time that meets a minimum quantity requirement under the latter strategy (Chen et al., 2001; Wang, 2004). In contrast, the supplier offers a price discount for every unit that is ordered at (and only at) an arrival point of a replenishment from the outside source under the former strategy. We refer to this discount scheme as *time discount*. Second, while the two incentive schemes share a common purpose of inducing buyers to comply with the coordination mechanism, the primary purpose of a quantity discount is to induce buyers to increase their order quantities, whereas the primary purpose of a time discount is to induce buyers to synchronize their orders with replenishments at the supplier. Finally, in response to the different incentive schemes that are adopted by the supplier, a buyer will always order in the same replenishment interval or order quantity under the latter strategy. However, a buyer may place a large order at a point with time discount and smaller orders subsequently under the former strategy. The former strategy provides a more effective mechanism to streamline inventory flow in the supply chain. We demonstrate in a numerical study that the proposed strategy is able to reduce system inventory by more than 6.6% and system inventory related cost by more than 4.6% as compared to the coordination strategy that combines quantity discounts and an integer-ratio policy. Furthermore, the proposed strategy is able to achieve a system cost that is not more than 2% higher than the minimum system cost in the numerical study. In addition, we also show that these observations are robust with respect to changes in the supply chain demand and cost structure. Therefore, the proposed strategy provides a highly effective coordination strategy for a decentralized supply chain.

These findings provide useful insights into the coordination of decentralized supply chains. First, time coordination provides a significant dimension for supply chain coordination. The proposed strategy focuses on time coordination and is able to achieve almost minimum system cost. In contrast, a substantial portion of the potential supply chain coordination benefit cannot be achieved by quantity discounts. Second, the findings provide a new interpretation, as well as a new application strategy, for quantity discounts. The proposed strategy offers only a simple price discount and is able to achieve better results than a strategy that combines a full quantity discount schedule and an integer-ratio coordination scheme. This suggests that time coordination is able to achieve the benefits of quantity discounts.

The remainder of the paper is organized as follows. Section 2 provides a brief review of the related literature. Section 3 develops a two-echelon supply chain model. Section 4 develops the optimal coordination strategy. The benefits of the strategy are demonstrated numerically in Section 5. Finally, concluding remarks are provided in Section 6.

2. Literature review

This study draws on and contributes to the current literature in supply chain coordination. Specifically, it is related to two categories of studies: those on the development of quantity discount policies and those on the synchronization of supply chain replenishment activities. We refer the reader to Dolan (1987) for an excellent synopsis of the motivations and managerial implications of quantity discount policies, and Silver et al. (1998) and Munson and Rosenblatt (1998) for reviews of the more recent literature on quantity discounts. Some recent developments on quantity discounts include Wang (2005) and Altintas et al. (2008). As the literature on quantity discounts has been well reviewed, we focus on studies in the second category.

Time coordination that synchronizes supply chain inventory activities was first considered within the context of a centralized supply chain. When there are heterogeneous buyers, and no restrictions are imposed on the timing of their replenishment orders, a full replenishment strategy that minimizes system cost typically entails non-stationary replenishment intervals for channel members (Graves and Schwarz, 1977). The structure of such a policy is often exceedingly complex and, thus, of little practical use. To overcome this difficulty, Roundy (1985, 1986) developed coordination mechanisms that required buyers to place orders in power-of-two or integer-ratio multiples of the supplier's replenishment interval. These policies are simple, able to achieve over 98% system optimality, and have subsequently applied extensively to various distribution network and cost structures (Roundy, 1989; Mitchell, 1986; Muchstadt and Roundy, 1987; Jackson et al., 1988; Iyogun and Atkins, 1993).

Recently, the power-of-two and integer-ratio policies have been applied to coordinate activities in a decentralized supply chain. Chen et al. (2001) first adopted the power-of-two policy for a supplier to coordinate independent buyers' replenishments in a decentralized distribution system. A common discount policy was developed to maximize system profit under the power-of-two requirement. However, because buyers get most of the benefits and the supplier may suffer a substantial loss under this discount scheme, each buyer must pay the supplier a franchise fee that was determined through individual negotiations. This strategy was later extended to a more general setting in which buyers were retailers competing for a common market (Bernstein and Federgruen, 2003).

Because individual incentive schemes may not always be permissible due to legal and implementation considerations, Wang (2001) considered the problem under the condition that no side-payments were allowed, and developed a mechanism that incorporated a power-of-two time coordination policy and a common quantity discount pricing policy. Although this coordination strategy was generally not able to achieve perfect coordination, it was able to substantially improve system profits over the baseline case of no time coordination. Furthermore, Wang (2004) later showed that an integer-ratio time coordination policy provided a more realistic, and generally more effective, strategy for the coordination of a decentralized supply chain.

In the meantime, Viswanathan and Piplani (2001) considered time coordination in a special case in which buyers' ordering cycles were restricted to being integer multiples of the supplier's replenishment interval, and Klastorin et al. (2002) studied another special case in which buyers' ordering cycles were restricted to being no longer than that of the supplier. The latter study also assumed that the supplier's replenishment interval was exogenously given, and considered the use of quantity discounts to induce buyers to place larger orders at the supplier's replenishment points. However, according to Roundy (1985), the effectiveness of an optimal nested policy can be arbitrarily close