



Coordinating the discount policies for retailer, wholesaler, and less-than-truckload carrier under price-sensitive demand: A tri-level optimization approach

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ABSTRACT

Quantity discounts have been broadly examined in decisions on the sale or purchase of goods. The analysis of coordinating the discount decisions for the retailer (buyer), the wholesaler (supplier), and the public transportation service provider (Less-Than-Truckload carrier), however, is still in its infancy. In this paper, we develop a tri-level programming approach to coordinate the three supply chain members' decisions on discount policies, when the demand is sensitive to the change in price. Both decentralized and centralized scenarios are examined, and a heuristic algorithm is presented to assist the three parties in establishing their discount schemes in a decentralized environment. Through a series of comprehensive numerical experiments based on the linear demand, we show that the price-sensitivity is a key motivation, for all parties, especially the carrier, to offer discounts. Specifically for the wholesale quantity discount, the data analyses also illustrate the different purposes and corresponding structures for the decentralized and centralized cases. For the former case, the discount is quantity-based, which encourages the buyer to increase the size of each order; while for the latter case, the discount is volume-based, which is used to boost the annual demand. The significant improvements to each party and to the entire supply chain resulting from the discount coordination are also demonstrated under various situations.

1. Introduction

As a complicated system that manufactures and transports products to customers, a supply chain (SC) involves multiple stages and diverse participants. Supply chain coordination deals with relationships among the SC members, and concerns how to align the individual objectives of those members, coordinate their decisions and activities, and achieve the benefits of overall goals with joint efforts (Li and Wang, 2007). Among various coordination mechanisms, the quantity discount is a powerful tool, prevalent in the inventory management realm. Traditional analyses of this problem consider primarily the viewpoint of the buyer: calculation of the optimal order quantity, which minimizes the buyer's total relevant costs. However, by switching to the perspective of the supplier, the situation becomes significantly different. Since the 1980s, researchers have shown that the quantity discount may be used to entice the buyer to

increase the order quantity so as to improve supplier's profits (Lal and Staelin, 1984; Monahan, 1984; Li and Wang, 2007). A detailed literature review can be found in the next section. While quantity discounts have been broadly studied, little has been done on their coordination with the transportation discount.

Transportation, though vital in connecting supply chain partners, has been usually ignored or assumed fixed when those firms make decisions on purchasing and re-supply of stock. In the past few decades, many scholars have realized the importance of transportation's impact on inventory decisions. Those researchers have been working on helping a buyer determine its replenishment policy, given both the quantity and transportation discounts. Despite all the efforts having been put into those discounts, the existing research takes the buyer's point of view. Few studies integrate decisions by the carrier into their investigation. To fill this gap in literature, the main purpose of the present research is to

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coordinate the discount decisions of *all* SC members, a retailer (buyer), a wholesaler (supplier/vendor), and an outside transportation service provider (Less-than-truckload carrier), in the case of demand that is dependent on price.

Less than truckload (LTL) and truckload (TL) transport of freight are the two types of common-carrier trucking services. A TL carrier moves goods directly from origin to destination. An LTL carrier, however, requires a network of terminals which permits collection of products from more than one customer. For the latter case, loads are combined at an origin terminal, delivered on a single vehicle to a destination terminal, and deconsolidated there for local delivery to the ultimate consignees (buyers or receivers of the goods). The essential concept involved in LTL transportation is “shipment consolidation”, which combines several small loads and dispatches a single, larger quantity on the same vehicle (Higginson and Bookbinder, 1994). Shipment consolidation policies have been examined independent of other decisions, while a relatively new line of research investigated the practice of making collaborative decisions on consolidation and inventory, which may increase SC channel efficiency. In the present research, we embed the idea of coordinating the shipment consolidation with inventory decisions and the determination of discounts by various SC members.

The contributions of our research is threefold. *First*, extending the existing literature in supply chain coordination, we study the situation containing three parties of a supply chain. The transportation consolidation decisions are integrated with the inventory and discount policies, so that the overall SC performance can be improved. *Second*, Under both decentralized and centralized scenarios, we start from the market equilibrium and then present corresponding mathematical models to help each party derive the corresponding discount scheme. The result shows that the discount can be used to coordinate a decentralized supply chain; but the *supply chain benefit* can be greatest when all members work together. We term this the “centralized case”. Please note that the procedure of determining discount schedules can be applied to any market situation, not necessarily only for the equilibrium obtained by the proposed approach. *Third*, through numerical experiments, we show that the wholesaler's discount under the decentralized case is quantity-based, which encourages the buyer to increase the size of each individual order; while for the centralized case, the discount is volume-based, which is used to boost the buyer's overall annual demand. Sensitivity analyses also reveal the impact of the price elasticity of demand and inventory holding costs on the discount decisions.

The remainder of this paper is organized as follows. A comprehensive review in relevant areas is conducted in Section 2. Section 3 presents the problem statement and discusses the fundamental assumptions and notation that are employed in the research. Then, Section 4 analyzes the decentralized situation to derive the initial market equilibrium and discount schedules through tri-level programming models. A heuristic solution procedure is proposed and studied, and further consideration regarding the over-declaration of shipment weight is also discussed. Section 5 examines the centralized situation, both without and with discounts. In Section 6, numerical experiments on the basis of a linear demand curve are conducted to illustrate the applicability of the proposed models. Decentralized and centralized cases are each studied. Additional sensitivity analyses are performed to provide further managerial insights about the discount coordination. Finally, conclusions and future research are discussed in Section 7.

2. Literature review

In this section, the three most relevant research streams are presented according to the perspectives of different SC parties: 1) joint decisions on inventory and transportation (buyer), 2) supply chain coordination with

quantity discounts (supplier), and 3) integrated inventory and shipment consolidation policies (carrier).

2.1. Joint decisions on inventory and transportation

Normally, the inventory and transportation decisions are made by different segments of an organization. However, the interaction between these two decisions is crucial to minimize an organization's total relevant costs, and thus, to improve overall performance. Impacts of this interaction are gradually emerging in the practical decision process. The following are studies that assist buyers in determining optimal replenishment policies with consideration of both the quantity and transportation discounts.

Russell and Krajewski (1991) presented an analytical algorithm for finding the optimal order quantity that reflects both transportation economics and quantity discounts. (This algorithm was adjusted by Carter et al. (1995) in adapting to anomalous cases present in the freight rate schedule). Tersine and Barman (1991) structured the quantity and freight discounts into replenishment decisions, concerning dual discount situations with an all-unit or incremental quantity discount, and all-weight or incremental freight discounts. Arcelus and Rowcroft (1992) compared the impacts of three cases of freight rate structures and quantity discounts on a profit-maximizing firm, with or without disposals. Russell and Krajewski (1992) proposed a mixed integer linear programming model to obtain a coordinated replenishment policy including multiple items from a common supplier, with the consideration of both quantity and transportation discounts. Based on the classical economic order quantity (EOQ) model, Tersine et al. (1995) analyzed a firm's lot-sizing problem by integrating quantity and transportation discounts into a restructured discount schedule. Decomposition rules were provided, so that the composite model can be disaggregated to other specific cases.

Elhedhli and Benli (2005) included a carload discount schedule in an optimal lot-sizing procedure and analyzed the resulting total cost function. Darwish (2008) examined the combined effects of purchasing and transportation issues on continuous-review inventory decisions under the condition of a stochastic demand rate. Ouyang et al. (2008) analyzed an integrated inventory system with a price-sensitive demand rate when both trade credit and freight rate are linked to the order quantity. Toptal (2009) presented a replenishment decision model with the consideration of a stepwise freight cost and an all-unit quantity discount.

Chang (2011) showed that existing algorithms for determining the optimal lot sizes, incorporating quantity and freight discounts, may lead to suboptimality. Key steps of the algorithms were then modified to achieve a global optimal solution. For a supply chain network consisting of a supplier and a set of retailers, Firoozi et al. (2013) extended the traditional location-inventory model by considering quantity discount in making joint decisions on inventory control and facility location. Mendoza and Ventura (2014) examined the EOQ model with all-units quantity discount schemes. Available transportation options were: TL, LTL, or a combination of both modes simultaneously. Shin et al. (2016) studied the continuous-review inventory model considering ordering-quantity-dependent transportation cost. For stochastic price-sensitive demand, Heydari and Norouzinassab (2015) presented a coordination mechanism combining the retail and wholesale discounts. The profitability of SC as well as all SC members can be improved by applying the proposed policy. Tsao et al. (2016) formulated various piecewise non-linear programming models for the distribution network design problems of multi-echelon, multi-item supply chains under volume (weight) discounts on transportation costs.

The aforementioned research investigated the quantity and transportation discounts from the buyer's point of view. However, by switching to the perspective of the parties who determine and offer the

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