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Supply chain coordination in vendor-managed inventory systems with stockout-cost sharing under limited storage capacity

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ABSTRACT

We examine vendor-managed inventory (VMI) systems with stockout-cost sharing between a supplier and a customer using an EOQ model with shortages allowed under limited storage capacity, in which a stockout penalty is charged to the supplier when stockouts occur at the customer. In the VMI systems the customer and the supplier minimize their own costs in designing a VMI contract and making replenishment decisions, respectively. We compare the VMI systems with an integrated supplier–customer system where the supply chain total cost is minimized. We show that VMI with stockout-cost sharing and the integrated supplier–customer system result in the same replenishment decisions and system performance if and only if the supplier's reservation cost is equal to the minimum supply chain total cost of the integrated system. On the other hand, we also show how VMI along with fixed transfer payments as well as stockout-cost sharing can lead to the supply chain coordination regardless of the supplier's reservation cost. We also provide several interesting computational results.

1. Introduction

Vendor-managed inventory (VMI) is a well-known and widely-used supply chain practice between a supplier and a customer (e.g., supplier–manufacturer or distributor–retailer), in which the supplier manages the inventory at the customer and decides when and how much to replenish. VMI started as a pilot program in the retail industry between Wal-Mart and P&G (Proctor & Gamble) in the 1980s and has been adopted by many supply chains such as Campbell Soup Company, Barilla SpA, Intel, and Shell Chemical (Bookbinder, Gumus, & Jewkes, 2010). VMI has been also studied by many researchers, most of whom investigate the benefits of VMI in various settings, study the problem of designing VMI contracts, or examine various operational issues/decisions in implementing VMI (Guan & Zhao, 2010).

On the other hand, several recent papers have examined integrated supplier–customer systems in the context of VMI (e.g., Battini, Gunasekaran, Faccio, Persona, & Sgarbossa, 2010; Bertazzi, Paletta, & Speranza, 2005; Braglia & Zavanella, 2003; Persona, Grassi, & Catena, 2005; Zhang, Liang, Yu, & Yu, 2007), in which the supplier minimizes the supply chain total cost, rather than his own cost, in making replenishment decisions for the supply chain. As a result, the integrated supplier–customer systems considered in these papers are essentially equivalent to the centralized systems with a single decision-maker who bears all the supply chain costs. As pointed out by Darwish and Goyal (2011), although this approach leads to the optimal system performance, it may not be in the best interests of the supplier or the customer.

The primary purpose of this paper is to examine how VMI may result in different replenishment decisions and system performances when the supplier and the customer minimize their own costs, compared with the integrated supplier–customer system in which the supplier minimizes the supply chain total cost. We also explore under what contractual agreements VMI can lead to the same replenishment decisions and system performance as in the integrated supplier–customer system.

The secondary purpose of this paper is to examine a VMI contract with stockout-cost sharing under limited storage capacity, in which a stockout penalty is charged to the supplier when stockouts occur at the customer. Since Fry, Kapuscinski, and Olsen (2001) examined a (z, Z)-type VMI contract, which specifies minimum and maximum inventory levels and the corresponding under- and overstocking penalties, many researchers have studied the (z, Z)-type VMI contract and its variants. For example, Shah and Goh (2006) examine the (z, Z)-type VMI contract in a deterministic setting,

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Darwish and Odah (2010) examine a VMI contract that specifies a maximum inventory level and a penalty for overstocking, and Lee and Cho (2014) examine a VMI contract that specifies fixed and proportional stockout penalties. In this paper we seek to characterize the optimal VMI contract with stockout-cost sharing under limited storage capacity and examine how the optimal contract is affected by the storage limit.

We examine two VMI systems between a supplier and a customer: VMI with stockout-cost sharing and VMI with fixed transfer payments and stockout-cost sharing. In our VMI systems, the customer designs and offers a VMI contract to the supplier. The supplier can accept or reject the contract and, if he accepts it, manages the inventory at the customer and makes replenishment decisions. The customer and the supplier minimize their own costs in designing a VMI contract and making replenishment decisions, respectively. In particular, the supplier has a reservation cost such that he accepts the contract as long as his minimum cost under the contract is less than or equal to his reservation cost. The supplier's reservation cost may be determined by his negotiating power, or, if the supplier and the customer are currently operating under a traditional system mode, it may be his cost in the current system.

In VMI with stockout-cost sharing, the VMI contract specifies a stockout penalty per unit backordered per unit time, which is paid by the supplier to the customer whenever stockouts occur at the customer. The VMI contract also specifies that the inventory at the customer is owned by the supplier until it is used by the customer (i.e., consignment stock). VMI with fixed transfer payments and stockout-cost sharing is the same as VMI with stockout-cost sharing, except that the VMI contract also specifies a per-period fixed transfer payment between the two firms.

We use a deterministic (Q, r) inventory model (also known as the EOQ model with shortages allowed) under limited storage capacity to examine and compare four business scenarios: two VMI systems described in the above, an integrated supplier–customer system (or integrated system) where the supplier minimizes the supply chain total cost, and a traditional system where the customer manages her own inventory. We show that VMI with stockout-cost sharing and the integrated system result in the same replenishment decisions and system performance if and only if the supplier's reservation cost is equal to the minimum supply chain total cost of the integrated system. This result implies that VMI and the integrated system may lead to different replenishment decisions and system performances, while providing a condition under which VMI can coordinate the supply chain without fixed transfer payments. On the other hand, we also show how VMI with fixed transfer payments and stockout-cost sharing can be designed to achieve supply chain coordination regardless of the supplier's reservation cost. We also provide several interesting computational results. In particular, our results suggest that VMI with stockout-cost sharing performs very well when the supplier's reservation cost is close to the minimum supply chain total cost of the integrated system, but that it may perform significantly worse than the integrated system, especially when the supplier's reservation cost is small or the storage limit is small.

2. Literature review

There exists a substantial amount of literature on VMI. As mentioned in the above, most of the papers investigate the benefits of VMI compared with the traditional system, study the problem of designing VMI contracts, or examine various operational issues/decisions in implementing VMI (Guan & Zhao, 2010). In this section we review some of the papers that are closely related to our paper.

Fry et al. (2001) examine a (z, Z)-type VMI contract, which specifies a minimum inventory level (z), a maximum inventory level (Z), and penalties, $b-$ and $b+$, for under- and over-stocking, respectively. In their model, $b-$, $b+$, and $Q = Z - z$ are set through mutual agreement between the supplier and the customer. Given the values of $b-$, $b+$, and Q, the customer chooses Z and then the supplier makes production and replenishment decisions. They characterize the optimal behavior of the supplier and the customer and provide guidelines for choosing the values of $b-$, $b+$, and Q to minimize the supply chain total cost. They suggest that VMI can perform significantly better than the traditional system in many settings, due to better coordination of production and delivery, but can perform worse in others. Note that our VMI models can be viewed as a special case of the (z, Z)-type VMI contract, where the minimum inventory level is zero (i.e., $z = 0$) with a stockout penalty and the maximum inventory level is imposed through the storage capacity.

Nagarajan and Rajagopalan (2008) consider a business scenario in which both a supplier and a retailer incur stockout costs when stockouts occur at the retailer. They examine a holding cost subsidy-type VMI contract where the retailer charges the supplier a holding cost based on average inventory at the retailer. Bichescu and Fry (2009) examine the effect of channel power on VMI performance in the (Q, r) inventory system with a VMI agreement in which the supplier chooses order quantity Q and the retailer chooses reorder point r. In their model the backorder-penalty costs are split between the supplier and the retailer, but how to split them is not a decision variable but a given parameter.

Lee and Cho (2014) examine the problem of designing a VMI contract with consignment stock and stockout-cost sharing in a (Q, r) inventory system between a supplier and a retailer, in which the contract specifies proportional and fixed stockout penalties paid by the supplier to the retailer when stockouts occur at the customer. Our VMI models are similar to theirs in that stockout costs are shared between the supplier and the customer. However, our VMI models extend theirs by incorporating limited storage capacity and fixed transfer payments. More importantly, the purpose of our paper is different from theirs: we examine how VMI and the integrated supplier–customer system can be different and under what conditions or contractual agreements VMI can coordinate the supply chain.

Lee and Ren (2011) examine the benefits of VMI in a global environment in which the supplier and the retailer face exchange rate uncertainty. In their VMI model, the retailer charges the supplier a stockout penalty, which is equal to her own backorder penalty cost, at the end of each period for the backorders that occurred during the period. They characterize the supplier's optimal policy and provide computational results on the benefits of VMI to the supplier, the retailer, and the supply chain and the impact of exchange rate uncertainty on the benefits of VMI. Their model is similar to ours in that the VMI contract specifies a stockout penalty, but they do not examine the problem of contract design.

Darwish and Goyal (2011) consider a VMI contract between a supplier and a buyer, which specifies a maximum inventory level and an over-stocking penalty. The supplier produces the product at a finite production rate and delivers a production lot in a number of equal-sized shipments. Under the VMI contract the supplier determines production and shipment lot sizes to minimize his total cost including the inventory-holding and ordering costs of himself and the buyer and the over-stocking penalty costs. They provide an algorithm to solve the supplier's problem. But they do not examine the buyer's contract design problem.

Recently, several papers have studied supply chain coordination with VMI. Bernstein, Chen, and Federgruen (2006) consider a supply chain with a supplier and multiple retailers. They identify a condition called EOA (Echelon Operational Autonomy), which may arise in VMI partnerships where the supplier minimizes the supply chain total cost and show that perfect coordination can be achieved via simple pricing schemes under the EOA condition. Wong, Qi, and Leung (2009) consider a supply chain with a supplier and multiple retailers in a single-period stochastic setting to examine how a sales rebate contract can coordinate the supply chain under VMI with