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Vendor-managed inventory in a global environment with exchange rate uncertainty

Jun-Yeon Lee *, Louie Ren

University of Houston-Victoria, School of Business Administration, 3007 N. Ben Wilson, Victoria, TX 77901, USA

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ABSTRACT

Vendor-managed inventory (VMI) is a well-known industry practice for supply chain collaboration. In this paper we consider a periodic-review stochastic inventory model to examine the benefits of VMI in a global environment, in which the supplier and the retailer face exchange rate uncertainty and incur different fixed ordering costs. Our study suggests that, despite of all the inventory costs transferred from the retailer, the supplier can benefit from VMI by achieving economies of scale in production/delivery. It also suggests that the supply chain total cost always decreases under VMI and the reduction of the supply chain total cost is larger when there is exchange rate uncertainty, compared with the case of no exchange rate uncertainty. We also provide some analytical results, including the optimality of a state-dependent (s, S) policy for the supplier.

1. Introduction

Vendor-managed inventory (VMI) is a well-known industry practice for supply chain collaboration, in which the supplier manages inventory at the retailer (or manufacturer) and decides when and how much to replenish. The benefits of VMI to the retailer include reduction of overhead costs and, if consignment stock is adopted, transfer of inventory costs to the supplier. On the other hand, the benefits of VMI to the supplier are not very straightforward. Cetinkaya and Lee (2000), Cheung and Lee (2002), Kleywegt et al. (2002), Zavanella and Zanoni (2009) and Darwish and Odah (2010) examine the benefits of VMI from shipment coordination when the supplier has VMI agreements with multiple retailers. Fry et al. (2001) and Savasaneril and Erkip (2010) examine the benefits of VMI from coordination of production and delivery (i.e., increased flexibility in the supplier's production and delivery plan). Toptal and Cetinkaya (2006) study the benefits of VMI from better use of transport vehicles (i.e., having full truckloads) in a single-period setting. Gumus et al. (2008) use a joint economic lot sizing framework with deterministic demand to examine the benefits of VMI, and suggests that the supplier can be better off under VMI from optimally choosing order frequencies that minimize his average total costs. Nagarajan and Rajagopalan (2008) study similar issues using both EOQ models and approximate formulations of stochastic inventory models. Kiesmüller and Broekmeulen (2010) consider a multi-product serial two echelon inventory system with stochastic demand and use a simulation study to examine the benefit of VMI from economies of scale in order picking activities at the upstream warehouse by adapting order quantities. Our paper is similar to some of the above papers in a sense that we examine the benefits of VMI from achieving economies of scale in production/delivery, but different in that we do so using an exact, dynamic formulation of stochastic inventory model.

This research is also motivated from a business case about Apple Computer (Dornier et al., 1998), in which Apple Cork, a manufacturing facility of Apple Computer in Ireland, required *international* suppliers to set up a supply hub near its facility. Shipment was arranged between the suppliers and a logistics service provider and did not involve Apple. Suppliers paid for freight, storage, and material handling. Apple did not take the ownership of the materials until they were pulled from the hub for delivery to Apple Cork's production line. This business case motivated us to study supply chain collaboration using VMI in a global environment.

In this paper we consider a periodic-review stochastic inventory model in a global environment, in which the supplier and the retailer face exchange rate uncertainty and incur different fixed ordering costs. The exchange rate is modeled as undergoing a Markovian transition with a known transition probability matrix. In the traditional retailer-managed inventory (RMI) scenario, the retailer places orders with the supplier to meet stochastic demands. She incurs fixed ordering costs, inventory-holding and backorder-penalty costs, and makes wholesale payments to the supplier at times of order receipts. The supplier incurs fixed and variable costs of production/delivery. On the other hand, under the VMI arrangement, the supplier manages inventory at the retailer and makes replenishment decisions. The inventory at the retailer is owned by the supplier, and the retailer makes wholesale payments to the supplier for the units consumed. The retailer charges penalty costs to the supplier for any unmet customer demands. All the payments are made using the retailer's currency. Note that, as a

* Corresponding author. Tel.: +1 281 275 8833.
E-mail address: leej@uhv.edu (J.-Y. Lee).

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result of this VMI arrangement, the retailer transfers all the inventory-related costs to the supplier except for the wholesale payments. The supplier and the retailer minimize their own expected total costs in the finite horizon problem and long-run average costs in the infinite horizon problem.

In the RMI model, the retailer's problem involves a standard periodic-review stochastic inventory model with fixed ordering costs. It is well-known that an (s, S) policy is optimal for this problem. The optimal (s, S) policy and the corresponding minimum expected long-run average costs for the retailer can be computed using, e.g., Zheng and Federgruen's (1991) algorithm. Given the retailer's optimal policy, the corresponding expected long-run average costs for the supplier can be easily calculated. In the VMI model, the supplier has to solve a periodic-review stochastic inventory problem with fixed ordering costs, in which some of the cost parameters are non-stationary due to exchange rate uncertainty. We show that a state-dependent (s, S) policy is optimal for the supplier's finite horizon problem. We also provide a simple upper bound for the optimal order-up-to levels. This upper bound enables us to solve the supplier's infinite horizon problem using a policy-iteration method (Howard, 1960). The retailer's expected long-run average cost is equal to the expected average wholesale payments.

Our computational study suggests that, while the retailer always benefits from VMI, the supplier is better off only when his fixed cost of production/delivery is much larger than the retailer's fixed ordering cost. This is because the VMI arrangement has two opposite effects on the supplier's total costs: (i) increase of inventory costs and (ii) cost reduction from economies of scale in production/delivery. But the latter becomes dominant, as the difference between the supplier's and the retailer's fixed ordering costs increase. Our study also suggests that the supply chain total cost always decreases under VMI and that the reduction of the supply chain total cost is larger when there is exchange rate uncertainty, compared with the case of no exchange rate uncertainty. We provide an interpretation for this result.

The contributions of this paper are threefold: first, our paper provides a simple stochastic model that captures the benefits of VMI in a global environment. Second, our study provides several interesting managerial insights. In particular, we suggest that, despite of all the inventory costs transferred from the retailer, the supplier can benefit from VMI by achieving economies of scale in production/delivery and that the benefits of VMI may be larger in a global environment. Third, we suggest that a state-dependent (s, S) policy is optimal when the cost parameters are affected by exchange rate uncertainty.

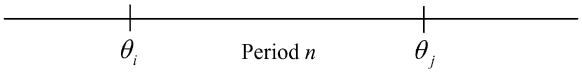
There exists a substantial amount of literature related with VMI. In addition to the papers mentioned in the above, the recent literature on VMI also include Almehdawe and Mantin (2010), who consider a supply chain that consists of a capacitated manufacturer and multiple retailers and compares two VMI scenarios: in the first scenario the manufacture is the leader and in the second scenario one of the retailers is the leader. They suggest that the total supply chain profit could be higher when the VMI arrangement is lead by a retailer. Guan and Zhao (2010) examine contracts for VMI between a single vendor and a single retailer operating with continuous review (r, Q) policy, and study a revenue-sharing contract for the consignment stock case and a franchising contract for the case where the inventory is owned by the retailer. Ru and Wang (2010) study and compare retailer managed consignment inventory (RMCI) and vendor managed consignment inventory (VMCI) arrangements in a single-period supply chain model with price-sensitive uncertain demand. In RMCI, the supplier specifies a consignment price and then the retailer decides her order quantity and retail price. In VMCI, the supplier chooses a consignment price together with the quantity to deliver and then the retailer decides only her retail price. They show VMCI performs better than RMCI. Xu and Leung (2009) consider a vendor–retail store channel with shelf-space restrictions and shelf-space-dependent uncertain demand, in which the vendor visits the retail store regularly and replenish the inventory at the retail store. They propose and analyze an approximate model to determine the optimal policy that maximizes the channel profit. Wong et al. (2009) examine how a sales rebate contract can be used for supply chain coordination in a two-echelon supply chain with a single supplier and multiple retailers in VMI partnership. Wang (2009) analyzes the traditional and VMI arrangements in a supply chain with random yield and uncertain demand in a single-period setting. Southard and Swenseth (2008) and Sari (2008) use simulation to study the benefits of VMI in various business scenarios. A more comprehensive literature review on VMI can be found in, e.g., Southard and Swenseth (2008). To our knowledge, however, there has been no academic paper that examines VMI in a global environment with exchange rate uncertainty.

The rest of this paper is organized as follows: in Section 2 we describe the basic model. In Sections 3 and 4 we present and analyze the RMI model and the VMI model, respectively. In Section 5 we provide computational results. Finally, Section 6 concludes this paper.

2. Basic model

Consider a periodic-review stochastic inventory model in which a supplier (he) produces and delivers a product to a retailer (she). The supplier incurs fixed cost K_S and variable cost c for production/delivery of the product. He uses a lot-for-lot production policy, and inventory is held only at the retailer. The production and delivery leadtime is assumed to be negligible. The retailer faces stochastic demand for the product, and unmet demands are backordered. Demands D in each period are independent and identically distributed. She incurs backorder-penalty cost b per period per unit backordered. The retailer pays wholesale price w per unit to the supplier. In the RMI model, the retailer incurs fixed ordering cost K_R and inventory-holding cost h_R per unit per period. In the VMI model, the supplier owns inventory at the retailer and incurs inventory-holding cost h_S per unit per period. The objectives of the retailer and the supplier are to minimize their own expected total costs in the finite-horizon problem and long-run average total costs per period in the infinite-horizon problem.

The supplier and the retailer use different currencies and face exchange rate uncertainty. Let θ be the number of units of the supplier's currency equivalent to 1 unit of the retailer's currency. We assume that the exchange rate, θ, can take on θ_i, $i=1,2,\ldots,k$, and that the exchange rate at the end of a period is the same as the one in the beginning of the next period. The exchange rate undergoes a Markovian transition with probability transition matrix $\Pi=\{\pi_{ij}\}$, where π_{ij} is the probability that the exchange rate is θ_j in the beginning of the next period given that it is θ_i in the beginning of the current period. Note that the exchange rate transition probabilities will be affected by the length of a period (e.g., month). This modeling approach to exchange rate fluctuations has been used by Gavirneni and Tayur (2001) and Gavirneni (2004).



All the costs of the supplier and the retailer are incurred in their own currencies, and we assume that all the payments between them are made in the retailer's currency.

3. Retailer-managed inventory

In the retailer-managed inventory (RMI) model, the retailer decides when and how much to order. She incurs fixed ordering costs, K_R, inventory-holding costs, h_R, and backorder-penalty costs, b.