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Optimal sourcing from a pool of suppliers with nonidentical salvage values

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ABSTRACT

We consider a firm offering a short life cycle product for sale in a single period. The product or a component incorporated in the product, we refer to either as the item in the sequel, is ordered in advance of the sales period from a pool of suppliers. Each supplier in the pool has a unique profile in terms of capacity, item price, and item salvage value. We study two cases: where supplier capacity is unlimited and where it is finite. For both cases we develop approaches managers can use to determine optimal sourcing plans. In the unlimited capacity case we use generalized versions of the newsvendor's critical ratio to select suppliers and determine order quantities, while in the case of finite capacity we develop an efficient algorithm that obtains an optimal solution. In addition we discuss how our approaches can be adapted to situations where suppliers are unreliable and where there is a service level objective. Lastly, we report the results of a numerical study in which we exercised our approaches for the problem settings considered in this paper. Our approaches generate sourcing plans that managers should find easy to appreciate: order from the lowest price supplier those units that have a high probability of selling, while for units whose sale is more doubtful, order such units from suppliers with salvage values larger than that of the lowest price supplier to hedge against high salvage costs.

1. Introduction

We consider a firm offering a short life cycle product for sale in a single period. Demand for the product is random. The product or a component incorporated in the product, we refer to either as the item in the sequel, is ordered in advance of the sales period from a pool of suppliers. Each supplier in the pool has a unique profile in terms of its capacity, item price, and item salvage value, where the salvage value may be negative, i.e. there may be a disposal cost. Note that in the situation where the firm is able to return leftover units of the item to the supplier who then does the salvaging, the salvage value is often referred to as the buy-back price. We assume the supplier pool has been pre-qualified, with the implication being that each potential supplier meets the firm's criteria regarding quality, financial strength, lead time requirements, etc. In most previous related research the salvage value of an item has been assumed to be the same across all suppliers, exceptions being the work of Bandyopadhyay and Paul (2010) and Chod et al. (2010). In this paper we treat the suppliers as heterogenous in all respects, hence the assumption of identical salvage values is relaxed. The fundamental problem of the firm in this setting is to determine the suppliers to source the item from and the quantity of the item to procure from each supplier in order to maximize expected profit.

The need to consider nonidentical salvage values in sourcing has to a large degree grown out of extended producer responsibility (EPR) environmental policies that have been implemented in most OECD countries. The goal of EPR policies is to make producers responsible "for managing the waste generated by their products put on the market" (OECD, 2014). In some industries producers are aided in this endeavor by their suppliers (see Jacobs and Subramanian (2012)). This is especially true with electronics where modular product architectures are the norm and hence components from different suppliers are interchangeable as long as they provide the same functionality. In this environment some suppliers, in an attempt to differentiate themselves from competitors, have taken to developing and designing items with more appealing characteristics in terms of material chemistry, disassembly, and recyclability, which in turn has led to items having nonidentical salvage values across suppliers. Our research in this paper is motivated by the adoption of such practice in electronics supply chains. A typical end product of the electronics industry is assembled from a wide range of components. Most of the components are low value, long life cycle and easily obtained. However a few are high value, short life cycle, and must be procured through more complex arrangements. In consumer electronics (e.g. mobile phones,

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computers, gaming consoles, etc.) according to Pourakbar et al. (2012) a typical end product may go through all its life cycle stages from development through final production within a year or less, which means that an assembler often has only a single opportunity to order a component falling into the latter category. In this paper we address this one shot ordering problem faced by firms with short life cycle products. In addition, we wish to highlight that the models we develop for the aforementioned one shot ordering problem can, with some adaption for initial inventories, also be used for the management of long life cycle products (e.g. printers, routers, etc.) near end of life, e.g. for final buys.

For any item that a firm must procure, sourcing can be understood as amounting to three decisions (see Burke et al. (2007)): 1) establishing a supplier pool (supplier evaluation); 2) choosing suppliers from the pool to use (supplier selection); and 3) determining the quantity to order from each supplier selected (quantity allocation). In this paper we assume the firm has already established a supplier pool. Our concern is with the supplier selection and quantity allocation decisions, in particular when treated in an integrated fashion. Much previous work has been undertaken on supplier selection as a stand alone problem, e.g. see the surveys of Weber et al. (1991), Degraeve et al. (2000), De Boer et al. (2001) and Ho et al. (2010). Most of this research has been multidimensional in nature, in the sense that objectives or criteria are employed that take into account not only price/cost, but also things such as quality, delivery, manufacturing capability, service, technology, and finance among others. By contrast in the integrated supplier selection and quantity allocation literature, a single objective is most typical, which is either to maximize profit or minimize cost. In this paper we have a single objective, which is to maximize profit, but we also incorporate a quality dimension with our consideration of nonidentical salvage values/buy-back prices. The use of buy-back prices as a mechanism to signal quality is well recognized (e.g. see Moorthy and Srinivasan (1995), Padmanabhan and Png (1995) and Cachon (2003)). As noted by Forker (1997), quality itself is a multidimensional construct, with the dimensions typically taken to include: performance, features, reliability, conformance, durability, and serviceability. We next review the integrated supplier selection and quantity allocation literature that concerns the single period, single product problem, which is the setting of the present paper.

Much of the early research on the integrated supplier selection and quantity allocation problem was deterministic in nature (see Pan (1989), Hong and Hayya (1992), Chaudhry et al. (1993), Weber and Current (1993), Current and Weber (1994), and Zeng (1998)). The earliest research examining stochastic demand was undertaken by Parlar and Wang (1993) and Anupindi and Akella (1993). Parlar and Wang (1993) considered a setting with two suppliers where the amount a supplier ships is a random function of the quantity ordered by the supplier's customer, while Anupindi and Akella (1993) studied several two supplier models where the production process of each supplier is uncertain. All subsequent stochastic work, unless noted otherwise, has concerned settings with more than two suppliers. Dada et al. (2007) investigated a setting where each supplier could be reliable or unreliable and the unreliability of a supplier equates to random capacity whereas the capacity of a reliable supplier is defined as infinite. Yang et al. (2007) and Federgruen and Yang (2008, 2009) considered settings where the suppliers have random yields. The optimal sourcing strategies for the unlimited capacity case and the finite capacity case were established by Burke et al. (2007). Awasthi et al. (2009) studied a setting where each supplier has minimum and maximum order sizes. Burke et al. (2009) examined an environment with unreliable suppliers and minimum order quantities. Tomlin (2009) considered a two supplier setting with minimum order quantities and unreliable suppliers but where the reliability of one supplier is known with certainty while there is only a forecast for the reliability of the other. Wang et al. (2010) investigated a two supplier problem with unreliable suppliers where a firm can exert effort to improve supplier reliability prior to ordering. Li and Zabinsky (2011) developed multi-objective models with volume discounts. Zhang and Zhang (2011) extended the work of Awasthi et al. (2009) by incorporating a fixed charge when a supplier is used. For a setting with two unreliable suppliers and service level requirements, Xanthopoulos et al. (2012) developed models for both risk neutral and risk adverse decision makers. Zhang and Chen (2013) extended the work of Zhang and Zhang (2011) by considering a problem where suppliers offer quantity discounts. Rather recently, Van Delft and Vial (2015) showed that the expected profit function of Burke et al. (2009) is actually only a lower bound on expected profit and provided the correct expression. Most recently, Ray and Jenamani (2016) developed models for both risk neutral and risk adverse decision makers in settings with service level requirements.

In the above cited work, unlike the present paper, salvage values were assumed to be the same across all suppliers. We end our literature review with a look at two papers where salvage values were not treated as identical. In one paper, Bandyopadhyay and Paul (2010) studied a single period setting with two suppliers competing to sell a single product to a retailer. Each supplier is capacity constrained and offers the product to the retailer at some wholesale price and takes back any leftovers from the retailer at a return or buy-back price. Formulating their setting as a game, Bandyopadhyay and Paul sought to show the existence of a mixed-strategy equilibrium although Lan et al. (2013) later showed a critical flaw in the equilibrium argument put forward by Bandyopadhyay and Paul. In the other paper, for a multi-product setting, Chod et al. (2010) considered a manufacturer of mass-customized modular end products assembled from multiple components purchased in advance of a sales period (each component may come in different versions). After uncertainty is resolved, end products are assembled and any left over components salvaged. Chod et al. derived a number of results pertaining to production flexibility for linear demand functions under the assumption that all versions of each component have identical salvage values; in a numerical study they relaxed the aforementioned assumption.

In this paper we consider a setting where the salvage value of an item is not the same across the suppliers in a pool. We first study the case where the capacity of each supplier is unlimited after which we examine the case where each supplier has finite capacity. For both cases we develop approaches that managers can employ to determine optimal sourcing plans, i.e. the suppliers to use and the quantity of the item to order from each supplier. Demand may follow any continuous distribution. The only material assumption we make is that procured items are sold/used on a lowest salvage value first basis. This means that if at the end of the sales period there are leftover units of the item that have been ordered from a supplier *i*, then every one of the units of the item procured from suppliers with a salvage value higher than supplier *i* will also be left in inventory. All of the above analysis proceeds under the assumption that suppliers are reliable. We also discuss how our solution approaches can be adapted to the situation where suppliers are unreliable. In addition the situation where there is a service level objective is entertained. Lastly we report the results of a numerical study in which we exercised our approaches for the problem settings considered in this paper.

The research we have undertaken in this paper makes both theoretical and practical contributions to the field of supply chain management. On the theory front, we generalize the critical ratio of the classic newsvendor model to the case of multiple suppliers with different salvage values. When the capacity of each supplier is unlimited, the use of generalized critical ratios is key in deciding whether to select a supplier. In addition, for the suppliers selected, critical ratios are also integral in deciding the quantity to order from each supplier. When the capacity of each supplier is finite, an algorithm we have developed finds an optimal solution quickly in no more steps than the number of suppliers in the pool, with the computational requirements of each step on the order of solving a newsvendor problem. On the practical side of things, our solution approaches for both the unlimited and finite capacity cases are easily implemented as computer programs. Furthermore, our approaches generate sourcing plans that managers should find easy to appreciate: order from the lowest price (highest profit margin) supplier those units