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A supplement to "A generalized algebraic model for optimizing inventory decisions in a centralized or decentralized multi-stage multi-firm supply chain"

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ABSTRACT

In this supplement, a number of integrated models under the integer multiplier coordination mechanism is generalized by allowing complete backorders penalized by not only linear but also fixed costs for some/all retailers. The optimal solution to such a three-stage generalized model is algebraically derived, from which optimal expressions for some well-known models are deduced. In addition, an expression for sharing the coordination benefits is modified, and a numerical example for illustrative purposes is presented. A ready future research work involving extension of the generalized model is suggested to conclude the supplement.

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1. Introduction

In the inventory/production literature, some researchers (such as Wu and Ouyang, 2003; Wee and Chung, 2007 and Chung and Wee, 2007) have constructed their models under the assumption of allowing complete backorders penalized by a linear (i.e. time-dependent) shortage cost. The main purpose of the supplement is to build a further generalized model incorporating complete backorders penalized by not only a linear but also a fixed shortage cost, and solve it algebraically. As a result, we can deduce and solve such special models as Khouja (2003), Cárdenas-Barrón (2007), Ben-Daya and Al-Nassar (2008), Seliaman and Ahmad (2009), and Leung (2009,2010a,b). In addition, with appropriate assignments as in Section 5 of Leung (2010a), we can also deduce and solve other special models: Yang and Wee (2002), Wu and Ouyang (2003) or Wee and Chung (2007), and Chung and Wee (2007). An extensive review of different optimization approaches used in inventory theory can be found in Cárdenas-Barrón (2010).

2. Assumptions, symbols and designations

The integrated production-inventory model is developed under the same assumptions as stated in Leung (2010b), with the exception of Assumption (13). Here, it is changed to "Shortages are allowed for some/all retailers and are completely backordered, and all backorders are made up at the beginning of the next order cycle."

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In addition to the symbols as defined in Leung (2010b), we also include the following:

$b_{nj} \equiv b_j$ = linear backordering cost of finished goods of firm $j(=1,\ldots,J_n)$ in stage n [hereafter called retailer $j(=1,\ldots,J_n)$], where $0 \leqslant b_j \leqslant \infty$ (\$ per unit per year)
$f_{nj} \equiv f_j$ = fixed backordering cost of finished goods of retailer $j(=1,\ldots,J_n)$, where $0 \leqslant f_j < \infty$ (\$ per unit)

For an individual retailer's EOQ model with complete backorders, we have

$\upsilon_{nj} \equiv \upsilon_j$ = backordering time of retailer $j(=1,\ldots,J_n)$
$\omega_{nj} \equiv \omega_j$ = individual cycle time of retailer $j(=1,\ldots,J_n)$ (a fraction of a year)
$TC_{nj}(\omega_{nj},\upsilon_{nj}) \equiv TC_j(\omega_j, \upsilon_j)$ = total relevant cost of retailer $j(=1,\ldots, J_n)$ (\$ per year)

For a centralized supply chain (or the integrated approach), we have

$t_{nj} \equiv t_j$ = backordering time of retailer $j(=1,\ldots,J_n)$
(t_j are decision variables, each with *non-negative* real values) (a fraction of a year)

For a decentralized supply chain (or the independent approach), we have

$\mu_{nj} \equiv \mu_j$ = backordering time of retailer $j(=1,\ldots,J_n)$
(μ_j are decision variables, each with *non-negative* real values) (a fraction of a year)

In addition to the designations in Leung (2010b), we also designate the following:

$$H_n^{(b)} = \sum_{j=1}^{J_n} \frac{D_{nj} b_j h_{nj}}{b_j + h_{nj}} + G_{n-1}, \tag{S1}$$

$$E_{nj} = \frac{D_{nj} f_j^2}{2(b_j + h_{nj})} \text{ for } j = 1,\ldots,J_n \text{ and } E_n = \sum_{j=1}^{J_n} E_{nj}, \tag{S2}$$

$$F_{nj} = \frac{D_{nj} f_j h_{nj}}{b_j + h_{nj}} \text{ for } j = 1,\ldots,J_n \text{ and } F_n = \sum_{j=1}^{J_n} F_{nj}, \tag{S3}$$

$$\alpha_n^{(b)} = S_{nJ} + B_{n-1,J} - E_n, \tag{S4}$$

and

$$\beta_n^{(b)} = \sum_{i=1}^{n-1} C_{iJ} + F_n. \tag{S5}$$

The total relevant cost per year of retailer $j(=1,\ldots,J_n)$, each associated with complete backorders and each backorder penalized by both a linear and fixed cost, is given by

$$TC_{nj} = \frac{D_{nj} h_{nj} (T_n - t_j)^2}{2T_n} + \frac{D_{nj} b_j t_j^2}{2T_n} + \frac{D_{nj} f_j t_j}{T_n} + \frac{S_{nj}}{T_n} \text{ for } j = 1,\ldots,J_n, \tag{S6}$$

where term 1 represents the holding cost of finished goods, terms 2 and 3 represent the backordering cost of finished goods and term 4 represents the ordering cost.

Expanding Eq. (S6) and grouping like terms yield

$$TC_{nj} = \frac{D_{nj}(b_j + h_{nj})}{2T_n} \left[t_j^2 - \frac{2(h_{nj} T_n - f_j) t_j}{b_j + h_{nj}} \right] + \frac{D_{nj} h_{nj} T_n}{2} + \frac{S_{nj}}{T_n}.$$

Using the complete squares method (by taking half the coefficient of t_j) advocated in Leung (2008a,b), and incorporating designations (S2) and (S3), we have

$$\begin{aligned} TC_{nj} &= \frac{D_{nj}(b_j + h_{nj})}{2T_n} \left(t_j - \frac{h_{nj} T_n - f_j}{b_j + h_{nj}} \right)^2 - \frac{D_{nj}(h_{nj} T_n - f_j)^2}{2(b_j + h_{nj}) T_n} + \frac{D_{nj} h_{nj} T_n}{2} + \frac{S_{nj}}{T_n} \\ &= \frac{D_{nj}(b_j + h_{nj})}{2T_n} \left(t_j - \frac{h_{nj} T_n - f_j}{b_j + h_{nj}} \right)^2 + \frac{D_{nj} b_j h_{nj} T_n}{2(b_j + h_{nj})} + \frac{S_{nj}}{T_n} - \frac{D_{nj} f_j^2}{2(b_j + h_{nj}) T_n} + \frac{D_{nj} f_j h_{nj}}{b_j + h_{nj}} \\ &= \frac{D_{nj}(b_j + h_{nj})}{2T_n} \left(t_j - \frac{h_{nj} T_n - f_j}{b_j + h_{nj}} \right)^2 + \frac{D_{nj} b_j h_{nj} T_n}{2(b_j + h_{nj})} + \frac{S_{nj} - E_{nj}}{T_n} + F_{nj}. \end{aligned} \tag{S7}$$

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