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Short communication

A pull system inventory model with carbon tax policies and imperfect quality items

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ABSTRACT

This paper develops a new inventory model with carbon tax policy and imperfect quality items in which the buyer exerts power over its supplier. It employs an order overlapping scheme to avoid shortages, overcomes some flaws in the literature, and develops two efficient solution algorithms. It also investigates different carbon tax systems on the performance of the model. Numerical results are discussed to bring some managerial insights.

1. Introduction

One of these unreasonable assumptions of the economic order quantity (EOQ) model [1] is that all units produced are of good quality, *e.g.*, [2]. EOQ models with imperfect quality have received considerable attention in the literature (*e.g.*, [3–10]). An interesting EOQ variant and more reasonable model than the EOQ have been proposed by Salameh and Jaber [11]. In their paper, a lot contains a certain percentage of defective items and a 100% inspection is conducted. At the end of the screening process, the defective items are sold at a discounted price as a single batch. Of interest to this paper is the work of Lin [3] who extended the EOQ model with imperfect quality to include quantity discounts and lot-splitting shipments for the retailer. Chang [4] corrected Lin's holding cost term and both the works assumed 'no shortages' during screening. Some researchers argued that this assumption may not hold when some conditions are present (*e.g.*, [12–14]). This implies that there are flaws in [3,4]. Maddah et al. [13] provided a good idea to overcome shortages by allowing the overlapping shipments. They assumed that good quality and defective items have equal holding costs. In practice, defective items are removed and stored in warehouse with a lower unit-holding cost [15]. The unit-holding costs for the good and defective items are therefore different in this paper. Modern manufacturing is actually a pull system in which deliveries must be made on an as-needed basis only. The 'order trigger' is in the retailer's hand and, thus, the retailer is powerful and has a bulk demand for commodities [16].

One environmental issue that has been given considerable attention is greenhouse-gas (GHG) emissions modeling from transportation and production, energy usage from production and storage activities as well as production waste disposal [17]. Some of the works that modified the EOQ to account for carbon emissions in different inventory situations are Wahab

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et al. [18], Bonney and Jaber [19], Chen et al. [20], Konur [21], Gurtu et al. [22], and Bazan et al. [23]. A framework for reducing GHG (mainly carbon) emissions and/or energy usage are found in Gurtu et al.'s [24] and Bazan et al.'s [25,26].

This paper therefore studies the pull system inventory model in which the retailer is the powerful player who dictates on its supplier the quantity discounts it desires. Moreover, this paper employs an order overlapping scheme to avoid shortages, which could efficiently rectify the shortages flaw shown in Chang's [4] work. The contributions of this paper are twofold. *First*, it corrects a flaw shown in the work of Chang [4]. *Second*, to the best of our knowledge, it is first that incorporates quantity discounts and a flat/progressive carbon tax rate into the pull system inventory model.

The remainder of this paper is organized as follows. Section 2 lists the notations and assumptions used in this paper and Section 3 develops a mathematical model with methodology and algorithm to obtain the overall optimal solution. Section 4 explores the impact of full progressive carbon tax on the optimal solution. A numerical example is provided in Section 5 to illustrate the proposed model. Finally, managerial insights are discussed in Section 6.

2. Notations and assumptions

The following notations and assumptions are used hereinafter to develop the proposed model:

(a) Notation:

Q	order size
D	demand rate
β	tax rate issued by regulatory agencies
g	fixed amount of carbon emission for the business activities
α	amount of carbon emission due to purchasing items
λ_1	amount of carbon emission due to inventory holding for good items
λ_2	amount of carbon emission due to inventory holding for imperfect items
x	screen rate, $x > D$
p	defective percentage in Q
$f(p)$	probability density function of p
m	selling price per unit
v	salvage value of per defective item, $v < c_j$
d	screening cost per unit
I	percentage of unit price
K	ordering cost per order
N	number of shipments per cycle (integer value)
R	receiving cost per shipment
T	planning horizon
q	size of shipment for each delivery which is given by $q = Q/N$
t	inventory depletion time for each shipment
Q_j	jth lowest quantity where $Q_{j-1} < Q_j$
c_j	unit-purchasing cost of jth level
I_g	holding cost rate for a unit of good item per period, expressed as a fraction of dollar value and $I_g > I_d$
I_d	holding cost rate for a unit of defect item per period, expressed as a fraction of dollar value
h_g	holding cost for a unit of good item per period, $h_g > h_d$
h_d	holding cost for a unit of defect item per period

(b) Assumptions:

(1) The demand rate is known and constant.
(2) Shortages are not allowed.
(3) There are defective items in each lot.
(4) The screening rate is greater than the demand rate, $x > D$.
(5) A lot is screened in full (100%). Defective items are withdrawn from inventory and sold as a single batch at a discounted price.
(6) The entire lot is produced and delivered in batches.
(7) Order overlapping scheme is assumed.
(8) Holding costs of good and defective items are different.
(9) An all-unit quantity discount scheme is adopted where c_j, $j = 0,1,\ldots, r$, is the discounted price when the order quantity is in the interval $[Q_j, Q_{j+1})$.

3. Mathematical model

We develop a mathematical model with the above assumptions in this section. The objective is to minimize the total cost, which the buyer's *perfect* item inventory from the *previous* shipment is just enough to meet the demand during the