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A one-vendor multi-buyer integrated production-inventory model: The 'Consignment Stock' case

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ABSTRACT

In recent years, companies have strengthened their supply agreements, and even the management of their inventories. To this aim, vendor-managed inventory (VMI) represents an interesting approach to stock monitoring and control, and it has been progressively considered and introduced in several companies. The research proposed investigates the way how a particular VMI policy, known as Consignment Stock (CS), may represent a successful strategy for both the buyer and the supplier.

The most radical application of CS may lead to the suppression of the vendor inventory, as this actor uses the buyer's warehouse to stock its finished products. As a counterpart, the vendor will guarantee that the quantity stored in the buyer's warehouse will be kept between a maximum level and a minimum one, also supporting the additional costs eventually induced by stock-out conditions. The buyer will pick up from its store the quantity of material needed to meet its production plans and the material itself will be paid to the buyer according to the agreement signed.

In previous studies, Braglia and Zavanella [2003. Modelling an industrial strategy for inventory management in supply chains: The 'Consignment Stock' case. International Journal of Production Research 41, 3793–3808] developed an analytical model of the CS policy, referring to a single-vendor and single-buyer situation. The same authors presented a comparison with the optimal solution available in the literature (in particular, with reference to Hill's model [1997. The single-vendor single-buyer integrated production-inventory model with a generalised policy. European Journal of Operational Research 97, 493–499]). The analytical results obtained allow the identification of the benefits and profitability that the CS approach determines in environments affected by uncertain demand.

In order to understand the potential benefits of the CS policy, an analytical model is offered with reference to the interesting industrial case of a single-vendor and multiple-buyer productive situation, thus obtaining the optimal replenishment decisions for both the vendor and buyers in such a situation. The results show how the CS policy works better than the uncoordinated optimisation.

1. Introduction

The present study makes reference to an industrial practice concerning the strategic management of inventories, known as Consignment Stock (CS). Initially, the authors observed it in a company manufacturing components for the automotive chain (Valentini and Zavanella, 2003; Braglia and Zavanella, 2003). This management strategy spread out rapidly in different manufacturing environments, confirming its strategic interest for companies and its positive attitude in being implemented in supply chains. However, the industrial implementation of CS

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agreements frequently requires the solution of some problems perceived by the two actors of the chain. In particular,

1. it is common opinion that the buyer gets the most advantages from the CS agreement, in particular when it is a large company interacting with a small–medium-sized vendor (supplier);
2. the vendor is frequently doubtful about the real advantages offered by the CS agreement, as he generally provides the same component/device to different customers and, therefore, he is unable to clearly perceive the real impact of the CS policy on his lot-sizing strategy.

The former opinion may find a further support in the need for a continuous exchange of digital information between the two actors, which generally introduces the topic of a uniform information system. Such a change may be costly for a small–medium company (in terms of personnel, too) and the opportunity of a partnership with the larger buyer may be unavoidable. The second concern refers to a situation that is extremely common in practice, e.g. when the vendor is a component or raw material manufacturer and his customers are assembly companies or manufacturers. Such a problem suggested the present analysis, which aims at investigating the single-vendor and multi-buyer environment so as to draw some managerial indications useful for understanding whether the CS policy may be successfully implemented in pyramidal chains.

According to the topics outlined, Section 2 offers the framework of the literature, so as to correctly locate the contribution in the scientific scenario. Section 3 presents the model notation and the assumptions introduced, while Section 4 focuses on the specific problem (single vendor and multi-buyer), introducing the notation and the model developed. Finally, a numerical example is proposed to validate the model and draw the managerial issues that it addresses (Section 5), and a sensitivity analysis is carried out to explore the influence of the relevant parameters (Section 6).

2. Literature review

2.1. Single-vendor single-buyer models

A large number of noticeable studies emerged in last years related to buyer–vendor coordination. In his pioneering studies (1976 and 1977), Goyal suggested a joint economic lot-size model where the objective is to minimise the total relevant costs for both the vendor and the buyer. Afterwards, the model was generalised by Banerjee (1986a, b), Goyal (1988) himself and Goyal and Gupta (1989). These models assume that a perfect balance of power exists between the vendor and the buyer, enforced by contractual agreement. However, other studies develop models, the aim of which is to minimise the vendor's total annual cost subject to the maximum cost that the buyer may be prepared to incur (e.g. Lu, 1995).

Some years later (1997 and 1999), Hill's contributions focused on a model to minimise the total costs per year of the buyer–vendor system. The basic assumption is that the vendor only knows the buyer's demand and his order frequency. Consequently, the model may be applied when co-operation between the two parties exists.

In Goyal (2000), it is possible to find an improvement to the approach for the optimal policy for a single-vendor single-buyer integrated production-inventory system considering the capacity constraint determined by the transport equipment.

Valentini and Zavanella (2003) present an industrial case and performance analysis of CS, and Braglia and Zavanella (2003) propose the related analytical approach and some performance evaluation of the CS policy. Moreover, Zanoni and Grubbström (2004) provide a full analytical solution.

Ben-Daya and Hariga (2004) relax the assumption of deterministic demand and assume that the lead time is varying linearly with the lot size. They consider the lead time composed of a lot-size-dependent run time and constant delay times such as moving, waiting and setup times.

Hoque and Goyal (2006) develop a heuristic solution procedure to minimise the total cost of setup or ordering, inventory holding and lead-time crashing for an integrated inventory system under controllable lead time between a vendor and a buyer.

Under the assumption of deterministic demand, Hill and Omar (2006) summarise the previous research on the single-vendor single-buyer integrated production-inventory problem and, additionally, provide an improvement to the CS case, offering an analytical solution that considers different batch dimensions within a replenishment cycle.

Zhou and Wang (2007) present a model, which neither requires the buyer's unit holding cost to be greater than the vendor's nor assumes the structure of the shipment policy. The model is extended to the situation with shortages permitted, based on shortages being allowed to occur only for the buyer. The paper also presents a corresponding production-inventory model for deteriorating items.

Finally, Sarmah et al. (2006) present a literature review dealing with buyer–vendor coordination models, under a deterministic environment, classifying them and identifying the critical issues and future research lines.

2.2. Single-vendor multiple-buyer models

The integrated inventory models for the one-vendor multi-buyer case have been discussed by a number of other authors. Although Lal and Staelin (1984) worked on the development of a quantity discount schedule for a vendor facing several groups of homogeneous purchasers, their model presents some shortcomings. The most important one being that, while assuming deterministically known purchaser orders, they also assume that the vendor's production policy will be unaffected by changes in the purchasers' order quantities. Joglekar (1988) pointed out that, particularly in a many-purchaser situation, purchasers' order sizes affect not only the vendor's revenue stream (which Lal and Staelin (1984) considered) but also his manufacturing cost stream (which Lal and Staelin (1984) ignored). Dada and Srikanth (1987) also developed an integrated model, which was built on the Lal and Staelin (1984) approach, and therefore retained the same shortcomings.

Joglekar and Tharthare (1990) proposed an individually responsible and rational decision approach to the economic lot sizes for one vendor and many purchasers. They claimed that the co-operation proposed by earlier authors was antithetical to the free enterprise system and they strongly argued in favour of allowing each party to adopt its own independently derived optimal replenishment policy.

Banerjee and Banerjee (1994) further developed an analytical model for coordinated inventory control between a vendor and multiple buyers dealing with a single product under stochastic demands and lead times through a common cycle approach. They focused their attention on the use of electronic data interchange (EDI). They argued that EDI makes the link between multiple buyers and the supplier feasible on a real-time basis and it is possible for the supplier to monitor the consumption pattern of the buyers. As a result, it is not necessary for the buyers to place an order, but the supplier can send the needed material according to a pre-arranged decision system. In their paper, the authors assume that the parties deal with a single product and they agree to ship the materials at fixed intervals (common to all buyers). At regular intervals, the quantity of material shipped by the vendor to each buyer depends on the quantity on hand, as a pre-determined replenish-up-to quantity is to be reached.

Lu (1995) argued that all the previous studies assumed that the vendor must know the buyer's holding and ordering costs, which are quite difficult to estimate unless the buyer is willing to reveal the true values. Therefore, Lu considered another circumstance, in which the objective is to minimise the vendor's total cost per year, subject to the maximum cost that the buyer may be prepared to incur.

Viswanathan and Piplani (2001) proposed a model to study and analyse the benefit of coordinating supply chain inventories by means of common replenishment epochs or time periods. A one-vendor multi-buyer supply chain is considered for a single product. Under their strategies, the vendor specifies common replenishment periods and requires all buyers to replenish only at pre-determined time periods. However, the authors did not include any inventory cost of the vendor in the model. Woo et al. (2001) considered an integrated inventory model where a single vendor purchases and processes raw materials in order to deliver finished items to multiple buyers at a common cycle. The vendor and all the buyers are willing to invest in reducing the ordering cost (e.g. establishing an EDI-based inventory control system) in order to decrease their joint total cost. Their work is an extension of the model by Banerjee and Banerjee (1994), in which the vendor makes replenishment decisions for all the buyers so as to optimise the joint total cost.

Boyaci and Gallego (2002) analysed inventory and pricing policies that jointly maximize the channel profit in a supply chain consisting of one wholesaler and one or more retailers under deterministic price-sensitive customer demand. The authors show how an optimal policy can be implemented cooperatively by an inventory consignment agreement.

More recently, Siajadi et al. (2006) proposed a multiple shipment policy for joint economic lot size. The study shows that a multiple shipment policy is more beneficial than a single shipment policy, as considered by Banerjee (1986a, b). Some issues emerge from the study: in particular, the incurred saving is shown to increase as the total demand rate approaches the production rate and the model appears to be weakly influenced by the variation of the main inputs. Another interesting model is presented by Kim et al. (2006), where the situation of a three-stage supply chain is considered: the last level of the chain consists of multiple retailers, which interact with a single manufacturer procuring raw material at the first and single-resource level. Each retailer may require a different type of item. The heuristic proposed gives rise to a limited error, this being influenced by some input parameters. The industrial environments of reference are chemical and petrochemical chains.

3. Notation and assumptions

The following notations may be introduced:

A_1	batch setup cost faced by the vendor (€/setup)
$A_{2,i}$	order emission cost faced by the ith buyer (€/order)
h_1	vendor holding cost per item and per time unit (€/item time unit)
$h_{2,i}$	ith buyer holding cost per item and per time unit (€/item time unit)
P	vendor production rate (continuous) (item/time unit)
d_i	demand rate seen by the ith buyer (continuous) (item/time unit)
Y	number of buyers
T	ordering or production cycle time (time unit)
n_i	ith buyer number of transport operations per production cycle time
q_i	ith buyer quantity transported per delivery (item)
TC	average total costs of the system per time unit, function of n_i and T (€/time unit)

A cycle is defined as the period during which the vendor incurs in one setup activity, thus producing the amount of components to be delivered to the Y buyers so as to allow them to satisfy the demand seen by the buyers themselves during the cycle. The cycle is replicated identically within the time horizon. It is also assumed that $P>D$, where $D=\sum_{i=1}^{Y} d_i$. As far as the relative values of the holding costs, two different situations may be found in practice, as discussed in Sections 3.1 and 3.2.

3.1. Case $h_{2,i} > h_1\ \forall i$

This situation refers to the assumption of items increasing their value while descending the production–distribution chain. As a consequence, goods are preferably kept in the vendor's warehouses until the buyer asks for a further shipment: this situation is discussed in the model proposed by Siajadi et al. (2006).

3.2. Case $h_{2,I} < h_1\ \forall i$

The opposite situation can be found in practice, especially as a consequence of the CS inventory parameter settings (for more detail, see Valentini and Zavanella, 2003). This case is also discussed in Hill and Omar (2006), where the authors comment the situation of a small specialist (with consistent holding costs) acting as a vendor and a large manufacturer (with limited holding costs) as a buyer.

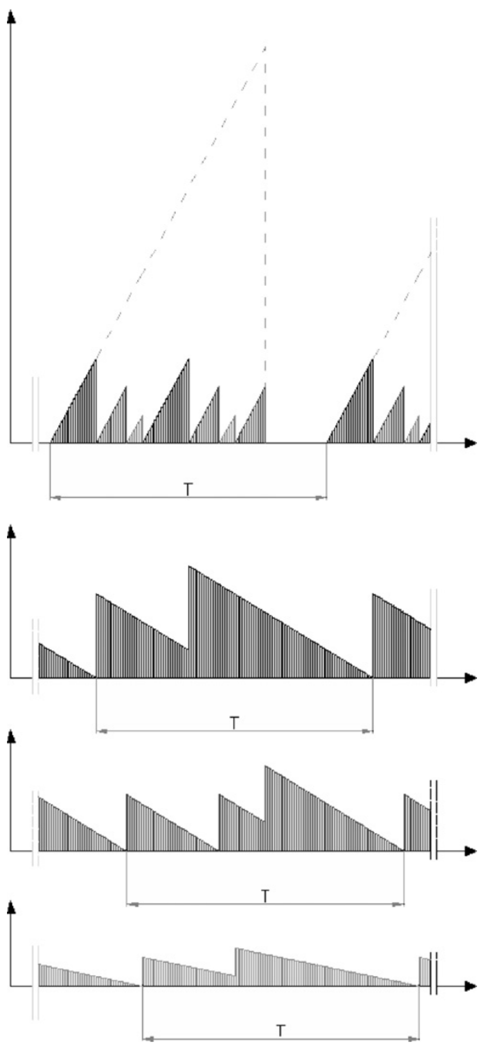

Fig. 1. Vendor and buyer stocks against time, with a production cycle time length equal to *T*.

The present study investigates the case $h_{2,i} < h_1\ \forall i$. In a similar environment, the aim is to minimise the stock held by the vendor, shipping all the stocks available whenever a delivery is ready for transportation. The shipment policy is based on making equal-sized shipments (possibly different for different buyers) while production is taking place, the last shipment being made as soon as production finishes. According to the results offered in the literature (e.g. Hill and Omar, 2006), this shipment policy could be improved by adopting differently sized transports for each buyer. Of course, the practical implementation of this enhanced policy should be evaluated according to the industrial case considered.

Fig. 1 shows the stock trend of a one-vendor and three-buyer case with $n_1 = 2$, $n_2 = 3$ and $n_3 = 2$.

4. The analytical model

According to the notation given and to the environment described in Section 3, the vendor's average cost per time unit presents two factors contributing to its determination:

- Setup cost: A_1/T.
- Holding cost: $h_1(T/2)\sum_{j=1}^{Y} d_j^{\,2}/n_jP$.

As a consequence, the total costs in charge to the vendor may be calculated as follows:

$$TC_{\text{vendor}} = \frac{A_1}{T} + h_1 \frac{T}{2P}\sum_{j=1}^{Y}\frac{d_j^2}{n_j} \tag{1}$$

The two costs in charge to each buyer are

- Order emission cost: $(1/T)n_iA_{2,i}$.
- Holding cost: $(T/2)(h_{2,i}d_i)(1-d_i/P+d_i/n_iP)$.

As a consequence, the total costs per time unit in charge to each buyer may be calculated as follows:

$$TC_{\text{buyer},i} = \frac{1}{T} n_i A_{2,i} + \frac{T}{2} h_{2,i} d_i \left(1 - \frac{d_i}{P} + \frac{d_i}{n_i P}\right) \tag{2}$$

Finally, the total average costs for the whole system are

$$TC = TC_{\text{vendor}} + \sum_{i=1}^{Y} TC_{\text{buyer},i} = \frac{1}{T}\left(A_1 + \sum_{i=1}^{Y} n_i A_{2,i}\right) + h_1 \frac{T}{2}\sum_{j=1}^{Y}\frac{d_j^2}{n_j P} + \frac{T}{2}\sum_{i=1}^{Y} h_{2,i} d_i \left(1 - \frac{d_i}{P} + \frac{d_i}{n_i P}\right) \tag{3}$$

Of course, when $Y = 1$, the cost function is equal to the cost function of the single-vendor single-buyer CS case (Braglia and Zavanella, 2003). This property may be easily shown, remembering that $TD = nq$.

The cost minimisation is subjected to two constraints:

- at least one shipment for each buyer will occur within the cycle *T*. Therefore, within the same cycle *T*, a second shipment to any buyer may be done only when all the other buyers in the system have received their first lot;
- as far as the delivery sequence is concerned, the first buyer gets the first delivery, followed by the second and so on up to the last buyer *Y*. Within the same cycle

T, more equal-sized deliveries to the same buyer may occur, but the sequence described must be observed. However, under the assumptions made, it should be underlined that the sequencing of the deliveries to the buyers is not relevant to the cost function.

The environment described may be summed up as follows. The total number of decision makers is equal to (Y+1), i.e. one vendor and Y buyers. In a collaborative perspective, the objective is to minimise the total costs of the whole system, i.e. the sum of the costs pertaining to the set of the (Y+1) actors. This case refers to a supply chain where partners interact in a competitive partnership, and it will be discussed in Section 4.1. Such a collaborative environment may be effectively compared with a situation where each buyer acts individually, thus assuming the quantities of the other buyers as given and consequently trying to minimise his own costs. This case will be discussed in Section 4.2.

Of course, both of the problems are preliminarily defined by the total costs of the vendor and of each buyer (previously defined as TC_{vendor} and $TC_{buyer,i}$) and the consequent TC function.

4.1. The joint optimum

The objective function of the one-vendor–Y-buyers system becomes

$$\mathrm{TC} = \mathrm{TC}_{\mathrm{vendor}} + \sum_{i=1}^{Y} \mathrm{TC}_{\mathrm{buyer},i} = \frac{1}{T}\left(A_1 + \sum_{i=1}^{Y} n_i A_{2,i}\right) + \frac{T}{2}\sum_{i=1}^{Y}\left((h_1 + h_{2,i})\frac{d_i^2}{n_i P} + h_{2,i} d_i\left(1 - \frac{d_i}{n_i P}\right)\right)$$

The function presents the following decision variables: T and n_j with $j = 1,2, \ldots, Y$. Whatever the values of the n_i variable, T will be determined by

$$T^* = \sqrt{\frac{2(A_1 + \sum_{i=1}^{Y} n_i A_{2,i})}{h_1 \sum_{i=1}^{Y} d_i^2/n_i P + \sum_{i=1}^{Y} h_{2,i} d_i (1 - d_i/P + d_i/n_i P)}}$$

The T^* value leads to the minimum total cost (with respect to T alone):

$$\mathrm{TC}^* = \sqrt{2\left(\sum_{i=1}^{Y}(h_1 + h_{2,i})\frac{d_i^2}{n_i P} + h_{2,i} d_i\left(1 - \frac{d_i}{P}\right)\right)\left(A_1 + \sum_{j=1}^{Y} n_j A_{2,j}\right)}$$

However, minimising the TC^* function requires that

$$\frac{\partial}{\partial n_i}\left(h_1 \sum_{i=1}^{Y}\frac{d_i^2}{n_i P} + \sum_{i=1}^{Y} h_{2,i} d_i\left(1 - \frac{d_i}{P} + \frac{d_i}{n_i P}\right)\right) \times \left(A_1 + \sum_{j=1}^{Y} n_j A_{2,j}\right) = 0 \quad \text{with } i = 1,2,\ldots,Y$$

i.e.

$$\left(-h_1 \frac{d_i^2}{n_i^2 P} - h_{2,i}\frac{d_i^2}{n_i^2 P}\right)\left(A_1 + \sum_{j=1}^{Y} n_j A_{2,j}\right) + A_{2,i}\sum_{j=1}^{Y}\left(\frac{h_1 d_j^2}{n_j P} + h_{2,j} d_j\left(1 - \frac{d_j}{P} + \frac{d_j}{n_j P}\right)\right) = 0$$

Let us assume

$$\frac{A_{2,i} n_i^2 P}{(h_1 + h_{2,i}) d_i^2} = \frac{(A_1 + \sum_{j=1}^{Y} n_j A_{2,j})}{\sum_{j=1}^{Y}(h_1 d_j^2/n_j P + h_{2,j} d_j (1 - d_j/P + d_j/n_j P))} = K \text{ and } n_i = \sqrt{K}\sqrt{\frac{(h_1 + h_{2,i}) d_i^2}{A_{2,i} P}}$$

where K is independent of the individual n_i. Then

$$K = \frac{(A_1 + \sum_{j=1}^{Y} n_j A_{2,j})}{\sum_{j=1}^{Y} h_1 d_j^2/n_j P + h_{2,j} d_j (1 - d_j/P + d_j/n_j P)}$$

After some algebraic steps, it is possible to obtain

$$\sqrt{K} = \sqrt{\frac{A_1}{\sum_{j=1}^{Y} h_{2,j} d_j (1 - d_j/P)}} \quad \text{and, consequently,}$$

$$n_i^* = \sqrt{\frac{(h_1 + h_{2,i}) d_i^2 A_1}{A_{2,i} P \sum_{j=1}^{Y} h_{2,j} d_j (1 - d_j/P)}}$$

The values determined for n_i^* and T^* allow the calculation of the minimum total cost TC^*.

4.2. The sequential solution

In this case, the vendor's total costs TC_{vendor} present T as the decision variable, while the n_i values are given. Each buyer's total costs TC_{buyer} present n_i as the decision variable, while T is given. Therefore, the decisions are taken sequentially so that the vendor's optimal choice about T depends on the n_i values and it may be simply obtained differentiating TC_{vendor} as in (1) with respect to T:

$$T^{**} = \sqrt{\frac{2PA_1}{h_1 \sum_{j=1}^{Y} d_j^2/n_j}}$$

where the n_i values are chosen by each buyer so as to minimise its TC_{buyer} function. Differentiating TC_{buyer} itself as in (3) with respect to n_i the optimal value is equal to

$$n_i^{**} = T d_i \sqrt{\frac{h_{2,i}}{2A_{2,i} P}} \quad \text{with } i = 1,2,\ldots,Y$$

and n_i^{**} depends on T.

The two equations may be combined, thus obtaining the sequential solution, which is equal to

$$T^{**} = \frac{A_1\sqrt{2P}}{h_1 \sum_{j=1}^{Y} d_j \sqrt{A_{2,j}/h_{2,j}}}$$

$$n_i^{**} = \frac{A_1 d_i \sqrt{h_{2,i}/A_{2,i}}}{h_1 \sum_{j=1}^{Y} d_j \sqrt{A_{2,j}/h_{2,j}}}$$

5. Numerical illustration

In this section, a numerical example is given in order to show the effectiveness of the model introduced in the previous section. The basic assumption is that the holding costs decrease as the stock moves down the supply chain.

We follow the illustrative example proposed in Goyal (1988) and used by subsequent authors, but the values of the two holding costs per unit are reversed and demand is split between the different buyers ($Y>1$).

We consider the situation with two buyers, with different demands and order costs.

$P=3200$	Item/year
$D=1500$	Item/year
$d_1=500$	Item/year
$d_2=1000$	Item/year
$A_1=400$	€/setup
$A_{2,1}=75$	€/order
$A_{2,2}=25$	€/order
$h_1=5$	€/item year
$h_{2,1}=4$	€/item year
$h_{2,2}=4$	€/item year

The application of the joint optimum model leads to the following results:

n_1	n_2	T^*	TC_{vendor}	$TC_{buyer,1}$	$TC_{buyer,2}$	TC^*
1	3	0.425	1134.1	601.7	849.9	2585.7

The application of the sequential solution model leads to the following results:

n_1	n_2	T^{**}	TC_{vendor}	$TC_{buyer,1}$	$TC_{buyer,2}$	TC^{**}
2	7	1.37	578.7	1374.1	2136.4	4089.1

Therefore, the adoption of the joint optimum policy, instead of the sequential solution, originates the following economic impact:

TC savings	Vendor savings	Buyer 1 savings	Buyer 2 savings
37%	−96%	56%	60%

In this situation, total savings are consistent and, furthermore, they are related to significant advantages for the buyers, i.e. the channel savings occur at the vendor's expenses.

6. Sensitivity analysis

The set of results illustrated in Section 5 suggested the sensitivity analysis commented hereafter. Its aim is to identify the parameters that are more relevant to the performance of the system and to appreciate the influence of the problem parameters on the joint optimum solution proposed.

The first experiment is shown in Fig. 2. It refers to the analysis of the cost savings obtained by the application of the joint optimum policy instead of the sequential solution, while varying the ratio of the holding costs. Preliminary results showed that the behaviours of the cost-saving curves do not depend on the absolute value of the holding costs, but only on their relative ratio. The graph highlights the area of application of the model, i.e. when h_1 is larger than h_2.

The analysis of Fig. 2 suggests that the joint management of inventories is always beneficial for the chain (TC curve), with benefits decreasing for large h_1/h_2 ratios. However, these benefits are obtained, thanks to savings for the two buyers and relevant losses of the vendor.

A second analysis (Fig. 3) refers to the cost savings obtained while varying the ratio between total demand (D) and production ratio (P).

The results show how the lower the D/P ratio the larger the benefits for the chain. Consistent benefits are determined for the buyer at low D/P values. Results seem to be consistent with the notes in Siajadi et al. (2006) concerning the influence of demand rate versus the productivity one.

Finally, the analysis proposed in Fig. 4 discusses the trend of cost savings with respect to the setup/order cost, i.e. $A_1/(A_{21}+A_{22})$. In this case, the most relevant savings for the system are obtained with the largest values of the ratio, giving substantial advantages to the buyers. Moreover, the main finding is that, for the data assigned, low values of the ratio determine a decrease of the system advantages in favour of lower vendor losses and lower buyer advantages: with the lowest ratio (i.e. 0.5), the system advantages are obtained with savings for the vendor and for one of the buyers, while the second buyer faces losses.

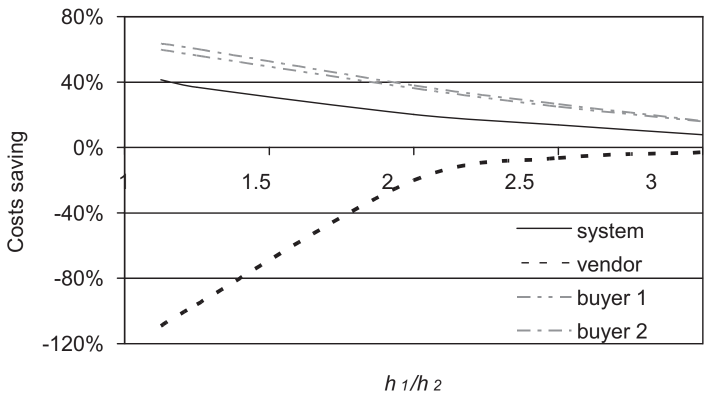

Fig. 2. System, buyer and vendor relative cost savings while varying h_1/h_2 ratio.

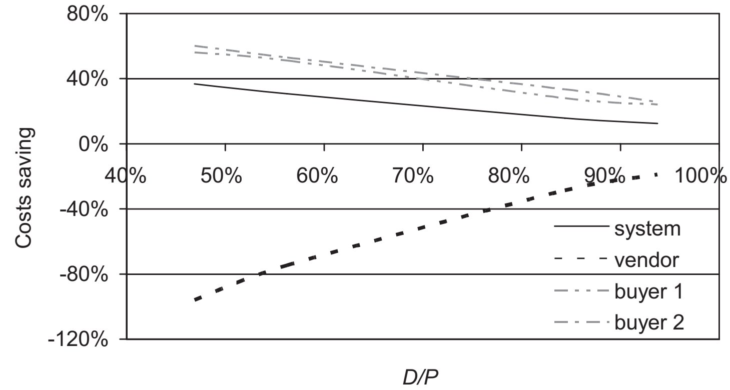

Fig. 3. System, buyer and vendor relative cost savings while varying *D*/*P* ratio.

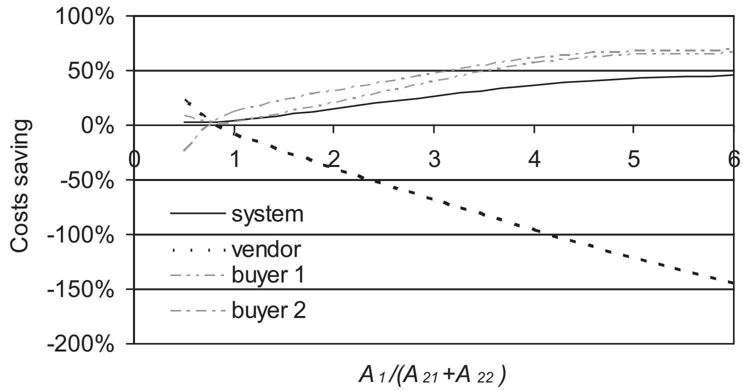

Fig. 4. System, buyer and vendor relative cost savings while varying $A_1/(A_{21}+A_{22})$ ratio.

The results discussed above are obtained under a specific set of the parameter values. However, according to additional experiments carried out, different outcomes may be observed while varying the values themselves. In other terms, it could happen that all the losses are in charge to the buyers or all of the actors take an advantage from the adoption of a joint policy.

7. Conclusions

The present study aimed at proposing a model for a single-vendor multi-buyer system, integrated in a shared management of the buyers' inventory, so as to pursue a reduction or the stability of the holding costs while descending the chain. The inventory management is carried out according to the CS practice and, consequently, the model extends the results offered in Braglia and Zavanella (2003). The model appears to be simpler than the analytical model developed by Siajadi et al. (2006), which is, however, based on Hill's (1997, 1999) assumptions and consequently suitable for a supply chain with holding costs increasing while descending the chain itself.

The results show that the joint management of the inventory gives rise to economic benefits, which, however, may be modest or relevant according to the structure of the chain. The results themselves suggested the development of a sensitivity analysis, which allowed drawing some interesting remarks on the influence of the parameters relevant to the economic performance of the supply chain (Section 5).

The expected extensions of the study refer to

- the analysis of batches of different sizes (as for the single-vendor single-buyer model proposed by Hill and Omar, 2006);
- the analysis of the lead-time effects;
- the implementation in the model of stochastic demand, so as to appreciate the benefits introduced by the CS approach with respect to the classical inventory management agreement between the actors of the chain.

However, the most significant improvement of the study is represented by the analytical study of the influence of the problem parameters on the cost savings, which should be able to allow the full understanding of the system behaviour and of its features, as perceived in Section 6 devoted to the sensitivity analysis.

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