

**"A SENSITIVITY ANALYSIS OF STOCHASTIC,  
INVENTORY SYSTEMS"**

**by**

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**A S E N S I T I V I T Y   A N A L Y S I S  
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S Y S T E M S**

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## Abstract

This paper derives sensitivity properties of the single item inventory model with stochastic demand and positive setup costs. The analysis emphasizes the effect of changes in the variability of the leadtime demand. For the order-quantity/reorder-point systems, we prove that when the variability of the leadtime demand increases: (i) the optimal order quantity increases, but, somewhat contrary to the conventional wisdom, the optimal reorder point does not necessarily increase; (ii) the minimum cost of the inventory system increases, and it increases at a slower rate than and converges to the cost of the optimal base-stock policy; and (iii) the cost performance becomes more robust to the choice of order quantity. In addition, we also show that both the optimal reorder point and the optimal order-up-to level decrease (increase) as the inventory holding (shortage penalty) cost increases.

## 1. Introduction

It is common sense that, for the management of inventories, the variability of the leadtime demand has a negative impact on the precision of control and on costs. An effective way of reducing the variability of the leadtime demand is to shorten the leadtime itself. This reduction requires effort and extra cost. With the current emphasis on "just-in-time" inventory management, and on "time-based" competition, there are increasing needs for a more precise analysis of the effect of the variability of the leadtime demand on the control and performance of inventory systems. This paper addresses this problem for one of the widely used stochastic inventory systems, the order quantity/reorder point system.

The order quantity/reorder point system is also referred to as the  $(Q,r)$  system, where an order of  $Q$  units is placed as soon as the inventory position (i.e., the inventory on hand plus on order minus backorders) drops to the critical level  $r$ . This inventory control system is the simplest model that simultaneously addresses economies of scale in order quantities, and a random (leadtime) demand. The cost function of the  $(Q,r)$  system has been well known for about three decades, ever since the publication of the popular textbook by Hadley and Whitin (1963). However, it had been perceived to be too complex to analyze, and, until very recently, our knowledge of the optimal control of this system had been limited. We refer readers to Lee and Nahmias(1989) and Federgruen and Zheng(1988) for recent reviews of the related literature.

From a modeling point of view, two simple inventory models, the EOQ model and the base stock model, are special cases of the  $(Q,r)$  model. The EOQ model crystallizes the tradeoff between the

inventory holding costs and the fixed ordering costs by assuming a deterministic demand. It is clear that a positive (deterministic) leadtime does not affect the EOQ model in any essential way because of the predictable leadtime demand. The base stock model, on the other hand, stresses the balance between the inventory holding costs and the shortage penalty costs by assuming away the fixed ordering costs. In a base stock model, an order is placed to restore the inventory position to a fixed "base stock" (or "order-up-to") level whenever a demand occurs. The optimal order-up-to level can be determined by minimizing the expected inventory holding costs and shortage penalty costs, which is essentially the newsboy problem where the demand for newspaper is interpreted as the leadtime demand. The optimal order-up-to point, which is often referred to as the newsboy point, enjoys a closed form solution. In that case, the effect of the variability of the leadtime demand is relatively simple to analyze.

With little theoretical support, it has often been argued that in a  $(Q,r)$  system, the order quantity should be determined by the EOQ formula in order to exploit the economies of scale, while the reorder point should be set to the expected leadtime demand plus some safety stock reflecting the variance of the leadtime demand and the service level (or the costs associated with shortage). While this argument is intuitive and therefore has played an important role in popularizing the model, it essentially dismisses the  $(Q,r)$  model by the rough functional segregation of the two control parameters.

Our analysis is based on recent results of Zheng(1989), who proves for the first time that the  $(Q,r)$  model can be viewed as an aggregation of a variant of the EOQ model and the base stock model. In his analysis, after the reorder point is chosen optimally for any given order quantity, the  $(Q,r)$  model reduces to a problem of finding the best tradeoff between the average ordering cost and the average holding and penalty cost. The average cost of the model is shown to be the sum of two components: the cost of the optimal base stock policy and a cost function that is very similar but smaller than that of the EOQ model (with backorder allowed). The analysis of these two cost components has led to the establishment of a number of properties of the stochastic inventory systems. In particular, it is shown in Zheng (1989) that the optimal order quantity of the  $(Q,r)$  model is larger than the corresponding EOQ, that the EOQ is a good heuristic when economies of scale prevail, that the cost of the  $(Q,r)$  model is bounded below by the maximum of the cost of the EOQ model and the cost of the base stock model, and bounded above by the sum of these costs, and that the expected total cost of the  $(Q,r)$  system is more robust to the choice of order quantity than the corresponding EOQ system. By comparing a system with stochastic leadtime demand with the corresponding deterministic EOQ system, these results provide first cut answers

to the analysis of the effect of the variability of the leadtime demand.

The results presented in this paper augment the above results by further showing how changes in the variability of the leadtime demand affect the optimal control parameters and the system cost performance. Specifically, we show that when the variability of the leadtime demand is increased: (i) the optimal order quantity increases, but, somewhat contrary to the conventional wisdom, the optimal reorder point does not necessarily increase; (ii) the minimum cost of the inventory system increases, and it increases at a slower rate than and converges to the cost of the optimal base-stock policy; and (iii) the cost performance becomes more robust to the choice of order quantity. We also show that both the optimal reorder point and order-up-to level decrease (increase) as the inventory holding (shortage penalty) cost rate increases, which complement the results on the effects of the fixed order cost of Zheng(1989): namely, that the optimal order quantity increases and the optimal reorder point decreases as the fixed ordering cost increases.

Two recent papers are relevant. Gerchack(1990) derives comparative statics for the  $(Q,r)$  model for both backlogging and lost sale models. For backlogging models, some of his results are similar to ours, but they appear with some qualifications which are not needed in our case. These qualifications are apparently due to the use of an approximate cost function, which systematically undercharges holding costs. Gerchack and Mossman(1988) investigate the effect of the leadtime demand variability, and conclude that the relationship between the variance of the leadtime demand and both the optimal reorder point and the optimal order quantity is not definitive. Again, this discrepancy appears to be due to the use of the approximate cost function.

The paper is organized as follows. Section 2 describes the model and notation. The effect of changes in the cost parameters is discussed in Section 3. Section 4 is devoted to the analysis of changes in the variability of the leadtime demand. In section 5, we discuss the sensitivity of the system performance to changes of the various problem parameters and the potential application of the cost insensitivity to the choice of order quantity. Section 6 is a brief conclusion.

## 2. Model and notation

We consider a single-item continuous-review inventory system that faces a stationary stochastic demand. Unless otherwise specified, the notation and assumptions are the same as in Zheng(1989). The arrival rate is denoted by  $\lambda$ . Replenishment orders are delivered after a positive leadtime  $L$ . All stockouts are backordered. The relevant costs are a fixed replenishment cost  $K$  for each order

placed and proportional inventory holding (penalty) costs accumulating at constant rate  $h$  ( $p$ ) per unit stock (backorder) per unit time. The criterion is the (long run) average total cost per unit time.

We assume the demand process and the leadtime are such that, under a  $(Q,r)$  policy, the following three conditions are satisfied: (a) both the inventory position and inventory level processes have a limiting distribution; (b) the fundamental equation  $IL = IP - D$  holds and  $IP$  and  $D$  are independent, where  $IL$  and  $IP$  denote the steady state inventory level and inventory position respectively,  $D$  the leadtime demand; (c)  $IP$  is uniform between  $r$  and  $r + Q$ . It is well known that these conditions are satisfied if the demand process is a Poisson or a renewal process and the leadtime is constant. These conditions can also be shown to hold when the leadtime is stochastic, under certain assumptions (see Zipkin 1986), and when the demand process is a Markov-Chain-Driven process (see Zipkin 1991). These conditions are required for the cost function (2) below to hold. [Since the entire analysis of Zheng(1989) is based on (2), the assumption of constant leadtime in Zheng(1989) can be replaced by the above three more general conditions.]

Let  $G(y)$  be the rate (per unit time) at which the conditional expected inventory (holding and penalty) costs accumulate when the inventory position equals  $y$ . Let  $F(\cdot)$  be the distribution function (cdf) of the leadtime demand  $D$ . By condition (b) we have

$$G(y) = E[h(y - D)^+ + p(D - y)^+] = (h + p) \int_{-\infty}^y F(x) dx - p(y - ED) \quad (1)$$

where  $E$  denotes the expectation over the leadtime demand. It is well known that  $G(\cdot)$  is a convex function. By (c), the average cost function of a  $(Q,r)$  system can be written as:

$$c(Q, r) = \frac{\lambda K + \int_r^{r+Q} G(y) dy}{Q} \quad (2)$$

Equation (2) is exact when the cumulative demand can be modeled as a nondecreasing stochastic process with stationary increments and continuous sample paths (see Browne and Zipkin 1991). It is an adequate approximation when the demand is a counting process (and  $Q$  is not too small). We treat both the reorder point and the order quantity as continuous decision variables.

Let  $y^o$  be the minimum point of  $G(\cdot)$ . It is well known that  $y^o = F^{-1}(\frac{p}{h+p})$ . (Throughout this paper, we assume, for notational convenience, that  $F(\cdot)$  is continuous and strictly increasing.) When  $K = 0$ , the base stock policies are optimal. In that case,  $y^o$  is the optimal order-up-to level and  $G(y^o)$  is the optimal average cost. In the sequel, we refer to  $y^o$  and  $G(y^o)$  as the newsboy point and the newsboy cost, respectively.

Let  $r^*$  and  $Q^*$  denote the optimal reorder point and the optimal order quantity. The following lemma is established in Zheng(1989).

**Lemma 1**  $Q = Q^*$  and  $r = r^*$  if and only if  $c(Q, r) = G(r) = G(r + Q)$ ,  $r^* < y^* < r^* + Q^*$ .

The optimality equations in the above lemma are simply the first order condition of the cost function. The last part of the lemma follows from  $G(r^*) = G(r^* + Q^*)$  and the convexity of function  $G$ .

### 3. Changes in the cost parameters

It has been shown (Zheng 1989) that the optimal order quantity increases and the optimal reorder point decreases as the fixed ordering cost  $K$  increases. In order to obtain further comparative statics results, we need to differentiate various components of the model with respect to  $h$  and  $p$ . For clarity, we will write expressions such as  $\partial G(y)/\partial h$  without explicitly incorporating the dependency of  $G(y)$  on  $h$  in the notation. We also denote  $dG(y)/dy$  by  $G'(y)$ .

Let the optimal order-up-to level be denoted by  $S^*$  ( $S^* = r^* + Q^*$ ). We first show that both the optimal reorder point and order-up-to level decrease (increase) as the holding (penalty) cost rate increases. Define  $a(y) = E[(y - D)^+]$ . Note that  $a(\cdot)$  is a convex increasing function.

**Proposition 1**  $\partial r^*/\partial h < 0$ ,  $\partial r^*/\partial p > 0$ ,  $\partial S^*/\partial h < 0$ ,  $\partial S^*/\partial p > 0$ .

**Proof:** By totally differentiating the optimality condition  $G(r) = G(r + Q) = c(r, Q)$  with respect to  $h$  at  $r = r^*$ ,  $Q = Q^*$ , we get

$$\frac{\partial G(r)}{\partial h} + G'(r)\frac{\partial r}{\partial h} = \frac{\partial G(r + Q)}{\partial h} + G'(r + Q)\left(\frac{\partial r}{\partial h} + \frac{\partial Q}{\partial h}\right) = \frac{\partial c}{\partial h}, \quad (3)$$

where the last term has been simplified by recognizing that  $\partial c/\partial r = 0$  and  $\partial c/\partial Q = 0$  at  $r = r^*$ ,  $Q = Q^*$ . From (1), we have  $G'(y) = (h + p)F(y) - p$  and  $\partial G(y)/\partial h = a(y)$ . From (2),  $\partial c/\partial h = (\int_{r^*}^{r^*+Q^*} a(y)dy)/Q^*$ . Solving for  $\partial r^*/\partial h$  in (3), we get

$$\frac{\partial r^*}{\partial h} = \frac{(\int_{r^*}^{r^*+Q^*} a(y)dy)/Q^* - a(r^*)}{(h + p)F(r^*) - p}.$$

Since  $a(y)$  is increasing, the numerator is positive. It follows from Lemma 1,  $F(r^*) < p/(h + p)$ , which implies that the denominator is negative. Thus,  $\partial r^*/\partial h > 0$ . The proof is similar for the other three cases.  $\square$

## 4. Changes in the leadtime demand

In this section, we study how the variability of the leadtime demand affects the optimal order quantity, the cost performance, and its sensitivity to the choice of order quantity. Throughout the analysis, we compare systems with different mean and variance of leadtime demand, while assuming that all the other parameters (i.e.,  $K$ ,  $h$ ,  $p$  and  $\lambda$ ) remain unchanged. Note that the cost function (2) depends on the leadtime demand only through the expected inventory cost function  $G$ .

We start by briefly reviewing some useful results from Zheng (1989). To focus on the role of order quantity, we assume that the reorder point is chosen optimally for any given order quantity. Let  $r(Q)$  be the optimal reorder point for a given  $Q$ . The reorder-point is characterized by the following lemma:

**Lemma 2** *For any  $Q > 0$ ,  $r = r(Q)$  if and only if  $G(r) = G(r + Q)$ , and  $r(Q) < y^o < r(Q) + Q$ .*

Let  $C(Q) \stackrel{\text{def}}{=} \min_r c(Q, r)$ . Let  $H(Q) \stackrel{\text{def}}{=} G(r(Q))$ ,  $Q > 0$ , with  $H(0) \stackrel{\text{def}}{=} G(y^o)$ . Since  $\int_{r(Q)}^{r(Q)+Q} G(y) dy = \int_0^Q H(y) dy$ , the optimal order quantity  $Q^*$  solves

$$\min_{Q>0} C(Q) = \min_{Q>0} (\lambda K + \int_0^Q H(y) dy)/Q. \quad (4)$$

$H(Q)$  can be interpreted as the marginal (expected) inventory cost for the  $Q$ -th unit in a batch. Since  $C(Q)$  is convex, the first order condition of (4) gives

$$C(Q^*) = H(Q^*), \quad (5)$$

which is simply one of the optimality equations in Lemma 1.

Let  $A(Q) \stackrel{\text{def}}{=} QH(Q) - \int_0^Q H(y) dy$ . Condition (5) is then equivalent to the following lemma.

**Lemma 3**  *$Q = Q^*$  if and only if  $A(Q) = \lambda K$ .*

Furthermore, we have

**Lemma 4**  *$H(\cdot)$  and  $A(\cdot)$  are increasing convex functions.  $H(Q) > \frac{hp}{h+p}Q$ ,  $H'(0) = 0$  and  $H'(Q) \uparrow \frac{hp}{h+p}$  as  $Q \uparrow \infty$ .*

Lemmas 3 and 4 are illustrated in Figure 1. The following lemma is geometrically obvious, therefore its proof is omitted.

**Lemma 5** For  $\beta > 1 (< 1)$  and  $Q > 0$ ,  $H(\beta Q) < (>) \beta H(Q)$ .

[Figure 1 approximately here]

Before proceeding with the formal analysis, it is helpful to conjecture about our results on the basis of the geometrical intuition given in Figure 1. The asymptotic line of  $H(Q)$ ,  $H_d(Q) = hpQ/(h + p)$ , can be interpreted as the marginal inventory cost function of the system with deterministic leadtime demand. It is geometrically clear that the introduction of variability of the leadtime demand increases the expected marginal inventory cost. It is also economically intuitive that a more variable leadtime demand should yield a higher  $H$ -curve. With the asymptotic line remaining the same, we expect a higher  $H$ -curve to be flatter. For fixed  $Q$ ,  $A(Q)$  is the shaded area between the  $H$ -curve and the horizontal line  $z = H(Q)$ . At the optimal order quantity  $Q^*$ , this area equals  $\lambda K$  (Lemma 3). Therefore, a flatter  $H$ -curve, which makes the shaded area smaller for fixed  $Q$ , requires a larger  $Q^*$ . Consequently, our first conjecture is that  $Q^*$  increases with the variability of the leadtime demand.

Furthermore, since  $Q^*$  depends only on the *shape* but not on the absolute height of the  $H$ -curve, it is conceptually helpful to decompose  $H(\cdot)$  in two parts:

$$H(Q) = G(y^o) + H_o(Q).$$

Let  $C^*$  be the optimal average cost of the  $(Q, r)$  system, i.e.,  $C^* = \min_{Q>0} C(Q)$ . Then, (4) can be rewritten as

$$C^* = G(y^o) + C_o^*$$

with  $C_o^* = \min_{Q>0} C_o(Q) \stackrel{\text{def}}{=} (\lambda K + \int_0^Q H_o(y) dy)/Q$ .  $H_o(\cdot)$  can be interpreted as the part of the marginal inventory cost that can be used to trade off the ordering cost through the choice of order quantity, and therefore  $H_o$  is referred to as the *controllable* inventory cost. Note that  $H_o$  is a vertical shift of  $H$ . Therefore, a more variable leadtime demand would be associated with a flatter  $H_o$ -curve. Since  $H_o(0) = 0$ , a flatter  $H_o$ -curve means  $H_o(Q)$  is smaller. Hence, for any  $Q > 0$  fixed,  $H_o(Q)$  should decrease as the variability of the leadtime demand increases. This leads us to more conjectures. First, as variability of the leadtime demand increases, the controllable inventory cost  $H_o(Q)$  is diminishing, so is  $C_o^*$ . Therefore, the optimal average cost of the system, which is the

sum of the newsboy cost and  $C_o^*$ , should grow more slowly than the newsboy cost when variability of the leadtime demand increases, and it should be close to the newsboy cost when the variability is high. Second, for more variable leadtime demand, the total average cost should be less sensitive to the choice of order quantity because  $C_o(Q)$  is smaller and it is the only part of the total cost that is affected by  $Q$ . We proceed to prove these conjectures analytically.

To proceed with the analysis, we need a clear definition of the variability of the leadtime demand. We assume in the sequel that the leadtime demand distribution takes the form of  $F(x) = \Phi(\frac{x-\mu}{\sigma})$ , where  $\mu$  and  $\sigma$  are its mean and standard deviation respectively, and  $\Phi$  is strictly increasing. Then, the variability of the leadtime demand can be unambiguously represented by  $\sigma$ . We will show how the optimal control parameters and the optimal costs change as  $\sigma$  changes. The above assumption is certainly satisfied when the leadtime demand is Normal, which is often an adequate approximation when the (mean) leadtime demand is not too small. The above construction is also a special case of the general notion of convex-ordering; see Rothschild and Stiglitz (1970) for a discussion.

We note that the variance of the leadtime demand is determined by both the demand process and the leadtime. When the demand process is given exogenously, the variance of the leadtime demand is affected only by the leadtime. For deterministic leadtimes, a longer leadtime typically leads to a larger variance of the leadtime demand. When a Normal distribution is used to approximate the leadtime demand,  $\sigma$  is often assumed to be linear to  $\sqrt{L}$ . When the leadtime is stochastic, the variance of the leadtime demand is determined by the variability of the demand process and by the mean and the variance of the leadtime. More specifically,  $\sigma$  can be computed by using the conditional variance formula (interested readers are referred to Zipkin 1991 for a detailed discussion).

The  $G$ -function can now be written as

$$\begin{aligned} G(y) &= (h + p) \int_{-\infty}^y \Phi\left(\frac{z-\mu}{\sigma}\right) dz - p(y - \mu) \\ &= \sigma[(h + p) \int_{-\infty}^{\frac{y-\mu}{\sigma}} \Phi(z) dz - p(\frac{y-\mu}{\sigma})]. \end{aligned} \quad (6)$$

We observe that a change of  $\mu$  in (6) would only cause a horizontal shift of the  $G(\cdot)$ -function, which does not affect the newsboy cost nor the  $H(\cdot)$ -function. The reexamination of equation (4) yields the following proposition.

**Proposition 2** *For a given demand process, the optimal order quantity and the minimum cost of the  $(Q, r)$  system are independent of the mean of the leadtime demand.*

Therefore, in the sequel, we set  $\mu = 0$  in (6) for notational simplicity. Moreover, we add the subscript  $\sigma$  to all the notation to indicate its dependency upon the leadtime demand variance (subscript  $d$  instead of 0 is used to indicate zero variance of the leadtime demand, which can be true either when the demand process is deterministic or the leadtime is zero).

It follows from (6) that

$$G_\sigma(y) = \sigma G_1(y/\sigma) \quad (7)$$

where  $G_1(y) = (h + p) \int_{-\infty}^y \Phi(y) dy - py$  is the (shifted) expected inventory cost function when the variance of the leadtime demand is 1.

Let  $y_\sigma^o$  be the minimum point of  $G_\sigma(\cdot)$ . The following result is immediate.

**Proposition 3** *The newsboy cost grows linearly in  $\sigma$ ,  $G_\sigma(y_\sigma^o) = \sigma G_1(y_1^o)$ .*

**Proof:** By (7),  $y_\sigma^o = \sigma y_1^o$ . □

The following lemma is crucial:

**Lemma 6**  $H_\sigma(Q) = \sigma H_1(Q/\sigma)$

**Proof:** By definition of  $H$ , we need to show

$$G_\sigma(r_\sigma(Q)) = \sigma G_1(r_1(Q/\sigma)). \quad (8)$$

Since by (7)  $\sigma G_1(r_1(Q/\sigma)) = G_\sigma(\sigma r_1(Q/\sigma))$ , (8) is equivalent to  $G_\sigma(r_\sigma(Q)) = G_\sigma(\sigma r_1(Q/\sigma))$ . Thus, it suffices to show  $r_\sigma(Q) = \sigma r_1(Q/\sigma)$ , which follows from the following equations

$$\begin{aligned} G_\sigma(\sigma r_1(Q/\sigma)) &= \sigma G_1(r_1(Q/\sigma)) = \sigma G_1(r_1(Q/\sigma) + Q/\sigma) \\ &= G_\sigma(\sigma r_1(Q/\sigma) + Q) \end{aligned}$$

where the first and the third equations are due to (7), and the second is by Lemma 1. □

Now, we are able to show

**Corollary 1** *For any fixed  $Q > 0$ ,  $H_\sigma(Q)$  is increasing in  $\sigma$ .*

**Proof:** It suffices to prove  $H_\sigma(Q) > H_1(Q)$  for any  $\sigma > 1$ . By Lemma 5,  $H_1(Q/\sigma) > H_1(Q)/\sigma$  for  $\sigma > 1$ . By Lemma 6,  $H_\sigma(Q) = \sigma H_1(Q/\sigma)$ . Therefore,  $H_\sigma(Q) > H_1(Q)$ .  $\square$

**Corollary 2** For any fixed  $Q > 0$ ,  $H'_\sigma(Q)$  and  $H_{\sigma,\sigma}(Q)$  are decreasing in  $\sigma$ ;  $H'_\sigma(Q) \downarrow 0$  as  $\sigma \uparrow \infty$ .

**Proof:** Differentiating the equation in Lemma 6, we have  $H'_\sigma(Q) = H'_1(Q/\sigma)$ . Fix  $Q > 0$ . The fact that  $H'_\sigma(Q)$  is decreasing in  $\sigma$  follows from the convexity of  $H_1$ .  $H_{\sigma,\sigma}(Q)$  is decreasing in  $\sigma$  because  $H'_{\sigma,\sigma}(Q)(= H'_\sigma(Q))$  is decreasing and  $H_{\sigma,\sigma}(0) = 0$ . The rest of the corollary is due to  $H'_1(0) = 0$ .

**Corollary 3** For fixed  $Q > 0$ ,  $A_\sigma(Q)$  is decreasing in  $\sigma$ ;  $A_\sigma(Q) \downarrow 0$  as  $\sigma \uparrow \infty$ .

**Proof:** It follows from Corollary 2 and  $A'_\sigma(Q) = QH'_\sigma(Q)$  that  $A'_\sigma(Q) \downarrow 0$  as  $\sigma \uparrow \infty$ . The corollary then follows from  $A_\sigma(0) = 0$  and  $A(Q) = \int_0^Q A'(y) dy$ .  $\square$

The effect of variability of the leadtime demand on the optimal order quantity is now clear. The following proposition is a direct implication of Lemma 4 and Corollary 3.

**Proposition 4** The optimal order quantity  $Q_\sigma^*$  increases in  $\sigma$ . Moreover  $Q_\sigma^* \uparrow \infty$  as  $\sigma \uparrow \infty$ .

We note for contrast that the reorder point is not necessarily increasing in  $\sigma$ , particularly when  $p$  is not very large relative to  $h$ . Zheng(1989) provides counter examples which show that the reorder point of a stochastic  $(Q,r)$  system can be lower than that of the corresponding EOQ system ( $\sigma = 0$ ).

Although the optimal order quantity grows with  $\sigma$ , the following proposition shows that it grows at a rate slower than  $\sigma$ .

**Proposition 5**  $\frac{Q_\sigma^*}{\sigma}$  is decreasing in  $\sigma$ , and  $\frac{Q_\sigma^*}{\sigma} \downarrow 0$  as  $\sigma \uparrow \infty$ .

**Proof:**

$$\begin{aligned}\lambda k = A_\sigma(Q_\sigma^*) &= Q_\sigma^* H_\sigma(Q_\sigma^*) - \int_0^{Q_\sigma^*} H_\sigma(y) dy \\ &= \sigma^2 \left[ \frac{Q_\sigma^*}{\sigma} H_1(Q_\sigma^*/\sigma) - \int_0^{Q_\sigma^*/\sigma} H_1(y) dy \right] \\ &= \sigma^2 A_1(Q_\sigma^*/\sigma).\end{aligned}$$

The proposition follows from the fact that  $A_1$  is increasing and  $A_1(0) = 0$ .  $\square$

Then the following result is also immediate.

**Proposition 6** (a) The optimal controllable cost  $C_{o,\sigma}^*$  is decreasing in  $\sigma$ , and  $C_{o,\sigma}^* \downarrow 0$  as  $\sigma \uparrow \infty$ ;  
(b) The optimal average cost  $C_\sigma^*$  is increasing in  $\sigma$ , but the increase is slower than the newsboy cost, and  $C_\sigma^* \sim \sigma G_1(y_1^\sigma)$  as  $\sigma \uparrow \infty$ .

**Proof:** (a) Since  $H_{o,\sigma}(y)$  is decreasing in  $\sigma$ , so is the controllable cost function  $C_o(Q)$  and its minimum  $C_o^*$ . By Lemma 8 in Zheng(1989), we have  $C_{o,\sigma}Q_\sigma^* \leq 2\lambda K$ , thus  $C_{o,\sigma} \downarrow 0$  as  $\sigma \uparrow \infty$  because  $Q_\sigma^* \uparrow \infty$  as  $\sigma \uparrow \infty$ .

(b) The cost function (4) and Corollary 1 imply that  $C_\sigma^*$  is increasing in  $\sigma$ .  $C_\sigma^* \sim \sigma G_1(y_1^\sigma)$  because  $C_\sigma^* = G_\sigma(y_\sigma^\sigma) + C_{o,\sigma}$ ,  $C_{o,\sigma} \downarrow 0$  as  $\sigma \uparrow \infty$  and Proposition 4.  $\square$

Finally, we show that the total cost is more robust to the choice of order quantity when the demand variance is larger. More specifically, we show that  $e_\sigma(\alpha) \stackrel{\text{def}}{=} \frac{C_\sigma(\alpha Q_\sigma^*)}{C_\sigma^*}$  decreases as  $\sigma$  increases. This result augments the inequality  $e_\sigma(\alpha) \leq e_d(\alpha)$  (where  $e_d(\alpha) = \frac{1}{2}(\alpha + 1/\alpha)$ ) established in Zheng(1989).

**Proposition 7** For  $\alpha > 0$ ,  $e_\sigma(\alpha)$  is decreasing in  $\sigma$ , and  $e_\sigma(\alpha) \downarrow 1$  as  $\sigma \uparrow \infty$ .

**Proof:**

$$\begin{aligned} e_\sigma(\alpha) = \frac{C_\sigma(\alpha Q_\sigma^*)}{C_\sigma^*} &= \frac{\lambda k + \int_0^{Q_\sigma^*} H_\sigma(y) dy + \int_{Q_\sigma^*}^{\alpha Q_\sigma^*} H_\sigma(y) dy}{\alpha Q_\sigma^* C_\sigma^*} \\ &= \frac{1}{\alpha} \left( 1 + \frac{\int_{Q_\sigma^*}^{\alpha Q_\sigma^*} H_\sigma(y) dy}{Q_\sigma^* H_\sigma(Q_\sigma^*)} \right) \\ &= \frac{1}{\alpha} \left( 1 + \frac{\int_1^\alpha H_\sigma(\beta Q_\sigma^*) d\beta}{H_\sigma(Q_\sigma^*)} \right) \\ &= \frac{1}{\alpha} \left( 1 + \int_1^\alpha \frac{H_1(\beta Q_\sigma^*/\sigma)}{H_1(Q_\sigma^*/\sigma)} d\beta \right) \end{aligned}$$

where the third equation is due to (5) and the fifth Lemma 6. In view of Proposition 5, it suffices to show that

$$\psi(Q) \stackrel{\text{def}}{=} \frac{H_1(\beta Q)}{H_1(Q)}$$

is increasing in  $Q$  for  $\beta > 1$  and decreasing for  $\beta < 1$ . We show the former, the latter is similar.

For  $\beta > 1$ ,

$$\psi'(Q) = \frac{1}{H_1^2(Q)} [\beta H_1'(\beta Q) H_1(Q) - H_1'(Q) H_1(\beta Q)] > 0$$

where the inequality follows from

$$\frac{H_1'(\beta Q)}{H_1'(Q)} > 1 \geq \frac{H_1(\beta Q)}{\beta H_1(Q)}$$

where the first inequality is due to the convexity of  $H_1$  and the second follows from Lemma 5.  $\square$

## 5. Sensitivity of the System Cost

In this section, we briefly discuss how the problem parameters affect the cost performance of a  $(Q,r)$  system. It is well known that, due to the square root formula, the cost of the EOQ model is robust to change in all its parameters  $(K, h, p, \lambda)$ . It would be interesting to know whether this robustness carries over to the cost of the  $(Q,r)$  system.

First, since the ordering cost  $K$  affects only the cost function  $C_o$ , which is smaller than that of the EOQ and diminishing as  $\sigma$  increases, the system cost is robust, and it is more robust when the leadtime demand is more variable. This can be verified formally as follows. Differentiating  $(\lambda K + \int_0^{Q^*} H_\sigma(y) dy)/Q_\sigma^*$  with respect to  $K$  yields  $dC_\sigma^*/dK = \lambda/Q_\sigma^*$ . Since  $Q_\sigma^*$  increases in  $\sigma$ ,  $dC_\sigma^*/dK$  decreases in  $\sigma$ .

The effect of change in the holding cost  $h$  or the penalty cost  $p$  is more involved because the change affects both the newsboy cost and  $C_o^*$ . Since the newsboy model does not enjoy the same degree of insensitivity as the EOQ model, we do not expect that the average cost of the  $(Q,r)$  system to be as robust to change in  $h$  or  $p$ , unless the effect of economies of scale dominates.

We can also quantify, at least approximately, the effect of a change in the leadtime on the cost performance of the  $(Q,r)$  system. A change in the leadtime affects both the mean and standard deviation of the leadtime demand. Since the mean does not have any impact on the optimal average cost, the system's cost would be affected only through the change of  $\sigma$ . Assuming that the leadtime demand is constant and  $\sigma$  is linear in  $\sqrt{L}$ , we conclude, by Proposition 6, that the change in the system cost is sublinear in  $\sqrt{L}$ , and approximately linear in  $\sqrt{L}$  when  $L$  (and hence  $\sigma$ ) is large. When the leadtime is stochastic, not only its mean, but also its standard deviation would have an impact on  $\sigma$ . The reader is referred to Zipkin(1991) for a discussion.

If a change in  $\lambda$  does not cause a change in the leadtime demand, then its effect on the system performance is identical to that of  $K$  because  $\lambda$  and  $K$  are symmetric in the cost function (see (2)). This assumption, however, is very ~~implausible~~ in practice. Typically, a change in the demand rate induces a change in  $\sigma$ . In this case, the global effect is more complex. Assuming that the leadtime  $L$  is constant and the demand process is Poisson (but approximately Normal), we have  $\sigma = \sqrt{\lambda L}$ . Therefore, the Newsboy cost changes linearly in  $\sqrt{\lambda}$  (Proposition 3);  $C_{\sigma,\sigma}^*$  is affected by change of both  $\lambda$  and  $\sigma$ . The effect of  $\lambda$  on  $C_{\sigma,\sigma}^*$  is sublinear in  $\sqrt{\lambda}$ . Since the effect of  $\sigma$  on  $C_{\sigma,\sigma}^*$  is in the opposite direction as indicated by Proposition 6(a), the total average cost  $C_\sigma^*$  must be sublinear to  $\sqrt{\lambda}$ . In other words, the average cost of the  $(Q,r)$  system is more robust to change in the demand rate than that of the EOQ model.

Finally, we comment on Proposition 7, which states that a larger variance in the leadtime demand makes the average cost more robust to the choice of order quantity *assuming the reorder point is always chosen optimally*. Care is needed in interpreting this insensitivity result. In particular, we cannot conclude from this proposition that the average cost is insensitive to inaccurate data. The reason is that when a suboptimal order quantity is chosen because of the inaccuracy of some parameter estimates, the reorder point is unlikely to be set optimally (with respect to the chosen order quantity).

This proposition, and Theorem 4 in Zheng(1989), are motivated by their potential usefulness for analyzing multi-stage stochastic systems. For multi-stage systems with constant demand, such an insensitivity property of the EOQ model has led to remarkable worst case performance bounds for the power-of-two heuristic policies (Roundy 1985, 1986). Here, we briefly discuss how these insensitivity results for the  $(Q,r)$  model could be useful for similar analysis on some plausible policies for multi-stage stochastic inventory systems. For multi-stage inventory systems where demands are stochastic and where there are fixed costs for inventory replenishment at each stage, a plausible control policy is to use an order-quantity/reorder-point policy at each stage. Since upstream stages are the suppliers for their downstream stages, the order quantities of different stages should be coordinated. For example, it is plausible to use the “integer ratio policy,” under which the order quantity of an upstream stage is restricted to an integer multiple of that of a downstream stage (if the downstream stage is the only customer of the upstream stage); see e.g. De Bodt and Graves(1985). Such a quantity coordination across different stages imposes a constraint on the choice of order quantities, but not on the reorder points; that is, while the order quantity at a stage may be required, for the global coordination, to deviate from its own “optimal” value the reorder point remains “local”, and can be chosen optimally for the choice of order quantity. Our insensitivity

results indicate that such a quantity coordination would not cause a significant cost increase from each stage's minimum cost. For systems with deterministic demands, Roundy(1986) showed by his lower bounding theorem that the sum of the single-stage minimum cost of all the stages (with some additional minor constraints on the order quantities) is a lower bound on the system-wide average cost, which in turn leads a very tight worst case performance of the power-of-two policies (which are a subset of the integer ratio policies). For stochastic systems, a parallel lower bounding theorem seems significantly more difficult to formulate. However, even in the absence of such a theorem, the heuristic policies that require quantity coordination across different stages are much encouraged by our insensitivity results for the single-item  $(Q,r)$  system. For a serial system with Poisson demand at the lowest stage, an accurate cost evaluation procedure has been devised (Chen and Zheng 1991 a) for echelon stock order-quantity/reorder point policies. Numerical studies(Chen and Zheng 1991 b) show that for a fairly wide range of data these policies are indeed close to optimal. Research on worst case analysis of heuristic policies for multi-stage systems is in progress.

## 6. Conclusion

Combining the results of this paper with those of Zheng(1989), we now have a more complete understanding of the behavior of  $(Q,r)$  systems. By assuming that the leadtime demand is (approximately) Normal, a  $(Q,r)$  system can be fully characterized by the cost parameters  $K, h, p$  and the demand parameters  $\lambda, \sigma$ . It is shown in Zheng(1989) that when  $K$  is large relative to  $\sigma$ , the  $(Q,r)$  model behaves like the EOQ model in every respect, and that the optimal control parameters and the optimal average cost of the EOQ model (with backorder allowed) are very good approximations of those of the  $(Q,r)$  model. The results of this paper show that when  $\sigma$  is large relative to  $K$ , on the other hand, the expected marginal inventory cost function  $H_\sigma$  is relatively flat. In that case. we can use a large order quantity to offset the ordering cost without incurring much increase in the average inventory cost; consequently, the total average cost of the system is close to the newsboy cost.

Strictly speaking, the  $(Q,r)$  model only applies to continuous review inventory systems with unit demand. When the inventory system is reviewed periodically, or when the demand size is random, the reorder point can be "overshot," in which case the control policy must be revised. A well known inventory system that accommodates the overshot is the  $(s,S)$  system, where an order is placed to increase the inventory position to  $S$  as soon as the inventory position drops to or below  $s$ . Here  $s$  denotes the reorder point and  $S$  the order-up-to level. The order quantity is no longer

(S-s), the difference between the order-up-to level and reorder point, but that plus the overshoot, which varies from order to order. Another variation that can accommodate the overshoot is the so called (nQ, r) system, where an order is placed whenever the inventory position drops to or below the reorder point r. The order quantity is chosen to be an integer (n) multiple of Q such that the inventory position is raised to between r+1 and r+Q. For recent analyses on these systems, see Zheng(1990), Zheng and Federgruen(1991) and Zheng and Chen(1990). Although the (Q,r) model appears as a special case of the more general (s,S) and (nQ,r) models, the qualitative properties derived for the former shed light on these general stochastic inventory systems. It should especially be emphasized that when the overshoot is not significant relative to the order quantity, the behavior of (s,S) and (nQ,r) systems is similar to that of (Q,r) systems.

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### References

- [1] Browne S. and P. Zipkin 1989 *Inventory Models with Continuous, Stochastic Demands*, Graduate School of Business, Columbia University.
- [2] Chen F. and Y.-S. Zheng(1991a) *Evaluating the Performance of a Serial Inventory System with Stochastic Demand*, Working paper, Department of Decision Sciences, Wharton School, University of Pennsylvania.
- [3] Chen F. and Y.-S. Zheng(1991b) *A Lower Bounding Framework for Stochastic Inventory Systems with Setup Costs* Working paper, Department of Decision Sciences, Wharton School, University of Pennsylvania.
- [4] deBott, M. A. and S. C. Graves(1985) *Continuous Review Policies for a Multi-Echelon Inventory Problems with Stochastic Demand*, Management Science, 31, 1286-1295.

- [5] Federgruen A. and Y.-S. Zheng 1988 *A Simple and Efficient Algorithm for Computing Optimal  $(r, Q)$  Policies in Continuous-Review Stochastic Inventory Systems*, Operations Research, to appear.
- [6] Gerchack 1990 *Analytical Comparative Statics for the Continuous Review Inventory Model*, Operations Research Letters V.9, 215-217.
- [7] Gerchack and Mossman 1988 *The Effect of demand randomness on lot sizes, safety stocks and costs*, working paper, Department of Industrial and Operations Engineering, University of Michigan.
- [8] Hadley, G. and T. M. Whitin 1963 *Analysis of Inventory Systems*, Prentice-Hall, Englewood Cliffs, NJ.
- [9] Lee, H. and Nahmias, S. 1989 *Single product, single-location models*, Chapter 2 in Handbook in Operations Research and Management Science, Vol. 4: Logistics of Production and Inventory (eds. S. Graves, A. Rinnooy Kan and P. Zipkin), North Holland, Amsterdam.
- [10] Rothschild, M. and J.E. Stiglitz 1970 *Increasing Risk: a Definition*, Journal of Economic Theory, 2, 225-243.
- [11] Roundy, R. 1985 *98% Effective Integer-Ratio Lot-Sizing for One Warehouse Multi-retailer Systems*, Management Science, 31, 1416-1430.
- [12] Roundy, R. 1986 *A 98% Effective Lot-Sizing Rule for a Multi-Product, Multi-Stage Production Inventory Systems*, Mathematics of Operations Research, 11, 699-727.
- [13] Zheng Y. S. 1989 *On Properties of Stochastic Inventory Systems*, Management Science, to appear.
- [14] Zheng Y.-S. 1990 *A Simple Proof for Optimality of  $(s, S)$  Policies in Infinite Horizon Inventory Systems* Journal of Applied Probability, to appear.
- [15] Zheng Y.-S. and F. Chen 1990 *Inventory Policies with Quantized Ordering*, Naval Research Logistics, to appear.
- [16] Zheng Y.-S. and A. Federgruen, 1991 *Finding Optimal  $(s, S)$  Policies is About as Simple as Evaluating a Single Policy* Operations Research 39, 654-665.
- [17] Zipkin, P. 1986 *Stochastic Leadtimes in Continuous-Time Inventory Models*, Navel Research Logistics Quarterly, 33 763-774.

- [18] Zipkin, P. 1991 *Foundation of Inventory Management*, Version 1.0, Columbia University,  
Manuscript to be published.

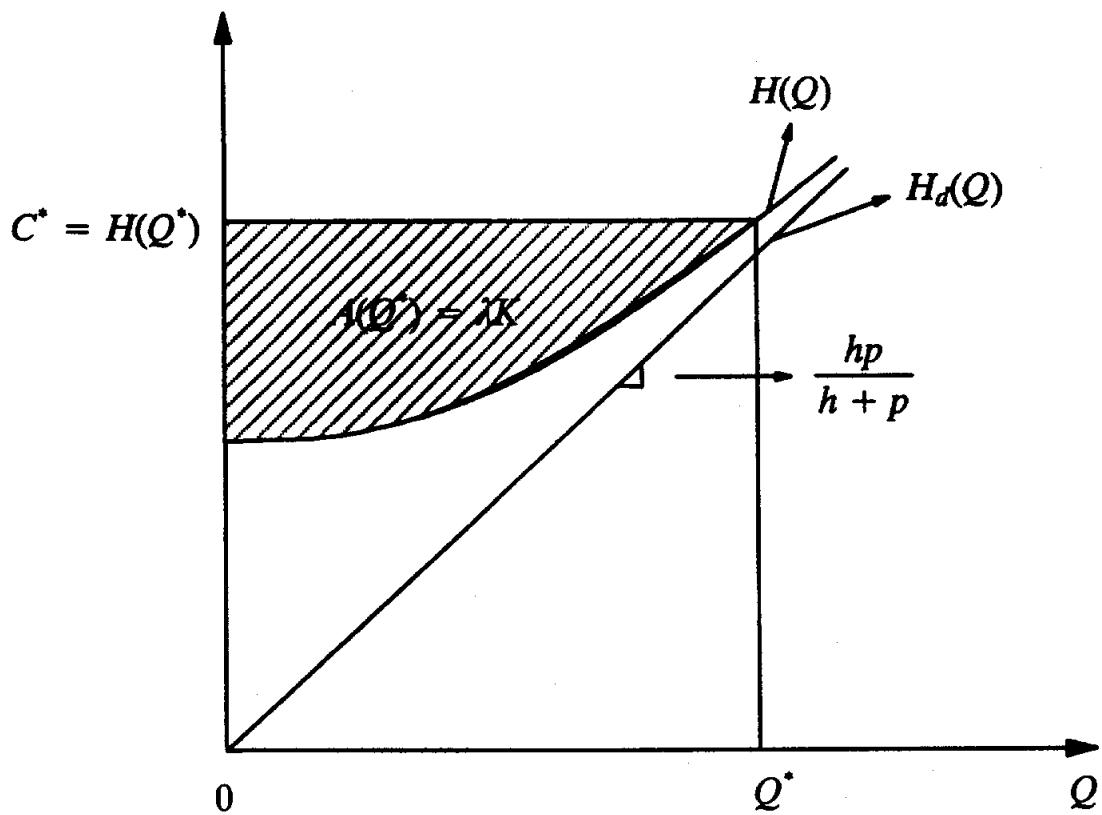


Figure 1  
 $H(\cdot), A(\cdot)$  – functions and the optimality condition

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89/54	S. BALAKRISHNAN and Mitchell KOZA	"Organisation costs and a theory of joint ventures", September 1989.	89/67 (FIN)	Peter BOSSAERTS and Pierre HILLION	"Market microstructure effects of government intervention in the foreign exchange market", December 1989.
89/55	H. SCHUTTE	"Euro-Japanese cooperation in information technology", September 1989.			
89/56	Wilfried VANHONACKER and Lydia PRICE	"On the practical usefulness of meta-analysis results", September 1989.			
89/57	Taeckwon KIM, Lars-Hendrik RÖLLER and Mihkel TOMBAK	"Market growth and the diffusion of multiproduct technologies", September 1989.	<u>1990</u>		
89/58 (EP, TM)	Lars-Hendrik RÖLLER and Mihkel TOMBAK	"Strategic aspects of flexible production technologies", October 1989.	90/01 TM/EP/AC	B. SINCLAIR-DESGAGNÉ	"Unavoidable Mechanisms", January 1990.
89/59 (OB)	Manfred KETS DE VRIES, Daphna ZEVADI, Alain NOEL and Mihkel TOMBAK	"Locus of control and entrepreneurship: a three-country comparative study", October 1989.	90/02 EP	Michael BURDA	"Monopolistic Competition, Costs of Adjustment, and the Behaviour of European Manufacturing Employment", January 1990.
89/60 (All)	Enver YUCESAN and Lee SCHRUBEN	"Simulation graphs for design and analysis of discrete event simulation models", October 1989.	90/03 TM	Arnoud DE MEYER	"Management of Communication in International Research and Development", January 1990.
89/60 (All)	Susan SCHNEIDER and Arnoud DE MEYER	"Interpreting and responding to strategic issues: The impact of national culture", October 1989.	90/04 FIN/EP	Gabriel HAWAWINI and Eric RAJENDRA	"The Transformation of the European Financial Services Industry: From Fragmentation to Integration", January 1990.
89/61 (All)			90/05 FIN/EP	Gabriel HAWAWINI and Bertrand JACQUILLAT	"European Equity Markets: Toward 1992 and Beyond", January 1990.

90/06 FIN/EP	Gabriel HAWAWINI and Eric RAJENDRA	"Integration of European Equity Markets: Implications of Structural Change for Key Market Participants to and Beyond 1992", January 1990.	90/17 FIN	Nathalie DIERKENS	"Information Asymmetry and Equity Issues", Revised January 1990.
90/07 FIN/EP	Gabriel HAWAWINI	"Stock Market Anomalies and the Pricing of Equity on the Tokyo Stock Exchange", January 1990.	90/18 MKT	Wilfried VANHONACKER	"Managerial Decision Rules and the Estimation of Dynamic Sales Response Models", Revised January 1990.
90/08 TM/EP	Tawfik JELASSI and B. SINCLAIR-DESGAGNÉ	"Modelling with MCDSS: What about Ethics?", January 1990.	90/19 TM	Beth JONES and Tawfik JELASSI	"The Effect of Computer Intervention and Task Structure on Bargaining Outcome", February 1990.
90/09 EP/FIN	Alberto GIOVANNINI and Jae WON PARK	"Capital Controls and International Trade Finance", January 1990.	90/20 TM	Tawfik JELASSI, Gregory KERSTEN and Stanley ZIANTS	"An Introduction to Group Decision and Negotiation Support", February 1990.
90/10 TM	Joyce BRYER and Tawfik JELASSI	"The Impact of Language Theories on DSS Dialog", January 1990.	90/21 FIN	Roy SMITH and Ingo WALTER	"Reconfiguration of the Global Securities Industry in the 1990's", February 1990.
90/11 TM	Enver YUCESAN	"An Overview of Frequency Domain Methodology for Simulation Sensitivity Analysis", January 1990.	90/22 FIN	Ingo WALTER	"European Financial Integration and Its Implications for the United States", February 1990.
90/12 EP	Michael BURDA	"Structural Change, Unemployment Benefits and High Unemployment: A U.S.-European Comparison", January 1990.	90/23 EP/SM	Damien NEVEN	"EEC Integration towards 1992: Some Distributional Aspects", Revised December 1989
90/13 TM	Soumitra DUTTA and Shashi SHEKHAR	"Approximate Reasoning about Temporal Constraints in Real Time Planning and Search", January 1990.	90/24 FIN/EP	Lars Tyge NIELSEN	"Positive Prices in CAPM", January 1990.
90/14 TM	Albert ANGEHRN and Hans-Jakob LÜTHI	"Visual Interactive Modelling and Intelligent DSS: Putting Theory Into Practice", January 1990.	90/25 FIN/EP	Lars Tyge NIELSEN	"Existence of Equilibrium in CAPM", January 1990.
90/15 TM	Arnoud DE MEYER, Dirk DESCHOOLMEESTER, Rudy MOENAERT and Jan BARBE	"The Internal Technological Renewal of a Business Unit with a Mature Technology", January 1990.	90/26 OB/BP	Charles KADUSHIN and Michael BRIMM	"Why Networking Fails: Double Binds and the Limitations of Shadow Networks", February 1990.
90/16 FIN	Richard LEVICH and Ingo WALTER	"Tax-Driven Regulatory Drag: European Financial Centers in the 1990's", January 1990.	90/27 TM	Abbas FOROUGHI and Tawfik JELASSI	"NSS Solutions to Major Negotiation Stumbling Blocks", February 1990.
			90/28 TM	Arnoud DE MEYER	"The Manufacturing Contribution to Innovation", February 1990.

90/29 FIN/AC	Nathalie DIERKENS	"A Discussion of Correct Measures of Information Asymmetry", January 1990.	90/40 OB	Manfred KETS DE VRIES	"Leaders on the Couch: The case of Roberto Calvi", April 1990.
90/30 FIN/EP	Lars Tyge NIELSEN	"The Expected Utility of Portfolios of Assets", March 1990.	90/41 FIN/EP	Gabriel HAWAWINI, Itzhak SWARY and Ik HWAN JANG	"Capital Market Reaction to the Announcement of Interstate Banking Legislation", March 1990.
90/31 MKT/EP	David GAUTSCHI and Roger BETANCOURT	"What Determines U.S. Retail Margins?", February 1990.	90/42 MKT	Joel STECKEL and Wilfried VANHONACKER	"Cross-Validating Regression Models in Marketing Research", (Revised April 1990).
90/32 SM	Srinivasan BALAKRISHNAN and Mitchell KOZA	"Information Asymmetry, Adverse Selection and Joint-Ventures: Theory and Evidence", Revised, January 1990.	90/43 FIN	Robert KORAJCZYK and Claude VIALLET	"Equity Risk Premium and the Pricing of Foreign Exchange Risk", May 1990.
90/33 OB	Caren SIEHL, David BOWEN and Christine PEARSON	"The Role of Rites of Integration in Service Delivery", March 1990.	90/44 OB	Gilles AMADO, Claude FAUCHEUX and André LAURENT	"Organisational Change and Cultural Realities: Franco-American Contrasts", April 1990.
90/34 FIN/EP	Jean DERMINE	"The Gains from European Banking Integration, a Call for a Pro-Active Competition Policy", April 1990.	90/45 TM	Soumitra DUTTA and Piero BONISONE	"Integrating Case Based and Rule Based Reasoning: The Possibilistic Connection", May 1990.
90/35 EP	Jae Won PARK	"Changing Uncertainty and the Time-Varying Risk Premium in the Term Structure of Nominal Interest Rates", December 1988, Revised March 1990.	90/46 TM	Spyros MAKRIDAKIS and Michèle HIBON	"Exponential Smoothing: The Effect of Initial Values and Loss Functions on Post-Sample Forecasting Accuracy".
90/36 TM	Arnoud DE MEYER	"An Empirical Investigation of Manufacturing Strategies in European Industry", April 1990.	90/47 MKT	Lydia PRICE and Wilfried VANHONACKER	"Improper Sampling in Natural Experiments: Limitations on the Use of Meta-Analysis Results in Bayesian Updating", Revised May 1990.
90/37 TM/OB/SM	William CATS-BARIL	"Executive Information Systems: Developing an Approach to Open the Possibles", April 1990.	90/48 EP	Jae WON PARK	"The Information in the Term Structure of Interest Rates: Out-of-Sample Forecasting Performance", June 1990.
90/38 MKT	Wilfried VANHONACKER	"Managerial Decision Behaviour and the Estimation of Dynamic Sales Response Models", (Revised February 1990).	90/49 TM	Soumitra DUTTA	"Approximate Reasoning by Analogy to Answer Null Queries", June 1990.
90/39 TM	Louis LE BLANC and Tawfik JELOSSI	"An Evaluation and Selection Methodology for Expert System Shells", May 1990.	90/50 EP	Daniel COHEN and Charles WYPLOSZ	"Price and Trade Effects of Exchange Rates Fluctuations and the Design of Policy Coordination", April 1990.

90/51 EP	Michael BURDA and Charles WYPLOSZ	"Gross Labour Market Flows in Europe: Some Stylized Facts", June 1990.	90/63 SM	Sumantra GHOSHAL and Eleanor WESTNEY	"Organizing Competitor Analysis Systems", August 1990
90/52 FIN	Lars Tyge NIELSEN	"The Utility of Infinite Memes", June 1990.	90/64 SM	Sumantra GHOSHAL	"Internal Differentiation and Corporate Performance: Case of the Multinational Corporation", August 1990
90/53 EP	Michael Burda	"The Consequences of German Economic and Monetary Union", June 1990.	90/65 EP	Charles WYPLOSZ	"A Note on the Real Exchange Rate Effect of German Unification", August 1990
90/54 EP	Damien NEVEN and Colin MEYER	"European Financial Regulation: A Framework for Policy Analysis", (Revised May 1990).	90/66 TM/SE/FIN	Soumitra DUTTA and Piero BONISONE	"Computer Support for Strategic and Tactical Planning in Mergers and Acquisitions", September 1990
90/55 EP	Michael BURDA and Stefan GERLACH	"Intertemporal Prices and the US Trade Balance", (Revised July 1990).	90/67 TM/SE/FIN	Soumitra DUTTA and Piero BONISONE	"Integrating Prior Cases and Expert Knowledge in a Mergers and Acquisitions Reasoning System", September 1990
90/56 EP	Damien NEVEN and Lars-Hendrik RÖLLER	"The Structure and Determinants of East-West Trade: A Preliminary Analysis of the Manufacturing Sector", July 1990	90/68 TM/SE	Soumitra DUTTA	"A Framework and Methodology for Enhancing the Business Impact of Artificial Intelligence Applications", September 1990
90/57 FIN/EP/ TM	Lars Tyge NIELSEN	Common Knowledge of a Multivariate Aggregate Statistic", July 1990	90/69 TM	Soumitra DUTTA	"A Model for Temporal Reasoning in Medical Expert Systems", September 1990
90/58 FIN/EP/TM	Lars Tyge NIELSEN	"Common Knowledge of Price and Expected Cost in an Oligopolistic Market", August 1990	90/70 TM	Albert ANGEHRN	"Triple C': A Visual Interactive MCDSS", September 1990
90/59 FIN	Jean DERMINE and Lars-Hendrik RÖLLER	"Economies of Scale and Scope in the French Mutual Funds (SICAV) Industry", August 1990	90/71 MKT	Philip PARKER and Hubert GATIGNON	"Competitive Effects in Diffusion Models: An Empirical Analysis", September 1990
90/60 TM	Peri IZ and Tawfik JELASSI	"An Interactive Group Decision Aid for Multiobjective Problems: An Empirical Assessment", September 1990	90/72 TM	Enver YÜCESAN	"Analysis of Markov Chains Using Simulation Graph Models", October 1990
90/61 TM	Pankaj CHANDRA and Mihkel TOMBAK	"Models for the Evaluation of Manufacturing Flexibility", August 1990	90/73 TM	Arnaud DE MEYER and Kastha FERDOWS	"Removing the Barriers in Manufacturing", October 1990
90/62 EP	Damien NEVEN and Menno VAN DUK	"Public Policy Towards TV Broadcasting in the Netherlands", August 1990	90/74 SM	Sumantra GHOSHAL and Nitin NOHRIA	"Requisite Complexity: Organising Headquarters-Subsidiary Relations in MNCs", October 1990

90/75 MKT	Roger BETANCOURT and David GAUTSCHI	"The Outputs of Retail Activities: Concepts, Measurement and Evidence", October 1990	90/87 FIN/EP	Lars Tyge NIELSEN	"Existence of Equilibria in CAPM: Further Results", December 1990
90/76 MKT	Wilfried VANHONACKER	"Managerial Decision Behaviour and the Estimation of Dynamic Sales Response Models", Revised October 1990	90/88 OB/MKT	Susan C. SCHNEIDER and Reinhard ANGELMAR	"Cognition in Organizational Analysis: Who's Minding the Store?" Revised, December 1990
90/77 MKT	Wilfried VANHONACKER	"Testing the Keyck Scheme of Sales Response to Advertising: An Aggregation-Independent Autocorrelation Test", October 1990	90/89 OB	Manfred F.R. KETS DE VRIES	"The CEO Who Couldn't Talk Straight and Other Tales from the Board Room," December 1990
90/78 EP	Michael BURDA and Stefan GERLACH	"Exchange Rate Dynamics and Currency Unification: The Ostmark - DM Rule", October 1990	90/90 MKT	Philip PARKER	"Price Elasticity Dynamics over the Adoption Lifecycle: An Empirical Study," December 1990
90/79 TM	Anil GABA	"Inferences with an Unknown Noise Level in a Bernoulli Process", October 1990			
90/80 TM	Anil GABA and Robert WINKLER	"Using Survey Data in Inferences about Purchase Behaviour", October 1990	1991		
90/81 TM	Tewfik JELASSI	"Du Présent au Futur: Bilan et Orientations des Systèmes Interactifs d'Aide à la Décision," October 1990	91/01 TM/SM	Luk VAN WASSENHOVE, Leonard FORTUIN and Paul VAN BEEK	"Operational Research Can Be More for Managers Than They Think!," January 1991
90/82 EP	Charles WYPLOSZ	"Monetary Union and Fiscal Policy Discipline," November 1990	91/02 TM/SM	Luk VAN WASSENHOVE, Leonard FORTUIN and Paul VAN BEEK	"Operational Research in the Environment," January 1991
90/83 FIN/TM	Nathalie DIERKENS and Bernard SINCLAIR-DESGAGNE	"Information Asymmetry and Corporate Communication: Results of a Pilot Study", November 1990	91/03 FIN	Pekka HIETALA and Timo LÖYTTYNIMI	"An Implicit Dividend Increase in Rights Issues: Theory and Evidence," January 1991
90/84 MKT	Philip M. PARKER	"The Effect of Advertising on Price and Quality: The Optometric Industry Revisited," December 1990	91/04 FIN	Lars Tyge NIELSEN	"Two-Fund Separation, Factor Structure and Robustness," January 1991
90/85 MKT	Avijit GHOSH and Vikes TIBREWALA	"Optimal Timing and Location in Competitive Markets," November 1990	91/05 OB	Susan SCHNEIDER	"Managing Boundaries in Organizations," January 1991
90/86 EP/TM	Olivier CADOT and Bernard SINCLAIR-DESGAGNE	"Prudence and Success in Politics," November 1990	91/06 OB	Manfred KETS DE VRIES, Danny MILLER and Alain NOEL	"Understanding the Leader-Strategy Interface: Application of the Strategic Relationship Interview Method," January 1990 (89/11, revised April 1990)

91/07 EP	Olivier CADOT	"Lending to Insolvent Countries: A Paradoxical Story," January 1991	91/19 MKT	Vikas TIBREWALA and Bruce BUCHANAN	"An Aggregate Test of Purchase Regularity". March 1991
91/08 EP	Charles WYPLOSZ	"Post-Reform East and West: Capital Accumulation and the Labour Mobility Constraint," January 1991	91/20 MKT	Darius SABAVALA and Vikas TIBREWALA	"Monitoring Short-Run Changes in Purchasing Behaviour", March 1991
91/09 TM	Spyros MAKRIDAKIS	"What can we Learn from Failure?", February 1991	91/21 SM	Sumantra GHOSHAL, Harry KORINE and Gabriel SZULANSKI	"Interunit Communication within MNCs: The Influence of Formal Structure Versus Integrative Processes", April 1991
91/10 TM	Luc Van WASSENHOVE and C. N. POTTS	"Integrating Scheduling with Batching and Lot-Sizing: A Review of Algorithms and Complexity", February 1991	91/22 EP	David GOOD, Lars-Hendrik RÖLLER and Robin SICKLES	"EC Integration and the Structure of the Franco-American Airline Industries: Implications for Efficiency and Welfare", April 1991
91/11 TM	Luc VAN WASSENHOVE et al.	"Multi-Item Lotsizing in Capacitated Multi-Stage Serial Systems", February 1991	91/23 TM	Spyros MAKRIDAKIS and Michèle HIBON	"Exponential Smoothing: The Effect of Initial Values and Loss Functions on Post-Sample Forecasting Accuracy", April 1991 (Revision of 90/46)
91/13 EP	Michael BURDA	"Labor and Product Markets in Czechoslovakia and the Ex-GDR: A Twin Study", February 1991	91/24 TM	Louis LE BLANC and Tawfik JELASSI	"An Empirical Assessment of Choice Models for Software Evaluation and Selection", May 1991
91/14 MKT	Roger BETANCOURT and David GAUTSCHI	"The Output of Retail Activities: French Evidence", February 1991	91/25 SM/TM	Luk N. VAN WASSENHOVE and Charles J. CORBETT	"Trade-Offs? What Trade-Offs?" April 1991
91/15 OB	Manfred F.R. KETS DE VRIES	"Exploding the Myth about Rational Organisations and Executives", March 1991	91/26 TM	Luk N. VAN WASSENHOVE and C.N. POTTS	"Single Machine Scheduling to Minimize Total Late Work", April 1991
91/16 TM	Arnoud DE MEYER and Kasra FERDOWS et.al.	"Factories of the Future: Executive Summary of the 1990 International Manufacturing Futures Survey", March 1991	91/27 FIN	Nathalie DIERKENS	"A Discussion of Correct Measures of Information Asymmetry: The Example of Myers and Majluf's Model or the Importance of the Asset Structure of the Firm", May 1991
91/17 TM	Dirk CATTRYSSSE, Roelof KUIK, Marc SALOMON and Luk VAN WASSENHOVE	"Heuristics for the Discrete Lotsizing and Scheduling Problem with Setup Times", March 1991	91/28 MKT	Philip M. PARKER	"A Note on: 'Advertising and the Price and Quality of Optometric Services', June 1991
91/18 TM	C.N. POTTS and Luk VAN WASSENHOVE	"Approximation Algorithms for Scheduling a Single Machine to Minimize Total Late Work", March 1991	91/29 TM	Tawfik JELASSI and Abbas FOROUGHI	"An Empirical Study of an Interactive, Session-Oriented Computerised Negotiation Support System (NSS)", June 1991

91/30 MKT	Wilfried R. VANHONACKER and Lydia J. PRICE	"Using Meta-Analysis Results in Bayesian Updating: The Empty Cell Problem", June 1991	91/43 SM	Sumantra GHOSHAL and Christopher BARTLETT	"Building Transnational Capabilities: The Management Challenge", September 1991
91/31 FIN	Renzal KABIR and Theo VERMAELEN	"Insider Trading Restrictions and the Stock Market", June 1991	91/44 SM	Sumantra GHOSHAL and Nitin NOHRIA	"Distributed Innovation in the 'Differentiated Network' Multinational", September 1991
91/32 OB	Susan C. SCHNEIDER	"Organisational Sensemaking: 1992", June 1991	91/45 MKT	Philip M. PARKER	"The Effect of Advertising on Price and Quality: An Empirical Study of Eye Examinations, Sweet Lemons and Self-Deceivers", September 1991
91/33 EP	Michael C. BURDA and Michael FUNKE	"German Trade Unions after Unification - Third Degree Wage Discriminating Monopolists?", June 1991	91/46 MKT	Philip M. PARKER	"Pricing Strategies in Markets with Dynamic Elasticities", October 1991
91/34 FIN	Jean DERMINE	"The BIS Proposal for the Measurement of Interest Rate Risk, Some Pitfalls", June 1991	91/47 MKT	Philip M. PARKER	"A Study of Price Elasticity Dynamics Using Persistence Replacement/Multiple Purchase Diffusion Models", October 1991
91/35 FIN	Jean DERMINE	"The Regulation of Financial Services in the EC, Centralization or National Autonomy?" June 1991	91/48 EP/TM	H. Landis GABEL and Bernard SINCLAIR-DESGAGNE	"Managerial Incentives and Environmental Compliance", October 1991
91/36 TM	Albert ANGEHRN	"Supporting Multicriteria Decision Making: New Perspectives and New Systems", August 1991	91/49 TM	Bernard SINCLAIR-DESGAGNE	"The First-Order Approach to Multi-Task Principal-Agent Problems", October 1991
91/37 EP	Ingo WALTER and Hugh THOMAS	"The Introduction of Universal Banking in Canada: An Event Study", August 1991	91/50 SM/TM	Luk VAN WASSENHOVE and Charles CORBETT	"How Green is Your Manufacturing Strategy?", October 1991
91/38 EP	Ingo WALTER and Anthony SAUNDERS	"National and Global Competitiveness of New York City as a Financial Center", August 1991	91/51 MKT	Philip M. PARKER	"Choosing Among Diffusion Models: Some Empirical Guidelines", October 1991
91/39 EP	Ingo WALTER and Anthony SAUNDERS	"Reconfiguration of Banking and Capital Markets in Eastern Europe", August 1991	91/52 EP	Michael BURDA and Charles WYPLOZ	"Human Capital, Investment and Migration in an Integrated Europe", October 1991
91/40 TM	Luk VAN WASSENHOVE, Dirk CATTRYSSE and Marc SALOMON	"A Set Partitioning Heuristic for the Generalized Assignment Problem", August 1991	91/53 EP	Michael BURDA and Charles WYPLOZ	"Labour Mobility and German Integration: Some Vignettes", October 1991
91/41 TM	Luk VAN WASSENHOVE, M.Y. KOVALYOU and C.N. POTTS	"A Fully Polynomial Approximation Scheme for Scheduling a Single Machine to Minimize Total Weighted Late Work", August 1991	91/54 TM	Albert ANGEHRN	"Stimulus Agents: An Alternative Framework for Computer-Aided Decision Making", October 1991
91/42 TM	Rob R. WEITZ and Tawfik JELASSI	"Solving A Multi-Criteria Allocation Problem: A Decision Support System Approach", August 1991			

91/55 EP/SM	Robin HOGARTH, Claude MICHAUD, Yves DOZ and Ludo VAN DER HEYDEN	"Longevity of Business Firms: A Four-Stage Framework for Analysis", November 1991	92/03 OB	Manfred F.R. KETS DE VRIES	"The Family Firm: An Owner's Manual", January 1992
91/56 TM/EP	Bernard SINCLAIR-DESGAGNE	"Aspirations and Economic Development", November 1991	92/04 SM	Philippe HASPESLAGH and David JEMISON	"Making Acquisitions Work", January 1992
91/57 MKT	Lydia J. PRICE	"The Indirect Effects of Negative Information on Attitude Change", November 1991	92/05 TM	Xavier DE GROOTE	"Flexibility and Product Diversity in Lot-Sizing Models", January 1992 (revised)
91/58 OB	Manfred F. R. KETS DE VRIES	"Leaders Who Go Crazy", November 1991	92/06 FIN	Theo VERMAELEN and Kees COOLS	"Financial Innovation: Self Tender Offers in the U.K.", January 1992
91/59 OB	Paul A. L. EVANS	"Management Development as Glue Technology", November 1991	92/07 TM	Xavier DE GROOTE	"The Flexibility of Production Processes: A General Framework", January 1992 (revised)
91/60 TM	Xavier DE GROOTE	"Flexibility and Marketing/Manufacturing Coordination", November 1991 (revised)	92/08 TM	Luk VAN WASSENHOVE, Leo KROON and Marc SALOMON	"Exact and Approximation Algorithms for the Operational Fixed Interval Scheduling Problem", January 1992
91/61 TM	Arnoud DE MEYER	"Product Development in the Textile Machinery Industry", November 1991	92/09 TM	Luk VAN WASSENHOVE, Roelof KUIK and Marc SALOMON	"Statistical Search Methods for Lot-sizing Problems", January 1992
91/62 MKT	Philip PARKER and Hubert GATIGNON	"Specifying Competitive Effects in Diffusion Models: An Empirical Analysis", November 1991	92/10 SM	Yves DOZ and Heinz THANHEISER	"Regaining Competitiveness: A Process of Organisational Renewal", January 1992
91/63 EP	Michael BURDA	"Some New Insights on the Interindustry Wage Structure from the German Socioeconomic Panel", December 1991	92/11 TM	Enver YUCESAN and Sheldon JACOBSON	"On the Intractability of Verifying Structural Properties of Discrete Event Simulation Models", February 1992
91/64 FIN	Jean DERMINE	"Internationalization of Financial Markets, Efficiency and Stability", December 1991	92/12 FIN	Gabriel HAWAWINI	"Valuation of Cross-Border Mergers and Acquisitions", February 1992
1992			92/13 TM	Spyros MAKRIDAKIS and Michèle HIBON et.al.	"The M2-Competition: A Budget Related Empirical Forecasting Study", February 1992
92/01 MKT/EP/TM	Wilfried VANHONACKER	"CONPRO*DOGIT: A New Brand Choice Model Incorporating a Consideration Set Formation Process", January 1992	92/14 MKT	Lydia PRICE	"Identifying Cluster Overlap with NORMIX Population Membership Probabilities", February 1992
92/02 MKT/EP/TM	Wilfried VANHONACKER	"The Dynamics of the Consideration Set Formation Process: A Rational Modelling Perspective and Some Numerical Results", January 1992			