Journal of Industrial and Systems Engineering
Vol. 9, special issue on supply chain, pp 1 – 16
Winter (January) 2016

Coordination of pricing, ordering, and lead time decisions in a manufacturing supply chain

Jafar Heydari[1*], Yousef Norouzinasab[1]

[1]*School of Industrial Engineering, College of Engineering, University of Tehran*
J.Heydari@ut.ac.ir

Abstract

In this article, an incentive policy is proposed to coordinate ordering, lead time and pricing strategies in a two-echelon manufacturing supply chain (SC) consisting of one manufacturer and one retailer. The system is faced with a stochastic demand which depends on both price and lead time.The manufacturer decides on production size and manufacturing acceleration rate while the retailer determines the retail price and order size. A game theory approach is proposed to analyze both members' decision making process. An integrated decision making process where both members cooperate as a single entity, aiming to maximize system-wide profit is formulated. Finally a coordination mechanism based on adjusting wholesale price is proposed to convince both members to decide jointly. Numerical experiments demonstrate that whole SC profitability as well as both members profitability is increased by applying the proposed scheme. Results indicate that the coordinated decision making decreases both retail price and lead time length, while it causes an increase in order size.

Keywords: Manufacturing process acceleration; supply chain coordination; stochastic price and lead time sensitive demand; game theory; lead time reduction.

1- Introduction and literature review

A supply chain is an integrated logistic network consisting of entities such as suppliers, manufacturers, warehouses, distributors, retailers and their relationships toward managing the material, financial and information flows. In the traditional decision making with absence of coordination, each SC member makes decisions based on its own interests, without considering the influences on other SC members. As a result, the performance of whole SC may be reduced due to complex interaction between decisions made by each party (Masihabadi and Eshghi, 2011). The model presented in this paper has three main subjects: (1) replenishment decisions, (2) lead time reduction, and (3) pricing decisions.

The important role of replenishment policies in supply chains and inventory management is undeniable. To be sure that customer demand is satisfied without delay and mitigate under stocking risk, keeping appropriate amount of inventory is necessary. There are various companies throughout the supply chain where each company expects to adopt its optimal replenishment strategy that makes a disadvantage to the other ones (Glock, 2012).

---

* Corresponding Author
ISSN: 1735-8272,

Lead time reduction (if applicable) is also profitable from several aspects such as less shortage occasions, reduction in bullwhip effect, lower safety stock, more accurate forecasts, and smaller order sizes which result in lower level of finished products' inventory (Leng and Parlar, 2009; Chung et al., 2014). However, lead time reduction is expensive and therefore it will be applicable when it can compensate for its costs.

In addition to importance of two previously mentioned subjects (replenishment policies and lead-time reduction) in the supply chain management, pricing strategies can also improve the efficiency of SC dramatically (Mokhlesian et al., 2015). Pricing policies play an important role where customer demand depends on retail price.

A well-designed SC coordination plan can guarantee improvement of SC members' performance and subsequently integrate the SC decisions simultaneously (Govindan et al., 2012). The most common contracts can be mentioned as the wholesale price discount contracts (Chen, 2011; Du et al., 2013; Huang et al., 2014), revenue-sharing contracts (Linh and Hong, 2009; Rhee et al., 2014; Heese and Kemahlıoğlu-Ziya, 2016), buy-back contracts (Hou et al., 2010; Zhao et al., 2014), quantity-flexibility contracts (Sethi et al., 2004; Lian and Deshmukh, 2009) and sales rebate contracts (Wong et al., 2009; Chiu et al., 2012). SC contracts for both forward and reverse supply chains have been reviewed and classified by Govindan et al., (2013).

Starting from a game-theory evaluation of pricing, ordering, production and delivery policies in a traditional manufacturer-retailer supply chain, this paper proposes a wholesale price policy as an intensive plan to improve supply chain performance. For this purpose, a new sensitivity based game theory approach (Ghotbi et al., 2014) is applied to determine the Nash equilibrium and evaluate the decisions. Finally an algorithm based Li & Liu's (2006) work is proposed to coordinate the system.

This paper contributes in the literature by integrating key decisions of SC members toward maximizing total SC profit while none of SC members incur losses. These key decisions are pricing and ordering decisions for the retailer and lead time and batch sizing decisions for the manufacturer. In the investigated SC, the retailer has the authority of deciding on retail price and order size; on the other hand, the manufacturer can control lead times by spending more. Decreasing lead time is possible by acceleration of manufacturing process. Acceleration of manufacturing process increases the production costs and therefore the manufacturer should solve a trade-off between increased manufacturing costs and benefits of lead time reduction. In the investigated model, the benefits of reducing the lead times for the manufacturer can be characterized from two aspects: (1) encouraging the retailer to be committed to globally-optimum decisions, and (2) increasing demand. Customers expect to get the lowest prices and shortest delivery times; therefore demand is dependent to both retail price and lead time.

Streams of researches that investigate the joint decision making on pricing, replenishment, and lead time reduction policies in supply chain management are related to this research.

There is a large body of literature that focuses on joint economic lot sizing (JELS) issues under various assumptions. JELS models as a planning tools are especially effective and useful in situations where supply chain members establish a long-term relationship with their partners. An example is automotive industries (Glock, 2012).

Goyal (1977) proposed a single vendor-single buyer system (SVSB) that the vendor with an infinite production rate sells a product to the buyer in equal-sized shipments. He shows that the total relative costs will be decreased with a joint decision on lot size. In the line of thought that producing a larger size of the buyer's order quantity at the vendor may reduce system related costs, a more general SVSB model was developed where the vendor produces an integer multiplier of buyer's order quantity.

Some researchers have considered the pricing strategy simultaneously with lot size decisions to manage the supply chain effectively. Coordination of pricing and ordering decisions in a multi-echelon pharmacological supply chain is investigated using a game theory approach (Noori- daryan and Taleizadeh, 2016). Boyacı and Gallego (2002) analyzed the coordination of both pricing and lot sizing decisions in a single wholesaler-multiple retailer system faced with deterministic price sensitive demand. They showed that an inventory consignment selling agreement can maximize the channel profits. Khouja(2006) formulated and solved models for optimal jointly decisions on ordering and pricing strategies under a deterministic price and rebate sensitive demand. The results showed that offering rebates can improve the profit dramatically. Recently, some papers focus on the problem of coordination of ordering and pricing policies, for example see (Chen and Simchi-Levi, 2006; You and Hsieh, 2007; Ouyang et al., 2009; Yıldırmaz et al., 2009; Wang et al., 2015).

The other stream of related literature considers lead time reduction. Hill and Khosla (1992) developed a conceptual framework to compare the benefits and costs of lead time reduction for a single manufacturer faced with a lead time sensitive demand. Johnson (2003) presented a conceptual framework to evaluate the impact of lead time reduction and some other factors on reducing manufacturing throughput time. Ben-Daya and Hariga (2003) developed a stochastic inventory model with a controllable lead time and learning consideration. Pan and Hsiao (2005) investigated an integrated inventory system where backordering and lead time are negotiable. Chang et al. (2006) studied the ordering cost and lead time reduction in an integrated SVSB system. They presented two models in their study: (1) model in which there is no relation between lead time crashing and ordering cost reduction and (2) model in which ordering cost reduction and lead time are interacted. Anli et al. (2007) addressed and modeled the variable lead time resulted from the increasing incremental work in processin coordinating a system. Ouyang et al. (2007) developed an integrated inventory model involving imperfect production process where a joint decision making on process quality, order quantity, reorder point,lead time, and the frequency of deliveries is made simultaneously.

Leng and Parlar (2009) investigated a game-theory model of lead-time reduction in a single manufacturer single retailer system. They considered that the lead time consists of three components: setup time, production time and shipping time. They developed a profit sharing contract and showed that by coordinated decision making the members' performance will be improved. Li et al. (2012) investigated the coordination policies in a SVSB system with controllable lead times. Their numerical experiments showed that lead time reduction can reduce the inventory cost. Jha and Shanker (2014) investigated an integrated inventory problem with transportation in a single vendor and multi-buyer decentralized system in which the lead time components of the buyers can be reduced. Heydari (2014a) developed a coordination policy as 'per order extra payment' to counteract the harmful effect of supplier lead time in a two-echelon supply chain. In another work, Heydari (2014b) considered the reduction of lead-time fluctuations as a coordination mechanism to coordinate the service level in a two echelon system. Sarkaret al.(2015) investigated a continuous review inventory system with lead time, backorder price discount, order quantity, reorder point, and process quality as decision variables. Zhu (2015) proposed a franchise contract with a contingent rebate to coordinate capacity, pricing, and lead-time decisions in a single supplier single retailer system faced with a price and lead time sensitive demand.

Following the previous researches, this paper focuses mainly on a coordination mechanism to integrate pricing, ordering, and lead time policies simultaneously in a dyadic manufacturer retailer system. Specifically, this paper investigates a decentralized system where customer demand is sensitive to both price and lead time. The retailer replenishes based on a continuous inventory system and decides about the retail price. On the other hand, the manufacturer determines production size and manufacturing acceleration rate. By accelerating the manufacturing process, the manufacturer can reduce lead times. To align the interests of both members to act in line with the total system, a wholesale price policy is adopted.

2- Decision models

In this article a dyadic manufacturer-retailer supply chain is investigated. The market demand is assumed to be stochastic and following the normal distribution. Expected demand is sensitive to both retail price and lead time length while demand variance is fixed and independent from retail price or lead time length. The retailer uses a (r,Q) continuous review system. The retailer is authorized to decide about order size and retail price. The manufacturer decides about production batch size and also manufacturing acceleration rate. By accelerating the manufacturing process, lead time is reduced but the manufacturer's unit production cost will be increased.

The notations in the proposed mathematical models are as follows:

Decision variables:	
p	Retail price
Q	Retailer order size
L	Lead time length
n	Manufacturer lot size multiplier (a non negative integer)
Parameters:	
$d(p,L)$	Expected demand rate at retail price p and lead time length L
σ_D	Standard deviation of demand
w	Wholesale price
$c(L)$	Manufacturer unit manufacturing cost at lead time length L
h_m	Manufacturer unit inventory holding cost per year
S_m	Manufacturer fixed cost incurred by handling each retailer order
h_r	Retailer unit inventory holding cost per year
S_r	Retailer ordering cost per order
π	Shortage cost per unit for the retailer
k	safety stock factor
R	Manufacturer production rate
b	price-elasticity coefficient of demand
β	Lead time-elasticity coefficient of demand

Subscripts *r*, *m*, and *sc* in each decision variable denote retailer, manufacturer, and whole SC, respectively.

2-1- Traditional decision model

Under a traditional decision making situation, the retailer determines order size Q and retail price p while the manufacturer decides about n and L. All decisions under decentralized model are made individually without considering the consequences on other SC members. The expected customer demand rate $d(p,L)$ is assumed to be a linear function of retail price p (Emmons and Gilbert, 1998). Based on Hill and Khosla (1992) lead time length L affects expected demand as $d(p,L)=a-bp+\beta/\sqrt{L}$. $Pr_r(Q,p)$ expresses the retailer expected annual profit for a pair (Q,p) as follows.

$$\Pr_r(Q,\,p) = (p-w)\left(a-bp+\beta\big/\sqrt{L_m^*}\right) - \frac{\left(a-bp+\beta\big/\sqrt{L_m^*}\right)}{Q}S_r - h_r\left(\frac{Q}{2}+k\sigma_{D_L}\right) - \frac{\pi\sigma_{D_L}Gu(k)\left(a-bp+\beta\big/\sqrt{L_m^*}\right)}{Q} \quad (1)$$

Where, the first term denotes the retailer expected annual revenue. The second and third terms are associated with expected annual ordering and inventory holding costs, respectively. The last term is expected annual shortage costs.

In equation (1), σ_{D_L} denotes the standard deviation of demand during replenishment lead time that can be calculated as $\sigma_{D_L} = \sigma_D\sqrt{L_m^*}$.

Since demand follows a normal probability distribution then the expected shortages will be $\sigma_{D_L}Gu(k)$ where $Gu(k) = \int_k^\infty \frac{(z-k)}{\sqrt{2\pi}} e^{\frac{-z^2}{2}}dz$, in which z is a standard normal random variable (Silver et al., 1998).

Both decision variables Q and p are under the authority of the retailer and are determined so as to maximize the retailer profit.

Profit function of the retailer is concave with respect to both Q and p simultaneously when $2Q\left(a - bp + \frac{\beta}{\sqrt{L}}\right) > b\left(S_r + \pi\sigma_D\sqrt{L}Gu(k)\right)$; (see Appendix 1 for proof).Using first-order optimality condition, the optimal values of Q and p so that maximize the retailer profit function can be calculated as

$$Q_r^* = \frac{\sqrt{2h_r\sqrt{L_m^*}\left(\left(\sigma_D Gu(k)\pi\beta + S_r\left(a-bp_r^*\right)\right)\sqrt{L_m^*} + L_m^*\sigma_D Gu(k)\pi\left(a-bp_r^*\right)+\beta S_r\right)}}{h_r\sqrt{L_m^*}} \tag{2}$$

$$p_r^* = \frac{\left((a+bw)Q_r^* + bS_r\right)\sqrt{L_m^*} + b\pi\sigma_D Gu(k)L_m^* + \beta Q_r^*}{2bQ_r^*\sqrt{L_m^*}} \tag{3}$$

Where, Q_r^* and p_r^* denote optimal order size and optimal retail price for the retailer, respectively, and L_m^* refers to optimal lead time length from the manufacturer perspective.

The manufacturer's unit production cost is considered as a function of lead time length L given by $c(L) = c_1 - c_2\sqrt{L}$ which is adopted from Huang et al. (2011) who assumes the manufacturer production cost a linear function of lead time; where c_1 is the base production cost when the manufacturer adopts a just in time policy and c_2 is the lead time-elasticity coefficient of production cost which indicates that the unit production cost decreases by increasing lead-time length. Let $Pr_m(n,L)$ expresses the manufacturer expected annual profit for a pair of (n,L), then it can be formulated as:

$$\begin{aligned} \Pr_m(n,L) = {} & \left(w-\left(c_1-c_2\sqrt{L}\right)\right)\left(a-bp_r^*+\beta/\sqrt{L}\right) - \frac{\left(a-bp_r^*+\beta/\sqrt{L}\right)}{nQ_r^*}S_m \\ & -\frac{1}{2}h_m Q_r^*\left(n-1-\frac{(n-2)\left(a-bp_r^*+\beta/\sqrt{L}\right)}{R}\right) \end{aligned} \tag{4}$$

Where, the first term denotes the manufacturer's expected annual revenue; the second term refers to the manufacturer's annual order-handling costs and the last term denotes the manufacturer's annual holding costs. The manufacturer profit function is simultaneously concave with respect to n and L under some circumstances (see Appendix 2 for details). Using first-order optimality condition, the optimal values of n and L from the manufacturer perspective can be calculated as

$$n_m^* = \frac{\sqrt{2RS_m h_m\left(\left(bp_r^*+R-a\right)\sqrt{L_m^*}-\beta\right)\left(\left(a-bp_r^*\right)\sqrt{L_m^*}+\beta\right)}}{h_m Q_r^*\left(\left(bp_r^*+R-a\right)\sqrt{L_m^*}-\beta\right)} \tag{5}$$

$$L_m^* = \frac{\beta\left(h_m n_m^*\left(n_m^*-2\right)Q_r^{*2} + 2Rn_m^* Q_r^*\left(w-c_1\right) - 2RS_m\right)}{2Rn_m^* c_2 Q_r^*\left(a-bp_r^*\right)} \tag{6}$$

Either $\lfloor n_m^* \rfloor$ or $\lceil n_m^* \rceil$ that leads to larger value of $Pr_m(n,L)$ is the optimal n from the manufacturer viewpoint. Under decentralized decision making each player tries to optimize its objective function, thus we are involved with a non-cooperative game model. It is assumed that the players know each other's equilibrium strategies and players gain nothing if individually change their own decisions. Thus the Nash equilibrium solution can be applied to obtain the optimal values of each player's decision variables.

Herein we take advantages of a sensitivity based approach presented by Ghotbi et al., (2014) to determine Nash solution. For each player an approximate rational reaction set (RRS) is provided by mentioned approach where iterative solving of RRSs leads to Nash solution. Let $x(y) = (Q_r^*, p_r^*)$ and $y(x) = (L_m^*, n_m^*)$ are the retailer and manufacturer's optimal decision vectors, i.e. RRSs, respectively, which varies depending on each other. If these two sets' intersection exists, it will be the Nash solution for the decentralized decision making.

Let $f(x,y) = x - x(y)$ and $g(x,y) = y - y(x)$. The Nash solution will be obtained by solving $f(x,y) = g(x,y) = 0$. To find the solution, an initial guess (x_1, y_1) should be picked and the next approximation (x_2, y_2) will be obtained by solving

$$x = x(y_1) + \frac{dx^*}{dy}(y - y_1) \tag{7}$$

$$y = y(x_1) + \frac{dy^*}{dx}(x - x_1) \tag{8}$$

The iteration will be continued to converge values of *x* and *y*. To simplify the procedure, we use the smallest feasible values of decision variables as the initial guess.

2-2- Centralized decision model

Assume that there is a central decision maker who aims to maximize the SC wide profit and mitigate the SC inefficiencies. In this situation all decisions are made from viewpoint of the entire SC.
Let $Pr_{sc}(Q,p,n,L)$ expresses the SC expected annual profit function that is the sum of the retailer and manufacturer expected annual profit.

$$\begin{aligned}\mathrm{Pr}_{sc}(Q,p,n,L) = {} & \left(p - \left(c_1 - c_2\sqrt{L}\right)\right)\left(a - bp + \beta/\sqrt{L}\right) - \frac{\left(a - bp + \beta/\sqrt{L}\right)}{nQ} S_m \\ & - \frac{1}{2} h_m Q \left(n - 1 - \frac{(n-2)\left(a - bp + \beta/\sqrt{L}\right)}{R}\right) - \frac{\left(a - bp + \beta/\sqrt{L}\right)}{Q} S_r \\ & - h_r\left(\frac{Q}{2} + k\sigma_{D_L}\right) - \frac{\pi\sigma_D\sqrt{L}\,Gu(k)\left(a - bp + \beta/\sqrt{L}\right)}{Q}\end{aligned} \tag{9}$$

Using first-order optimality condition, the optimum values of *Q*, *p*, *n* and *L* so that maximize SC expected annual profit will be obtained as follows:

$$Q_{sc}^* = \frac{\sqrt{2\left(\begin{array}{c}\left(\begin{array}{l}\left(\beta\pi\sigma_D Gu(k) + S_r\left(a - bp_{sc}^*\right)\right)n_{sc}^* + S_r\left(a - bp_{sc}^*\right)\sqrt{L_{sc}^*} \\ + \left(\beta S_r + L_{sc}^*\pi\sigma_D Gu(k)\left(a - bp_{sc}^*\right)\right)n_{sc}^* + \beta S_m\end{array}\right) \\ Rn_{sc}^*\left(\left(h_m\left(bp_{sc}^* + R - a\right)n_{sc}^* + \left(2\left(a - bp_{sc}^*\right) - R\right)h_m + h_r R\right)\sqrt{L_{sc}^*} - \beta(n-2)h_m\right)\end{array}\right)}}{n_{sc}^*\left(\sqrt{L_{sc}^*}\left(h_m\left(n_{sc}^*\left(bp_{sc}^* + R - a\right) + 2\left(a - bp_{sc}^*\right) - R\right) + Rh_r\right) - \beta(n-2)h_m\right)} \tag{10}$$

$$p_{sc}^* = -\frac{\begin{array}{l}\left(\frac{1}{2} bh_m n_{sc}^{*2} Q_{sc}^{*2} + \left(\left(\left(-c_1 Q_{sc}^* - S_r\right)b - aQ_{sc}^*\right)R - bh_m Q_{sc}^{*2}\right)n_{sc}^* - bRS_m\right)\sqrt{L_{sc}^*} \\ + n_{sc}^*\left(L_{sc}^*\left(c_2 Q_{sc}^* - \pi\sigma_D Gu(k)\right)b - \beta Q_{sc}^*\right)R\end{array}}{2bRn_{sc}^* Q_{sc}^*\sqrt{L_{sc}^*}} \tag{11}$$

$$n_{sc}^* = \frac{\sqrt{2RS_m h_m\left(\left(bp_{sc}^* + R - a\right)\sqrt{L_{sc}^*} - \beta\right)\left(\left(a - bp_{sc}^*\right)\sqrt{L_{sc}^*} + \beta\right)}}{h_m Q_{sc}^*\left(\left(bp_{sc}^* + R - a\right)\sqrt{L_{sc}^*} - \beta\right)} \tag{12}$$

$$L_{sc}^* = \frac{\beta\left(h_m n_{sc}^*\left(n_{sc}^* - 2\right)Q_{sc}^{*2} - 2RQ_{sc}^* n_{sc}^*\left(c_1 - p_{sc}^*\right) - 2R\left(n_{sc}^* S_r + S_m\right)\right)}{2Rn_{sc}^*\left(\left(-k\sigma_D h_r + c_2\left(a - bp_{sc}^*\right)\right)Q_{sc}^* - \pi\sigma_D Gu(k)\left(a - bp_{sc}^*\right)\right)} \tag{13}$$

It is obvious that the SC profit under the centralized model is greater than the decentralized model.
According to Equations (10)-(13) the values of SC decision variables are circularly depending on each other, so an iterative procedure is developed to calculate optimal values of decision variables simultaneously. The solution algorithm is illustrated in Figure 1.

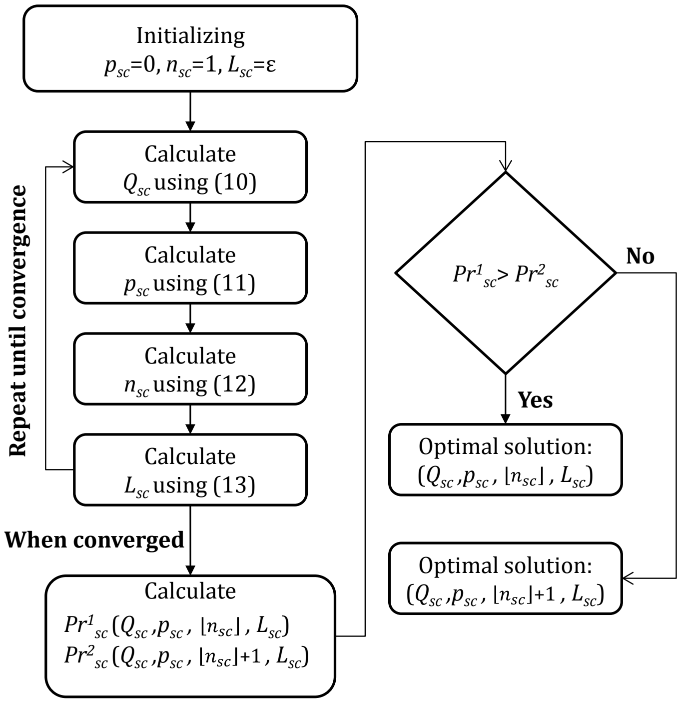

Figure 1. Proposed iterative solution procedure

Although centralized model improves the SC wide profitability, it cannot guarantee more profitability for all members beyond the decentralized model. Thus, to encourage the members to be committed on centralized solution, it is essential to design an incentive mechanism so that improve their profitability.

2-3- Coordination model and incentive scheme

Transition from traditional to centralized decisions may lead to loss for some SC members, so it may not be accepted by both members without appropriate arrangements.

To optimize system wide profitability, the retailer is required to change its decisions from (Q_r^*, p_r^*) to(Q_{sc}^*, p_{sc}^*) and the manufacturer moves from (L_m^*, n_m^*) to (L_{sc}^*, n_{sc}^*). In this regard, the retailer should apply coefficients$d_Q = \frac{Q_{sc}^*}{Q_r^*}$and $d_p = \frac{p_{sc}^*}{p_r^*}$on order size and retail price decisions respectively and the manufacturer should apply coefficients $d_L = \frac{L_{sc}^*}{L_m^*}$ and $d_n = \frac{n_{sc}^*}{n_m^*}$onlead time length and lot size multiplier, respectively.

On the other hand, to ensure both members to gain more profit after applying the abovementioned coefficients, a wholesale price policy is adopted. In the proposed mechanism the coefficient d_w will be applied on whole sale price *w*; coefficient d_w will be greater than 1when the manufacturer losses profit in transition from decentralized to centralized model and it will be less than 1 if the retailer incurs losses.

The improved profit of the retailer during migration from traditional model toward coordinated decision making will be$Pr_r(d_w, d_Q Q_r^*, d_p p_r^*, d_L L_m^*, d_n n_m^*) - Pr_r(Q_r^*, p_r^*)$. To guarantee the participation of the retailer in the plan,d_w must be small enough to ensure a positive value for$Pr_r(d_w, d_Q Q_r^*, d_p p_r^*, d_L L_m^*, d_n n_m^*) - Pr_r(Q_r^*, p_r^*)$. In this way, a maximum acceptable value for d_w from the retailer perspective is extracted which is called d_w^{max}.

$$d_w^{\max} = \frac{1}{w}\left(\begin{array}{l} d_p p_r^* - \dfrac{S_r}{d_Q Q_r^*} - \dfrac{\pi \sigma_{D_L} Gu(k)}{d_Q Q_r^*} \\ -\dfrac{1}{\left(a - b\,d_p p_r^* + \beta \big/ \sqrt{d_L L_m^*}\right)} \left(h_r \left(\dfrac{d_Q Q_r^*}{2} + k\sigma_{D_{d_L L_m^*}} \right) - \Pr_r\left(Q_r^*, p_r^*\right) \right) \end{array} \right) \tag{14}$$

A similar procedure can be applied to find minimum affordable value for d_w from the manufacturer perspective which is called d_w^{min}

$$d_w^{\min} = \frac{1}{w}\left(\begin{array}{l} \dfrac{S_m}{n_{sc}^* d_Q Q_r^*} + \left(c_1 - c_2\sqrt{d_L^* L_m^*}\right) + \dfrac{\Pr_m\left(n_m^*, L_m^*\right)}{\left(a - bd_p p_r^* + \beta \big/ \sqrt{d_L^* L_m^*}\right)} \\ \dfrac{1}{2} h_m d_Q Q_r^* \left(\dfrac{n_{sc}^* - 1}{\left(a - bd_p p_r^* + \beta \big/ \sqrt{d_L^* L_m^*}\right)} - \dfrac{\left(n_{sc}^* - 2\right)}{R} \right) \end{array} \right) \tag{15}$$

Appling the coefficient d_w^{min} on the manufacturer wholesale price *w*, assigns the total benefit of coordinated decision making to the retailer, while applying d_w^{max} assigns all benefits to the manufacturer. We define α as relative bargaining power of the retailer in respect to the manufacturer, where $0 \leq \alpha \leq 1$. Small value of α denotes more bargaining power for the manufacturer while large value of α means more bargaining power for the retailer. We use a linear profit sharing mechanism based on bargaining power of SC members to find an appropriate value for d_w. Based on the proposed mechanism, the coefficient d_w can be calculated as,

$$d_w = \alpha d_w^{\min} + \left(1 - \alpha\right) d_w^{\max} \tag{16}$$

Based on Equation (16), if the manufacturer is the dominant member then α=0 and $d_w = d_w^{max}$, in this case all benefits achieved by the manufacturer. Conversely, if the retailer is the dominant member then α=1 and $d_w = d_w^{min}$.

3- Numerical experiments and sensitivity analyses

A set of test problems can evaluate the effectiveness of the proposed model. Table 1 presents data for the investigated test problems. Table 2 illustrates the result of applying the proposed model on the three test problems. As illustrated in Table 2, decision making under the centralized structure is more economical than the traditional structure from the whole SC viewpoint. Under centralized structure, the retailer orders more than decentralized model and decreases the retail price. On the other hand, the manufacturer adopts a lead time acceleration plan. However, it should be noted that in the centralized structure the retailer incurs losses that should be compensated. Compensation for the retailer's losses can be taken using a well-designed contract. In the proposed model, to induce the retailer to participate in the coordination plan, the manufacturer adopts a wholesale price policy such that both members benefit from the SC improved profit.

Table 1. Data for the three investigated test problems

	Test problem 1	**Test problem 2**	**Test problem 3**
w	390	400	510
a	10000	12000	9000
b	15	16	11
β	160	190	150
h_r	20	32	35
h_m	25	35	37
S_r	8000	6000	4000
S_m	9000	6500	6550
π	40	37	50
c_1	185	160	230
c_2	170	155	190
σ_D	40	30	50
R	11000	14000	17000
k	0.95	0.95	0.95
α	0.5	0.8	0.3

As shown in Table 2, after applying the proposed coordination plan, both members profitability as well as whole SC profitability are increased respect to the traditional decision making. The proposed pricing policy can divide the benefits of joint decision making between two members based on their relative bargaining power. The adjusted wholesale price is specified based equation (16).

By applying the proposed model SC and its members have a more profit beyond those in the decentralized structure, thus the proposed scheme is capable of coordinating the ordering, pricing, production and lead time decisions, simultaneously.

Table 2. The results of running model for decentralized, centralized and coordination modes

	Test Problem 1	**Test Problem 2**	**Test Problem 3**
Traditional structure			
Q_r^*	1354.03	1069.77	658.56
p_r^*	547.83	595.29	685.01
n_m^*	1.06➔1	1.12➔1	1.30➔1
L_m^*	0.1042	0.1156	0.1465
$c(L_m^*)$	130.13	107.30	157.27
$d(p_r^*, L_m^*)$	2278.29	3034.31	1856.80
Pr_r	332254.71	558012.75	301265.99
Pr_m	573407.61	865634.07	635146.26
Pr_{sc}	905662.32	1423646.81	936412.25
Centralized structure			
Q_{sc}^*	2193.77	1649.94	1468.70
p_{sc}^*	430.92	459.56	528.81
n_{sc}^*	1.00➔1	1.08➔1	0.89➔1
L_{sc}^*	0.0628	0.0767	0.0720
$c(L_{sc}^*)$	142.39	117.07	179.02
$d(p_{sc}^*, L_{sc}^*)$	4174.42	5332.98	3742.15
Pr_r	133409.10	271490.31	33882.91
Pr_m	1006118.74	1476851.68	1215911.34
Pr_{sc}	1139527.84	1748368.16	1249794.25

Coordinated structure			
d_Q	1.6202	1.5423	2.2301
d_p	0.7866	0.7720	0.7720
d_L	0.6032	0.6639	0.4914
d_n	1	1	1
d_w^{min}	0.7394	0.7169	0.6957
d_w^{max}	0.8779	0.8657	0.8599
d_w	0.8086	0.7467	0.8106
Pr_r	444971.98	811893.50	395280.59
Pr_m	694555.86	929104.25	854513.66
Pr_{sc}	1139527.84	1748368.16	1249794.25

To evaluate the impact of two significant system parameters, i.e. β and c_2,on the profitability of SC and performance of the proposed model, a set of sensitivity analyses is conducted. Sensitivity analyses show the capability of the proposed mechanism for coordinating SC. Test problem 1 provides the required data for sensitivity analyses.

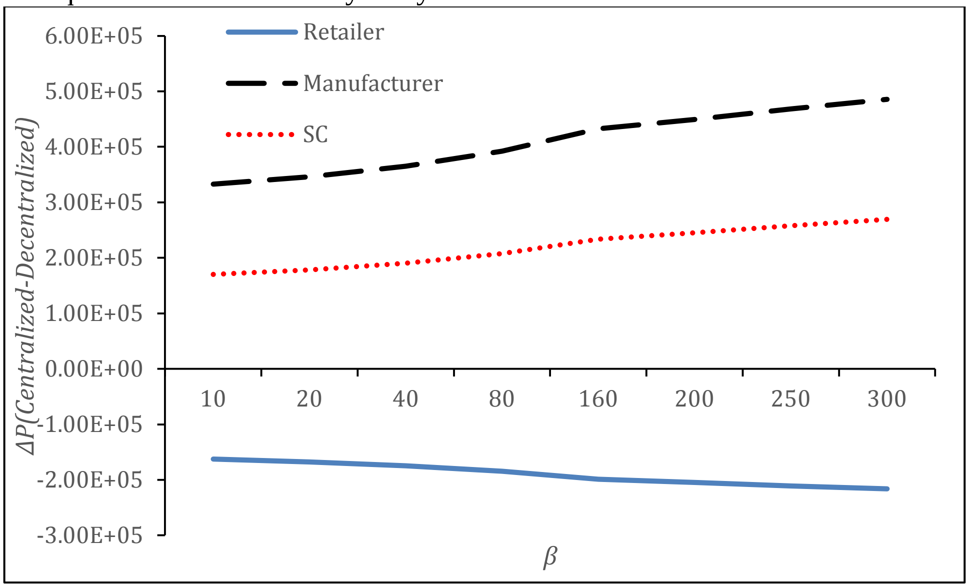

Figure 2. Changes in profitability by centralization (respect to the decentralized model) for various values of β

Figures 2 shows changes in profitability of SC members as well as whole SC by shifting from decentralized to centralized structure. In Figure 2, ΔP denotes difference between profitability in decentralized and centralized structures, e.g. ΔP for the manufacturer is calculated as $Pr_m(L_{sc}^*, n_{sc}^*, Q_{sc}^*, p_{sc}^*) - Pr_m(L_m^*, n_m^*, Q_r^*, p_r^*)$. As shown in Figure 2, the retailer incurs losses during transition from decentralized to centralized structure for all values of β. Figure 2 confirms that there is a need for designing an incentive scheme to compensate the retailer losses. Figure 3 shows that the proposed model is able to ensure the profitability of all its members.

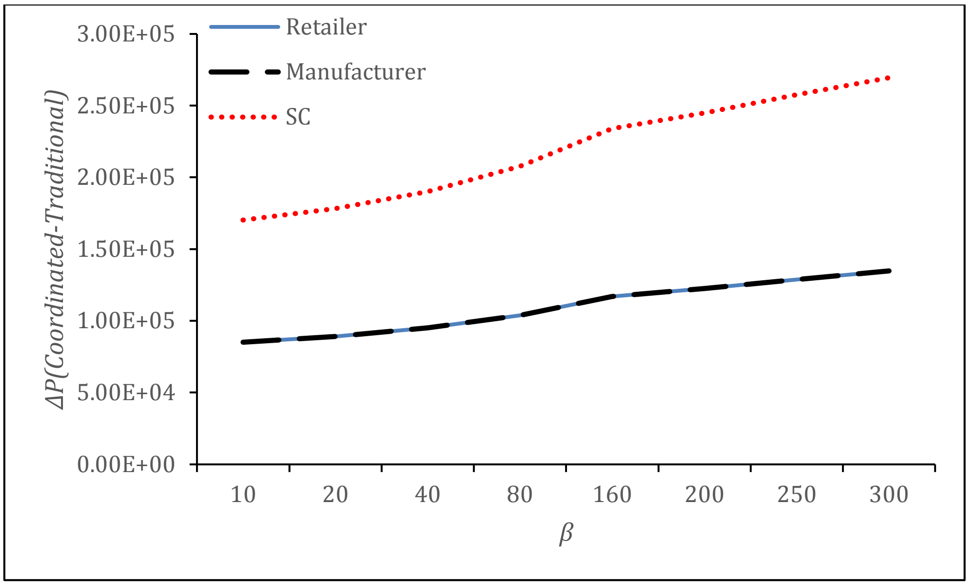

Figure 3. Changes in profitability by coordination (respect to the decentralized model) for various values of β

According to Figure 3, shifting from decentralized to coordinated structure is profitable for both members as well as whole SC. Since in test problem 1 α is equal to 1, then both members earning from coordinated decision making is the same and as a result the retailer and the manufacture curves overlaps. As illustrated in Figure 3,by increasing the demand sensitivity to lead time length the proposed model creates more profit.

To investigate the capability of the proposed model in achieving channel coordination a set of experiments are conducted. Figure 4 demonstrates that for various values of β there is a feasible interval [d_w^{min},d_w^{max}]; i.e. d_w^{min} is always less thand_w^{max}.

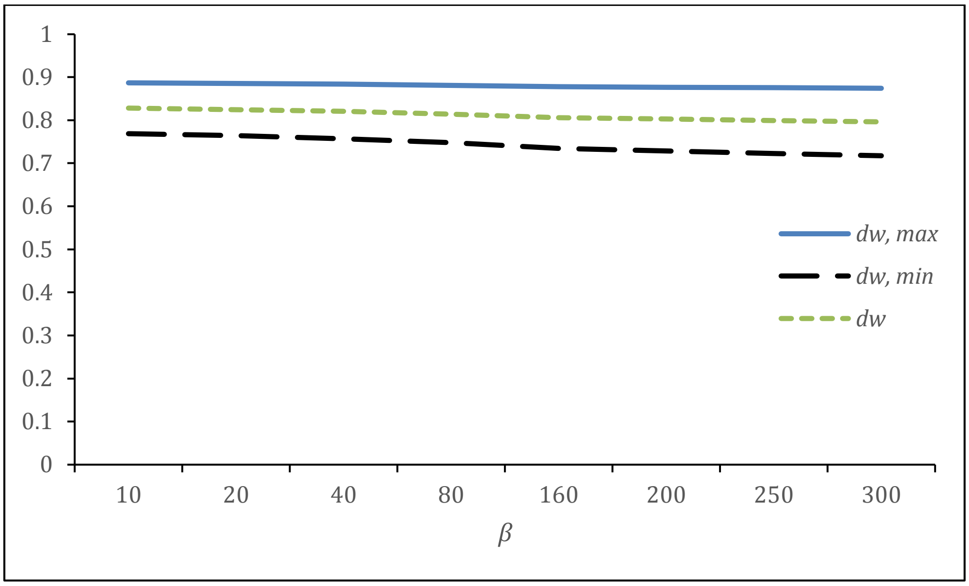

Figure 4. Interval [$\mathrm{d_w^{min}}$,$\mathrm{d_w^{max}}$] over changing β

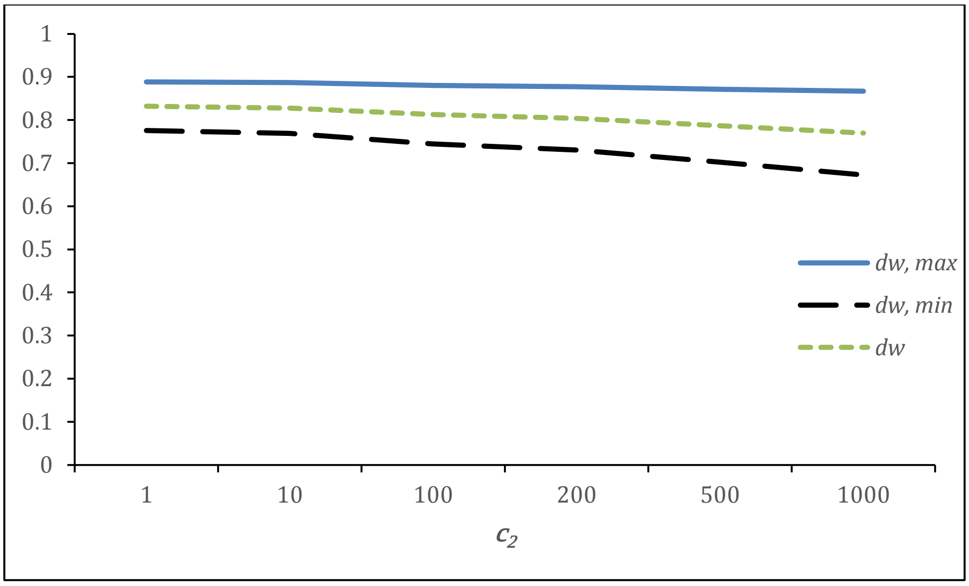

Figure 5. Interval [d_w^{min},d_w^{max}] over changing c_2

As shown in Figure 5, changes in c_2 cannot affect the model capability in achieving channel coordination; interval [d_w^{min},d_w^{max}] remains a non-empty interval for various values of c_2.

4 - Conclusion

Making decisions individually without considering the consequences on other SC members may cause system inefficiency. The ordering, pricing, and lead time reduction strategies have significant impact on flow of material throughout the SC. This study aims to fill a literature gap in this area by proposing a wholesale price contract as an intensive policy to mitigate the consequences of traditional decision making while improve the SC and its members profitability. This contract aims to improve SC efficiency through efficient pricing strategy which is capable of increasing market demand as well as reducing SC operational cost by coordinating the retailer order quantity in light of lead time reduction through manufacturing process acceleration. In the investigated model SC faces with a stochastic demand where expected value of demand depends on both price and lead time. Minimum and maximum values of wholesales price are extracted such that both members have enough incentive to participate in the joint decision making process. The proposed model advises for accelerating manufacturing process which implies increase of manufacturing costs. At the same time, the model advises for reducing retail price which in turn causes for increasing market demand. Numerical experiments illustrate that the proposed model is capable of achieving channel coordination. Considering complementary products in a multi-product model is an appropriate alternative for extending the current work.

References

Anli, O. M., M. C. Caramanis and I. C. Paschalidis (2007). "Tractable supply chain production planning, modeling nonlinear lead time and quality of service constraints." Journal of Manufacturing Systems 26(2): 116-134.

Ben-Daya, M. and M. Hariga (2003). "Lead-time reduction in a stochastic inventory system with learning consideration." International Journal of Production Research 41(3): 571-579.

Boyacı, T. and G. Gallego (2002). "Coordinating pricing and inventory replenishment policies for one wholesaler and one or more geographically dispersed retailers." International Journal of Production Economics 77(2): 95-111.

Chang, H.-C., L.-Y. Ouyang, K.-S. Wu and C.-H. Ho (2006). "Integrated vendor–buyer cooperative inventory models with controllable lead time and ordering cost reduction." European Journal of Operational Research 170(2): 481-495.

Chen, J. (2011). "Returns with wholesale-price-discount contract in a newsvendor problem." International Journal of Production Economics 130(1): 104-111.

Chen, X. and D. Simchi-Levi (2006). "Coordinating inventory control and pricing strategies: The continuous review model." Operations Research Letters 34(3): 323-332.

Chiu, C.-H., T.-M. Choi, H.-T. Yeung and Y. Zhao (2012). "Sales rebate contracts in fashion supply chains." Mathematical Problems in Engineering 2012.

Chung, W., S. Talluri and R. Narasimhan (2014). "Quantity Flexibility Contract in the Presence of Discount Incentive." Decision Sciences 45(1): 49-79.

Du, R., Banerjee, A., Kim, S.L., (2013). “Coordination of two-echelon supply chains using wholesale price discount and credit option” International Journal of Production Economics, 143(2): 327-334.

Emmons, H. and S. M. Gilbert (1998). "Note. The role of returns policies in pricing and inventory decisions for catalogue goods." Management science 44(2): 276-283.

Ghotbi, E., W. A. Otieno and A. K. Dhingra (2014). "Determination of Stackelberg–Nash equilibria using a sensitivity based approach." Applied Mathematical Modelling 38(21): 4972-4984.

Glock, C. H. (2012). "The joint economic lot size problem: A review." International Journal of Production Economics 135(2): 671-686.

Govindan, K., Diabat, A., & Popiuc, M. N. (2012). “Contract analysis: A performance measures and profit evaluation within two-echelon supply chains”. Computers & Industrial Engineering, 63(1), 58-74.

Govindan, K., Popiuc, M. N., & Diabat, A. (2013). “Overview of coordination contracts within forward and reverse supply chains”. Journal of Cleaner Production, 47, 319-334.

Goyal, S. (1977). "An integrated inventory model for a single manufaturer-single customer problem." The International Journal of Production Research 15(1): 107-111.

Heese, H.S., Kemahlıoğlu-Ziya, E., (2016). “Don't ask, don't tell: Sharing revenues with a dishonest retailer” European Journal of Operational Research, 248(2): 580-592.

Heydari, J. (2014a). "Coordinating manufaturer′ s reorder point: A coordination mechanism for supply chains with long manufaturer lead time." Computers & Operations Research 48: 89-101.

Heydari, J. (2014b). "Lead time variation control using reliable shipment equipment: An incentive scheme for supply chain coordination." Transportation Research Part E: Logistics and Transportation Review 63: 44-58.

Hill, A. V. and I. S. Khosla (1992). "Models for optimal lead time reduction." Production and Operations Management 1(2): 185-197.

Hou, J., A. Z. Zeng and L. Zhao (2010). "Coordination with a backup supplier through buy-back contract under supply disruption." Transportation Research Part E: Logistics and Transportation Review 46(6): 881-895.

Huang, K.L., Kuo, C.W., Lu, M.L., (2014). “Wholesale price rebate vs. capacity expansion: The optimal strategy for seasonal products in a supply chain” European Journal of Operational Research, 234(1): 77-85.

Huang, Y.-S., W.-J. Su and Z.-L. Lin (2011). "A study on lead-time discount coordination for deteriorating products." European Journal of Operational Research 215(2): 358-366.

Jha, J. and K. Shanker (2014). "An integrated inventory problem with transportation in a divergent supply chain under service level constraint." Journal of Manufacturing Systems 33(4): 462-475.

Johnson, D. J. (2003). "A framework for reducing manufacturing throughput time." Journal of manufacturing systems 22(4): 283-298.

Khouja, M. (2006). "A joint optimal pricing, rebate value, and lot sizing model." European Journal of Operational Research 174(2): 706-723.
Leng, M. and M. Parlar (2009). "Lead-time reduction in a two-level supply chain: Non-cooperative equilibria vs. coordination with a profit-sharing contract." International Journal of Production Economics 118(2): 521-544.

Li, J., & Liu, L. (2006). Supply chain coordination with quantity discount policy. International Journal of Production Economics, 101(1), 89-98.

Li, Y., X. Xu, X. Zhao, J. H. Y. Yeung and F. Ye (2012). "Supply chain coordination with controllable lead time and asymmetric information." European Journal of Operational Research 217(1): 108-119.

Lian, Z. and A. Deshmukh (2009). "Analysis of supply contracts with quantity flexibility." European Journal of Operational Research 196(2): 526-533.
Linh, C. T. and Y. Hong (2009). "Channel coordination through a revenue sharing contract in a two-period newsboy problem." European Journal of Operational Research 198(3): 822-829.

Masihabadi, S., Eshghi, K., (2011). “Coordinating a Seller-Buyer Supply Chain with a Proper Allocation of Chain’s Surplus Profit Using a General Side-Payment Contract” Journal of Industrial and Systems Engineering, 5(2): 63-79.

Mokhlesian, M., Zogordi, S.H., Nakhai Kamal Abadi, I., Albadvi, A., (2015). “Pricing decisions in a two-echelon decentralized supply chain using bi-level programming approach” Journal of Industrial and Systems Engineering, 8(1): 106-124.

Noori- daryan, M., Taleizadeh, A.A. (2016). “Coordinating Pricing and Ordering Decisions in a Multi-Echelon Pharmacological Supply Chain under Different Market Power using Game Theory” Journal of Industrial and Systems Engineering, In Press.

Ouyang, L.-Y., C.-H. Ho and C.-H. Su (2009). "An optimization approach for joint pricing and ordering problem in an integrated inventory system with order-size dependent trade credit." Computers & Industrial Engineering 57(3): 920-930.

Ouyang, L.-Y., K.-S. Wu and C.-H. Ho (2007). "An integrated vendor–buyer inventory model with quality improvement and lead time reduction." International Journal of Production Economics 108(1): 349-358.

Pan, J. C.-H. and Y.-C. Hsiao (2005). "Integrated inventory models with controllable lead time and backorder discount considerations." International Journal of Production Economics 93: 387-397.

Rhee, B.V.D., Schmidt, G., Veen, J.A.A.V.D., Venugopal, V., (2014). “Revenue-sharing contracts across an extended supply chain” Business Horizons, 57(4):473-482.

Sarkar, B., B. Mandal and S. Sarkar (2015). "Quality improvement and backorder price discount under controllable lead time in an inventory model." Journal of Manufacturing Systems 35: 26-36.

Sethi, S. P., H. Yan and H. Zhang (2004). "Quantity Flexibility Contracts: Optimal Decisions with Information Updates." Decision Sciences 35(4): 691-712.

Silver, E., D. F. Pyke and R. Peterson (1998). "Inventory management and production planning and scheduling."

Wang, C., R. Huang and Q. Wei (2015). "Integrated pricing and lot-sizing decision in a two-echelon supply chain with a finite production rate." International Journal of Production Economics 161: 44-53.

Wong, W.-K., J. Qi and S. Leung (2009). "Coordinating supply chains with sales rebate contracts and vendor-managed inventory." International Journal of Production Economics 120(1): 151-161.

Yıldırmaz, C., S. Karabatı and S. Sayın (2009). "Pricing and lot-sizing decisions in a two-echelon system with transportation costs." OR spectrum 31(3): 629-650.

You, P.-S. and Y.-C. Hsieh (2007). "An EOQ model with stock and price sensitive demand." Mathematical and Computer Modelling 45(7): 933-942.

Zhao, Y., Choi, T.M., Cheng, T.C.E., Sethi, S.P., Wang, S., (2014). “Buyback contracts with price-dependent demands: Effects of demand uncertainty” European Journal of Operational Research, 239(3): 663-673.

Zhu, S. X. (2015). "Integration of capacity, pricing, and lead-time decisions in a decentralized supply chain." International Journal of Production Economics 164: 14-23.

Appendix 1

Concavity of the retailer expected annual profit function:

To prove concavity it is necessary to calculate the Hessian matrix of the retailer expected annual profit. We have:

$$H\left(\Pr_r\left(Q,p\right)\right)=\begin{bmatrix}\partial^2 \Pr_r\left(Q,p\right)/\partial Q^2 & \partial^2 \Pr_r\left(Q,p\right)/\partial Q\partial p \\ \partial^2 \Pr_r\left(Q,p\right)/\partial p\partial Q & \partial^2 \Pr_r\left(Q,p\right)/\partial p^2\end{bmatrix}$$

where,

$$\frac{\partial^2 \Pr_r\left(Q,\ p\right)}{\partial Q^2}=-\frac{2\left(a-bp+\beta/\sqrt{L_s^*}\right)}{Q^3}\left(S_r+\pi\sigma_D\sqrt{L_s^*}Gu\left(k\right)\right)$$

$$\frac{\partial^2 \Pr_r\left(Q,\ p\right)}{\partial p^2}=-2b$$

$$\frac{\partial^2 \Pr_r\left(Q,\ p\right)}{\partial Q\partial p}=\frac{\partial^2 \Pr_r\left(Q,\ p\right)}{\partial p\partial Q}=-\frac{b}{Q^2}\left(S_r+\pi\sigma_D\sqrt{L_s^*}Gu\left(k\right)\right)$$

Sufficient condition requires the first principal minor of the above the Hessian matrix be negative and the second one be positive. The first one is the same as the first element of the main diagonal that has a negative value and the second one is positive when:

$$2Q\left(a-bp+\beta/\sqrt{L_s^*}\right)>b\left(S_r+\pi\sigma_D\sqrt{L_s^*}Gu\left(k\right)\right) \tag{17}$$

Appendix 2

Concavity of the manufacturer expected annual profit function:

To prove concavity of the manufacturer expected annual profit function we have to calculate the Hessian matrix as follows:

$$H\left(\Pr_s\left(n,L\right)\right)=\begin{bmatrix}\partial^2 \Pr_s\left(n,L\right)/\partial n^2 & \partial^2 \Pr_s\left(n,L\right)/\partial n\partial L \\ \partial^2 \Pr_s\left(n,L\right)/\partial L\partial n & \partial^2 \Pr_s\left(n,L\right)/\partial L^2\end{bmatrix}$$

where,

$$\frac{\partial^2 \Pr_s\left(n,L\right)}{\partial n^2}=-\frac{2\left(a-bp_r^*+\beta/\sqrt{L}\right)S_s}{n^3Q_r^*}$$

$$\frac{\partial^2 \Pr_s\left(n,L\right)}{\partial L^2}=-\frac{nRQ_r^*\left(3\beta\left(c_1-w\right)+Lc_2\left(a-bp_r^*\right)\right)+3\beta RS_s-\frac{3}{2}n\left(n-2\right)\beta h_sQ_r^{*2}}{4Q_r^*RnL^{5/2}}$$

$$\frac{\partial^2 \Pr_s\left(n,L\right)}{\partial n\partial L}=\frac{\partial^2 \Pr_s\left(n,L\right)}{\partial n\partial L}=-\frac{\beta\left(n^2Q_r^{*2}h_s+2RS_s\right)}{4RQ_r^*n^2L^{3/2}}$$

The first principal minor of the Hessian matrix is the same as its first element of the main diagonal which is negative. The second principal minor is positive when:

$$8R\sqrt{L}\begin{pmatrix}nRQ_r^*\left(3\beta\left(c_1-w\right)+Lc_2\left(a-bp_r^*\right)\right)\\ +3\beta RS_s-\frac{3}{2}n\left(n-2\right)\beta h_sQ_r^{*2}\end{pmatrix}\left(a-bp_r^*+\beta/\sqrt{L}\right)S_s>\beta^2\left(n^2Q_r^{*2}h_s+2RS_s\right)^2 \tag{18}$$