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REVENUE AND RISK SHARING IN VIEW OF UNCERTAIN DEMAND DURING THE PANDEMICS

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Abstract. Due to stochastic demand during the pandemics and uncertain environment, the vendor and the retailer share their risks and benefits by applying revenue sharing and markdown policy in order to reduce the risks and achieve a win-win contract. Three supply chain coordination policies, decentralized policy, centralized vendor-retailer policy and centralized vendor-retailer revenue sharing policy are developed. An example with uniform probability demand is used to illustrate the model. The result shows that the revenue sharing contract is more attractive for the retailer, and the centralized policy is more attractive for the vendor. Therefore, price markdowns are used to share benefits. The sensitivity analysis shows that the number of markdowns is not sensitive to the variances in the uniform demand distribution. A win-win contract based on a revenue sharing and price markdown is developed. A case example shows that the mechanism of price markdowns and revenue sharing contract affect the optimal supply chain profit in view of the pandemics and uncertain environment.

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1. Introduction

Due to the outbreak of the new coronavirus (*i.e.*, COVID-19) pandemic more than 2 years ago, the operations of supply chains have been impacted most significantly, especially in supply chain coordination and collaboration [30]. In any epidemic outbreaks period, the inventory replenishment problem of supplier-retailer coordinated and collaborated system always have high demand uncertainty [31–33]. In recent years, many companies and sectors have therefore been experiencing more numbers of epidemic outbreaks and different types of demand uncertainty challenges. Retailers and manufacturers of innovative consumer electronic, fashion and athletic products usually encounter uncertain demands due to the nature of the products. The uncertainty in the demand and supply is aggravated by the pandemic which affect the logistic efficiency of the supply chain and the cost of raw materials. Moreover, raw material suppliers have disrupted or reduced their production

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due to lockdown during the epidemic outbreaks, as described in Haren and Simchi-Levi [14]. Furthermore, uncertain demand will cause the overall profitability of the supply chain integration and coordination to be affected, especially during the outbreak of the epidemic or the end of the product cycle life or sales period. Since the start of the pandemic (2019) until today (2022), we had many examples of disruptions. But a good example that has a big impact in the demand and supply is happening in the auto industry. Due to workforce disruptions, semiconductor and parts shortages, global suppliers cannot satisfy all the orders, and the global demand is affected. Some researchers and enterprises have developed strategies and methods to overcome the challenges of supplier-retailer coordination system [15, 23, 24]. Contract policies of supplier-retailer coordinated and collaborated system have been investigated by many researchers and enterprises in recent years [4, 5, 7]. Since different contract policies influence system performance in different ways, it is important to choose the best contract policy for collaborative supply chains. Some of the contract policies are the wholesale price contract [48], buyback contract [44, 52], quantity discount contract [28], revenue sharing contract [6, 16, 21, 35] and other contract combinations [11,48]. In a revenue sharing contract, the vendor reduces their product price offered to the retailer who shares a percentage of their revenue with the vendor. Revenue sharing contracts have been applied widely for video renting and other innovative consumer electronic or fashion product industries. Innovative consumer electronic or fashion products have a limited time demand. When the peak product demand time has passed, products are sold at a very low price. These products usually have random and price dependent demand [17, 18, 35]. However, the retailer can forecast customer demand from historical data. Sometimes, the retailer's forecast is not accurate, and the real demand can be lower or higher than the expected demand due to the pandemics and uncertain environment (*e.g.*, Personal Computer, Notebook, Mobile Phone etc). Consequently, some retailers will reduce the selling price to attract more demand before the sales period is over. The problem becomes more complex and interesting when a retailer has a revenue sharing contract with his vendor. Therefore, we explore the effect on a revenue sharing contract when the retailer reduces the selling price on the uncertain demand and environment.

Many researchers have investigated revenue sharing policy benefits. Cachon and Lariviere [2] investigated the benefits and drawbacks of revenue sharing contracts. They concluded that revenue sharing contracts are attractive only if the retailer's action does not influence demand. Giannoccaro and Pontrandolfo [13] introduced supply chain coordination using revenue sharing contracts for a three-stage supply chain. They found that contract design can improve the total profit of the players so as to achieve win-win situations. Kebing *et al.* [19] considered the implementation of revenue-sharing contracts to maximize channel distribution with price-sensitive demand. Yao *et al.* [50] investigated revenue sharing contracts with two competing retailers. They found that the revenue sharing contract was more flexible and effective in improving supply chain performance than the price contract. Palsule-Desai [29] concluded that revenue sharing contracts could coordinate supply chains for the multi-period contractual situation. Revenue sharing contracts can not only coordinate forward logistic but also reverse logistics [22]. Revenue sharing is not only for two parties but also effective for more than two parties in a supply chain channel [43]. Combination of the revenue sharing contract with a quantity discount model for short life cycle products was developed by Sarathi *et al.* [38]. They considered price-dependent demand and stock dependent demand in their model. Arani *et al.* [1] developed a mixed revenue-sharing contracts model and applied the model to a fashion apparel supply chain in Iran. Xie *et al.* [47] developed revenue and cost-sharing contracts for dual-channel closed-loop supply chains where products are sold online and offline. Raza [35] proposed supply chain coordination strategy for joint pricing, order quantity, and Corporate Social Responsibility (CSR) investment decisions in a two-level supply chain model and applied various game-theoretic settings to analyse the decentralized, centralized, and a centralized revenue sharing policies for each of three demand situations (*e.g.*, the price-and-CSR investment dependent deterministic, and price-and-CSR investment dependent stochastic demand with/without partially known demand information). Chernonog [6] proposed a two-level supply chain model in which a dominant retailer develops a strategic information sharing mechanism through a consignment contract with revenue sharing and applied it in mobile marketing. From the literature review, it can be seen that revenue sharing is still an interesting topic to be explored and applied by researchers, especially in the environment of rapid demand or marketing variation.

Innovative consumer electronic or fashion products during the pandemics and uncertain environment have the characteristic of random demand and price sensitivity [5, 7, 37]. Petruzzi and Dada [34] developed a pricing newsboy inventory problem model using order quantity and product price as the decision variables. Khouja [20] developed a single period newsboy inventory problem with multiple discount and price dependent demands. He concluded that compared to the classical newsboy inventory problem, multiple discounts result in higher order quantities. Tsay [41] studied price markdown practices and strategic balance among supply chain channels and retail pricing behavior. You [51] studied the optimal pricing and ordering quantity model by considering price and time-dependent demand. Modak and Kelle [25] separately studies centralized and decentralized dual-channel supply chains under price and delivery-time dependent stochastic customer demand. Urban and Baker [42] developed a product price and markdown price for different seasons. Namin *et al.* [27] investigated the impact of varied markdown pricing policies for fashion apparel market. They concluded that timely decision making could improve sale and revenue. Chung *et al.* [9] investigated the markdown price problem for a multi-echelon supply chain. They found that markdown price time was an important factor to make an effective decision. Wang and Webster [48] showed the strengths and limitations of the percentage of retail price markdown and quantity markdown money for unsold perishable goods *via* clearance pricing. Shah *et al.* [39] developed the markdown option model for a two-level Stackelberg game model. A markdown optimization model for more than one product and considering a cross-price effect between many products was investigated by Cosgun *et al.* [10]. Nagare and Dutta [26] developed markdowns for single-period inventory models in two market scenarios with price-sensitive segments and price insensitive segments. Gholami *et al.* [12] developed an efficient iterative algorithm to solve multi-period bi-level channel optimization problem considering dynamic price-dependent stochastic demand. Canyakmaz *et al.* [3] investigated the most critical challenges of inventory problem for each enterprise where customer demand is dependent on a stochastic price process which consequently impacts customer arrivals between ordering cycles. They found that under certain conditions, a price-dependent base stock policy is optimal on the both backorder and lost-sale cases. Taleizadeh *et al.* [40] investigated the effect of cost of advertisement and promotional cost sharing on the coordination of a two-echelon supply chain considering under uncertain demand. Yadav *et al.* [49] proposed a non-cooperative Stackelberg game model in a two-level supply chain with imperfect quality and allowable shortage. Our paper continues and extends the works of Shah *et al.* [39] and Raza [35] and considers revenue sharing contracts instead of competitive strategy. From our literature review, although this study on newsboy inventory model with supply chain coordination mechanisms, revenue sharing or markdown policies are a lot, no models simultaneously consider these situations mentioned above. The contribution of this research and other authors is presented as shown in Table 1.

The contribution of this paper is to examine three different newsboy inventory problem models to derive a win-win contract based on revenue sharing policy and price markdown. The models are single vendor-retailer channels using with a multiple price markdown mechanism in the decentralized policy, centralized coordination and centralized coordination with revenue sharing contracts respectively. In the centralized coordination with revenue sharing contract, the retailer's gain and deficit is shared with the vendor. To strength supply chain coordination to achieve win-win situations, this article also considers a multiple price markdown mechanism to find out the opportunities for reducing the selling price to attract more demand on the uncertain environment before the end of the product cycle life or sales period. This circumstance does not exist in the decentralized model or the centralized coordination without revenue sharing contracts where only the retailer obtains a loss when the selling price is marked down. We present this paper in four sections: Section one explains the research background and literature review on the newsboy inventory problem, price markdown and revenue sharing. In Section two, the newsboy inventory problems with price markdowns for decentralized, centralized coordination and revenue sharing are developed. Section three provides an example to clarify the models and presents sensitivity analyses to evaluate the performance of the decentralized coordination model, the centralized coordination model and the centralized coordination model with revenue sharing contract. Section four is the conclusions of the study. A case example shows that the mechanism of price markdowns and revenue sharing contract affect the optimal supply chain profit in view of the pandemics and uncertain environment. Therefore,

TABLE 1. Contribution of selected authors.

Author(s)	Newsboy inventory problem	Coordination mechanisms	Revenue sharing	Markdown policy	Demand uncertainty	Pandemics
Khouja [20]	√				√	
Urban and Baker [42]	√			√	√	
Petruzzi and Dada [34]	√				√	
Tsay [41]	√			√	√	
Giannoccaro and Pontrandolfo [13]		√	√			
Cachon and Lariviere [2]		√	√			
You [51]	√				√	
Kebing *et al.* [19]		√	√			
Wang and Webster [45]		√		√		
Chung *et al.* [9]		√		√		
Mafakheri and Nasiri [22]		√	√			
Palsule-Desai [29]		√	√			
Paul *et al.* [31]	√	√			√	
Paul *et al.* [32]a,b	√	√			√	
Sanh *et al.* 2014	√	√		√	√	
Sarathi *et al.* [38]	√	√	√		√	
Arani *et al.* [1]		√	√			
Cheng *et al.* [5]	√	√	√		√	
Choi *et al.* [7]	√	√			√	
Hu *et al.* [16]	√	√	√			
Liu *et al.* [21]	√	√	√			
Namin *et al.* [27]		√			√	
Nagare and Dutta [26]	√	√		√	√	
Raza [35]	√	√			√	
Xie *et al.* [47]		√	√			
Chen *et al.* [4]		√	√			
Haren and Simchi-Levi [14]	√	√			√	√
Paul *et al.* [30]	√	√			√	√
Taleizadeh *et al.* [40]	√	√	√		√	
Chernonog [6]	√	√	√			
Gholami *et al.* [12]		√			√	
Mashud *et al.* [23],	√	√			√	√
Mashud *et al.* [24]	√	√			√	
Yadav *et al.* [49]	√	√			√	
This paper	√	√	√	√	√	√

the purpose of this paper is to develop a model to demonstrate how revenue and risk sharing can help to coordinate the uncertain demand system during the pandemic.

2. Mathematical model

In this section, mathematical models for the newsboy inventory problem with markdown price options are developed. Firstly, newsboy inventory problems with multiple price markdown options for the retailer are developed. A single time period in newsboy inventory problem has$h$ times price marked down. We then develop the decentralized vendor-retailer policy and centralized vendor-retailer policy. In the last part, a centralized vendor-retailer policy with revenue sharing contracts is developed. The following assumptions are used throughout the paper:

1. Demand is stochastic and dependent on price.
2. Multiple markdown prices are applied to sell all items ordered by the retailer.
3. The initial retailer's unit selling price is known.
4. When the price is marked down, the retailer will spend some of their earnings for advertising.

Parameter notations:

P:	Retailer's unit selling price
Po:	Initial retailer's unit selling price
b:	Dependent demand parameter
F:	Advertising cost
C:	Vendor's unit selling price
S:	Vendor's unit cost

Decision variables:

h:	Frequency of price markdown
Q:	Ordering quantity

This paper is an extended model of Shah *et al.* [39]. The same assumption as in Shah *et al.* [39] is applied in our models. In order to motivate consumer's demand, the retailer considers price marking down h times. This is to maximize the total profit in a single time period for the vendor-retailer supply chain problem. We then develop the decentralized vendor-retailer policy and centralized vendor-retailer policy without/with revenue sharing contracts. For a given h and the supplier's price-dependent parameter, the retailer's optimal order quantity is obtained in the three different newsboy inventory problem models.

2.1. The vendor-retailer decentralized model

2.1.1. The retailer's problem

The retailer price and expected retailer profit follows the model from Shah *et al.* [39] as follows:

$$P = W - bx, \tag{2.1}$$

$$\begin{aligned} E(BP(h)) = \frac{1}{\beta-\alpha}\Bigg[& P_0\begin{pmatrix} Q(\beta-Q)+\frac{P_0Q(h-1)}{hb} \\ +\frac{P_0^2}{12b^2h^2}(-2h+1)(h-1)\end{pmatrix} \\ & + \frac{P_0}{2}\left(\left(Q-\frac{(h-1)P_0}{hb}\right)^2 - \alpha^2 + \frac{F(1-h)}{b}\right) \\ & + \left(\frac{P_0^2\sum\limits_{i=0}^{h-1} i}{h^2b} - (h-1)F\right)\left(Q - \frac{(h-1)P_0}{hb} - \alpha\right)\Bigg] - CQ \end{aligned} \tag{2.2}$$

where W is the price-dependent parameter, b is the dependent demand parameter and x is random demand quantity with a given distribution. For simplicity, we assume the stochastic demand quantity in this study is uniformly distributed with the range $[\alpha, \beta]$.

The retailer optimal order quantity for decentralized policy (Q_h^*) can be derived from the first derivative of (2.2) in Q, and one has:

$$\frac{\partial E(BP(h))}{\partial Q} = \frac{1}{\beta-\alpha}\begin{bmatrix} P_0(\beta-2Q)+\frac{P_0^2}{hb}(h-1) \\ +P_0(Q-\frac{P_0(h-1)}{hb})+\frac{P_0^2 0.5h(h-1)}{h^2b} \\ -(h-1)F - C(\beta-\alpha)\end{bmatrix} = 0$$

$$Q_h^* = \frac{1}{2hbP_0}\left(2P_0\beta bh + P_0^2(h-1) + 2Fhb(1-h) - 2Chb(\beta-\alpha)\right). \tag{2.3}$$

The second order derivative of (2.2) in Q can be represented as:

$$\frac{\partial E^2(BP(h))}{\partial Q^2} = -\frac{P_0}{\beta - \alpha} \tag{2.4}$$

Since the value of (2.4) is negative when the values of P_0, β, and α are positive and $\beta > \alpha$, the $E(BP(h))$ is concave.

2.1.2. The vendor's problem

In the decentralized policy, the vendor revenue can be modeled as follows:

$$E(SP) = (C - S)Q \tag{2.5}$$

The optimal decentralized policy solution is derived by determining the retailer optimal order quantity using (2.3) and substituting it into (2.2) and (2.5).

2.2. The vendor-retailer centralized model

The integrated vendor-retailer policy can be derived by integrating the retailer and vendor expected profit. In this policy, the vendor still has no risk, and the retailer takes all risks. The expected profit of the centralized vendor-retailer integrated policy can be represented as:

$$\begin{aligned} E(SBP(h)) = (C-S)Q + \frac{1}{\beta-\alpha}\Bigg[& P_0\begin{pmatrix} Q(\beta-Q) \\ +\frac{P_0Q(h-1)}{hb} \\ +\frac{P_0^2}{12b^2h^2}(-2h+1)(h-1) \end{pmatrix} \\ & + \frac{P_0}{2}\left(\left(Q - \frac{(h-1)P_0}{hb}\right)^2 - \alpha^2 + \frac{F(1-h)}{b}\right) \\ & + \left(\frac{P_0^2\sum_{i=0}^{h-1} i}{h^2b} - (h-1)F\right)\left(Q - \frac{(h-1)P_0}{hb} - \alpha\right) - CQ(\beta-\alpha).\Bigg] \end{aligned} \tag{2.6}$$

The retailer optimal order quantity can be extracted from the first order derivative of (2.6) in Q, and one has:

$$\frac{\partial E(SBP(h))}{\partial Q} = \frac{1}{\beta-\alpha}\begin{bmatrix} P_0(\beta-2Q) + \frac{P_0^2}{hb}(h-1) \\ +P_0(Q - \frac{P_0(h-1)}{hb}) + \frac{P_0^2 0.5h(h-1)}{h^2b} \\ -(h-1)F - S(\beta-\alpha) \end{bmatrix} = 0$$

$$Q^*_{SBh} = \frac{1}{2hbP_0}\left(2P_0\beta bh + P_0^2(h-1) + 2Fhb(1-h) - 2Shb(\beta-\alpha)\right) \tag{2.7}$$

Since $S < C$, Q^*_{SBh} is greater than Q^*_h. The vendor's benefit from the centralized vendor-retailer collaboration is larger than the decentralized vendor-retailer policy. The expected profit of the centralized vendor-retailer model is also concave for a uniformly distributed demand.

2.3. The vendor-retailer centralized revenue sharing model

In the revenue sharing contract with price markdowns, the retailer shares the risk with the vendor. The vendor offers lower prices to the retailer, and the retailer will share his revenue with the vendor. In this model, the vendor takes some risks when the retailer applies price markdowns because the retailer price markdown reduces the vendor profit. The vendor's expected profit of revenue sharing contract policy is:

$$
\begin{aligned}
E(SRS(h)) &= \int_{Q}^{\infty} (1-\varphi) P_0 Q f(x_0) \mathrm{d}x_0 \\
&+ \sum_{j=1}^{h} \int_{Q-jP_0/hb}^{Q-(j-1)P_0/hb} (1-\varphi) \begin{bmatrix} \frac{j}{h} P_0 x_0 \\ + \frac{h-j}{h} P_0 Q \\ + \frac{P_0^2}{bh^2} \sum_{i=0}^{j-1} i \end{bmatrix} f(x_0) \mathrm{d}x_0 \\
&+ \int_{0}^{Q-(h-1)P_0/hb} (1-\varphi) \left[\frac{j}{h} P_0 x_0 + \frac{P_0^2}{bh^2} \sum_{i=0}^{j-1} i \right] f(x_0) \mathrm{d}x_0 + (C_{RS} - S) Q
\end{aligned}
\tag{2.8}
$$

where φ is the retailer's percentage profit, and C_{RS} is vendor's item selling price in the revenue sharing policy. When random demand quantity x_0 has a uniform distribution with the range $[\alpha, \beta]$, the expected vendor revenue can be represented as:

$$
\begin{aligned}
E(SRS(h)) = \frac{1}{\beta - \alpha} &\left[(1-\phi) P_0 \begin{pmatrix} Q(\beta - Q) \\ + \frac{P_0 Q(h-1)}{hb} \\ + \frac{P_0^2}{12b^2h^2} (-2h+1)(h-1) \end{pmatrix} + (1-\phi) \frac{P_0}{2} \left(\left(Q - \frac{(h-1)P_0}{hb} \right)^2 - \alpha^2 \right) \right. \\
&\left. + (1-\phi) \left(\frac{P_0^2 \sum_{i=0}^{h-1} i}{h^2 b} \right) \left(Q - \frac{(h-1)P_0}{hb} - \alpha \right) \right] + (C_{RS} - S) Q.
\end{aligned}
\tag{2.9}
$$

The retailer's expected profit of the revenue sharing policy is:

$$
\begin{aligned}
E(BRS(h)) &= \int_{Q}^{\infty} \varphi P_0 Q f(x_0) \mathrm{d}x_0 \\
&+ \sum_{j=1}^{h} \int_{Q-jP_0/hb}^{Q-(j-1)P_0/hb} \begin{bmatrix} \varphi \frac{j}{h} P_0 x_0 + \varphi \frac{h-j}{h} P_0 Q \\ + \varphi \frac{P_0^2}{bh^2} \sum_{i=0}^{j-1} i - jF \end{bmatrix} f(x_0) \mathrm{d}x_0 \\
&+ \int_{0}^{Q-(h-1)P_0/hb} \left[\varphi \frac{j}{h} P_0 x_0 + \varphi \frac{P_0^2}{bh^2} \sum_{i=0}^{j-1} i - (h-1)F \right] f(x_0) \mathrm{d}x_0 - C_{RS} Q.
\end{aligned}
\tag{2.10}
$$

For uniform demand distribution, the retailer's expected profit of the revenue sharing policy could be derived as:

$$
\begin{aligned}
E(BRS(h)) = \frac{1}{\beta - \alpha} &\left[\phi P_0 \begin{pmatrix} Q(\beta - Q) \\ + \frac{P_0 Q(h-1)}{hb} \\ + \frac{P_0^2}{12b^2h^2} (-2h+1)(h-1) \end{pmatrix} \right. \\
&+ \frac{P_0}{2} \left(\phi \left(\left(Q - \frac{(h-1)P_0}{hb} \right)^2 - \alpha^2 \right) + \frac{F(1-h)}{b} \right)
\end{aligned}
$$

$$+\left(\frac{\phi P_0^2\sum_{i=0}^{h-1} i}{h^2 b}-(h-1)F\right)\left(Q-\frac{(h-1)P_0}{hb}-\alpha\right)\Bigg]-C_{RS}Q. \tag{2.11}$$

The total expected revenue sharing policy of the vendor-retailer centralized model is:

$$\begin{aligned}E(RS(h)) &= E(SRS(h))+E(BRS(h))\\ E(RS(h)) &= (C_{RS}-S)Q+\frac{1}{\beta-\alpha}\left[P_0\begin{pmatrix}Q(\beta-Q)\\ +\frac{P_0 Q(h-1)}{hb}\\ +\frac{P_0^2}{12b^2h^2}(-2h+1)(h-1)\end{pmatrix}\right.\\ &\quad+\frac{P_0}{2}\left(\left(Q-\frac{(h-1)P_0}{hb}\right)^2-\alpha^2+\frac{F(1-h)}{b}\right)\\ &\quad\left.+\left(\frac{P_0^2\sum_{i=0}^{h-1} i}{h^2 b}-(h-1)F\right)\left(Q-\frac{(h-1)P_0}{hb}-\alpha\right)\right]-C_{RS}Q\end{aligned} \tag{2.12}$$

The revenue sharing policy expected profit (2.12) is similar to the expected profit of the centralized policy (2.6), so the retailer optimal order quantity for revenue sharing policy is similar to (2.7). Finally, we use the solution-solving procedure in Shah *et al.* [39] to derive the optimal frequency of price markdown h^* in three different contract models. As shown from Tables 2–4, the solution-solving procedure iterates the values of the decision variable h to derive the optimal ordering quantity units Q^* from the retailer until the optimal total profit of the supply chain is obtained in the three different newsboy inventory problem models.

3. Numerical example and sensitivity analysis

In this section, an example is demonstrated to illustrate the mathematical models and analyze the newsboy inventory problem with markdown in the decentralized policy, the centralized vendor-retailer policy, and the revenue sharing policy. Consider W uniformly distributed on [420, 620], $b = 0.05$, and $F = 100$ which implies that x_0 is uniformly distributed with $\alpha = 8000$ and $\beta = 12\,000$ for $P_0 = \$20$. In the decentralized policy, one has $C = \$10$ and $S = \$5$. In this policy, the retailer decides the optimal order quantity (Q^*) and then orders Q^* units from the vendor. We assume the retailer wants to markdown the initial price for a maximum of 7 times. Detailed descriptions of the decentralized policy are shown in Table 2; the bold highlights represent the optimal solution. The optimal profit is derived when there are six setting prices with five price markdowns. The optimal vendor profit is equal to \$50708.3, the retailer profit = \$91381.7 and the total profit = \$142090 with the optimal order quantity = 10141.7.

When the centralized vendor-retailer policy is applied, the vendor acts as the decision maker, and the results are shown in Table 3. The optimal profit is derived when there are six price settings with five price markdowns. The retailer optimal order quantity in the centralized vendor-retailer policy is 1000 units higher than the decentralized policy. In this policy, the optimal vendor profit = \$55708.3, the retailer profit = \$88881.7 and the total profit = \$144590.

In the revenue sharing policy, the vendor offers an item selling price of \$6 to the retailer. This price is \$4 lower than the vendor's item selling price in the decentralized policy and the centralized vendor-retailer policy. As compensation, the retailer shares 25% of his revenue with the vendor. The optimal order quantity and profit of this revenue sharing policy is shown in Table 4. In the revenue sharing policy, the optimal profit is derived when the price is marked down 5 times. One has the optimal order quantity = 11141.7, the vendor profit = \$51276.5,

Table 2. Optimal quantity and profit for decentralized policy.

h	Q	Vendor profit	Retailer profit	Total profit
1	10000.0	50000.0	90000.0	140000.0
2	10095.0	50475.0	90922.6	141397.6
3	10123.3	50616.7	91200.6	141817.3
4	10135.0	50675.0	91315.6	141990.6
5	10140.0	50700.0	91365.0	142065.0
6	**10141.7**	**50708.3**	**91381.7**	**142090.0**
7	10141.4	50707.1	91379.6	142086.7
8	10140.0	50700.0	91365.9	142065.9

Notes. Bold values denote optimal solution.

Table 3. Optimal quantity and profit for vendor-retailer centralized policy.

h	Q	Vendor profit	Retailer profit	Total profit
1	11000.0	55000.0	87500.0	142500.0
2	11095.0	55475.0	88422.6	143897.6
3	11123.3	55616.7	88700.6	144317.3
4	11135.0	55675.0	88815.6	144490.6
5	11140.0	55700.0	88865.0	144565.0
6	**11141.7**	**55708.3**	**88881.7**	**144590.0**
7	11141.4	55707.1	88879.6	144586.7
8	11140.0	55700.0	88865.9	144565.9

Notes. Bold values denote optimal solution.

Table 4. Optimal quantity and profit for revenue sharing policy.

h	Q	Vendor profit	Retailer profit	Total profit
1	11000.0	50500.0	92000.0	142500.0
2	11095.0	50985.0	92912.6	143897.6
3	11123.3	51140.7	93176.6	144317.3
4	11135.0	51213.6	93276.9	144490.5
5	11140.0	51253.4	93311.6	144565.0
6	**11141.7**	**51276.5**	**93313.5**	**144590.0**
7	11141.4	51290.2	93296.6	144586.8
8	11140.0	51297.8	93268.1	144565.9

Notes. Bold values denote optimal solution.

the retailer profit = \$93313.5 and the total profit = \$144590. The total profit of revenue sharing policy is similar to that of the centralized vendor-retailer policy.

The example shows that the centralized vendor-retailer and revenue sharing policy have higher total profits than the decentralized policy. The vendor and retailer profits are shown in Figure 1. The figure shows that the centralized vendor-retailer policy has the largest vendor profit, but has the lowest retailer profit. The vendor is the benefitor in the centralized vendor-retailer policy. Table 5 shows the percentage profit increase (decrease) in the centralized and the revenue sharing policies when compared with the decentralized policy.

Table 5 shows that centralized supply chain policies have a bigger total profit than the decentralized policy. The total profit of the centralized vendor-retailer and revenue sharing policy is 1.76% higher than the

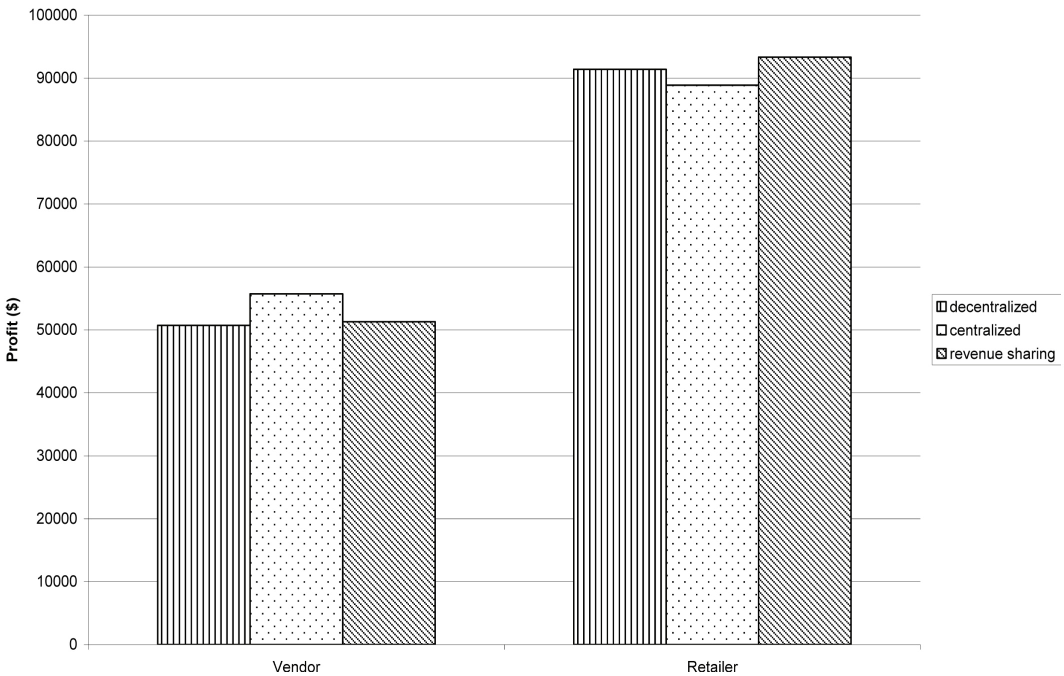

FIGURE 1. Comparison of vendor and retailer profit.

TABLE 5. Percentage of profit increase (decrease) in centralized and revenue sharing policy when compared with the decentralized policy.

	Percentage of profit increase (decrease)		
	Vendor profit	Retailer profit	Total profit
Centralized	9.86	(2.74)	1.76
Revenue sharing	1.12	2.11	1.76

TABLE 6. Decentralized optimal solution for varying variance.

Case	α	β	h	Vendor profit	Retailer profit	Total profit
1	9000	11000	6	50708.3	96346.6	147055.0
2	8000	12000	6	50708.3	91381.7	142090.0
3	7000	13000	6	50708.3	86393.3	137101.7
4	6000	14000	6	50708.3	81399.2	132107.5

decentralized policy. The retailer's profit in the centralized vendor-retailer policy is 2.74% lower than his profit in the decentralized policy. In the revenue sharing policy, the benefit of the integrated policy is shared between vendor and retailer; this is to ensure both players have higher profits than the decentralized policy.

Keeping a constant demand mean, the effect of varying demand variance is studied during the sensitivity analyses. The results are shown in Tables 6–8. It is clear that the number of price markdown decisions in any

Table 7. Centralized policy optimal solution for varying variance.

Case	α	β	h	Vendor profit	Retailer profit	Total profit
1	9000	11000	6	53208.3	95096.6	148305.0
2	8000	12000	6	55708.3	88881.7	144590.0
3	7000	13000	6	58208.3	82643.3	140851.7
4	6000	14000	6	60708.3	76399.2	137107.5

Table 8. Revenue sharing policy optimal solution for varying variance.

Case	α	β	h	Vendor profit	Retailer profit	Total profit
1	9000	11000	6	51019.8	97285.2	148305.0
2	8000	12000	6	51276.5	93313.4	144590.0
3	7000	13000	6	51528.8	89322.9	140851.7
4	6000	14000	6	51779.9	85327.6	137107.5

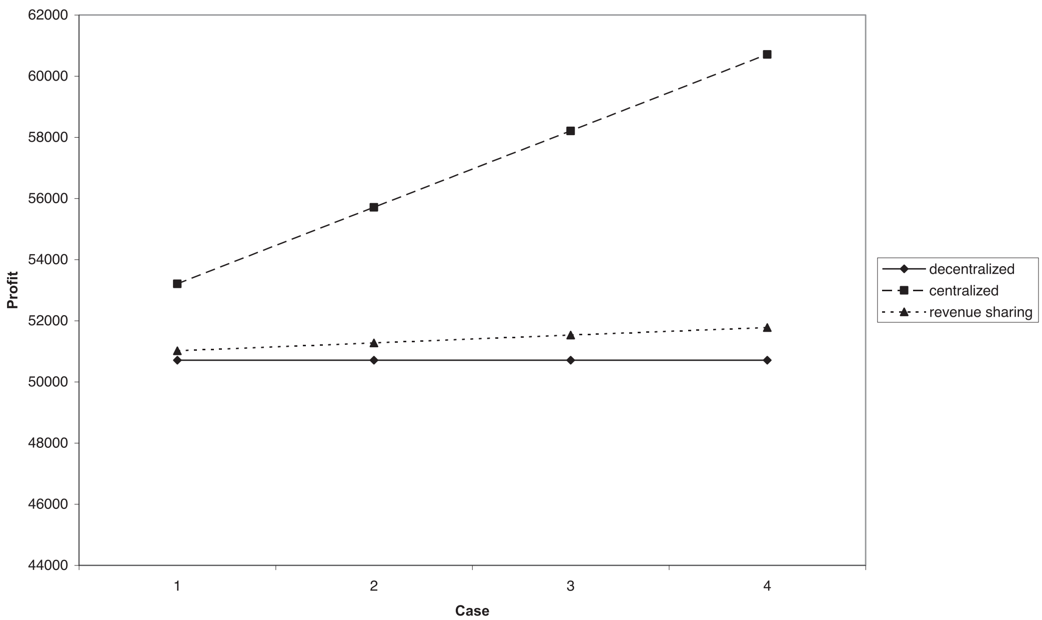

Figure 2. Vendor profit for varying demand variance.

strategies is not sensitive to the varying demand variance. The tables also show that when the demand variance increases, the total supply chain profit decreases.

Figure 2 exhibits a rapid increase in vendor profits as the demand variance increases in the centralized policy, the decentralized policy, and the revenue sharing policy. In the centralized policy, the vendor has an advantage when demand variance increases. In Figure 3, as demand variances increase, the retailer has a lower profit in all strategies. The revenue sharing policy is better for the retailer than the centralized policy. As demand variance increases, the retailer profit reduces slower in the revenue sharing policy than in the centralized policy. Figure 4 shows the decentralized policy has the worst total profit.

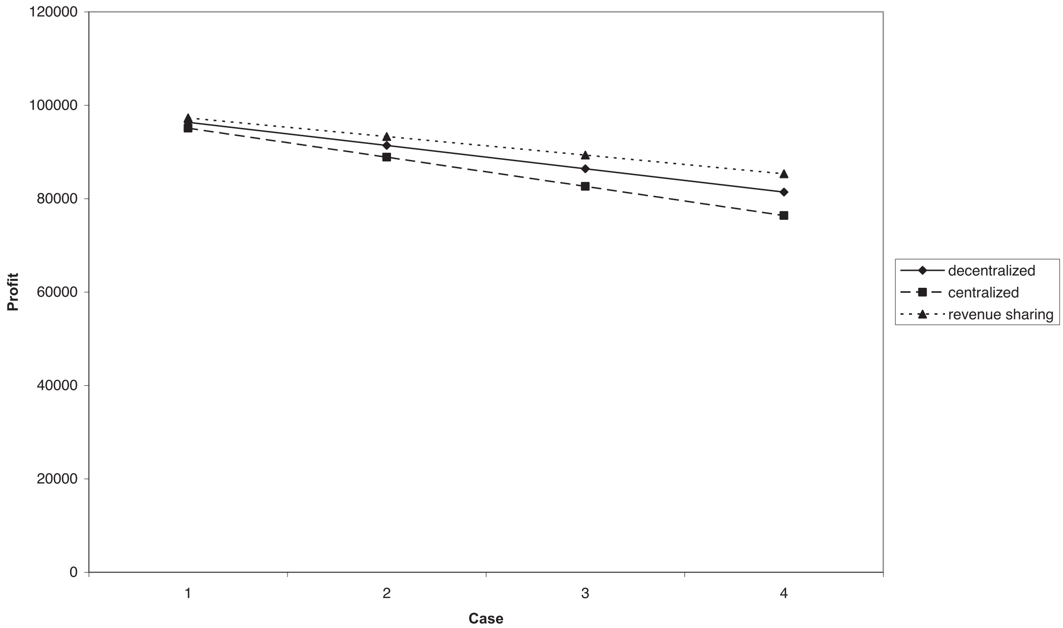

FIGURE 3. Retailer profit for varying demand variance.

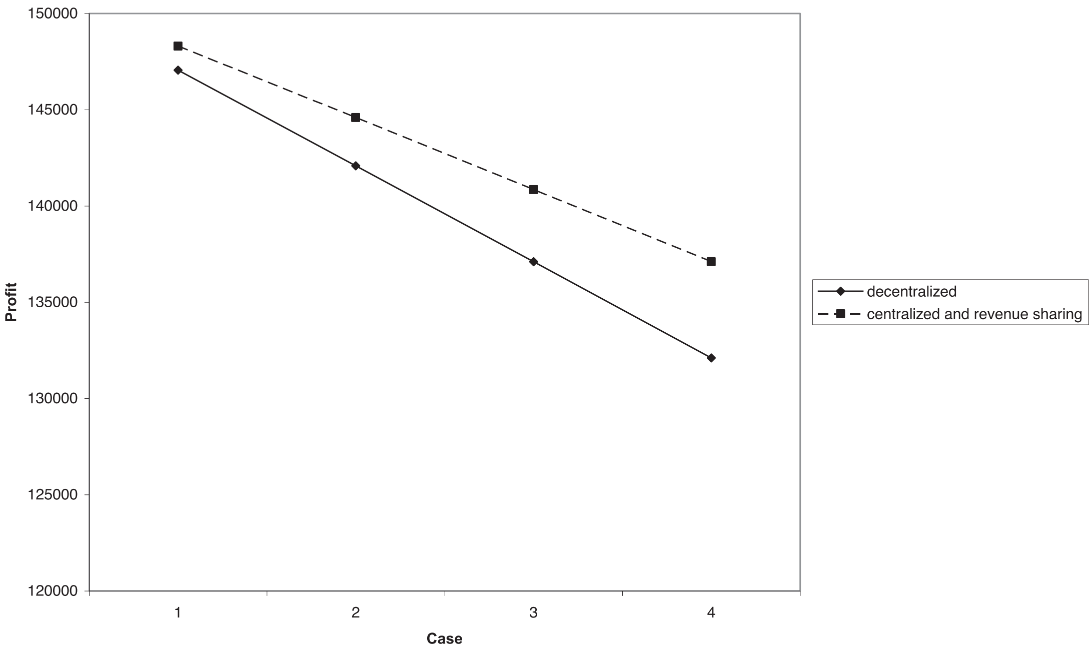

FIGURE 4. Total supply chain profits for varying demand variance.

4. Conclusion

A win-win contract based on a revenue sharing and price markdown is developed in this study. Three supply chain policies, decentralized, centralized vendor-retailer and revenue sharing, have been considered. A case example shows that the numbers of price markdowns affect the optimal supply chain profit. However, the sensitivity analysis shows that the supply chain profit is not very sensitive to varying demand variances. The centralized and revenue sharing policy between the vendor and the retailer results in an optimal supply chain profit. In the centralized vendor-retailer and revenue sharing policy, the total supply chain profit is more stable than the decentralized policy for varying demand variance. When the vendor has more bargaining power than the retailer, he will opt for centralized policy, but with equal bargaining power, they will opt for revenue sharing policy. This paper also discusses the application of markdown prices for single vendor-retailer channel supply chain policies. The managerial insights of this study indicates that the mechanism of price markdowns and revenue sharing contract affect the optimal supply chain total profit in view of the pandemics and uncertain environment and achieves a win-win situation in supply chain coordination and collaboration. Application of price markdown for one vendor with more than one retailer relationship or more than two-echelon supply chain channels can be considered for future research.

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References

[1] H.V. Arani, M. Rabbani and H. Rafiei, A revenue-sharing option contract toward coordination of supply chains. *Int. J. Prod. Econ.* **178** (2016) 42–56.

[2] G.P. Cachon and M.A. Lariviere, Supply chain coordination with revenue-sharing contracts: Strengths and limitations, *Manage. Sci.* **51** (2005) 30–44.

[3] C. Canyakmaz, S. Özekici and F. Karaesmen, An inventory model where customer demand is dependent on a stochastic price process. *Int. J. Prod. Econ.* **212** (2019) 139–152.

[4] Y. Chen, S.-H. Chung and S. Guo, Franchising contracts in fashion supply chain operations models, practices, and real case study. *Ann. Oper. Res.* **291** (2020) 83–128.

[5] Z.P. Cheng, X.D. Yang and A.A. Tsay, Designing structured supply contracts under demand and price uncertainty in an open supply chain. *Ann. Oper. Res.* **257** (2017) 519–536.

[6] T. Chernonog, Strategic information sharing in online retailing under a consignment contract with revenue sharing. *Ann. Oper. Res.* **300** (2021) 621–641.

[7] T.-M. Choi, K. Govindan, X. Li and Y.J. Li, Innovative supply chain optimization models with multiple uncertainty factors. *Ann. Oper. Res.* **257** (2017) 1–14.

[8] T.-M. Choi, Supply chain financing using blockchain impacts on supply chains selling fashionable products. *Ann. Oper. Res.* (2020). https://doi.org/10.1007/s10479-020-03615-7.

[9] W. Chung, S. Talluri and R. Narasimhan, Price markdown scheme in a multi-echelon supply chain in a high-tech industry. *Eur. J. Oper. Res.* **215** (2011) 581–589.

[10] Ö. Cosgun, U. Kula and C. Kahraman, Markdown optimization for an apparel retailer under cross-price and initial inventory effects. *Knowledge-Based Syst.* **120** (2017) 186–187.

[11] F. El-Ouardighi, Supply quality management with optimal wholesale price and revenue sharing contracts: A two-stage game approach. *Int. J. Prod. Econ.* **156** (2014) 260–268.

[12] R.A. Gholami, L.K. Sandal and J. Ubøe, A solution algorithm for multi-period bi-level channel optimization with dynamic price-dependent stochastic demand. *Omega* **102** (2021) 102297.

[13] I. Giannoccaro and P. Pontrandolfo, Supply chain coordination by revenue sharing contracts. *Int. J. Prod. Econ.* **89** (2004) 131–139.

[14] P. Haren and D. Simchi-Levi, How Coronavirus could impact the global supply chain by mid-March. *Harvard Bus. Rev.* (2020). Retrieved May 13, 2020.

[15] Md.R. Hasan, T.C. Roy, Y. Daryanto and H.M. Wee, Optimizing inventory level and technology investment under a carbon tax, cap-and-trade and strict carbon limit regulations. *Sustainable Prod. Consumption* 25 (2021) 604–621.

[16] B. Hu, D. Xu and C. Meng, Inconsistency of retailer's optimal policies and channel performance under revenue sharing contracts. *Int. J. Prod. Econ.*, 183 (2017) 53–65.

[17] O. Jadidi, M.Y. Jaber and S. Zolfaghari, Joint pricing and inventory problem with price dependent stochastic demand and price discounts. *Comput. Indust. Eng.* **114** (2017) 45–53.

[18] M. Johari, S.-M. Hosseini-Motlagh, M. Nematollahi, M. Goh, and J. Ignatius, Bi-level credit period coordination for periodic review inventory system with price-credit dependent demand under time value of money. *Transp. Res. Part E* **114** (2018) 270–291.

[19] C. Kebing, G. Chengxiu and W. Yan, Revenue-sharing contract to coordinate independent participants within the supply chain. *J. Syst. Eng. Electron.* **18** (2007) 520–526.

[20] M. Khouja, The newsboy problem under progressive multiple discounts. *Euro. J. Oper. Res.* **84** (1995) 458–466.

[21] X.F. Liu, J. Li, J. Wu and G.Q. Zhang, Coordination of supply chain with a dominant retailer under government price regulation by revenue sharing contracts, *Ann. Oper. Res.* **257** (2017) 587–612.

[22] F. Mafakheri and F. Nasiri, Revenue sharing coordination in reverse logistics. *J. Cleaner Prod.* **59** (2013) 185–196.

[23] A.H.M. Mashud, Md.R. Hasan, Y. Daryanto and H.M. Wee, A resilient hybrid payment supply chain inventory model for post Covid-19 recovery. *Comput. Indust. Eng.* **157** (2021a) 107249.

[24] A.H.M. Mashud, D. Roy, Y. Daryanto and H.M. Wee, Joint price deteriorating inventory model considering product life cycle and advance payment a discount facility. *RAIRO Oper. Res.* **55** (2021b) S1069–S1088.

[25] N.M. Modak and P. Kelle, Managing a dual-channel supply chain under price and delivery-time dependent stochastic demand, *Eur. J. Oper. Res.* **272** (2019) 147–161.

[26] M. Nagare and P. Dutta, Single-period ordering and pricing policies with markdown, multivariate demand dan customer price sensitivity. *Comput. Indust. Eng.* **125** (2018) 451–466.

[27] A. Namin, B.T. Ratchford and G.P. Soysal, An empirical analysis of demand variations and markdown policies for fashion retailers. *J. Retailing Consum. Serv.* **38** (2017) 126–136.

[28] T. Nie and S. Du, Dual-fairness supply chain with quantity discount contracts. *Eur. J. Oper. Res.* **258** (2017) 491–500.

[29] O.D. Palsule-Desai, Supply chain coordination using revenue-dependent revenue sharing contracts. *Omega* **41** (2013) 780–796.

[30] S.K. Paul and P. Chowdhury, Strategies for managing the impacts of disruptions during COVID-19 an example of toilet paper. *Global J. Flexible Syst. Manage.* **21** (2020) 283–293.

[31] S.K. Paul, R. Sarker and D. Essam, A disruption recovery model in a production-inventory system with demand uncertainty and process reliability. *Lect. Notes Comput. Sci.* **8104** (2013) 511–522.

[32] S.K. Paul, A. Azeem, R. Sarker and D. Essam, Development of a production inventory model with uncertainty and reliability considerations. *Optim. Eng.* **15** (2014a) 697–720.

[33] S.K. Paul, R. Sarker and D. Essam, Managing real-time demand fluctuation under a supplier-retailer coordinated system. *Int. J. Prod. Econ.* **158** (2014b) 231–243.

[34] N.C. Petruzzi and M. Dada, Pricing and the newsvendor problem: A review with extensions. *Oper. Res.* **47** (1999) 83–194.

[35] S.A. Raza, Supply chain coordination under a revenue-sharing contract with corporate social responsibility and partial demand information. *Int. J. Prod. Econ.* **205** (2018) 1–14.

[36] S.A. Raza, F.C. Abdullakutty, S. Rathinam and S.M. Govindaluri, Multi-objective framework for process mean selection and price differentiation with leakage effects under price-dependent stochastic demand. *Comput. Indust. Eng.* **127** (2019) 698–708.

[37] S.Y. Ren, H.-L. Chan and P. Ram, A comparative study on fashion demand forecasting models with multiple sources of uncertainty. *Ann. Oper. Res.* **257** (2017) 335–355.

[38] G.P. Sarathi, S.P. Sarmah and M. Jenamani, An integrated revenue sharing and quantity discounts contract for coordinating a supply chain dealing with short life-cycle products. *Appl. Math. Model.* **38** (2014) 4120–4136.

[39] N.H. Shah, G.A. Widyadana and H.M. Wee, Stackelberg game for two-level supply chain with price markdown option. *Int. J. Comput. Math.* **91** (2014) 1054–1060.

[40] A.A. Taleizadeh, K. Govindan and N. Ebrahimi, The effect of promotional cost sharing on the decisions of two-level supply chain with uncertain demand. *Ann. Oper. Res.* **290** (2020) 747–781.

[41] A.A. Tsay, Managing retail channel overstock: Markdown money and return policies. *J. Retailing* **77** (2001) 457–492.

[42] T.L. Urban and R.C. Baker, Optimal ordering and pricing policies in a single-period environment with multivariate demand and markdowns. *Eur. J. Oper. Res.* **103** (1997) 573–583.

[43] B. Van der Rhee, G. Schmidt, J.A.A. Van der Veen and V. Venugopal, Revenue-sharing contracts across an extended supply chain. *Bus. Horiz.* **57** (2014) 473–482.

[44] S.V. Venkataraman and D. Asfaw, Buyback contract under asymmetric information about retailer's loss aversion nature. *Ann. Oper. Res.* **295** (2020) 385–409.

[45] C.X. Wang and S. Webster, Markdown money contracts for perishable goods with clearance pricing. *Eur. J. Oper. Res.* **196** (2009) 1113–1122.

[46] X. Wang, X. Wang and Y. Su, Wholesale-price contract of supply chain with information gathering. *Appl. Math. Model.* **37** (2013) 3848–3860.

[47] J. Xie, W. Zhang, L. Liang, Y. Xia, J. Yin and G. Yang, The revenue and cost sharing contract of pricing and servicing policies in a dual-channel closed-loop supply chain. *J. Cleaner Prod.* **191** (2018) 364–383.

[48] F. Wang, A. Diabat and L. Wu, Supply chain coordination with competing suppliers under price-sensitive stochastic demand. *Int. J. Prod. Econ.* **234** (2021) 108020.

[49] R. Yadav, S. Pareek and M. Mittal, Stackelberg models in two-level supply chain with imperfect quality items with allowable shortages. *Sci. Iran.* (2021). https://doi.org/10.1080/23270012.2021.1944350.

[50] Z. Yao, S.C.H. Leung and K.K. Lai, Manufacturer's revenue-sharing contract and retail competition. *Eur. J. Oper. Res.* **186** (2008) 637–651.

[51] P.S. You, Inventory policy for products with price and time-dependent demands. *J. Oper. Res. Soc.* **56** (2005) 870–873.
[52] Y. Zhao, T.-M. Choi, T.C.E. Cheng, S.P. Sethi and S. Wang, Buyback contracts with price-dependent demands: Effects of demand uncertainty. *Eur. J. Oper. Res.* **239** (2014) 663–673.