A Game-Theoretic Framework for Analyzing the Impact of Social Responsibility and Supply Chain Profitability

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DECLARATION OF INTEREST

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Abstract

Supply chain collaboration plays an important role in profit maximization. Contract coordination is a successful strategy for collaboration and profit-sharing in supply chains. The study of contract coordination in supply chains under uncertainty and stochastic environmental conditions has attracted the attention of many researchers. We propose a single-period newsvendor model with one manufacturer and one retailer in the supply chains. The proposed model considers two variables, including order quantity and investment in corporate social responsibility, where the demand is stochastic and follows a normal standard distribution. The model considers quantity flexibility, advanced purchasing discounts (APDs), and buyback contracts under cooperative conditions. Numerical examples are used to exhibit the applicability of the model under various conditions, including the two-demand distribution and three coordination contracts. We demonstrate an ideal scenario where the APD contracting results in the most overall supply chain profit and increases for each supply chain partner.

Keywords: supply chain contracts; corporate social responsibility; buyback contracts; advanced purchase discount; quantity flexibility.

1. Introduction

Supply chain (SC) management requires coordination of production, inventory, order quantity, pricing, and advertising among the SC partners to achieve the best mix of productivity and profitability. Various SC collaboration strategies have been proposed in the literature (Thomas & Griffin, 1996). SC collaboration helps companies gain a competitive advantage and improve productivity and profitability (Sarmah et al., 2008). Contract coordination is a widely used SC collaboration tactic used to increase competitive advantage (Chaharsooghi et al., 2011). The study of SC contracting in a stochastic environment has drawn the attention of many researchers (Hu & Feng, 2017; Fan et al., 2019). Advanced purchasing discounts (APDs), bonuses, buyback, cost-sharing, credit, option, effort sharing, green contracting, markdown contracting, profit sharing, quantity discounting, quantity flexibility, revenue sharing, risk sharing, sale rebate, two-part tariff, wholesale pricing, are among commonly adopted contracting methods.

On the other hand, corporate social responsibility (CSR) in an SC context is defined as SC members' social and ethical behavior for all its stakeholders that including its shareholders, end customers, employees, and managers (Panda, 2014). In SC modeling, quantitative and measurable variables are necessary to measure CSR effects. There are various references for classifying the social responsibility indicators, including the Global Reporting Initiative (GRI), which classifies labor practices, good and suitable work, human rights, product, and social responsibility. Several indicators have been investigated for quantitative measurement of social responsibility, such as vacation, staff turnover, wage level of sexes, and promotion rate. (Simoes et al., 2016; Mahdiraji et al., 2019a; Mahdiraji et al., 2019b; Mahdiraji et al., 2020). Accidents' indicators, number of reported accidents per year, health coverage, number of employees with social security, health insurance, sex ratio between male and female employees, level of payment between genders, income distribution among employees, and forced labor factors, all of which are key indicators for measuring the sustainability and social responsibility (ILO, 2017, online; Mahdiraji et al., 2019). Considering these facts, moving toward sustainable supply chains (SSC) according to the triple bottom line (TBL) is unavoidable (Ahmed and Sarkar, 2019). Also, the recent developments of industry 4.0 technologies and their impacts on SCs (i.e., digital supply chain (DSC) or SC 4.0) are making the SSC achievable (Birkel and Muller, 2021). However, considering all of the benefits of industry 4.0 on DSCs, some scholars have considered the risks of moving toward digitalization (Wang et al., 2020). The risks dealing with social responsibilities and humanity have resulted in Industry 5.0 as a human-centric solution (Nahavandi, 2019). Accordingly, considering social responsibility indicators and the efforts and investments in this area is necessary while designing supply chains toward sustainability. These investments and efforts should be beneficial for the entire SC and the members to encourage them. As a result, the main motivation of this research is to design an integrated game-theoretic framework to compare and benchmark different coordination contracts while considering the profit of the members and the investment and efforts they have taken toward CSR.

Many scholars (e.g., Feng et al., 2017; Modak et al., 2020) have introduced a qualitative analysis of the CSR indicators on SCs coordination and profitability. Some rare cases (e.g., Liu et al., 2019; Mahdiraji et al., 2020; Khosroshahi et al., 2021) have also introduced quantitative research methods to analyze the impacts of CSR on SCs profitability. Even some scholars focused on the negative indicators of CSR, such as the "forced labor" in non-cooperative and cooperative SCs under deterministic demand (Mahdiraji et al., 2020). Some scholars introduced different approaches to designing coordination contracts from a game theory perspective while considering all three pillars of sustainability (e.g., Raj et al., 2018). Some focused on combined contracts while optimizing CSR and other critical decision variables such as price, inventory, order quantity, etc. (e.g., Jokar and Hosseinin-Motlagh, 2020). By considering the relevant literature alongside the articles analyzed in Table 1, to the best knowledge of the authors, many areas still have not been covered, including (i) identifying, selecting, and investigating the impact of a measurable positive indicator of CSR on SCs collaboration and profitability, (ii) considering the impact of positive CSR indicator on SC demand under uncertain circumstances with different scenarios, (iii) analyzing and comparing different coordination mechanisms on SCs profitability by including CSR indicator with uncertain demand while simultaneously optimizing order quantity, wholesale price, CSR indicator, and SC profitability. Hence, the main objective of this research is to design an integrated game-theoretic-based framework to study the impacts of different coordination contracts on SC profitability while including positive CSR indicators, order quantity, and different uncertain demand functions. Accordingly, to scrutinize the effect of CSR on SCs profitability, in this research, the investment in social responsibility is considered a positive determinant factor that affects the profitability of the SC. The main research questions include (i) how and how much this factor affects the SC and members' profit, (ii) which player benefits more if investment in social responsibility increases or not, (iii) under what type of coordination contract and collaboration in the SC does the overall profit increases. Note that the research questions are responded to while the demand function is uncertain and probabilistic to present more realistic models and analytics. In this regard, two probabilistic demand distributions are analyzed to compare and benchmark different circumstances.

The remainder of this paper is organized as follows. Section 2 presents the basic concepts and literature on SC collaboration and contract coordination. In Section 3, we present the modeling preliminaries and notations along with the fundamental retailer-manufacturer and centralized models. Section 4 presents our results and sensitivity analysis. In Section 5, we conclude with our conclusions and future research directions.

2. SC collaboration and contract coordination literature

Usually, SCs aim to maximize their overall profit by engaging an inappropriate target and distributing equitable shares to all parties. The SC is primarily designed to improve communication amongst its members by developing long-term relationships to increase profit margins (Govindan et al., 2012). In reality, a decision made by one member impacts other members of the SC (Heydari, 2014). Many studies indicated that where a conflicting approach can increase the profitability of one member at the expense of others (Jia et al., 2013; Mahdiraji et al., 2019). However, a cooperative decision-making approach enhances the overall profitability of all members. In SC coordination, four main approaches are considered as coordination mechanisms, including information technology, information sharing, joint decision making, and coordination contracts (Albrecht, 2009). Coordination contracts are among the most important and popular methods in theory and practice for attaining coordination among SC members. Therefore, this research concerns modeling the coordination contracts and optimization of SC profit margin consisting of a retailer and a manufacturer. At the same time, they are engaged in a positive CSR indicator and uncertain demand situation.

Among all designed coordination contracts, (1) wholesale price, (2) two-part tariff, (3) buyback, (4) revenue sharing, (5) quantity flexibility, (6) backup, (7) sales rebate, (8) quantity discount, (9) combined or hybrid contracts, and (10) debate contracts have been implemented more in the relevant literature (Govindan et al., 2013; Mahdiraji et al., 2020). In this regard, the game theory could be used to design cooperative models for SC members in two different approaches, including negotiation and coalition approaches (Cachon, 2003). The demand type (deterministic or stochastic) could determine the type of contract that is more suitable, as some coordination contracts are appropriate for the deterministic condition, some for uncertainty, and some for both circumstances (Govindan et al., 2013; Mahdiraji et al., 2014). In this research, based on the uncertain demand, considered contracts consist of buyback, advanced purchase discount, and quantity flexibility contracts, most of which are examined in terms of their structure in a stochastic demand environment. These contracts have been more popular in previous literature (Mahdiraji et al., 2020); thus, the authors focused on these three contracts to analyze the positive effect of CSR on SC profitability.

The buyback contract applies to many industries, including perishable and agricultural products. In the buyback contract, at the end of the sales season, the manufacturer purchases the surplus inventory at retail with the price of (B); thereby, the loss and risk of the surplus inventory will decrease (Taleizadeh et al., 2018). In other words, in this contract, after paying the wholesale price to the purchased units, the manufacturer buys the remaining surplus units at a lower price than the wholesale price and pays more than the salvage value (Sainathan & Groenevelt, 2019; Tsao, 2019). This contract applies to many industries that produce short-lived products, including fashion clothes, hardware, and software, greeting cards, magazines, newspapers, etc. This contract is more attractive in the high inventory cost and the short product life span (Mahdiraji et al., 2012; Farhat et al., 2019).

A quantity flexibility contract involves scenarios for SC structure in different stochastic situations. Companies that have used quantity flexibility contracts include Toyota, HP, and IBM (Tsay & Lovejoy, 1999). This contract establishes obligations for the retailer based on the specified order quantity (Sainathan & Groenevelt, 2019). In this contract, the retailer orders based on a certain percentage, and if the items are not sold, the manufacturer will guarantee a full refund for all agreed range items (Simchi-Levi et al., 2009). This contract can make the buyer's willingness to pay flexible and reduce the bullwhip effect. It is usually used to divide demand uncertainty costs among SC members (Giannoccaro & Pontrandolfo, 2004). The difference between this contract and the buyback contract is the number of items that can be returned by the buyer and the price the seller proposes. The buyback contract provides a partial refund for the returns, and the quantity flexibility contract accepts some total returns (Simchi-Levi et al., 2009). According to the 2008 International Monetary Fund, Advance Payment Discount Contract (APD) accounts for 19-22% of worldwide SC financing cases (Zhao & Huchzermeier, 2019; Jing et al., 2012).

The *Advance-purchase discount (APD)* contract was first studied by Cachon (2004). He considered a two-level SC, including a manufacturer and a retailer, and tried to measure the effect of inventory risk on the decentralized SC compared to the centralized state. Finally, he concluded that inventory risk could be divided between the retailer and the manufacturer using the Advance-purchase discount (APD) contract. Other scholars have developed the Cachon (2004) model, for example, examining the variations in the two different wholesale prices and their effect on the transfer of inventory among SC members by Lai et al. (2009) and Dong and Zhu (2007). Two wholesale prices, including pre-book wholesale price and the at-once wholesale price, are suggested in the APD contract. The retailer orders a (Q) size, and the manufacturer guarantees it at a pre-booking price; however, some extra inventory will be available to the retailer for an at-once wholesale price, and both members are at risk of inventory due to demand fluctuations (He & Khouja, 2011).

Table 1 provides SC contract backgrounds by the number of SC members (echelon), type of contract, type of demand in uncertain conditions, demand distribution, and distribution function.

Table1. Classification of uncertain models in coordination contracts

Author and year	SC Echelon		Type of contract													Demand Uncertainty Type		Demand Distribution function						Newsvendor model
	Two	Three	Risk sharing	Option, Credit	Revenue sharing	cost-sharing	Wholesale, discount	buyback	Subsidiary	transfer	Profit-sharing	flexible	two-part tariff	Two-part tariff	information	Stochastic	Probabilistic	Exponential	Normal	Gamma	Uniform	Geometric	Triangular	
Xu (2010)	✓			✓												✓			✓					✓
Chaharsooghi & Heydari (2010)	✓			✓													✓							
Krishnan & winter (2011)	✓				✓												✓		✓					
Toktas-palut & Ulengin (2011)	✓					✓			✓	✓							✓	✓						✓
Lee & Rhee (2011)	✓			✓													✓			✓				✓
Zhao & Shi (2011)	✓				✓		✓										✓	✓						✓
Li et al. (2011)	✓						✓										✓		✓					
He & Khouja (2011)	✓				✓		✓	✓									✓			✓				✓
Huang et al. (2011; li et al. (2013)	✓						✓										✓					✓		✓
Hu & Xu (2012)	✓						✓									✓								✓
Seifert et al. (2012)		✓					✓										✓				✓			✓
Govindan et al. (2012)	✓				✓		✓	✓				✓					✓		✓					✓
Babich et al. (2012)	✓							✓								✓								✓
Wang et al. (2013)	✓						✓									✓								✓
Wu (2013)	✓							✓									✓				✓			✓
Palsule-desai (2013)	✓				✓												✓		✓					
Chen & Su (2014)	✓				✓												✓		✓					✓
Govindan & Popiuc (2014)		✓			✓											✓								✓
Sun & Debo (2014)	✓						✓										✓				✓			
Cobb & Johnson (2014)	✓			✓													✓		✓					✓
Feng et al. (2014)	✓				✓												✓		✓					✓
Hsueh (2014)	✓				✓												✓		✓					✓
Pedrielli et al. (2015)	✓			✓													✓		✓		✓		✓	✓
Alaei & Setak (2015)	✓				✓												✓				✓			✓
Wang et al. (2015)	✓			✓				✓								✓								✓
Avinadav et al. (2015)	✓				✓		✓										✓		✓					✓
Lei et al. (2015)	✓				✓											✓	✓				✓			✓
Xu et al. (2015)	✓							✓									✓	✓						
Yin & Ma (2015)	✓			✓													✓		✓		✓			✓
Chow et al. (2015)	✓						✓										✓				✓			✓
Cao et al. (2015)	✓										✓						✓				✓			✓
Li et al. (2016)	✓		✓														✓				✓			✓
Hu et al. (2016)		✓			✓											✓								✓
Hu et al. (2016)	✓					✓	✓		✓					✓			✓		✓					✓
Pfeiffer (2017)	✓				✓		✓							✓			✓		✓					✓
Yang et al. (2017)	✓			✓	✓												✓		✓					✓
Yan et al. (2017)	✓						✓										✓	✓						✓

Author and year	SC Echelon		Type of contract													Demand Uncertainty Type		Demand Distribution function						Newsvendor model
	Two	Three	Risk sharing	Option, Credit	Revenue sharing	cost-sharing	Wholesale, discount	buyback	Subsidiary	transfer	Profit-sharing	flexible	two-part tariff	Two-part tariff	information	Stochastic	Probabilistic	Exponential	Normal	Gamma	Uniform	Geometric	Triangular	
Zhang & Ren (2018)		✓			✓	✓										✓								✓
Becker-peth & Thonemann (2018)	✓				✓											✓								✓
Ye et al. (2018)	✓			✓													✓				✓			✓
Wang et al. (2019)	✓					✓	✓										✓				✓			✓
Li et al. (2019)	✓				✓												✓		✓					✓
Hu & Feng (2019)	✓				✓											✓								✓
PROPOSED RESEARCH	✓						✓	✓				✓					✓		✓					✓

From three main perspectives, the novelty of this paper is considerable, the probabilistic distributions, the coordination contracts, and the CSR index. First of all, it is obvious that most of the previous studies are reviewed with the assumption of continuous demand, either normal or exponential; however, both normal and standard normal distributions are considered in this research. Moreover, as Table 1 denotes, in the vast majority of cases, only one coordination contract is considered for investigating the collaboration; nonetheless, quantity flexibility, advanced discount, and buyback contract are studied different benchmarking approaches in SC coordination in this research. Furthermore, considering a specific CSR index in the demand function prepares a suitable tool to analyze the effect of CSR on each member and SC overall profit, never been considered previously in any related research. The integrated model designed in this research is considered from different perspectives, including (i) reflecting seven different scenarios for the uncertain demand function, including Normal, Standard Normal, and uniform distributions, (ii) investigating and benchmarking several coordination contracts and their impacts on SC profitability including wholesale, buyback, APD and quantity flexible, and (iii) considering combined decision variables including order quantity, wholesale price, and CSR indicator. However, as mathematical models are designed based on their assumptions, this research also deals with some limitations in the designed model, including (i) considering two echelons and one member in each echelon, (ii) not including multi-product and multi-period approaches in modeling, (iii) environmental aspects have not been reflected in the model, and (iv) all kinds of distribution function and contracts have not been benchmarked.

3. Modeling preliminaries and notations

In this research, the considered SC has one manufacturer and one retailer. The research period is considered a single period with the assumptions of the newsvendor sales model. This sales model includes two decision variables, the investment on corporate social responsibility investment (cost) and the amount of retailer order quantity. The manufacturer imposes a cost of τ_M on a unit of product for carrying out social responsibility. This cost depends on the amount of demand. Remark that, τ_M is considered as the unit of investment in CSR. The negative effect of CSR (as forced labor) on SC contract profits was considered recently (Mahdiraji et al., 2020). In this research, the positive effect of CSR, considering uncertainty in demand, is questioned. To do so, Hsueh (2014) considered the extent of corporate social responsibility performance as a function of investment and is measurable through the function $BL(\tau_M) = 1 - \frac{1}{(0.5\tau_M+1)}$. If the investment or cost is zero, the social responsibility function will also be zero as well $BL(0) = 0$. In general, a higher CSR performance level requires higher costs and leads to more market demand. Thus, the authors considered that market demand (D) has a normal distribution with a mean and variance of $(\mu_0 + aBL(\tau_M), \sigma^2)$ and μ_0 mean distribution when CSR is not performed. Note that $a > 0$ is a positive parameter representing the maximum mean increase in CSR performance.

During the sales season, (D) market demand is unknown. Moreover, in this SC, perishable or seasonal products are sold to end customers. Moreover, demand is examined under the assumption of the standard normal and normal distribution function. Remark that the contracts examined in this study include buyback, quantity flexibility, and advanced purchase discount contracts. The considered problem and SC are presented in Figure 1.

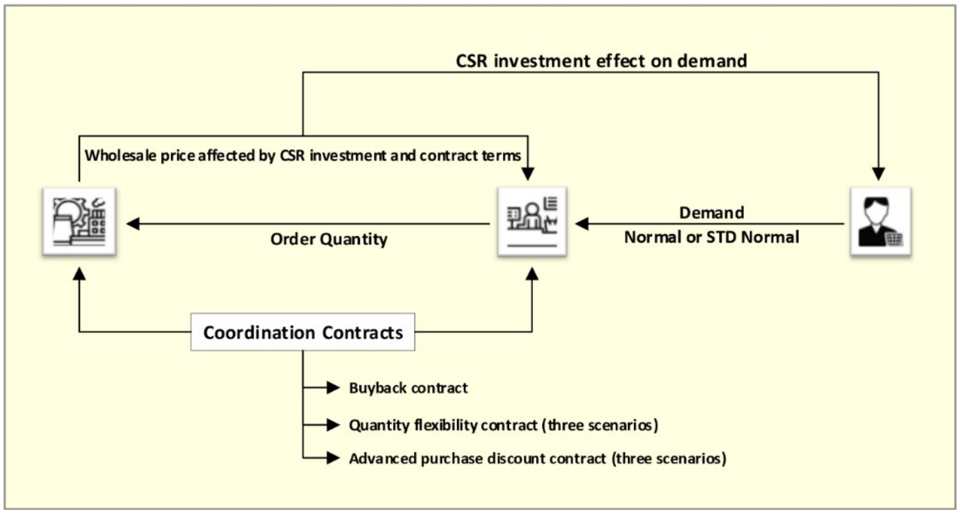

Figure 1. Supply chain model

In all three centralized models and SC contracts, given the cost terms, the lost customer satisfaction for the manufacturer (g_M) and for the retailer (g_R), the net profit from the salvage or surplus product for the manufacturer (S_M) and for the retailer (S_R), are considered. For centralized situation, in the buyback contract, the retailer is able to return its surplus inventory at the price of $B < w_M$. In the quantity flexibility contract, the retailer is committed to optimizing the SC. In Table 2, all symbols used in this study are shown along with their descriptions.

Table 2. Notations and descriptions

Functions					
ESold	number of expected sales	ECost	expected costs	$f(Q_R)$	PDF of the retailer order quantity
ESalvage	expected salvage value	EProfit	expected profit	$f\left(\frac{Q_R - \mu}{\sigma}\right)$	normal distribution PDF
ELost	expected lost sale	$H(Q)$	The demand of the order level Q	π_{SC}	supply chain profit
F(Q)	CDF of the order quantity	π_R	retailor profit	π_M	manufacturer profit
Parameters					
s	Salvage value of a unit	C_U	Cost of a fractional unit	τ_{SC}	cost of investment on corporate social responsibility
g	Customer dissatisfaction of a unit	C_O	Cost of a surplus unit	δ	Quantity flexibility contract parameter
c	Cost of buying or producing a product	M	average demand	σ	the standard deviation of demand
P	Cost	Q	Order quantity	S_R	salvage value for the retailer
D	Demand	μ_0	demand without social permission	P_R	Retail Price
CSR	Corporate Social Responsibility	R	cost of re-ordering during the season	g_R	Customer dissatisfaction for the retailer
$BL(\tau_M)$	Corporate Social Responsibility Performance	w_M	Wholesale price	B	Redemption price
a	Social Responsibility Performance Factor	c_R	Cost of buying a unit of retailer product	R_{Q_M}	Early season order surplus inventory
S_M	salvage value for the manufacturer	g_M	Customer dissatisfaction for manufacturer	σ^2	Demand variance
Decision Variables					
τ_M	cost of investment in social responsibility	Q_{SC}	Centralized order quantity	Q_R	Retailer order quantity

CDF= cumulative distribution function; PDF=Probability density function

3.1. Fundamentals of Retailer-Manufacturer models

The research framework of this article consists of three stages. In the first stage, the authors modeled the retailer and manufacturer's implications and examined the concavity of their payoff functions. Then, the best response of each player is emanated by the result of solving first order derivation of payoff functions based on Nash definition. Then, in the second step, the authors have modeled, examined the concavity, optimized and extracted the best responses for each player in centralized mode, and designed coordination contracts based on buyback, quantity flexibility, and advanced purchase discount assumptions. Eventually, by a numerical example, sensitivity analysis, and conclusions are demonstrated.

The authors presented the retailer and manufacturer profit functions with the symbols of π_R and π_M, respectively. The consequence of the retailer and manufacturer can include expected sales (sales and profits of surplus salvages) and expected costs (lost sales and purchase costs and other costs). Eqs. (1) to (5) present the expected relationships for all statistical distributions and SC members. These relationships include expected sales, expected salvage value, lost sales, expected cost, and profit (Cachon, 2003; 2007).

$$\mathrm{ESold} = H(Q) + Q\big(1 - F(Q)\big) \qquad \text{Expected sales units} \qquad (1)$$

$$\mathrm{ESalvage}(Q) = QF(Q) - H(Q) \qquad \text{Expected salvage value} \qquad (2)$$

$$\mathrm{ELost}(q) = \mu - H(Q) - Q\big(1 - F(\mathrm{Q})\big) \qquad \text{Expected lost sales} \qquad (3)$$

$$\mathrm{ECost} = (C_U + C_O)\big(QF(Q) - H(Q)\big) + C_U(\mu - Q) \qquad \text{Expected costs} \qquad (4)$$

$$\begin{aligned}\mathrm{EProfit}(Q) &= (p - s + g)\big(H(Q) - QF(Q)\big) + (p - c + g)Q - g\mu \\ &= \mathrm{p.\,ESold}(Q) + \mathrm{s.\,ESalvage}(Q) - \mathrm{g.\,ELost}(Q) - cQ\end{aligned} \qquad \text{Expected profit} \qquad (5)$$

The manufacturer is responsible for the social responsibility, and the retailer is responsible for the quantity of order. The amount of each of these variables affects the entire SC. The cost of social responsibility increases the demand, thereby increasing the order quantity and, eventually, manufacturers selling price.

In the profit function of the retailer, the expected sales, the surplus inventory and the expected deficiency along with the standard normal distribution are considered as $H(Q) = \int_{D=0}^{Q}(D)f(D)dD$ and $\mu = \int_{D=0}^{\infty}(D)f(D)dD$ and for the normal distribution areas $H(Q) = \mu F(z) - \sigma f(z) \rightarrow H(Q_R) = \mu F(\frac{Q_R-\mu}{\sigma}) - \sigma f\left(\frac{Q_R-\mu}{\sigma}\right)$, where $z = \frac{Q_R-\mu}{\sigma}$. In the above expression μ and σ are the mean and standard deviation of demand, $F(z)$ and $f(z)$ are cumulative functions and probable density for the standard normal distribution, and $z = \frac{Q-\mu}{\sigma}$. Note that, $F(z) = F(Q_R)$; however, $(Q_R) \neq f(z)$. Hence, the final result of the retailer's profit function is shown in Eq. (6). (See Appendices A and B for more information and proof).

$$\begin{aligned}\pi_R = P_R.&\left(\left(\left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_M+1)}\right)\right)F\left(\frac{Q_R-\left(\mu_0+a\left(1-\frac{1}{(0.5\tau_M+1)}\right)\right)}{\sigma}\right) - \sigma f\left(\frac{Q_R-\left(\mu_0+a\left(1-\frac{1}{(0.5\tau_M+1)}\right)\right)}{\sigma}\right)\right) + Q\left(1 - F\left(\frac{Q_R-\left(\mu_0+a\left(1-\frac{1}{(0.5\tau_M+1)}\right)\right)}{\sigma}\right)\right)\right) \\ &+ S_R.\left(Q_R F\left(\frac{Q_R-\left(\mu_0+a\left(1-\frac{1}{(0.5\tau_M+1)}\right)\right)}{\sigma}\right) - \left(\left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_M+1)}\right)\right)F\left(\frac{Q_R-\left(\mu_0+a\left(1-\frac{1}{(0.5\tau_M+1)}\right)\right)}{\sigma}\right) - \sigma f\left(\frac{Q_R-\left(\mu_0+a\left(1-\frac{1}{(0.5\tau_M+1)}\right)\right)}{\sigma}\right)\right)\right) \\ &- g_R.\left(\left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_M+1)}\right)\right) - \left(\left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_M+1)}\right)\right)F\left(\frac{Q_R-\left(\mu_0+a\left(1-\frac{1}{(0.5\tau_M+1)}\right)\right)}{\sigma}\right) - \sigma f\left(\frac{Q_R-\left(\mu_0+a\left(1-\frac{1}{(0.5\tau_M+1)}\right)\right)}{\sigma}\right)\right) + Q_R\left(1 - F\left(\frac{Q_R-\left(\mu_0+a\left(1-\frac{1}{(0.5\tau_M+1)}\right)\right)}{\sigma}\right)\right)\right) \\ &- c_R Q_R - w_M Q_R\end{aligned} \qquad (6)$$

The manufacturer's profit function includes wholesale revenue, production cost, and social responsibility cost. In this function, it is assumed that the amount of revenue and costs of the manufacturer are directly dependent on the amount of the retailer's order and indirectly on the amount of the investment on corporate social responsibility. Normally, without considering the contract, no penalty or extra income is charged to the manufacturer. The consequence function of the manufacturer is shown in Eq. (7) as follows.

$$\pi_M = w_M \,.\, Q_R - C_M Q_R - \tau_M Q_R \tag{7}$$

The Nash equilibrium definition is considered to measure the best response of each player (member) of the SC. The Nash equilibrium N(G) is computable by the derivation of the utility or payoff function of each player regarding a specific decision variable (Rasmusen, 1990). In other words, the consequence of the retailer is derived from the Q_R value, and its optimal value is calculated. Subsequently, the value of the $Q_R{}^*$ is inserted into the profit function of the manufacturer and the best response of the manufacturer is emanated according to $\tau_M{}^*$. Accordingly, the best response for the manufacturer and the retailer is shown in Eq. (8) and (9). (See Online Appendix A, B, and C for more information and proof)

$$Q_R{}^* = \left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_M{}^*+1)}\right)\right) + F^{-1}\left(\frac{P_R - c_R - w_M + g_R}{P_R - S_R + g_R}\right)\sigma \tag{8}$$

$$\tau_M{}^* = -\frac{2\left(F^{-1}\left(\frac{(P_R - c_R - w_M + g_R)}{(P_R - S_R + g_R)}\right)\sigma + a + \mu_0\right) \pm \sqrt{2}\sqrt{a\left(F^{-1}\left(\frac{(P_R - c_R - w_M + g_R)}{(P_R - S_R + g_R)}\right)\sigma + a + \mu_0\right)(-C_M + w_M + 2)}}{F^{-1}\left(\frac{(P_R - c_R - w_M + g_R)}{(P_R - S_R + g_R)}\right)\sigma + a + \mu_0} \tag{9}$$

3.2. Centralized models

SC members can choose different coordination contracts depending on their desired level of cooperation (Ye et al., 2018). The desired cooperation level is determined based on the amount of acceptable risk, demand function, number of members, and product type, among others (Mahdirajij et al., 2015). The demand function could be deterministic or possibilistic, depending on the environmental uncertainties. Deterministic demand functions are used in predictable markets, and possibilistic demand functions are used in unpredictable markets with fuzzy, probabilistic, or stochastic demands (Mahdiraji et al., 2015). For the centralized SC in this research, we consider three coordination contracts of buyback contracts (Eqs. (13) to (16)), quantity flexibility (Eqs. (17) to (23)), and advanced purchase (Eqs. (24) to (31)) with normal distribution and normal standard distribution demand functions. Eq. (10) is used to model the overall profit of the SC. The best responses of each player are then determined from the Nash equilibrium definition (Mahdiraji et al., 2019 and 2020) using Eqs. (11) to (12).

In centralized decision-making, there is generally only one decision-maker for the SC network. Therefore, all decision variables are optimized globally. The authors have selected the order quantity and social responsibility investment (cost) as decision variables to maximize SC profit. First, the researchers combined the function of the manufacturer and the retailer, then simplified and replaced by coordination contracts. After examining the concavity of the whole function with respect to the decision variables, the optimal value of each decision variable has been obtained. The profit function of the overall SC is as follows.

$$\begin{aligned}\pi_{SC} = \pi_R + \pi_M = (P_R - S_R + g_R)\mu F\left(\frac{Q_R-\mu}{\sigma}\right) - (P_R - S_R + g_R)\sigma f\left(\frac{Q_R-\mu}{\sigma}\right) - (P_R - S_R + g_R)Q_R F\left(\frac{Q_R-\mu}{\sigma}\right) + \\ (P_R - c_R - w_M + g_R)Q_R - g_R\mu + w_M \,.\, Q_R - C_M Q_R - \tau_M Q_R\end{aligned} \tag{10}$$

Next Q_{SC} and τ_{SC} are derived from Eq. (10), by equalizing to zero and obtaining the value of $Q_{SC}{}^*$ and $\tau_{SC}{}^*$ (check Online Appendix D for more detail) as follows.

$$Q_{SC}{}^* = \left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_{SC}+1)}\right)\right) + F^{-1}\left(\frac{P_R - c_R + g_R - C_M - \tau_{SC}}{P_R - S_R + g_R}\right)\sigma \tag{11}$$

$$\tau_{SC}{}^* = root\left((z^3 + 4z^2 + z(2a+4) + 2a(c_R - g_R + C_M - P_R + g_R P_R - g_R S_R + g_R^2), z, 1 \; and \; 2 \; and \; 3)\right) \tag{12}$$

Given the complexities and the interdependencies among the variables involved here, the following search algorithm has been employed to find the final optimal value (Nematollahi et al., 2017).

- **Step 1:** Assume τ_{sc} is equal to zero and it is replaced in $Q_{SC}{}^*$,
- **Step 2:** The SC profit could be obtained by using the figures in Step 1,
- **Step 3:** Let $\tau_{sc} = \tau_{sc} + \varepsilon$, replace τ_{sc} with $\tau_{sc} + \varepsilon$ in $Q_{SC}{}^*$ and $Q_{SC}{}^*$ and compute both values,
- **Step 4:** Repeat Step 2 with the information in Step 3.

Clearly $Q_{sc}{}^*$ and $\tau_{sc}{}^*$ are accepted by SC members when they increase the total profit of the centralized SC compared to the decentralized total profit model; thus, $\prod_{sc}(Q_{SC}{}^* \,.\, \tau_{sc}{}^*) \geq \prod_{dc}(Q_R{}^* \,.\, \tau_M{}^*)$.

3.3. Buyback Contract

According to the buyback contract, the manufacturer buys the remaining surplus products from the retailer at the end of the sales season (Govindan et al., 2012). Note that, w_M is the wholesale price at the beginning of the sales season and B is the buyback price of the surplus product at the end of the period. The buyback price should not exceed the selling price because the retailer order will be infinite. In this contract, $(B < P_R)$ reduces the risk of sales and encourages the retailer to order more. In the buyback contract mode, the retailer's profit function is as in Eq. (13):

$$\pi_R = P_R.ESold(Q_{SC}{}^*, \tau_{SC}{}^*) + (B).ESalvage(Q_{SC}{}^*, \tau_{SC}{}^*) - g_R.ELost(Q_{SC}{}^*, \tau_{SC}{}^*) - c_R Q_{SC}{}^* - w_M Q_{SC}{}^* \qquad (13)$$

It is shown that the buyback price is intended for the retailer surplus instead of the salvage value, and in this contract, the inventory is not salvaged by the retailer. Finally, the retailer function is as follows in the buyback contract (check Online Appendix E for more detail).

$$\pi_R = P_R.\left(\left(\left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_{sc}^*+1)}\right)\right) F(Q_{SC}{}^*) - \sigma f\left(\frac{Q_{SC}{}^* - \left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_{sc}^*+1)}\right)\right)}{\sigma}\right)\right) + Q_{SC}{}^*\left(1 - F(Q_{SC}{}^*)\right)\right) + (B).\left(Q_{SC}{}^* F(Q_{SC}{}^*) - \left(\left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_{sc}^*+1)}\right)\right) F(Q_{SC}{}^*) - \sigma f\left(\frac{Q_{SC}{}^* - \left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_{sc}^*+1)}\right)\right)}{\sigma}\right)\right)\right) - g_R.\left(\left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_{sc}^*+1)}\right)\right) - \left(\left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_{sc}^*+1)}\right)\right) F(Q_{SC}{}^*) - \sigma f\left(\frac{Q_{SC}{}^* - \left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_{sc}^*+1)}\right)\right)}{\sigma}\right)\right) + Q_{SC}{}^*\left(1 - F(Q_{SC}{}^*)\right)\right) - c_R Q_{SC}{}^* - w_M Q_{SC}{}^* \qquad (14)$$

The consequence of the function of the manufacturer is as follows. This function includes wholesale revenue and salvage profits, loss of sales, cost of construction and social responsibility.

$$\pi_M = w_M \,.\, Q_{SC}{}^* + (S_M - B).ESalvage(Q_{SC}{}^*, \tau_{SC}{}^*) - g_M.ELost(Q_{SC}{}^*, \tau_{SC}{}^*) - C_M Q_{SC}{}^* - \tau_M Q_{SC}{}^* \qquad (15)$$

In the above function, the manufacturer reduces the received surplus inventory to the value of $(S_M - B)$ or the difference between the salvage profit and the buyback price, which reduces the manufacturer's income. On the other hand, it may happen before issuing the contract by increasing the overall sale. Finally, the manufacturer function is as follows in terms of the buyback contract as Eq. (16). (Check Online Appendix F for more details)

$$\pi_M = w_M \,.\, Q_{SC}{}^* + S_M.\left(Q_{SC}{}^* F(Q_{SC}{}^*) - \left(\left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_{sc}^*+1)}\right)\right) F(Q_{SC}{}^*) - \sigma f\left(\frac{Q_{SC}{}^* - \left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_{sc}^*+1)}\right)\right)}{\sigma}\right)\right)\right) - g_M.\left(\left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_{sc}^*+1)}\right)\right) - \left(\left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_{sc}^*+1)}\right)\right) F(Q_{SC}{}^*) - \sigma f\left(\frac{Q_R - \left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_{sc}^*+1)}\right)\right)}{\sigma}\right)\right) + Q_{SC}{}^*\left(1 - F(Q_{SC}{}^*)\right)\right) - C_M Q_{SC}{}^* - \tau_{sc}^* Q_{SC}{}^* \qquad (16)$$

3.4. Quantity flexibility contract

According to the quantity flexibility contract, the retailer commits to purchase $(1 - \delta)Q^*_{sc}$ units with the option of repaying more than the commitment during the sales season to the level of optimal order quantity. Note that, δ is the contract parameter and is a number between zero and one (Govindan et al., 2012; Nematollahi et al., 2017). Depending on the level of demand, three different scenarios have been considered as follows.

a) Demand should be less than the committed order $(D < ((1 - \delta)Q_{SC}{}^*)$. Given that demand is below the retailer's commitment level, the difference between the two should definitely be salvaged. Thus, the profit function of the retailer is as follows.

$$\pi_R = P_R.ESold(Q_{SC}{}^*, \tau_{SC}{}^*) - c_R(1 - \delta)Q_{SC}{}^* - w_M(1 - \delta)Q_{SC}{}^* + S_R.\left((1 - \delta)Q_{SC}{}^* - D\right) \qquad (17)$$

In view of the above relationship, the retailer's profit in the buyback contract is as follows.

$$\pi_R = P_R.\left(\left(\left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_{sc}^*+1)}\right)\right)F(Q_{SC}{}^*) - \sigma f\left(\frac{Q_{SC}{}^* - \left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_{SC}^*+1)}\right)\right)}{\sigma}\right)\right) + Q\left(1 - F(Q_{SC}{}^*)\right)\right) + S_R.\left((1-\delta)Q_{SC}{}^* - D\right) - c_R(1-\delta)Q_{SC}{}^* - w_M\,(1-\delta)Q_{SC}{}^* \tag{18}$$

The manufacturer will eventually sell at the committed amount; hence, for the manufacturer, the profit function is as follows.

$$\pi_M = w_M\,.\,(1-\delta)Q_{SC}{}^* - C_M(1-\delta)Q_{SC}{}^* - \tau_{sc}^*(1-\delta)Q_{SC}{}^* \tag{19}$$

b) Demand is between the committed order and the optimal SC quantity ($(1-\delta)Q_{SC}{}^* < D < Q_{SC}{}^*$). In this case, no surplus will be related to the retailer, and if the demand exceeds the committed amount, the retailer will have to order $Q_{SC}{}^*$ and if the demand is less than $Q_{SC}{}^*$, it will return the difference to the retailer at wholesale price. Thus, the profit function of the retailer is as follows.

$$\pi_R = P_R.ESold(Q_{SC}{}^*, \tau_{SC}{}^*) - c_R Q_{SC}{}^* + w_M\,(Q_{SC}{}^* - D) - w_M\,Q_{SC}{}^* \rightarrow \pi_R = P_R.\left(\left(\left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_{sc}^*+1)}\right)\right)F(Q_{SC}{}^*) - \sigma f\left(\frac{Q_{SC}{}^* - \left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_{SC}^*+1)}\right)\right)}{\sigma}\right)\right) + Q\left(1 - F(Q_{SC}{}^*)\right)\right) - c_R Q_{SC}{}^* + w_M\,(Q_{SC}{}^* - D) - w_M\,Q_{SC}{}^* \tag{20}$$

The manufacturer also salvages $(Q_{SC}{}^* - D)$ valued $(S_M - w_M)$. Hence, for the manufacturer, the profit function is as follows.

$$\pi_M = w_M\,.\,Q_{SC}{}^* + (S_M - w_M).(Q_{SC}{}^* - D) - C_M Q_{SC}{}^* - \tau_{sc}^* Q_{SC}{}^* \tag{21}$$

c) Demand is higher than the optimal SC order quantity ($D > Q_{SC}{}^*$). In this case, the penalty of the lost order will be added to the profit of the retailer, the manufacturer function, and the sales value of each is $Q_{SC}{}^*$. In this case, there is no salvage profit for either party. Thus, the profit function of the retailer is as follows.

$$\pi_R = P_R.ESold(Q_{SC}{}^*, \tau_{SC}{}^*) - g_R.ELost(Q_{SC}{}^*, \tau_{SC}{}^*) - c_R Q_{SC}{}^* - w_M\,Q_{SC}{}^* \rightarrow \pi_R = P_R.\left(\left(\left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_{sc}^*+1)}\right)\right)F(Q_{SC}{}^*) - \sigma f\left(\frac{Q_{SC}{}^* - \left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_{SC}^*+1)}\right)\right)}{\sigma}\right)\right) + Q\left(1 - F(Q_{SC}{}^*)\right)\right) g_R.\left(\left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_{sc}^*+1)}\right)\right)\left(\left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_{sc}^*+1)}\right)\right)F(Q_{SC}{}^*) - \sigma f\left(\frac{Q_{SC}{}^* - \left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_{SC}^*+1)}\right)\right)}{\sigma}\right)\right) + Q_{SC}{}^*\left(1 - F(Q_{SC}{}^*)\right)\right) - cQ_{SC}{}^* - w_M\,Q_{SC}{}^* \tag{22}$$

Hence, for the manufacturer, the profit function is as follows.

$$\pi_M = w_M\,.\,Q_{SC}{}^* - g_M.ELost(Q_{SC}{}^*, \tau_{SC}{}^*) - C_M Q_{SC}{}^* - \tau_{sc}^* Q_{SC}{}^* \rightarrow \pi_M = w_M\,.\,Q_{SC}{}^* - g_M.\left(\left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_{sc}^*+1)}\right)\right) - \left(\left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_{sc}^*+1)}\right)\right)F(Q_{SC}{}^*) - \sigma f\left(\frac{Q_{SC}{}^* - \left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_{SC}^*+1)}\right)\right)}{\sigma}\right)\right) + Q_{SC}{}^*\left(1 - F(Q_{SC}{}^*)\right)\right) - C_M Q_{SC}{}^* - \tau_{sc}^* Q_{SC}{}^* \tag{23}$$

3.5. Advanced purchase discount contract

In this contract, the retailer offers its order quantity prior to the sales season and is able to revive the higher demand order at the price of each unit $r > P_R$ during the season. However, the number of units ordered during the period will be limited to the early-season surplus inventory that was displayed with R_{Q_M} (Govindan et al., 2012). It is also assumed that if demand is low, the order quantity may be returned to the manufacturer's inventory. The retailer should meet demand. Consider that if the number of units equals the optimal order quantity in independent mode, there are three possible scenarios as follows.

a) Demand is less than the order quantity ($D < Q_{R_m}$). In this case, there is no resale order by the retailer, and the retailer risks unsold quantities. Thus, the profit function of the retailer is as follows.

$$\pi_R = P_R.ESold(Q_R, \tau_M) + S_R.ESalvage(Q_R, \tau_M) - c_R Q_R - w_M Q_R \rightarrow \pi_R = P_R.\left(\left(\mu F(Q_R) - \sigma f\left(\frac{Q_R-\mu}{\sigma}\right)\right) + Q(1 - F(Q_R))\right) + S_R.\left(Q_R F(Q_R) - \left(\mu F(Q_R) - \sigma f\left(\frac{Q_R-\mu}{\sigma}\right)\right)\right) - c_R Q_R - w_M Q_R \tag{24}$$

Then, the expression $\left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_M+1)}\right)\right)$ has been substituted instead of the mean in all possibilities; hence, equation 25 engenders.

$$\pi_R = P_R.\left(\left(\left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_M+1)}\right)\right) F(Q_R) - \sigma f\left(\frac{Q_R - \left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_M+1)}\right)\right)}{\sigma}\right)\right) + Q(1 - F(Q_R))\right) + S_R.\left(Q_R F(Q_R) - \left(\left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_M+1)}\right)\right) F(Q_R) - \sigma f\left(\frac{Q_R - \left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_M+1)}\right)\right)}{\sigma}\right)\right)\right) - c_R Q_R - w_M Q_R \tag{25}$$

In this case, the surplus inventory of manufacturer R(Q$_M$) is added to its expenses and the total surplus inventory should be salvaged. Hence, for the manufacturer, the profit function is as follows.

$$\pi_M = w_M . Q_R + S_M . R_{Q_M} - C_M(Q_R + R_{Q_M}) - \tau_M(Q_R + R_{Q_M}) \tag{26}$$

b) Demand between order quantity and demand plus surplus inventory ($Q_{R_m} < D < D + R_{Q_M}$). In this case, the retailer has no risk, and the manufacturer faces the risk of remaining inventory. As you can see despite the fact that the retailer has ordered the Q_{R_m} size, it has to meet the whole demand and pay the unit cost of r for the lost quantities. Thus, the profit function of the retailer is as follows.

$$\pi_R = P_R.D - r.ELost(Q_R, \tau_M) - c_R D - w_M Q_R \rightarrow \pi_R = P_R.D - r.\left(\mu - \left(\mu F(Q_R) - \sigma f\left(\frac{Q_R-\mu}{\sigma}\right)\right) + Q_R(1 - F(Q_R))\right) - c_R D - w_M Q_R \tag{27}$$

Next, $\left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_M+1)}\right)\right)$ has been substituted instead of the mean in all possibilities.

$$\pi_R = P_R.D - r.\left(\left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_M+1)}\right)\right) - \left(\left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_M+1)}\right)\right) F(Q_R) - \sigma f\left(\frac{Q_R - \left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_M+1)}\right)\right)}{\sigma}\right)\right) + Q_R(1 - F(Q_R))\right) - c_R D - w_M Q_R \tag{28}$$

In addition to earning, production $r.ELost(Q_R.\tau_M)$ by the manufacturer must salvage the remaining amount. Hence, for the manufacturer, the profit function is as follows.

$$\pi_M = w_M . Q_R + S_M.(R_{Q_M} - ELost(Q_R,\tau_M)) + r.ELost(Q_R,\tau_M) - C_M(Q_R + R_{Q_M}) - \tau_M(Q_R + R_{Q_M}) - w_M Q_R \rightarrow \pi_M = w_M . Q_R + S_M.\left(R_{Q_M} - \left(\left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_M+1)}\right)\right) - \left(\left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_M+1)}\right)\right)F(Q_R) - \sigma f\left(\frac{Q_R - \left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_M+1)}\right)\right)}{\sigma}\right)\right) + Q_R(1 - F(Q_R))\right)\right) + r.\left(\left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_M+1)}\right)\right) - \left(\left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_M+1)}\right)\right)F(Q_R) - \sigma f\left(\frac{Q_R - \left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_M+1)}\right)\right)}{\sigma}\right)\right) + Q_R(1 - F(Q_R))\right) - C_M(Q_R + R_{Q_M}) - \tau_M(Q_R + R_{Q_M}) \tag{29}$$

c) Demand is greater than total demand plus surplus inventory ($D > D + R_{Q_M}$). In this case, the deficiency cost will occur for both players and they will be penalized by $g_R.(ELost(Q_R,\tau_M) - R_{Q_M})$. Thus, the profit function of the retailer is as follows.

$$\pi_R = P_R.D - g_R.(ELost(Q_R,\tau_M) - R_{Q_M}) - c_R(Q_R + R_{Q_M}) - w_M(Q_R + R_{Q_M})) - \tau_M(Q_R + R_{Q_M}) \rightarrow \pi_R = P_R.D - g_R.\left(\mu - \left(\mu F(Q_R) - \sigma f\left(\frac{Q_R - \mu}{\sigma}\right)\right) + Q_R(1 - F(Q_R)) - R_{Q_M}\right) - c_R(Q_R + R_{Q_M}) - w_M(Q_R + R_{Q_M}) \rightarrow \pi_R = P_R.D - g_R.\left(\left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_M+1)}\right)\right) - \left(\left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_M+1)}\right)\right)F(Q_R) - \sigma f\left(\frac{Q_R - \left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_M+1)}\right)\right)}{\sigma}\right)\right) + Q_R(1 - F(Q_R))\right) - c_R(Q_R + R_{Q_M}) - w_M(Q_R + R_{Q_M}) \tag{30}$$

Hence, for the manufacturer, the profit function is as follows.

$$\pi_M = w_M(Q_{R_m} + R_{Q_M}) - g_M.(ELost(Q_R,\tau_M) - R_{Q_M}) - C_M(Q_{R_m} + R_{Q_M}) - \tau_M(Q_{R_m} + R_{Q_M}) - w_M Q_R \rightarrow \pi_M = w_M.(Q_{R_m} + R_{Q_M}) - g_M.\left(\mu - \left(\mu F(Q_R) - \sigma f\left(\frac{Q_R - \mu}{\sigma}\right)\right) + Q_R(1 - F(Q_R)) - R_{Q_M}\right) - C_M(Q_{R_m} + R_{Q_M}) - \tau_M(Q_{R_m} + R_{Q_M}) \rightarrow \pi_M = w_M.(Q_{R_m} + R_{Q_M}) - g_M.\left(\left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_M+1)}\right)\right) - \left(\left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_M+1)}\right)\right)F(Q_R) - \sigma f\left(\frac{Q_R - \left(\mu_0 + a\left(1 - \frac{1}{(0.5\tau_M+1)}\right)\right)}{\sigma}\right)\right) + Q_R(1 - F(Q_R)) - R_{Q_M}\right) - C_M(Q_{R_m} + R_{Q_M}) - \tau_M(Q_{R_m} + R_{Q_M}) \tag{31}$$

4. Model results and sensitivity analysis

In this section of the paper, a numerical example for testing the centralized models (cooperative contracts) have been considered. Table 3 present the numerical data for the parameters:

Table 3. Expected relations

μ_0	σ	a	P_R	w_M	C_M	c_R	S_R	S_M	g_R	g_M	B	r	δ	R_{Q_M}
0	1	30	30	20	12	2	10	9	14	8	15	24	0.201	29

Considering the models in the previous sections, the profit of the retailer and manufacturer is presented in Table 4. The profits are presented in US dollars, and eight conditions are considered, including buyback, three quantity flexibility conditions contract, and three APD conditions contracts.

Table 4. Supply chain members' profits in different conditions

Profit	Retailer	Manufacturer	SUM	SC profit ranking	Recommended to do it	profit-Retailer vs. Manufacturer
Buyback	1	12	13	8		R<S
Quantity flexibility cond.1	197	66	263	3	✓	R>S
Quantity flexibility cond.2	94	108	202	6		R<S
Quantity flexibility cond.3	2	4	5	9		R<S
APD contract cond.1	149	-120	28	7		R>S
APD contract cond.2	607	28	635	2	✓	R>S
APD contract cond.3	568	352	919	1	✓	R>S

As it is shown, quantity flexibility contracts are only offered in conditions 1 and APD contracts only in conditions 2 and 3. The reason for rejecting other cases is that the profit has decreased due to non-cooperation during the contract. Moreover, the profit and loss of the retailer and the manufacturer are presented in Figure 2.

Figure 2. Player's profit and loss in the supply chain

4.1. An analysis of the costs of social responsibility

Corporate social responsibility is one of the most important decision variables in this research. Table 5 shows the changes in SC profit in terms of changing social responsibility costs (investments), assuming other variables are constant.

Table 5. The analysis of the cost of social responsibility

Condition	τ=1	τ=3	τ=5	τ=7	τ=9	τ=15	τ=20
Buyback-Retailer	7	12	-13	-47	-86	-214	-326
Buyback- Manufacturer	61	40	-21	-95	-174	-420	-627
Quantity flexibility cond.1-Retailer	-8	156	227	266	290	327	340
Quantity flexibility cond.1- Manufacturer	62	75	53	19	-20	-147	-256
Quantity flexibility cond.2-Retailer	-184	39	134	186	219	267	283
Quantity flexibility cond.2- Manufacturer	209	140	77	15	-45	-221	-362
Quantity flexibility cond.3-Retailer	8	12	-13	-48	-88	-218	-330
Quantity flexibility cond.3- Manufacturer	51	31	-29	-101	-179	-423	-628
APD contract cond.1-Retailer	66	132	161	177	187	-218	210
APD contract cond.1- Manufacturer	-39	-80	-166	-266	-373	-423	-988
APD contract cond.2-Retailer	643	596	627	683	749	975	1173
APD contract cond.2- Manufacturer	11	38	12	-32	-84	-258	-411
APD contract cond.3-Retailer	872	638	511	420	346	164	35
APD contract cond.3- Manufacturer	486	408	290	160	24	-394	-744

The sensitivity analysis of this variable is also shown in Figure 3. The description of each of these images is summarized below. Note that the red color trend is for the manufacturer and blue for the retailer. The graphs demonstrate the behavior of profit ($) of players by the alternation of CSR (*Y*: Profit, *X*: CSR). Note that, τ as the cost of investment on corporate social responsibility could change in the values of 1, 3, 5, 7, 9, 15, and 20.

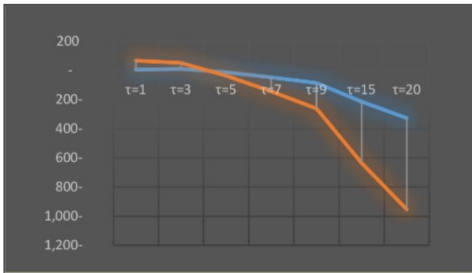

Figure 3(a)- Buyback

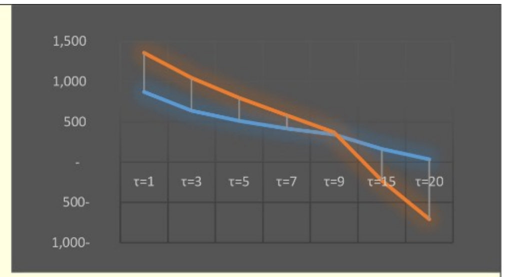

Figure 3(b)- APD contract cond.3

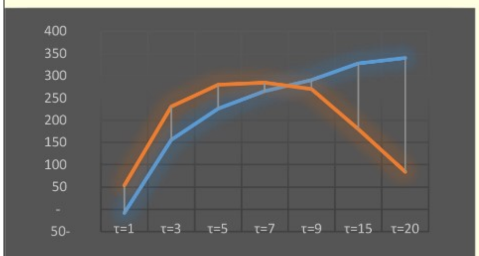

Figure 3(c)- Quantity flexibility cond.1

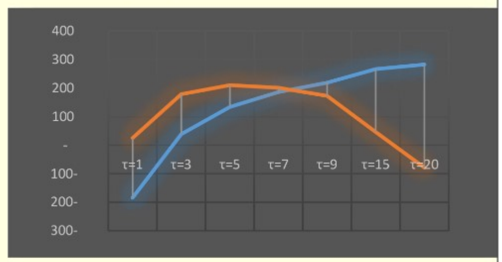

Figure 3(d)- Quantity flexibility cond.2

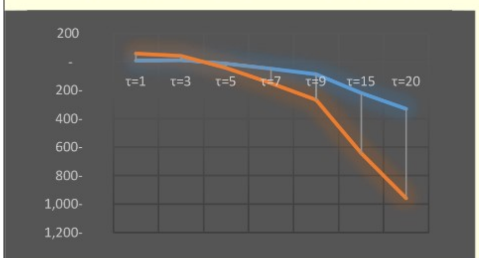

Figure 3(e)- Quantity flexibility cond.3

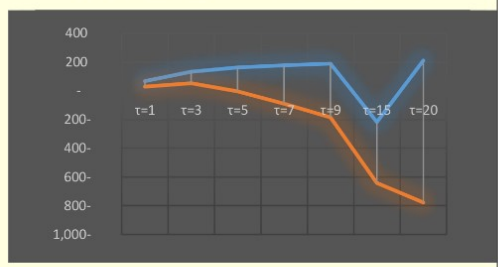

Figure 3(f)- APD contract cond.1

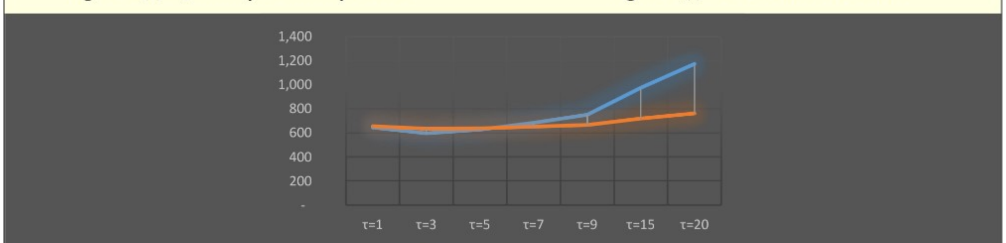

Figure 3(g)- APD contract cond.2

Note: Y-axis represents profit and X-axis represents CSR

Figure 3. Sensitivity analysis of corporate social responsibility

Based on 3(a), the trend of retailer profits is upward and for the manufacturer is upward and then downward. The manufacturer's sensitivity to social responsibility changes is more than the retailer's, and the trend is from the opposite direction. Based upon 3(c), both players are strongly susceptible to downward shifts in social responsibility, and the terms of this agreement result in loss. In 3(*f*), these conditions are only recommended for the manufacturer in the amounts of 2 and below. Based on 3(b), the above images show that in all cases except APD.COND2 the manufacturer's sensitivity to corporate social responsibility is more than the retailer and this sensitivity in Buyback, Quantity flexibility, and APD.COND3 is very intense and descending. Furthermore, in APD.COND.2, the upward trend of both SC members is incremental.

4.2. Sensitivity analysis of order quantity

The sensitivity analysis of retailers' order quantity is shown in Figure 4 and in Table 6. The descriptions of each of these images are summarized below.

Table 6. Sensitivity analysis of order quantity

Condition	Q=10	Q=20	Q=30	Q=40	Q=50	Q=100
Buyback-Retailer	-340	-135	61	-9	-79	-429
Buyback- Manufacturer	-200	-80	210	340	470	1120
Quantity flexibility cond.1-Retailer	4	196	112	16	-79	-559
Quantity flexibility cond.1- Manufacturer	32	64	96	128	160	320
Quantity flexibility cond.2-Retailer	-180	88	80	60	40	-60
Quantity flexibility cond.2- Manufacturer	183	113	43	-27	-97	-447
Quantity flexibility cond.3-Retailer	-340	-138	-60	-280	-500	-1,600
Quantity flexibility cond.3- Manufacturer	-200	-83	120	160	200	400
APD contract cond.1-Retailer	80	152	40	-80	-200	-800
APD contract cond.1- Manufacturer	-163	-123	-83	-43	-3	197
APD contract cond.2-Retailer	1304	874	184	-16	-216	-1,216
APD contract cond.2- Manufacturer	287	183	-83	-43	-3	197
APD contract cond.3-Retailer	522	436	502	282	62	-1,038
APD contract cond.3- Manufacturer	148	265	468	508	548	748

According to the information in Table 6, two members are more balanced and less sensitive to the increase of order quantity in APD.COND3 and both members are in the profitable zone. Note that, in Figure 4, the green color trend is for the manufacturer and blue for the retailer. The graphs demonstrate the behavior of profit ($) of players by the alternation of CSR (Y: Profit, X: Q). Note that Q as the order quantity could change in the values of 10, 20, 30, 40, 50, and 100.

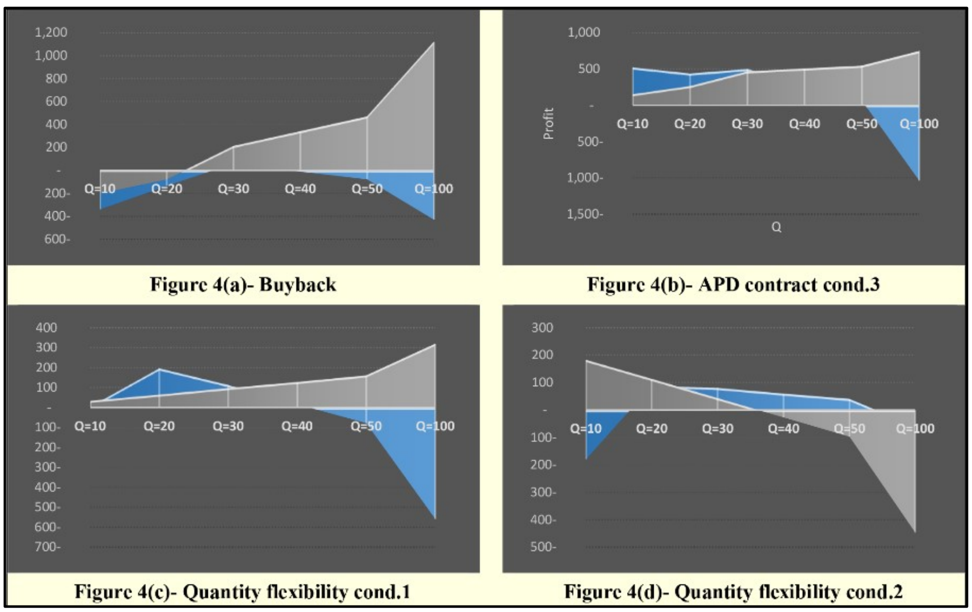

Figure 4(a)- Buyback

Figure 4(b)- APD contract cond.3

Figure 4(c)- Quantity flexibility cond.1

Figure 4(d)- Quantity flexibility cond.2

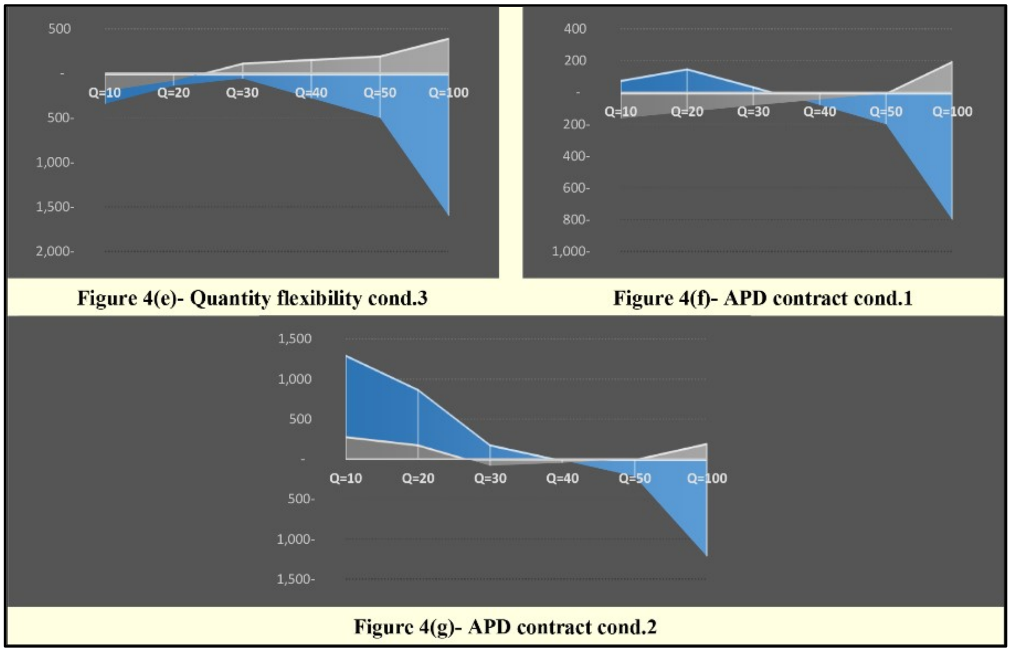

Figure 4(e)- Quantity flexibility cond.3

Figure 4(f)- APD contract cond.1

Figure 4(g)- APD contract cond.2

Figure 4. Sensitivity analysis of the quantity of order (Y: Profit-X: Q)

By Figure 4(a), the retailer is completely in a disadvantaged zone, and the profit of the manufacturer increases. Manufacturer sensitivity seems much more than a retailer. Retailer profits decrease as order increases, and manufacturers' profits increase as well. The sensitivity of both members appears to be equal. According to 4(b), after ordering 50, the centralized SC suffers loss; however, sensitivity to changes seems balanced. Considering 4(c), as order increases, retailer profits decrease, and manufacturers' profits increase as well. The sensitivity of both members appears to be equal. By 4(d), the retailer is mainly in profit mode, and the manufacturer's profit is decreasing. Manufacturer sensitivity seems much more than a retailer. By 4(e), the sensitivity of the retailer is greater than that of the manufacturer and only increases with the increase in profit order for the benefit of the manufacturer. As 4(f), the retailer's sensitivity is greater than that of the manufacturer and merely increases the order of profit for the benefit of the manufacturer and results in the loss of the retailer. Considering 4(g), the retailer's sensitivity is greater than the manufacturer and merely increases the order of profit for the benefit of the manufacturer and results in the loss of the retailer. Based on 4(b), both players have the same sensitivity and mainly benefits for them. According to the information in Figure 3, the two members are more balanced and less sensitive to the increase in the quantity of order under the terms of APD contract cond.,3 and both members are mainly in profit conditions.

4.3. Wholesale price sensitivity analysis

Figure 5 examines changes in SC members' profits with wholesale price changes. Note that the orange color trend is for the retailer and blue for the manufacturer. The graphs demonstrate the behavior of profit ($) of players by the alternation of the wholesale price (*Y*: Profit, *X*: *W*). Note that (*W*) as the order quantity could change in the values of 10, 15, 20, 25, 30, 40, and 100 ($).

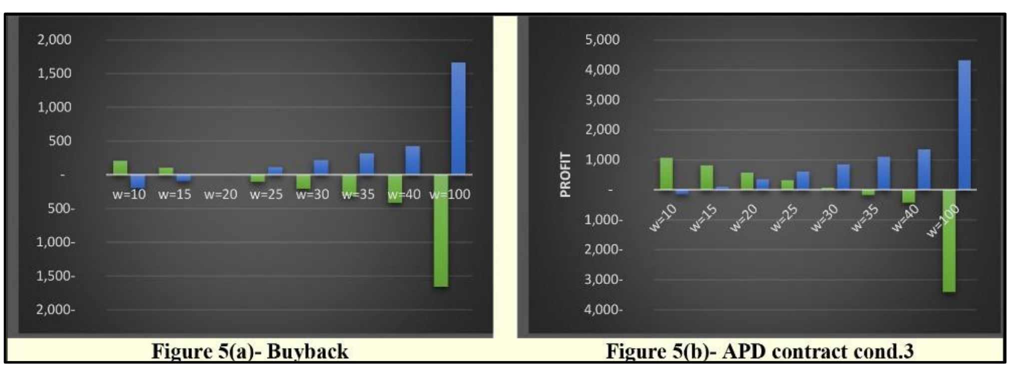

Figure 5(a)- Buyback

Figure 5(b)- APD contract cond.3

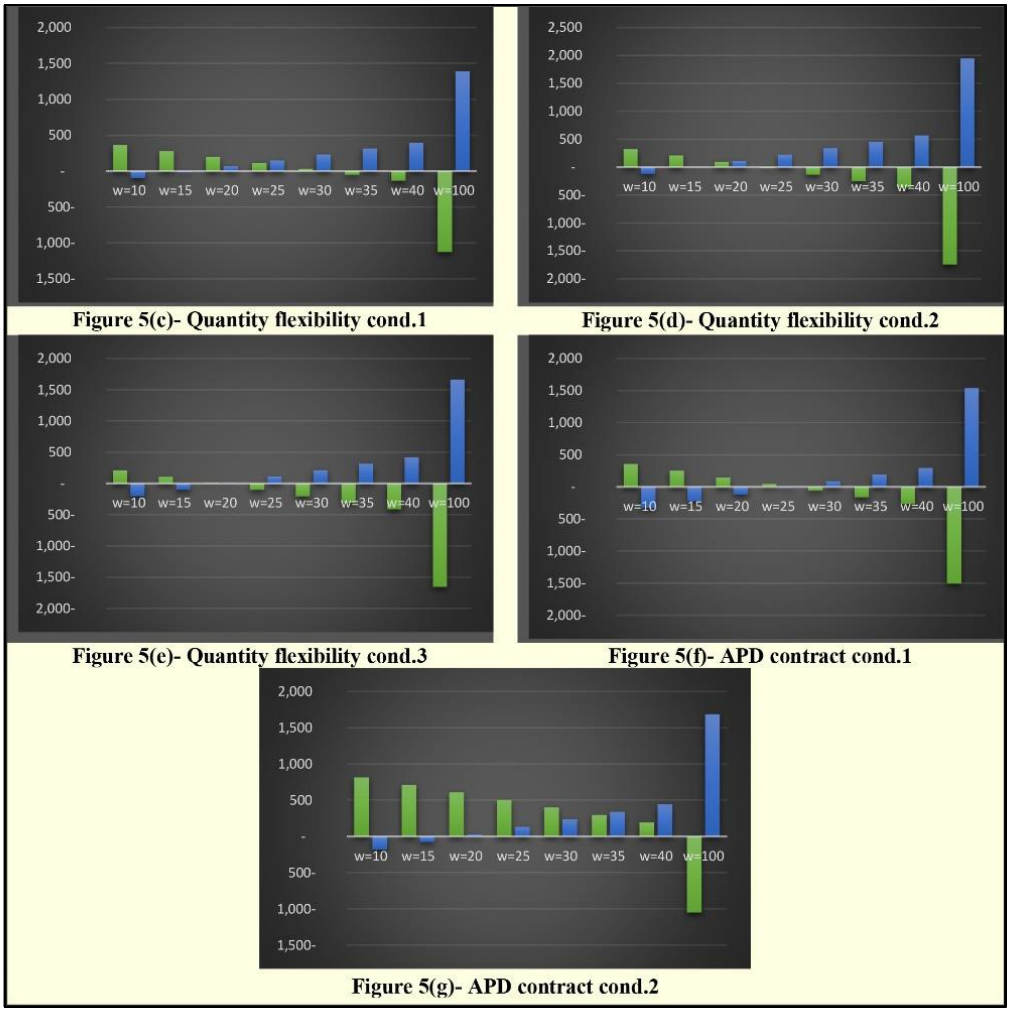

Figure 5. Price sensitivity analysis versus social responsibility investment (Y: Profit-X: W)

The results show that initially, at lower wholesale prices, the retailer will benefit and, by increasing the price, the manufacturer will benefit. The exception in APD.COND2 mode is that the retailer is profitable in most price terms and is less sensitive to price changes.

4.4. Comparison of standard and normal distributions

In this part of the research, in Table 7, the different conditions of the contracts are compared according to the different values of the standard normal distribution and the normal distribution. In this regard, three conditions are considered one for standard normal and two for normal distribution.

Table 7. Comparing seven scenarios on SC profitability

Conditions	Normal distribution (μ,σ)=(0,1)			Comparing the profit of players	A normal distribution (μ,σ)=(100,30)			Comparing the profit of players	A normal distribution (μ,σ)=(150,50)			Comparing the profit of players
	Retailer	Manufacturer	SUM		Retailer	Manufacturer	SUM		Retailer	Manufacturer	SUM	
Buyback	1	12	13	R<S	-642	223	-419	R<S	-1,113	365	-748	R<S
Quantity flexibility condition 1	197	66	263	R>S	2,185	453	2,638	R>S	3,170	659	3,828	R>S
Quantity flexibility condition 2	94	108	202	R<S	3,000	-739	2,262	R>S	4,473	-1,190	3,284	R>S
Quantity flexibility condition 3	2	4	5	R<S	-239	72	-167	R<S	-431	114	-317	R<S
APD contract condition 1	149	-120	28	R>S	796	364	1,160	R>S	1,091	621	1,712	R>S
APD contract condition 2	607	28	635	R>S	-564	1,292	728	R<S	-1,206	1,953	747	R<S
APD contract condition 3	568	352	919	R>S	-2,820	420	-2,401	R<S	-4,615	462	-4,153	R<S

The results indicate that quantity flexibility cond.1 and quantity flexibility cond.2 regardless of different values of mean and standard deviation are performable. Other cases are not recommended due to low profit. Furthermore, the results of both the normal and the standard normal distributions are only opposite in terms of accepting or rejecting flexibility cond.2, APD contract cond.2, APD contract cond.3; however, they are the same in other conditions.

5. Conclusion and future research directions

Coordinating an SC plays an important role in maximizing their overall profit. One of the coordination mechanisms is SC coordination contracts, which create conditions between SC members to share the profits of collaboration among the members. The study of SC contracts has attracted the attention of many researchers under stochastic environmental conditions and uncertainty. In this research, a single-period model of newsvendor sellers of the SC with one manufacturer and one retailer using two variables, including order quantity and cost of investment in corporate social responsibility, is considered. The demand is stochastic and has a normal and normal standard distribution. The models of this research are examined in a cooperative situation consisting of quantity flexibility, advanced purchasing discounts (APD), and buyback contracts.

Results indicate that in the APD contract, the retailer offers its pre-sales order quantity and is able to revive the higher demand order at a price per unit $r > P_{R_m}$ throughout the season. However, the number of units ordered during the period is limited to the beginning of the surplus inventory, represented by R_{Q_M}(Govindan et al., 2012). It is also assumed that if demand is low, the order quantity may be returned to the manufacturer's inventory. The retailer must necessarily meet the demand. Besides, in optimal conditions, the best contract in terms of profit increase in the SC is APD.COND3 because, in addition to increasing the total profits of the SC, it has led to an increase in the profits of individual members. APD.COND2 is the only contract that increases the profit and SC profits of each member with the same sensitivity for both players. Furthermore, in coordination contracts, there is no relationship between wholesale price changes and the cost of investing in social responsibility. In the standard normal and normal distributions, there were no alternations in the Q and τ values in any of the studied tests.

As previously indicated in the introduction and literature review section, the main contribution of this research was to consider (i) multiple decision variables (i.e., wholesale price, order quantity, and CSR indicator), (ii) several coordination contracts (i.e., APD, buyback and quantity flexibility), (iii) multiple uncertain demand functions (e.g., Normal) in an integrated fashion to investigate the impact of CSR indicator on the profitability of the members and the entire SC. This research aimed to design an inclusive model to satisfy the members' profit of a two-echelon supply chain and simultaneously encourage them to participate in social responsibility investments and efforts. Furthermore, to consider real-world circumstances, different scenarios, contracts, and demand distributions have been investigated.

In this research, a two-echelon SC consisting of one manufacturer and one retailer was studied. Including more members in each echelon, either manufacturer or retailer, might impact the SCs' efficiency, competition, pricing scenarios, social responsibility, complexity, and coordination mechanisms. For instance, the price and demand sensitivity and the competition significantly increase while more than one member is considered in each tier (e.g., Seyedhosseini et al., 2019). Moreover, the relationship quality and the collaboration level (i.e., manufacturer i with retailer j) negatively impact while the number of members increases in each echelon. As a result, the complexity of coordination increases (e.g., Chen et al., 2021).

On the other hand, as a result of competition, the diversity and quality of the products and the marketing and advertisement approaches improve while the number of manufacturers or retailers increases (Chakraborty et al., 2019). Notably, considering only two echelons and one member in each echelon is a limitation for this research. Scholars could investigate the impact of social responsibility indicators (i.e., forced labor in this research) for more advanced SCs. For instance, suppliers, distribution centers (DCs), logistic service providers (LSPs), whole-sellers, etc., are recommended for further examination. Moreover, in each echelon or level, more than one member is considered to comply with real-world cases.

After Table 1, the strength and weaknesses of the integrated approach were discussed. According to technical, mathematical, and statistical perspectives, this research considered three probabilistic distribution functions; however, other types of statistical distribution functions, including Gamma, Triangular, Poisson, etc., were not studied. Thus, in the future, it is recommended to investigate and benchmark other possible demand functions. Moreover, from the same perspective, stochastic demand and stochastic planning and optimization is recommendable while including CSR indicator. Also, from the game-theoretic perspective, this research included games with complete information (e.g., Nash and Stackelberg equilibrium); however, other game-theoretical approaches, including evolutionary games, signaling games, repetitive games, etc., have not been investigated. These approaches deal with time and incomplete information and reflect the real-world environment more accurately. In addition, some coordination contracts suitable for uncertain demand functions, such as revenue-sharing contracts, cost-sharing contracts, information-sharing contracts, risk-sharing contracts, etc., were not considered in this research. The mentioned contracts are popular while dealing with uncertain demand functions, as previous studies indicated (Mahdiraji et al., 2020).

From the CSR perspective, the efforts and investments in social responsibility were studied in this research. The objective was to minimize the total cost spent by the members of the SC. However, in the future, the benefits of CSR could be reflected in designing the models and studying how to maximize the positive impacts of CSR indicators on society, humans, and supply chains. Note that only two pillars of sustainability were included in the models of this research, and environmental sustainability was neglected. Hence, it is highly recommended to include this aspect in future investigations and make the designed model more inclusive toward SSC. In addition, this research has not included severe disruptions in SCs due to global pandemics such as COVID-19. Therefore in future studies, scholars can also focus on the impacts of global, political, environmental, etc., challenges on social responsibility investments by the SC members. Eventually, this research's integrated and inclusive approach was tested and analyzed via sensitivity analysis and numerical examples. However, it is recommended to employ the scheduled approach in real-world SCs with real numerical information and examine the reliability and robustness of the model in the future.

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