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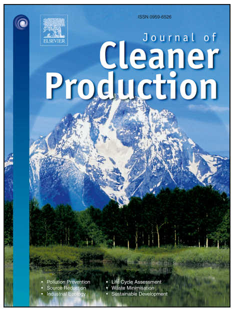

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Designing supply contracts for the sustainable supply chain using game theory

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Abstract

The importance of sustainable operations in supply chains has been widely recognised in practice and the extant literature. In this paper, we study coordination issues of a sustainable supply chain that arise due to simultaneous consideration of greening and corporate social responsibility (CSR) initiatives undertaken by supply chain agents. We specifically consider the scenario where the supplier is responsible for greening and the buyer is accountable for social responsibility. We analyse our model using two-stage Stackelberg game-theoretic approach where the supplier acts as a Stackelberg leader. In this context, we analyse the decentralised supply chain setting using five different contract types, namely wholesale price, linear two-part tariff (LTT), greening-cost sharing, revenue sharing, and revenue and greening-cost sharing contracts. We demonstrate how optimal greening level, CSR level, retail price and profits of supply chain agents are influenced by different contract types. Our analytical results show that greening and social efforts undertaken by supply chain agents are beneficial for the overall supply chain as long as consumer awareness towards greening and CSR exists. Our results show that channel coordinating mechanisms between supplier and buyer is conducive to improve greening and CSR level. LTT perfectly coordinates the supply chain. Through a numerical example with several key parameters we present the effectiveness of different contracts. The results reveal that as a profit maximising agent the supplier prefers LTT contract and the buyer prefers RGCS contract. This paper extends the understanding of supply chain coordination in the context of sustainability.

Keywords: sustainable supply chain; Stackelberg game; coordination; greening-cost sharing; revenue and greening-cost sharing

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1. Introduction

Sustainable supply chain management (SSCM) seeks to integrate economic, environmental, and social aspects in a supply chain (SC) (The Economist, 2009; Elkington, 1998). In recent times, SSCM is gaining attention among scholars and practitioners alike (Babbar et al., 2017; Lee and Tang, 2017). A practitioner's inclination towards SSCM is primarily due to regulatory pressures, increasing customer awareness, and mounting pressure from various stakeholders. A recent study conducted jointly by the World Economic Forum[1] and Accenture reveals that simultaneous adoption of socio-environmental and economic aspects in an organisation increases her revenue by 5-20%, brand value by 15-30% while at the same time greenhouse emissions can be reduced by 13-22 %. Many global firms such as Alcoa, PepsiCo, General Electric, Ford Motor Company, Nike, Exelon, PG&E, Starbuck's, Johnson & Johnson and Walmart are implementing sustainable practices in their supply chains[2]. Wal-Mart has partnered with Patagonia for developing eco-friendly products in order to turn her business '*Green*' (Burke, 2010). It is also putting corporate social responsibility (CSR) efforts to make its business more socially responsible[3]. Similarly, world's largest retail chain of natural and organic foods *Whole Foods Market (WFM)* is putting effort in CSR while insisting on its suppliers for putting effort in greening (Ma X, 2017). In another example, the beverages giant PepsiCo announced 2025 Sustainability Agenda designed to focus on the environment, health, and social issues across her supply chain. PepsiCo mandates her suppliers to implement green technology to reduce the carbon footprint[4] . In India many NGOs, trade organisations, and local population have accused PepsiCo of wasting groundwater, leading to its depletion. In order to address this concern of local stakeholders, PepsiCo has initiated several projects on water conservation and waste management under her CSR activities (Das, 2016). In this particular case, we observe that a firm allocates greening responsibilities to her upstream partners and she takes up the downstream responsibilities of CSR.

Our problem is specifically motivated by above examples where an upstream firm (either a supplier or a manufacturer) undertakes greening effort while a downstream firm (either a buyer or a

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[1]How to create sustainable supply chains | World Economic Forum [WWW Document], 2015. URL https://www.weforum.org/agenda/2015/03/how-to-create-sustainable-supply-chains (accessed 9.15.17).
[2]Best practices in sustainability: Ford, Starbucks and more | Guardian Sustainable Business | The Guardian [WWW Document], 2014. URL https://www.theguardian.com/sustainable-business/blog/best-practices-sustainability-us-corporations-ceres (accessed 9.10.17)
[3]Makower, J. (2015, November 17). Walmart sustainability at 10: An assessment. Retrieved from: https://www.greenbiz.com/article/walmart-sustainability-10-assessment, accessed on 11/01/2017.
[4]PepsiCo Launches 2025 Sustainability Agenda Designed to Meet Changing Consumer and Societal Needs | PepsiCo.com [WWW Document], 2016. URL http://www.pepsico.com/live/pressrelease/pepsico-launches-2025-sustainability-agenda-designed-to-meet-changing-consumer-a10172016 (accessed 8.20.17).

retailer) put efforts in CSR. Both players (supplier or buyer) may put these sustainable efforts simultaneously. However, the cases of suppliers undertaking greening effort and buyer putting CSR effort are more prevalent in practice (Ghosh and Shah, 2015, 2012; Ma P et al., 2017). We can intuitively understand that as most of the manufacturing activities are carried out by upstream firms, the supplier/manufacturer is more suited for exerting greening effort in order to reduce environmental impact of production. On the other hand, the downstream firms (buyer/retailer) are more likely to face the public directly. Therefore, the buyer tends to put more efforts on CSR to position herself as a socially responsible agent. Recent studies have indicated that green technology related investment is one of the major barriers in the implementation of sustainability (Esfahbodi et al., 2016; Jayaram and Avittathur, 2015). Moreover, manufacturing firms are only willing to adopt green technology or CSR activities if they enhance their profitability. This could be possible only if firms benefit from their sustainable image (Yang et al., 2017). Fortunately, customer awareness regarding sustainability has increased manifold in recent times and consumers are now willing to pay more for sustainable products. A recent survey conducted by Nielson[5] across 60 countries reveals that 55% of the respondents are willing to pay a premium for products and services which are committed towards positive greening and social efforts.

The above discussions on sustainable business practices raise the following research questions: (i) How an analytical model can be framed by simultaneous consideration of greening, social and economic aspects? (ii) Is it possible to design a channel coordination mechanism? (iii) Do supply chain agents benefit from these mechanism? In order to answer these questions, we apply two-stage game theoretic approach by investigating a dyadic SC consisting of one supplier (he) and one buyer (she). We consider both firms to be risk neutral in nature. In this setup, the supplier puts greening efforts and the buyer puts CSR efforts. The supplier and the buyer incur costs against greening and CSR efforts respectively. We consider that demand faced by the buyer is deterministic and positively influenced by greening and CSR efforts. We discuss five types of contracts: wholesale price (WP), linear two-part tariff (LTT), revenue sharing (RS), greening-cost sharing (GCS), and revenue and greening cost sharing (RGCS). We first consider the simplest possible contract form, that is, the WP contract. Though WP contract always leads to a suboptimal solution for the overall supply chain, still it remains one of the most prevalent contracts in practice (Corbett et al., 2004; Biswas et al., 2016). Subsequently, we have considered four different contracts. First, we have considered classical channel coordinating contracts, namely LTT and RS, and have investigated their effectiveness in the context of SSCM. In recent literature many scholars have considered sustainability specific contracts forms such as GCS and RS (Dong et al., 2016; Ghosh and

[5] The Sustainability Imperative [WWW Document], 2015. URL: http://www.nielsen.com/in/en/insights/reports/2015/the-sustainability-imperative.html (accessed 9.20.17).

Shah 2015; Yang & Chen, 2017). We have designed a hybrid contract RGCS and have compared the same with GCS and RS. Thus, our analysis covers investigation into classical as well as sustainability specific contracts by simultaneous consideration of greening and CSR efforts. Other contracts such as buyback contract and sales rebate are more popular for stochastic demand setting and markdown money is generally used for modelling risk averse supply chain agents (Dong et al., 2016; Shen et al., 2013). Hence, we have not considered these contracts for our analysis.

Our work contributes to the extant literature in several ways. First, we develop an analytical model by simultaneous consideration of economic, environmental, and social dimensions which so far has not been studied (Ansari & Kant, 2017; Reefke & Sundaram, 2017). Secondly, we investigate five different contracts and propose a coordination mechanism. Finally, we investigate one sustainability specific contract, RGCS, and comment upon its effectiveness.

The remainder of the paper is organised as follows: in Section 2, we review the related literature. We describe the problem setting and benchmark solution in Section 3. In Section 4, we discuss the results and their managerial implications for five different supply contracts for a decentralized sustainable SC. In Section 5, we present the results of a numerical example to illustrate the behaviour of optimal objective functions of different SC agents. Finally, we present conclusion in Section 6.

2. Related literature

In this section, we review related literature. First we review the related literature of sustainable supply chain. Subsequently, we review the extant literature on different channel coordination mechanisms for SSCM.

2.1. Sustainable supply chains

Taxonomical classification and detailed literature reviews of SSCM have been carried out by various scholars (Ansari & Kant, 2017; Ashby et al., 2012; Brandenburg et al., 2014; Rajeev et al., 2017). Majority of these reviews suggest that analytical modelling has been given less attention. As per Ashby et al. (2012), less than 25% surveys papers used quantitative techniques in SSCM. Reefke & Sundaram (2017) argue that simultaneous consideration of all the three dimensions in the analytical models is a challenge and is required to be investigated.

Majority of papers consider only economic aspect in analytical models while a few studies have additionally considered only environmental or greening aspect in their analytical models. Ghosh & Shah (2012, 2015) have analysed a dyadic green supply chain using game theoretic approach. Authors have shown how SC agents decide their decision variables when only the supplier puts greening effort in the supply chain. Swami & Shah (2013) examine firms' performances when both of them can exert greening effort. Recently, a few scholars have analysed dyadic green supply chain by considering carbon emission sensitive demand (Chen et al., 2017; Ma X et al., 2017; Xu et al., 2017). They have explored the impact of cap-and-trade regulations on SC. Zhu and He (2017) have extended the green supply chain model to a green supply chain network consisting of one manufacturer and two suppliers and have explored the impact on greenness due to competition between suppliers.

None of the aforementioned studies considers social impact in their analytical models and its influence on SC coordination. In recent past, some scholars (Bian et al., 2016; Hsueh, 2014 & 2015 ; Modak et al., 2014 ; Modak et al., 2016; Panda, 2014; Panda et al., 2015; Panda et al., 2017; Ni et al., 2010; Ni and Li, 2012) have analysed analytical models of socially responsible SC. Two different approaches have been adopted to incorporate social aspect in the SC models in extant literature. Few scholars (Bian et al., 2016; Modak et al., 2014; Modak et al., 2016; Panda, 2014; Panda et al., 2015; Panda et al., 2017) have examined social dimension in the form of consumer surplus. Others (Ma, P et al., 2017; Ni et al., 2010; Ni and Li, 2012; Hsueh, 2014 & 2015) have incorporated the social dimension as efforts put by SC agents. Ni and Li (2012) have analysed a dyadic supply chain under CSR aspect using simultaneous and sequential move games. Hsueh (2015) and Panda et al. (2015) have extended these models to three tier SC and have examined the optimal choices of SC agents. More recently, Panda et al. (2017) have explored the impact of CSR on closed-loop supply chain in a manufacturer-retailer setup. All these studies have considered only the social aspect in their model and its influence on SC coordination. They have not incorporated the influence of greening in their work.

In this paper we have considered greening and CSR along with economic dimension. Thus, we have incorporated all the three dimensions of sustainability in our analytical model. Our study is closely related to Ghosh & Shah (2012, 2015) and Panda et al. (2017) who have respectively examined the impact of greening and CSR on SC coordination. Our study differs from these scholars as we consider simultaneous treatment of greening and CSR in our model and the same is so far unreported in the extant literature.

2.2. Channel coordination mechanisms

Our work is closely related to the extant literature on SC coordination through supply contracts. Supply contract is one of the important tools to coordinate the supply chain (Tirole, 1988). Several contracts have been extensively studied in the traditional profit maximising SC literature such as WP contract (Corbett et al., 2004), LTT contract (Biswas et al., 2016), RS contract (Cachon and Lariviere, 2005), CS contract (Bhaskaran and Krishnan, 2009), buyback contract (Xiao et al., 2010), channel rebate contract (Taylor, 2002), and markdown money contract (Shen et al., 2013). In practice, WP contract is prevalent due to its simplistic structure, though it does not coordinate the SC. However, it serves as the lower bound for comparison with other coordinating contracts. LTT is one of the most efficient contracts from a supplier's perspective in order to extract the entire profit from the buyer (Tirole, 1988; Corbett et al., 2004). RS is a more flexible contract than LTT since as it distributes the revenue earned between the supplier and the buyer (Cachon and Lariviere, 2005). Some authors have suggested that CS contract is preferable over other contract types as high investment is required to start greening projects (Bhaskaran & Krishnan, 2009; Xu et al., 2017). For instance, in 2012, Terry Gou, founder and chairman of Foxconn, announced that Foxconn and Apple will share the initial cost of developing sustainable practices.

Discussion on coordination mechanism in SSCM context is scarce. A mechanism is said to be a channel coordinating one if it allows the decision parameters of a decentralised SC to be at par with those of a centralised SC (Biswas et al., 2016; Corbett et al., 2004). Therefore, a decentralised sustainable SC is said to be coordinated if the equilibrium values of greening level, CSR level, and order quantity match with those of a centralised sustainable SC. Few authors have analysed application of classical channel coordination mechanism such as LTT (Chen et al., 2017; Ghosh & Shah, 2012; Swami & Shah, 2013; Xu et al., 2017), RS (Song and Gao, 2018), CS (Ghosh & Shah, 2015; Yenipazarli, A, 2017; Xu et al., 2017) in the context of green SC. Similarly, other scholars have explored similar coordination mechanisms, namely LTT (Ma, P et al., 2017) and RS (Hsueh, 2014; Modak et al., 2016; Panda, 2014; Panda et al., 2017), in the context of socially responsible SC. The aforementioned studies have considered one dimension of sustainability (either greening or social responsiveness) in their model along with economic incentive. Simultaneous treatment of consideration of economic, environmental and social aspects through a common analytical model is absent in the extant literature. In this paper, we attempt to address this gap in the literature and develop optimal solution mechanism for a sustainable SC by considering five different types of contracts namely, WP, LTT, RS, GCS, and RGCS. In Table 1, we provide a summary of the reviewed literature in the context of SSCM literature which clearly indicates our contribution.

Table 1 : Summary of the Literature Review

Papers	**Supply contracts**	**Agent(s) put effort in**	**Objective Function**	**Demand is a function of**
Bian et al., (2016)	-		$\pi + CSR$	RP+ PD
Chen et al., (2017)	WP+LTT	G	$\pi + G$	RP + CE
Ghosh & Shah (2012,2015)	WP+LTT+CS	G	$\pi + G$	RP+ G
Hsueh (2014)	RS	CSR	$\pi + CSR$	RP +CSR
Hsueh (2015)	-	CSR	$\pi + CSR$	RP +GCS
Ma,P et al.(2017)	WP+LTT	CSR	$\pi + CSR$	RP +CSR +ME
Modak et al. (2014)	QD	CSR	$\pi + CSR$	RP
Modak et al. (2016); Panda (2014)	RS	CSR	$\pi + CSR$	RP

Panda et al. (2015)	CB	CSR	$\pi + CSR$	RP
Panda et al. (2017)	RS	CSR	$\pi + CSR$	RP
Ni et al. (2010)	WP	CSR	$\pi + CSR$	RP +CSR
Ni and Li (2012)	-	CSR	$\pi + CSR$	RP +CSR
Swami & Shah (2013)	WP+LTT	G	$\pi + G$	RP + G
Song and Gao (2018)	RS	G	$\pi + G$	RP + G
Xu et al. (2017)	WP+LTT+CS	G	$\pi + G$	RP + CE
Zhu and He, 2017	-	G	$\pi + G$	RP + G
Yenipazarli, 2017	WP+CS+RS	G	$\pi + G$	RP +G
Our Paper	**WP+LTT+GCS+RS +RGCS**	**G+CSR**	$\pi + G + CSR$	**RP +CSR+ G**

Note: **CB:** Contract Bargaining**;** **CS**: Cost sharing; **CE**: Carbon Emission; **CSR**: Corporate Social Responsibility; **G**:Greening; **RP**: Retail Price; **RGCS :** Revenue and greening-cost sharing; **ME**: Marketing Effort; π **:** Profit; **PD**: Product Differentiation; **QD**: Quantity Discount

3. Model formulation

We consider a two-echelon SC consisting of two risk-neutral agents: a supplier (he) and a buyer (she). The buyer procures either raw material or semi-finished product from the supplier. Subsequently, she produces a finished product and sells it in the final product market. We assume that the consumers are sensitive towards environment friendly characteristic of a product as well as CSR efforts put by SC agents. We consider a deterministic linear demand function faced by a buyer in the market as follows: $q = a - bp + \alpha_G \theta + \alpha_S y \left(a, b, \alpha_G, \alpha_S > 0\right)$ where, a is overall market potential, b is own-price sensitivity, p is retail price, q is order quantity, θ is greening level, y is corporate social responsibility (CSR) level, α_G and α_S are consumer sensitivity to greening and CSR levels respectively. Assumption of linear demand function allows us to formalize the market reaction with expositional simplicity (Banker et al., 1998; Chen et al., 2017; Choi, 1991; Corbett et al., 2004) and also provides us with tractable results to enable analytical comparisons across different cases (Corbett et al., 2004; Ji et al., 2017; Jamali and Rasti-Barzoki, 2018). From the demand function, we can observe that it decreases in retail price and increases in both greening and CSR levels.

The marginal costs of production for supplier and buyer are represented by s and c respectively. We assume that the supplier puts greening effort to produce green products and the buyer puts CSR effort in a decentralised supply chain. We further assume that: (i) cost of greening is nonlinearly increasing in θ and it is represented by $I_G \theta^2$ where $I_G (> 0)$ is greening investment parameter, (ii) cost of CSR is also nonlinearly increasing in y and it is represented by $I_S y^2$ where $I_S(>0)$ is CSR investment parameter. Assumption of cost nonlinearity represents the diminishing rate of returns for greening and CSR related activities.

At the beginning of the period, the supplier moves first, chooses her contract type and corresponding parameter(s), and greening level (θ) for the product. Subsequently, the buyer announces her order quantity (q) and chooses her CSR level (y). The buyer pays the supplier through the relevant transfer payment function. In WP contract, transfer payment function is: $T(w,q)=wq$, where w is the per-unit wholesale price. In LTT contract, transfer payment function is: $T(w,L,q)=wq+L.1_{[q>0]}$, where $1_{[q>0]}$ is a characteristic function and it is defined as: $1_{[q>0]}=[1\ if\ \ q>0;\ 0\ otherwise\ ]$, w is the per-unit price, and L is franchise fee. Transfer payment function for RS contract is: $T(w,k,q)=(1-k)(pq)+wq$, where k represents the fraction of revenue retained by buyer. In GCS contract, the buyer shares ψ proportion of greening cost and transfer payment function is: $T(w,\psi,q)=wq+\psi I_G\theta^2$. Similarly, the transfer payment function for RGCS contract is given by: $T(w,k,\psi,q)=(1-k)(pq)+wq+\psi I_G\theta^2$. The generalised optimisation problem for the supplier can be formulated as follows:

$$\max_{w,\theta} \pi_S(\cdot)=\max_{w,\theta}\{(1-k)pq+(w-s)q-(1-\psi)I_G\theta^2+L\} \tag{1}$$

$$s.t.\quad q=\underset{q,y,\psi,k,L}{\operatorname{argmax}}\pi_B(\cdot)=\{kp-(w+c)\}q-L-I_Sy^2-\psi I_G\theta^2\geq\bar{\pi}_B \tag{2}$$

$$\pi_S(\cdot)=(1-k)pq+(w-s)q-(1-\psi)I_G\theta^2+L\geq\bar{\pi}_S \tag{3}$$

$$q=a-bp+\alpha_G\theta+\alpha_S y \tag{4}$$

In (1) – (3), π_S and π_B are profits of supplier and buyer respectively; their reservation profits are given by $\bar{\pi}_S$ and $\bar{\pi}_B$. Incentive compatibility constraint of the buyer is represented by equality condition of (2). Individual rationality constraint of the supplier is given by (3) and that of the buyer is represented by the inequality condition of (2). All five contract types are represented by these special cases of the aforementioned generalized optimization problem: (a) $k=1, L=0$, and $\psi=0$ give WP contract; (b) $k=1, L\neq 0$, and $\psi=0$ represent LTT contract; (c) $0<k<1$, $L=0$, and $\psi=0$ give RS contract; (d)

$k = 1, L = 0$, and $0 < \psi < 1$ represent GCS contract; and (e) $0 < k < 1, L = 0$, and $0 < \psi < 1$ give RGCS contract. All relevant notations used in this paper are presented in Table 2.

Table 2: Notations Used

	Notations	Meaning/ Explanation
Decision variables	p	Unit selling price of the buyer
	q	Order quantity
	θ	Product greening improvement level
	y	CSR improvement level
	w	Per unit price
	L	Franchise fee
	k	Revenue sharing ratio
	ψ	Greening-cost sharing ratio
	π_S	Supplier's profit
	π_B	Buyer's profit
	π_C	Supply chain profit in centralised case
	π_{SC}	Total supply chain profit in decentralised case
Demand parameters	a	Market potential
	b	Consumer sensitivity to price
	α_G	Consumer sensitivity to greening
	α_S	Consumer sensitivity to CSR
Cost parameters	c	Buyer's marginal cost
	s	Supplier's marginal cost
	I_G	Supplier's greening investment cost
	I_S	Buyer's CSR investment cost
Subscript	WP	Wholesale price contract
	LTT	Linear two-part tariff contract
	GCS	Greening-cost sharing contract
	RS	Revenue Sharing contract
	$RGCS$	Revenue and greening-cost sharing contract

The optimal price, order quantity, greening level, CSR level, contract parameter(s) calculations are presented in the supplementary Appendix, which appears as an online companion of the paper. In the next section, we analyse the case of centralised SC that serves the purpose of benchmark solution for our subsequent analysis.

3.1 Centralized supply chain

In this section, we review the case of centralised SC. In a centralised system, the supplier and the buyer are vertically integrated. In this setup, all relevant decisions are taken by a central planner who possesses all the relevant information. The central planner decides the optimal retail price, order quantity, greening level, and CSR level for the entire SC. A centralised SC is devoid of double marginalisation problem and allows both SC agents to align their objectives perfectly. As a result, all equilibrium decisions of a centralised SC are globally optimised and they serve the purpose of benchmark solution for our subsequent analyses (Biswas et al., 2016; Nematollahi et al., 2017; Panda et al., 2017). The optimisation problem of the central planner is given by (5).

$$\max_{p,\theta,y} \pi_C(\cdot) = \{p-(s+c)\}q - I_G\theta^2 - I_S y^2 \tag{5}$$

From the Hessian matrix of (5), we can derive the condition for joint concavity of $\pi_C(\cdot)$ in (p,θ,y) and the same is presented in Proposition 1. Under the condition of joint concavity, we also calculate the optimal retail price, order quantity, greening level, CSR level, and total profit. These optimal results are presented below.

Proposition 1. *The central planner's profit function* $\pi_C(p,\theta,y)$ *is jointly concave in* (p,θ,y) *when* $0<\alpha_G^2/I_G+\alpha_S^2/I_S<4b$, *her optimal retail price is:* $p_C^* = (s+c)+2I_G I_S N_C/D_C$, *order quantity is:* $q_C^* = 2bI_S I_G N_C/D_C$, *greening level is:* $\theta_C^* = \alpha_S I_G N_C/D_C$, *CSR level is:* $y_C^* = \alpha_G I_S N_C/D_C$, *and total profit is:* $\pi_C^* = I_G I_S N_C^2/D_C$, *where* $N_C = a-b(s+c)$ *and* $D_C = 4bI_G I_S - (I_S\alpha_G^2 + I_G\alpha_S^2)$

From Proposition 1 we obtain the joint concavity condition for the profit function. The same is presented by: $0<\alpha_G^2/I_G+\alpha_S^2/I_S<4b$. In this condition, the expression $\alpha_G^2/I_G+\alpha_S^2/I_S$ signifies overall sustainability effort exerted by the SC. If the SC tends to focus only on greening then $\alpha_S \to 0$ and $\alpha_G \neq 0$. Under such circumstances the sustainability effort should satisfy the following condition so that the profit function remain concave in retail price and greening effort: $0<\lim_{\alpha_S\to 0}\left(\alpha_G^2/I_G+\alpha_S^2/I_S\right)<4b \Rightarrow 0<\alpha_G^2/I_G<4b$. This particular case is reported in the extant literature of greening SC (Ghosh and Shah 2012). On the other hand, if the SC tends to focus only on CSR then $\alpha_G \to 0$ and $\alpha_S \neq 0$. Under such circumstances the sustainability effort should satisfy the following condition so that the profit function remain concave in retail price and CSR effort: $0<\lim_{\alpha_G\to 0}\left(\alpha_G^2/I_G+\alpha_S^2/I_S\right)<4b \Rightarrow 0<\alpha_S^2/I_S<4b$. Thus, when a SC focuses on both greening and

CSR activities, then the aforementioned condition provides a generalized case for sustainability effort. It also provides the feasibility condition for the subsequent analysis of supply contracts. This generalized concavity condition signifies that though the optimal order quantity increses in both greening level and CSR level, but high investment on both of them would not lead to better firm performance; and the overall upper limit of investment is designated by the given condition. From the expression, we can also observe that this optimal investment is simultaneously dependent on consumer sensitivities and investment parameters. We can observe that centralised system orders more, earns more profit, sets higher greening level and CSR level with a higher α_G and α_S which is consistent with our intuition and corroborates with the literature (Ghosh and Shah 2012). On the other hand, higher investment in greening and CSR negatively impacts the profitability of a firm. This is precisely the reason why many firms show resistance to implement greening and CSR in practice. Moreover, the profit of a sustainable centralised SC is higher than that of its profit-only counterpart: $I_G I_S N_C^2 / D_C > \lim_{\substack{\alpha_G \to 0 \\ \alpha_S \to 0}} \left(I_G I_S N_C^2 / D_C \right) = N_C^2 / 4b$. From this observation, we can state that if the consumers are willing to pay higher for sustainable products and socially responsible operations, then manufacturing greener products and putting CSR effort is beneficial for the SC.

The generalizability of Proposition 1 can be understood from the following: If market demand is not influenced by CSR, then we have: $\alpha_S \to 0$ and $\alpha_G \neq 0$, and the SC turns into an *only* green SC. Under such circumstances, from Proposition 1, we can calculate optimal values for a centralised green supply chain as follows: (i) CSR level: $\lim_{\alpha_S \to 0} y_C^* = 0$, (ii) retail price: $\lim_{\alpha_S \to 0} p_C^* = (s+c) + 2I_G N_C / \left(4bI_G - \alpha_G^2\right)$, (iii) order quantity: $\lim_{\alpha_S \to 0} q_C^* = 2bI_G N_C / \left(4bI_G - \alpha_G^2\right)$, (iv) greening level: $\lim_{\alpha_S \to 0} \theta_C^* = \alpha_G N_C / \left(4bI_G - \alpha_G^2\right)$, and (v) centralised supply chain profit: $\lim_{\alpha_S \to 0} \pi_C^* = I_G N_C^2 / \left(4bI_G - \alpha_G^2\right)$. If market demand is not influenced by greening effort, then we have: $\alpha_G \to 0$ and $\alpha_S \neq 0$, and the SC turns into an *only* CSR SC. Under such circumstances, from Proposition 1 we can calculate optimal values for a centralised CSR supply chain as follows: (i) green level: $\lim_{\alpha_G \to 0} \theta_C^* = 0$, (ii) retail price: $\lim_{\alpha_G \to 0} p_C^* = (s+c) + 2I_S N_C / \left(4bI_S - \alpha_S^2\right)$, (iii) order quantity: $\lim_{\alpha_G \to 0} q_C^* = 2bI_S N_C / \left(4bI_S - \alpha_S^2\right)$, (iv) CSR level: $\lim_{\alpha_G \to 0} y_C^* = \alpha_S N_C / \left(4bI_S - \alpha_S^2\right)$, and (v) centralised supply chain profit: $\lim_{\alpha_G \to 0} \pi_C^* = I_S N_C^2 / \left(4bI_S - \alpha_S^2\right)$. If market demand is not influenced by either greening effort or CSR effort, then we have: $\alpha_G \to 0$ and $\alpha_S \to 0$, and the SC turns into an *only* profit SC. Under such circumstances, from Proposition 1 we can calculate optimal values for a centralised profit only supply chain as follows: (i) green level: $\lim_{\substack{\alpha_G \to 0 \\ \alpha_S \to 0}} \theta_C^* = 0$, (ii) CSR level: $\lim_{\substack{\alpha_G \to 0 \\ \alpha_S \to 0}} y_C^* = 0$, (iii) retail price: $\lim_{\substack{\alpha_G \to 0 \\ \alpha_S \to 0}} p_C^* = (s+c) + N_C/2b$, (iv) order quantity: $\lim_{\substack{\alpha_G \to 0 \\ \alpha_S \to 0}} q_C^* = N_C/2$, and (v) centralised supply chain profit: $\lim_{\substack{\alpha_G \to 0 \\ \alpha_S \to 0}} \pi_C^* = N_C^2/4b$.

4. Results and Discussions

In this section, we discuss the optimal results and their implications for five different supply contracts in decentralised SC setting using generalised optimisation problem as presented by (1) – (4). In this scenario, supplier and buyer make their decisions separately. The equilibrium retail prices, order quantities, greening level, CSR level, profits, and contract forms for these five contracts are compared. The comparison of results helps us to understand how green investment parameter, CSR investment parameter, consumer sensitivity towards greening and CSR affect various optimal SC parameters. To facilitate this discussion, we also present a numerical analysis at the end of the section.

4.1 Wholesale price (WP) contract

In a WP contract, the supplier first sets the wholesale price and the greening level. Subsequently, the buyer announces her order quantity or retail price and her CSR level. The supplier acts as a Stackelberg leader. We use backward induction method to solve this sequential move game. The optimal results for WP contract are presented in Proposition 2.

Proposition 2. *When the supplier trades with the buyer through WP contract, the optimal decision parameters are as follows: (i) retail price is:* $p_{WP}^* = I_G(D + 2I_S b)N_C / b(2DI_G - I_S\alpha_G^2) + c + s$, *(ii) order quantity is:* $q_{WP}^* = 2DI_S I_G N_C / (2DI_G - I_S\alpha_G^2)$, *(iii) greening level is:* $\theta_{WP}^* = I_S\alpha_G N_C / (2DI_G - I_S\alpha_G^2)$, *(iv) CSR level is:* $y_{WP}^* = I_G\alpha_C N_C / (2DI_G - I_C\alpha_G^2)$, *(v) wholesale price is* $: w_{WP}^* = DI_G N_C / b(2DI_G - I_S\alpha_G^2) + s$, *(vi) supplier's profit is:* $[\pi_S^*]_{WP} = I_G I_S N_C^2 / (2DI_G - I_S\alpha_G^2)$ *,(vii) buyer's profit is:* $[\pi_B^*]_{WP} = DI_G^2 I_S N_C^2 / (2DI_G - I_S\alpha_G^2)^2$, *and (viii) total supply chain profit is :* $[\pi_{SC}^*]_{WP} = I_G I_C (3I_G D - I_C\alpha_G^2) N_C^2 / (2DI_G - I_C\alpha_G^2)^2$, *where (a)* $N_C = a - b(s+c)$ *and (b)* $D = 4I_S b - \alpha_S^2$.

By simple algebraic calculations, we obtain: $\theta_C^* / \theta_{WP}^* > 2$ and $y_C^* / y_{WP}^* > 2$. These results indicate that in a WP contract, optimal greening and CSR levels are less than half of the corresponding values for a centralised SC. This finding suggests that SC agents need to puts higher efforts in greening and CSR in a decentralised SC if they trade through WP contract.

In sustainable SC, we further observe that $\left[\pi_{SC}^*\right]_{WP} / \pi_C^* > 3/4 \Rightarrow \left(\pi_C^* - \left[\pi_{SC}^*\right]_{WP}\right) / \pi_C^* < 1/4$. Therefore, the loss in SC profit due to double marginalization problem of WP contract is less than 25%. In the case of profit only SC this loss is exactly equal to 25%. This result corroborates with optimal WP contract calculated for traditional SC (Bhaskaran & Krishnan, 2009, Swami & Shah, 2013). Though WP contract is widely used in practice, this result indicates that through suitable design of supply contracts overall efficiency of a decentralized SC can be substantially improved. In the following subsections, we analyse four other supply contracts to investigate the optimal performance of a decentralised sustainable SC and compare them with the WP contract.

4.2 Linear two-part tariff contract (LTT)

Several scholars have analysed LTT contract in the context of profit only SC (Corbett et al., 2004; Biswas et al., 2016) and green SC (Ma, P et al., 2017; Ghosh and Shah 2012). Calculation of optimal LTT contract has not been discussed in the extant literature of sustainable SC. LTT contract is characterised by (a) a lump-sum payment (*L*) and (b) a per unit price (*w*). We calculate an optimal LTT contract in the context of sustainable SC and it is presented through Proposition 3.

Proposition 3. *When the supplier trades with the buyer through LTT contract, the optimal decision parameters are as follows: (i) per unit price is:* $w_{LTT}^* = s$, *(ii) lump-sum payment is:* $L_{LTT}^* = DI_S\left(I_G N_C / D_C\right)^2 - \bar{\pi}_B$, *(iii) retail price is:* $p_{LTT}^* = (s+c) + 2I_G I_S N_C / D_C$, *(iv) order quantity is:* $q_{LTT}^* = 2bI_G I_S N_C / D_C$, *(v) greening level is:* $\theta_{LTT}^* = \alpha_G I_S N_C / D_C$, *(vi) CSR level is:* $y_{LTT}^* = \alpha_S I_G N_C / D_C$, *(vii) supplier's profit is:* $\left[\pi_S^*\right]_{LTT} = \pi_C^* - \bar{\pi}_S$, *and (viii) buyer's profit is:* $\left[\pi_B^*\right]_{LTT} = \bar{\pi}_B$, *where (a)* $D = 4bI_S - \alpha_S^2$, *(b)* $N_C = a - b(s+c)$, *and (c)* $D_C = 4bI_S I_G - \left(I_S \alpha_G^2 + I_G \alpha_S^2\right)$.

From Proposition 3, we observe that classical LTT contract can perfectly coordinate a sustainable SC that focuses on both greening and CSR. It is evident from the following: $p_{LTT}^* = p_C^*$, $q_{LTT}^* = q_C^*$, $\theta_{LTT}^* = \theta_C^*$, and $y_{LTT}^* = y_C^*$. From these equations, we can observe that the equilibrium values of decentralised SC decision parameters (greening level, CSR improvement level, and order quantity) exactly match with those of centralised SC when the supplier uses LTT contract. In this contract, the supplier charges a unit price from the buyer that is equal to her own marginal cost. Therefore, he would not gain any profit by selling through the per unit price. He would gain his entire profit by the lum-sum amount paid by the buyer. The buyer would be only able to retain her own reservation profit. From Proposition 3, we can further observe that, if required, the supplier can allow the buyer to keep higher profit level and in that case, her lump-sum payment term follows the inequality: $\bar{\pi}_S \leq L^*_{LTT} \leq DI_S (I_G N_C / D_C)^2 - \bar{\pi}_B$. Such a situation arises when both SC agents possess comparable bargaining power.

4.3 Revenue sharing contract (RS)

A revenue-sharing contract plays an important role in coordinating the supply chain and improves overall performance (Cachon and Lariviere, 2005). However, RS contract has not been studied in the context of sustainable SC. The basic concept of RS contract is as follows: the buyer shares a fraction $(1-k)$ of her revenue (pq) with the supplier. The supplier moves first and chooses his wholesale price (w) and greening level (θ). Thereafter, the buyer decides her retail price (p), revenue share (k), and the CSR level (y). We calculate an optimal RS contract in the context of sustainable SC and it is presented through Proposition 4.

Proposition 4. *When the supplier trades with the buyer through RS contract, the optimal decision parameters are as follows: (i) revenue sharing ratio* (k) *is:* $k^*_{RS} = 1 - \alpha_G^2 (2I_S b - \alpha_S^2) / (8 I_G I_S b^2 - \alpha_S^2 \alpha_G^2)$ *, (ii) retail price is:* $p^*_{RS} = \{8 I_G b X_2 (2 I_G b - I_S \alpha_G^2 - I_G \alpha_C^2) + 32 I_S I_G^2 a b^2 + (s+c) \alpha_S^2 \alpha_G^4\} / (4DI_G b - \alpha_S^2 \alpha_G^2) X$ *, (iii) order quantity is:* $q^*_{RS} = 2 N_C I_G b (8 I_G I_S b^2 - \alpha_S^2 \alpha_G^2) / (4DI_G b - \alpha_S^2 \alpha_G^2) X$ *, (iv) greening level is:* $\theta^*_{RS} = N_C \alpha_G (8 I_G I_S b^2 - \alpha_S^2 \alpha_G^2) / (4DI_G b - \alpha_S^2 \alpha_G^2) X$ *, (v) CSR level is:* $y^*_{RS} = 2 I_G b N_C \alpha_S / (4DI_G b - \alpha_S^2 \alpha_G^2)$*, (vi) wholesale price is :* $w^*_{RS} = \{16 I_S I_G b^2 (I_G X_1 D - I_S \alpha_G^2 b X_2) + 4 I_S I_G b X_3 \alpha_G^4 + X_4 \alpha_S^2 \alpha_G^4\} / (4DI_G b - \alpha_S^2 \alpha_G^2) X$ *, (vii) supplier's profit is:* $[\pi^*_S]_{RS} = I_S N_C^2 (8 I_S I_G b^2 - \alpha_S^2 \alpha_G^2) / (4DI_G b - \alpha_S^2 \alpha_G^2) X$ *, (viii) buyer's profit is* $[\pi_B]_{RS} = 4 I_C I_G^2 b^2 N_C^2 / (4DI_G b - \alpha_C^2 \alpha_G^2) X$*, and (ix) total SC profit is :* $[\pi^*_{Sc}]_{RS} = I_G N_C^2 (12 I_S I_G b^2 - \alpha_S^2 \alpha_G^2) / (4DI_G b - \alpha_S^2 \alpha_G^2) X$*, where (a)* $N_C = a - b(s+c)$*, (b)*

$D = 4I_S b - \alpha_S^2$, *(c)* $X = 4I_G b - \alpha_G^2$, *(d)* $X_1 = a + bs - bc$, *(e)* $X_2 = a + bs + bc$, *(f)* $X_3 = a + 5bc - bs$, *and (g)* $X_4 = 2I_S bs + 2I_S bs - c\alpha_S^2$.

From Proposition 4, we can observe that under optimality condition the buyer has to share a higher proportion of revenue with the supplier as the consumer sensitivity to greening increases. Compared to WP contract, the buyer orders higher quantity in RS contract: $q_{RS}^* > q_{WP}^*$ and earns higher revenue as well. It is interesting to observe that the optimal greening and CSR levels improve with RS contract compared to WP contract: $\theta_{RS}^* > \theta_{WP}^*$ and $y_{RS}^* > y_{WP}^*$. In RS contract, the supplier and the buyer also earn higher profits compared to WP contract: $[\pi_S^*]_{RS} > [\pi_S^*]_{WP}$ and $[\pi_B^*]_{RS} > [\pi_B^*]_{WP}$. Therefore, RS contract is conducive to improve overall SC performance compared to the WP contract. If the final product's demand is not influenced by exerted CSR efforts, then we have: $\alpha_S \to 0$ and $\alpha_G \neq 0$, and under such circumstances the SC turns into a green SC. In that case, $k \in (1/2,1)$. It implies that in a green SC the buyer will retain more than 50% of earned revenue; both SC agents continue to generate more profit than WP contract. This result corroborates with the empirical findings those suggest that in a green SC the buyer pays her supplier 30–45% of earned revenue and retains more than 50% for herself (Bhaskaran and Krishnan, 2009) Hence, supplier and buyer would like to participate in RS contract.

4.4 Greening-cost sharing contract(GCS)

In GCS contract, the supplier invests in product greening $\left(I_G \theta_G^2\right)$ and the buyer offers to share a fraction (ψ) of the supplier's upfront cost of greening investment (Yenipazarli, 2017). In this contract, the buyer decides greening cost-sharing fraction (ψ) first. Thereafter, the supplier decides whether to accept this offer. If the supplier accepts buyer's cost-sharing agreement, then the supplier announces her contract term. Subsequently, the buyer announces her order quantity, CSR level, and shares ψ proportion of the greening cost. We calculate an optimal GCS contract in the context of sustainable SC and it is presented through Proposition 5.

Proposition 5. *When the supplier trades with the buyer through GCS contract, the optimal decision parameters are as follows: (i) greening cost sharing ratio is:* $\psi_{GCS}^* = I_S \alpha_G^2 / 4DI_G \in (0,\ 1/5)$*, (ii) retail price is:*

$$p_{GCS}^* = 4DI_G\left(2A_1 I_S b + DA_1 + Dbs\right) - I_S \alpha_G^2\left(5Dbs + 2A_1 I_S b + DA_1 - 2I_S b^2 s\right) / 2Db\left(4DI_G - 3I_S\alpha_G^2\right) + c$$

, (iii) wholesale price is: $w_{GCS}^* = 4DI_G\left(A_1 + bs\right) - I_S\left(A_1 + 5bs\right)\alpha_G^2 / 2b\left(4DI_G - 3I_S\alpha_G^2\right)$*, (iv) greening level is:* $\theta_{GCS}^* = 2I_S \alpha_G N_C / 4DI_G - 3I_S \alpha_G^2$*, (v) CSR level is:*

$y^*_{GCS} = \alpha_S N_S \left(4DI_G - I_S \alpha_G^2\right)/\,2D\left(4DI_G - 3I_S \alpha_G^2\right)$, *(vi) supplier's profit is:*
$\left[\pi^*_S\right]_{GCS} = I_S N_C^2 \left(4DI_G - I_S \alpha_G^2\right)/\,2D\left(4DI_G - 3I_S \alpha_G^2\right)$, *and (vii) buyer's profit is:*
$\left[\pi^*_B\right]_{GCS} = I_S N_C^2 \left(4DI_G + I_C \alpha_G^2\right)/\,4D\left(4DI_G - 3I_S \alpha_G^2\right)$, *where, (a)* $D = 4I_S b - \alpha_S^2$ *and (b)* $A_1 = a - bc$ *(c)* $N_C = a - b(s + c)$, *and (d)* $X_1 = a + bs - bc$.

From Proposition 5, we can make the following observations: The buyer's profit maximizes in cost-sharing fraction (ψ) only if $I_S \alpha_G^2 / 4DI_G \leq\in 1/5$. This condition clearly indicates that though a buyer can support the supplier in putting product greening effort but such a scenario would be a win-win for both SC agents only when the buyer shares up to 20% of the greening cost with supplier. This maximum limit for cost-sharing can be attributed to the fact that cost shared between the buyer and the supplier as well as the consumer sensitivity to greening benefits the supplier; however, the buyer benefits only from the latter. We can further observe from Proposition 5 that greening cost-sharing ratio (ψ) increases in both consumer sensitivities $\left(\alpha_{G,}\alpha_S\right)$ and it decreases in investment cost parameters $\left(I_{G,}I_S\right)$. From the perspective of sustainability, GCS contract performs better than WP contract as: $\theta^*_{GCS} > \theta^*_{WP}$ and $y^*_{GCS} > y^*_{WP}$. Both SC agents also earn higher profit in GCS contract compared to WP contract: $\left[\pi^*_S\right]_{GCS} > \left[\pi^*_S\right]_{WP}$ and $\left[\pi^*_B\right]_{GCS} > \left[\pi^*_B\right]_{WP}$. In GCS contract, the increase in buyer's profit is higher than the additional cost that she shares with the supplier. Therefore, GCS contact clearly provides a win-win situation for both SC agents.

4.5 Revenue and greening-cost sharing contract (RGCS)

In this section, we propose a new type of contract, namely RGCS. In this contract, the buyer pays the supplier a wholesale price (w) for each unit purchased, a fraction (k) of earned revenue (pq), and a fraction (ψ) supplier's greening cost. Thus, the buyer simultaneously agrees to RS as well as GCS payment structure and it leads to two pronged advantages for the supplier. In RGCS contract, the buyer first announces her choice for revenue sharing fraction and greening cost-sharing fraction. Subsequently the supplier chooses his optimal wholesale price (w) and greening level (θ). Based on these decisions, the buyer declares her order quantity and CSR level. We analyse optimal RGCS contract in the context of sustainable SC and the same is presented through Proposition 6.

Proposition 6. *When the supplier trades with the buyer through a RGCS contract, the optimal decision parameters are as follows: (i) revenue sharing ratio is :*
$k^*_{RGCS} = 1 - 2\alpha_G^2\left(2I_S b - \alpha_C^2\right)/\left(16 I_G I_S b^2 - \alpha_S^2 \alpha_G^2\right)$, *(ii) greening cost sharing ratio is :*

$\psi^{*}_{RGCS} = \alpha_G^2 \alpha_S^2 / 16 I_G I_S b^2$, *(iii) greening level is:*
$\theta^{*}_{RGCS} = 32 I_S^2 I_G b^3 \alpha_G N_C \alpha_G / \{4DI_G b(4I_S bX - \alpha_S^2 \alpha_G^2) - (2I_S b - \alpha_S^2)\alpha_S^2 \alpha_G^4\}$, *(iv) CSR level is:*
$y^{*}_{RGCS} = \alpha_C X(16 I_G I_C b^2 - \alpha_C^2 \alpha_G^2) N_C / 2\{4DI_G b(4I_C bX - \alpha_C^2 \alpha_G^2) - (2I_C b - \alpha_C^2)\alpha_C^2 \alpha_G^4\}$, *(v) supplier's profit is:* $[\pi_S^*]_{RGCS} = 2I_G I_S b(16 I_G I_S b^2 - \alpha_S^2 \alpha_G^2) N_C^2 / \{4DI_G b(4I_S bX - \alpha_S^2 \alpha_G^2) - (2I_S b - \alpha_S^2)\alpha_S^2 \alpha_G^4\}$, *and (vi) buyer's profit is:*

$$[\pi_B^*]_{RGCS} = I_S X(16 I_G I_S b^2 - \alpha_S^2 \alpha_G^2)^2 N_C^2 (4DI_G b - \alpha_S^2 \alpha_G^2) / 4\{4DI_G b(4I_S bX - \alpha_S^2 \alpha_G^2) - (2I_S b - \alpha_S^2)\alpha_S^2 \alpha_G^4\}^2$$

, where (a) $D = 4I_S b - \alpha_S^2$ *(b)* $X = 4I_G b - \alpha_G^2$, *and (c)* $N_C = a - b(s + c)$.

Proposition 6 implies that there exists a Pareto optimal solution under RGCS contract through which SC agents can maximise their profits. We can also observe that in RGCS contract, revenue sharing fraction improves compared to RS contract, $k^{*}_{RGCS} > k^{*}_{RS}$, and greening cost-sharing fraction deteriorates compared to GCS contract, $\psi^{*}_{RGCS} < \psi^{*}_{GCS}$. We can further observe from Proposition 6 that, if the final product demand is not influenced by CSR level, $\alpha_S \to 0$, then $k^{*}_{RGCS} = k^{*}_{RS}$ and $\psi^{*}_{RGCS} = 0$. This indicates that in absence of demand expansion due to CSR effort, then there is no difference between optimal RS and RGCS contracts. This result is counterintuitive in nature.

5. Numerical Analysis

In the preceding section, we have obtained the optimal values of different decision variables for centralised sustainable SC and those for decentralised sustainable SC using five different supply contracts. In this section, we numerically compare these supply contracts to gain further insights. We choose the following parametric values for our numerical analysis: $a = 100, b = 1, c = 5, s = 10, I_G = 3, I_S = 2, \overline{\pi}_S = 1557, \overline{\pi}_B = 528$. In this setup, we vary the value of consumer sensitivity to CSR (α_S) from 0.11 to 0.92 and the value of consumer sensitivity to greening (α_G) from 0.67 to 2.77. For the chosen range of α_S and α_G, overall sustainability effort always satisfy the following condition: $0 < \alpha_G^2 / I_G + \alpha_S^2 / I_S < 4b$. Therefore, the objectives functions of both SC agents are always concave over α_S and α_G within the chosen range. Thus, model parameters are chosen without any loss in generality for our numerical analysis.

In Fig.1, we have compared optimal greening levels for different supply contracts against the overall sustainability effort. We can see that optimal greening level is increasing in sustainability effort for all contract types. Product greening level is highest and equal to that of centralised SC for LTT contract and it is worst for WP contract. Comparison of greening level for all supply contracts is: $\theta_C^* = \theta_{LTT}^* > \theta_{RGCS}^* > \theta_{RS}^* > \theta_{CGS}^* > \theta_{WP}^*$.

[INSERT FIG. 1 HERE]

In Fig. 2, we have compared optimal CSR levels for all supply contracts against overall sustainability effort. Similar to optimal greening level, CSR level is also increasing in sustainability effort. CSR level is highest for LTT contract and worst for WP. Comparison of CSR levels yields: $y_C^* = y_{LTT}^* > y_{GCS}^* > y_{RS}^* > y_{RGCS}^* > y_{WP}^*$. An interesting observation is that the optimal CSR level for GCS contract is more than that of RGCS contract unlike the optimal greening level. This can be attributed to the fact that in case of RGCS contract, the buyer has to share both revenue and greening cost. As a result, her own effort for CSR reduces compared to GCS contract, where she shares only greening cost with the supplier.

[INSERT FIG. 2 HERE]

In Fig. 3, we compare the optimal per unit prices across five supply contracts. The per unit price is minimum for LTT contract. In case of RS and RGCS contracts, the per unit price is also relatively lower, as the buyer shares a fraction of her earned revenue with the supplier. These results corroborate with the extant literature on profit only SC (Cachon and Lariviere, 2005; Ghosh and Shah 2012). We can observe that in RGCS contract, the supplier sets lower per unit price compared to GCS and WP contracts. This can be attributed to the fact that in RGCS contract the buyer is required to share both her revenue and supplier's greening cost. Interestingly, we can also observe that per unit price decreases with the sustainability effort in case of RS and RGCS. The relationship between all per unit prices is as follows: $w_{LTT}^* < w_{RS}^* < w_{RGCS}^* < w_{WP}^* < w_{CGS}^*$

. [INSERT FIG. 3 HERE]

In Fig. 4, we compare the optimal supplier's profit for all supply contracts. Comparison between all these supplier's profit yields the following relationship: $\lfloor \pi_S^* \rfloor_{LTT} > \lfloor \pi_S^* \rfloor_{RGCS} > \lfloor \pi_S^* \rfloor_{RS} > \lfloor \pi_S^* \rfloor_{GCS} > \lfloor \pi_S^* \rfloor_{WP}$. Supplier's profit is highest under LTT contract and it is lowest under WP contract. Among RGCS, RS, and GCS contacts the supplier earns maximum in RGCS contract. This result is intuitive in nature as the supplier earns a share of revenue and his greening cost is shared with the buyer in RGCS contract. Among these three contracts the supplier earns minimum in GCS contract in spite of his cost sharing agreement with the buyer. Therefore, the supplier would prefer RGCS contract to all other contract types in case he is unable to implement LTT contract.

[INSERT FIG. 4 HERE]

In Fig. 5, we compare the optimal profits of the buyer for all five supply contracts. Comparison between all these buyer's profit yields: $[\pi_B^*]_{RGCS} > [\pi_B^*]_{CGS} > [\pi_B^*]_{RS} > [\pi_B^*]_{LTT} > [\pi_B^*]_{WP}$, if $\overline{\pi}_B > [\pi_B^*]_{WP}$. From the perspective of the buyer, she would always prefer RGCS contract over all other contract types as RGCS allows her to earn maximum profit.

[INSERT FIG. 5 HERE]

From Fig. 4 and 5, an interesting observation emerges. Among all the five supply contracts discussed, the supplier prefers LTT contract and the buyer prefers RGCS contract. This result is counterintuitive in nature as in RGCS agreement the buyer needs to share both her revenue and the greening cost with the supplier.

6. Conclusion

In this paper, we have designed a sustainable SC model by simultaneously considering greening and CSR efforts of SC agents. Subsequently we have analysed five supply contracts in this setup. To the best of our knowledge, such analytical model is hitherto unreported in the extant literature. Specifically, we have considered a two stage SC, where the upstream supplier is accountable for product greening, a downstream buyer is responsible for CSR activities, and the demand is dependent on both greening and CSR levels. In this context, we have first analysed a centralised SC setup for establishing the benchmark solution. Subsequently, we have analysed three classical contracts: WP, LTT, and RS. Then, we have further analysed two sustainability specific contracts: GCS and RGCS. We have presented the analytical results for all these contracts. We obtained the optimal contract parameter(s), order quantity, retail price, greening level, CSR level, supplier's profit, and buyer's profit. We have also numerically compared the optimal decisions for these supply contracts.

The generalizability of our model can be understood from the following: If market demand is not influenced by CSR effort, we have: $\alpha_S \to 0$ and $\alpha_G \neq 0$, and the SC turns into a greening only SC. Under such circumstances, from Propositions 2–6 we can calculate optimal values for a green supply chain using the limit: $\alpha_S \to 0$. Similarly if market demand is not influenced by greening effort, we have: $\alpha_G \to 0$ and $\alpha_S \neq 0$, and the SC turns into a socially responsible SC. Under such circumstances, from Proposition 2–6 we can calculate optimal values for a socially responsible SC using the limit: $\alpha_G \to 0$. If market demand is neither greening nor CSR, we have: $\alpha_G \to 0$ and $\alpha_S \to 0$, and the SC turns into a profit only SC. Under such circumstances, from Proposition 2-6 we can calculate optimal values for a profit only SC using limits: $\alpha_G \to 0$ and $\alpha_S \to 0$.

Apart from the mathematical generalizability, our model reveals several interesting takeaways for the practitioners. We provide a unified framework for practitioners to simultaneously incorporate greening and CSR related activities in their decision making in an objective way. Our study indicates that product greening and CSR activities are beneficial to SC agents, lead to higher order quantity and profit levels for SC agents if customers are sensitive towards them. SC managers would put effort for both greening and CSR, only if it leads to higher profitability. Through our analytical model, we have quantified the change in profits of SC agents due to sustainable effort for different supply contracts. In WP contract, we observe that optimal greening and CSR levels are almost half of their corresponding optimal values from centralised SC. In LTT, RS, GCS, and RGCS contracts these levels along with profits of SC agents improve. LTT contract perfectly coordinates a sustainable SC. In GCS contract, buyer at most shares 20% of greening investment with the supplier. Thus, we have obtained a threshold value of greening-cost sharing ratio for GCS contract. This would guide practitioners to decide *a priori* the extent of cost-sharing arrangement so that effective product greening decisions could be taken. When both RS and GCS contracts are available, the buyer prefers sharing her revenue with the supplier to sharing greening cost since the buyer is better off with RS contract. If consumer sensitivity towards CSR tends to zero, then a buyer's preference between RGCS and RS becomes indifferent and GCS contract become superfluous. The supplier always prefers LTT contract followed by RGCS; on the other hand, the buyer prefers RGCS contract followed by RS.

In the end, we would like to enlist a few limitations of our model and possible future research opportunities. We have analysed our model by assuming a demand function that is linearly dependent on retail price, greening and CSR levels. In reality, this relationship can also be nonlinear. Our model can be extended with nonlinear demand functions such that the relationship between order quantity and sustainability effort is nonlinear. We assume that the supplier acts as a Stackelberg leader in our model setting. However, in the real life, the buyer could be a leader or both could have equal power. It would be interesting to analyse how supply chain agent's decision will change in a different power structure. We have analysed the supply contracts using a single-period Stackelberg game. In future extension, this assumption can be relaxed and the model can be analysed using multi-period game. In this paper, we have considered a two stage SC though most of the real-life SCs are multi-stage. So, another interesting extension of our work can be the analysis of sustainable SC and supply contracts in a multi-echelon setting.

References

Ansari, Z.N., Kant, R., 2017. A state-of-art literature review reflecting 15 years of focus on sustainable supply chain management. J. Clean. Prod. 142, 2524–2543. https://doi.org/10.1016/j.jclepro.2016.11.023

Ashby, A., Leat, M., Hudson□Smith, M., 2012. Making connections: a review of supply chain management and sustainability literature. Supply Chain Manag. Int. J. 17, 497–516. https://doi.org/10.1108/13598541211258573

Babbar, S., Behara, R.S., Koufteros, X.A., Huo, B., 2017. Emergence of Asia and Australasia in operations management research and leadership. Int. J. Prod. Econ. 184, 80–94. https://doi.org/10.1016/j.ijpe.2016.11.018

Banker, R.D., Khosla, I., Sinha, K.K., 1998. Quality and Competition. Manage. Sci. 44, 1179–1192. https://doi.org/10.1287/mnsc.1070.0794ec

Bhaskaran, S.R., Krishnan, V., 2009. Effort, Revenue, and Cost Sharing Mechanisms for Collaborative New Product Development. Manage. Sci. 55, 1152–1169. https://doi.org/10.1287/mnsc.1090.1010

Bian, J., Li, K.W., Guo, X., 2016. A strategic analysis of incorporating CSR into managerial incentive design. Transp. Res. Part E Logist. Transp. Rev. 86, 83–93. https://doi.org/10.1016/j.tre.2015.11.012

Biswas, I., Avittathur, B., Chatterjee, A.K., 2016. Impact of structure, market share and information asymmetry on supply contracts for a single supplier multiple buyer network. Eur. J. Oper. Res. 253, 593–601. https://doi.org/10.1016/j.ejor.2016.03.014

Brandenburg, M., Govindan, K., Sarkis, J., & Seuring, S. (2014). Quantitative models for sustainable supply chain management: Developments and directions. Eur. J. Oper. Res.*233*(2), 299-312

Burke, M., 2010. Wal-Mart, Patagonia Team To Green Business [WWW Document]. Forbes. URL forbes/2010/0524/rebuilding-sustainability-eco-friendly-mr-green-jeans (accessed 10.20.17).

Cachon, G.P., Lariviere, M.A., 2005. Supply Chain Coordination with Revenue-Sharing Contracts: Strengths and Limitations. Manage. Sci. 51, 30–44. https://doi.org/10.1287/mnsc.1040.0215

Chen, X., Wang, X., Chan, H.K., 2017. Manufacturer and retailer coordination for environmental and economic competitiveness: A power perspective. Transp. Res. Part E Logist. Transp. Rev. 97, 268–281. https://doi.org/10.1016/j.tre.2016.11.007

Choi, S.C., 1991. Price Competition in a Channel Structure with a Common Retailer. Mark. Sci. 10, 271–296. https://doi.org/10.1287/mksc.10.4.271

Corbett, C.J., Zhou, D., Tang, C.S., 2004. Designing Supply Contracts: Contract Type and Information

Asymmetry. Manage. Sci. 50, 550–559. https://doi.org/10.1287/mnsc.1030.0173

Das, S., 2016. Pepsi soaks in the sun. The business-standard. https://doi.org/http://www.business-standard.com/article/specials/pepsi-soaks-in-the-sun-116111601889_1.html

Dong, C., Shen, B., Chow, P.S., Yang, L., Ng, C.T., 2016. Sustainability investment under cap-and-trade regulation. Ann. Oper. Res. 240, 509–531. https://doi.org/10.1007/s10479-013-1514-1

Elkington, J., 1998. Cannibals With Folks: The Triple Bottom Line of 21st Century Business, New Society Publishers.

Esfahbodi, A., Zhang, Y., Watson, G., 2016. Sustainable supply chain management in emerging economies: Trade-offs between environmental and cost performance. Int. J. Prod. Econ. 181, 350–366. https://doi.org/10.1016/j.ijpe.2016.02.013

Ghosh, D., Shah, J., 2015. Supply chain analysis under green sensitive consumer demand and cost sharing contract. Int. J. Prod. Econ. 164, 319–329. https://doi.org/10.1016/j.ijpe.2014.11.005

Ghosh, D., Shah, J., 2012. A comparative analysis of greening policies across supply chain structures. Int. J. Prod. Econ. 135, 568–583. https://doi.org/10.1016/j.ijpe.2011.05.027

Hsueh, C.-F., 2015. A bilevel programming model for corporate social responsibility collaboration in sustainable supply chain management. Transp. Res. Part E Logist. Transp. Rev. 73, 84–95. https://doi.org/10.1016/j.tre.2014.11.006

Hsueh, C.F., 2014. Improving corporate social responsibility in a supply chain through a new revenue sharing contract. Int. J. Prod. Econ. 151, 214–222. https://doi.org/10.1016/j.ijpe.2013.10.017

Jamali, M.-B., Rasti-Barzoki, M., 2018. A game theoretic approach for green and non-green product pricing in chain-to-chain competitive sustainable and regular dual-channel supply chains. J. Clean. Prod. 170, 1029–1043. https://doi.org/10.1016/j.jclepro.2017.09.181

Jayaram, J., Avittathur, B., 2015. Green supply chains: A perspective from an emerging economy. Int. J. Prod. Econ. 164, 234–244. https://doi.org/10.1016/j.ijpe.2014.12.003

Ji, J., Zhang, Z., Yang, L., 2017. Carbon emission reduction decisions in the retail-/dual-channel supply chain with consumers' preference. J. Clean. Prod. 141, 852–867. https://doi.org/10.1016/j.jclepro.2016.09.135

Lee, H.L., Tang, C.S., 2017. Socially and Environmentally Responsible Value Chain Innovations: New Operations Management Research Opportunities. Manage. Sci. mnsc.2016.2682. https://doi.org/10.1287/mnsc.2016.2682

Ma, P., Shang, J., Wang, H., 2017. Enhancing corporate social responsibility: Contract design under information asymmetry. Omega 67, 19–30. https://doi.org/10.1016/j.omega.2016.03.004

Ma, X., Ho, W., Ji, P., Talluri, S., 2017. Contract Design with Information Asymmetry in a Supply Chain under an Emissions Trading Mechanism. Decis. Sci. DOI: 10.1111/deci.12265

Modak, N.M., Panda, S., Mishra, R., Sana, S.S., 2016. A three-layer supply chain coordination in socially responsible distribution system. Tékhne 14, 75–87. https://doi.org/10.1016/j.tekhne.2016.06.001

Modak, N.M., Panda, S., Sana, S.S., Basu, M., 2014. Corporate social responsibility, coordination and profit distribution in a dual-channel supply chain. Pacific Sci. Rev. 16, 235–249. https://doi.org/10.1016/j.pscr.2015.05.001

Nematollahi, M., Hosseini-Motlagh, S.M., Heydari, J., 2017. Coordination of social responsibility and order quantity in a two-echelon supply chain: A collaborative decision-making perspective. Int. J. Prod. Econ. 184, 107–121. https://doi.org/10.1016/j.ijpe.2016.11.017

Ni, D., & Li, K. W. (2012). A game-theoretic analysis of social responsibility conduct in two-echelon supply chains. Int. J. Prod. Econ.. 138(2), 303-313.

Ni, D., Li, K.W., Tang, X., 2010. Social responsibility allocation in two-echelon supply chains: Insights from wholesale price contracts. Eur. J. Oper. Res. 207, 1269–1279. https://doi.org/10.1016/j.ejor.2010.06.026

Panda, S., Modak, N.M., Basu, M., Goyal, S.K., 2015. Channel coordination and profit distribution in a social responsible three-layer supply chain. Int. J. Prod. Econ. 168, 224–233. https://doi.org/10.1016/j.ijpe.2015.07.001

Panda, S., Modak, N.M., Cárdenas-Barrón, L.E., 2017. Coordinating a socially responsible closed-loop supply chain with product recycling. Int. J. Prod. Econ. 188, 11–21. https://doi.org/10.1016/j.ijpe.2017.03.010

Panda, S. (2014). Coordination of a socially responsible supply chain using revenue sharing contract. Transp. Res. Part E Logist. Transp. Rev. 67, 92-104.

Rajeev, A., Pati, R.K., Padhi, S.S., Govindan, K., 2017. Evolution of sustainability in supply chain management: A literature review. J. Clean. Prod. 162, 299–314. https://doi.org/10.1016/j.jclepro.2017.05.026

Reefke, H., Sundaram, D., 2017. Key themes and research opportunities in sustainable supply chain management – identification and evaluation. Omega 66, 195–211. https://doi.org/10.1016/j.omega.2016.02.003

Shen, B., Choi, T.M., Wang, Y., Lo, C.K.Y., 2013. The coordination of fashion supply chains with a risk-averse supplier under the markdown money policy. IEEE Trans. Syst. Man, Cybern. Part ASystems Humans 43, 266–276. https://doi.org/10.1109/TSMCA.2012.2204739

Swami, S., Shah, J., 2013. Channel coordination in green supply chain management. J. Oper. Res. Soc. 64, 336–351. https://doi.org/10.1057/jors.2012.44

Song, H., Gao, X., 2018. Green supply chain game model and analysis under revenue-sharing contract. J. Clean. Prod. 170, 183–192. https://doi.org/10.1016/j.jclepro.2017.09.138

Taylor, T. a., 2002. Supply Chain Coordination Under Channel Rebates with Sales Effort Effects. Manage. Sci. 48, 992–1007. https://doi.org/10.1287/mnsc.48.8.992.168

Tirole, J., 1988. The Theory of Industrial Organization: Jean Tirole. theory Ind. Organ. https://doi.org/10.1016/j.infsof.2008.09.005

The Economist [WWW Document], 2009. URL http://www.economist.com/node/14301663 (accessed 10.20.17).

Xiao, T., Shi, K., Yang, D., 2010. Coordination of a supply chain with consumer return under demand uncertainty. Int. J. Prod. Econ. 124, 171–180. https://doi.org/10.1016/j.ijpe.2009.10.021

Yan, R., Cao, Z., 2017. Product returns, asymmetric information, and firm performance. Int. J. Prod. Econ. 185, 211–222. https://doi.org/10.1016/j.ijpe.2017.01.001

Xu, X., He, P., Xu, H., & Zhang, Q. (2017). Supply chain coordination with green technology under cap-and-trade regulation. Int. J. Prod. Econ. 183, 433-442.

Yang, H., Chen, W., 2017. Retailer-driven carbon emission abatement with consumer environmental awareness and carbon tax: Revenue-sharing versus Cost-sharing. Omega (United Kingdom). https://doi.org/10.1016/j.omega.2017.06.012

Yang, H., Luo, J., Wang, H., 2017. The role of revenue sharing and first-mover advantage in emission abatement with carbon tax and consumer environmental awareness. Int. J. Prod. Econ. 193, 691–702. https://doi.org/10.1016/j.ijpe.2017.08.032

Yenipazarli, A., 2017. To collaborate or not to collaborate: Prompting upstream eco-efficient innovation in a supply chain. Eur. J. Oper. Res. 260, 571–587. https://doi.org/10.1016/j.ejor.2016.12.035

Zhu, W., He, Y., 2017. Green product design in supply chains under competition. Eur. J. Oper. Res. 258, 165–180. https://doi.org/10.1016/j.ejor.2016.08.053

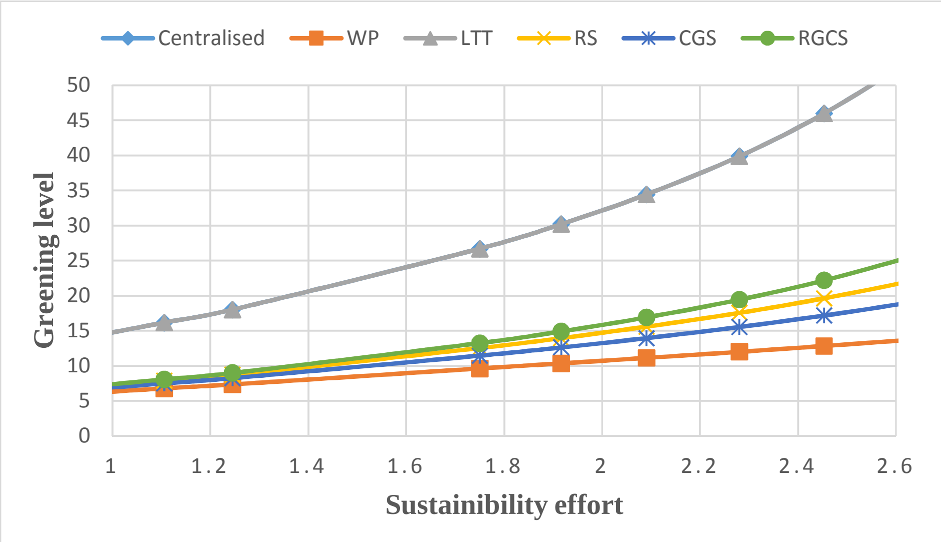

Fig.1. Greening level vs Sustainability effort

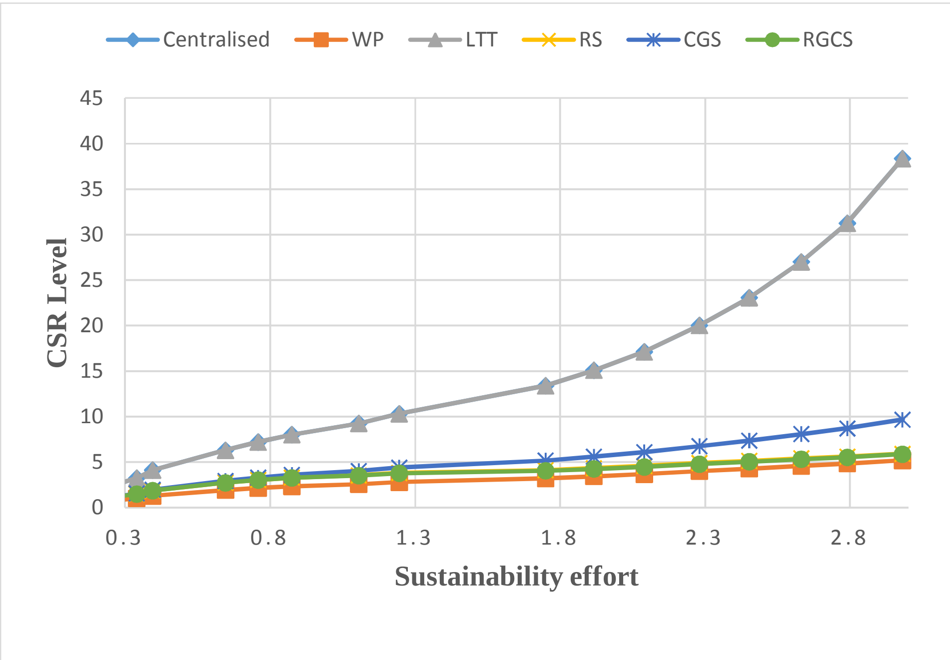

Fig.2. CSR level vs Sustainability effort

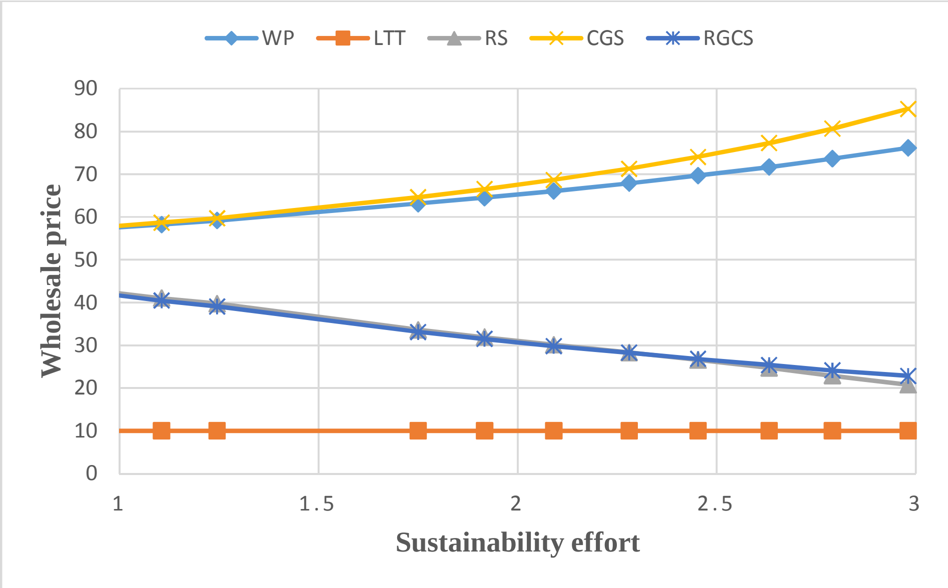

Fig.3. Wholesale price vs Sustainability effort

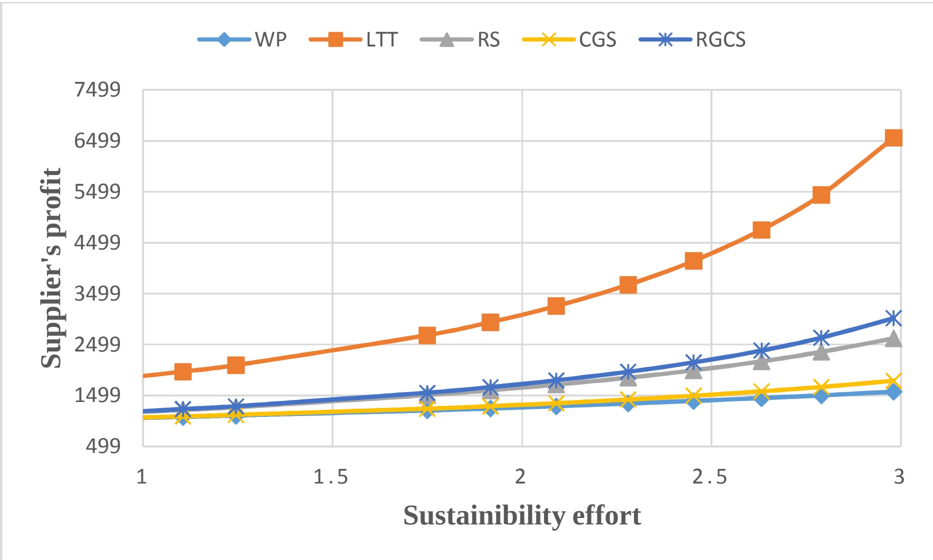

Fig.4. Supplier’s profit vs Sustainability effort

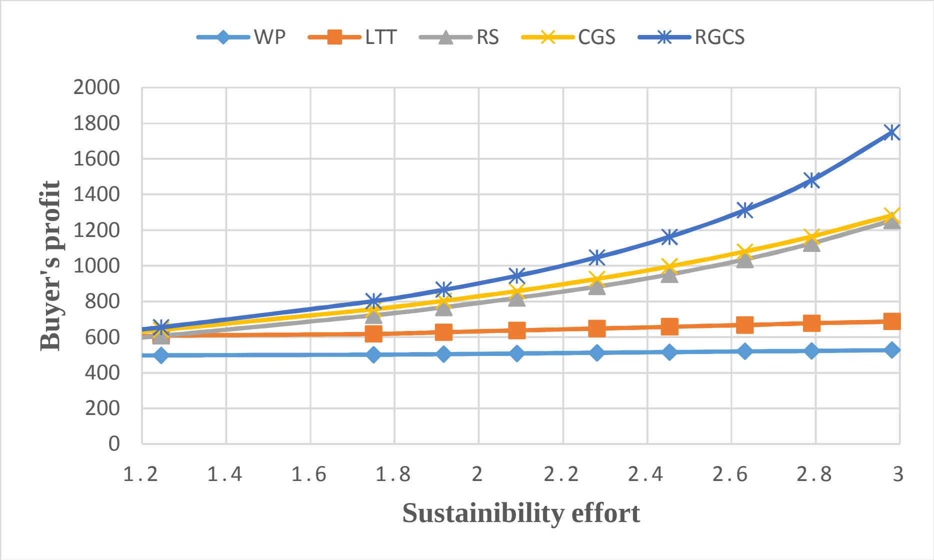

Fig.5. Buyer's profit vs Sustainability effort

Highlights:

- A generalised analytical model for sustainable supply chain is proposed
- Five cases of decentralized setup for five different types of contracts are compared
- A new type of hybrid contract RGCS is proposed
- Analysis showed that implementation of sustainability in supply chain is profitable for the firms