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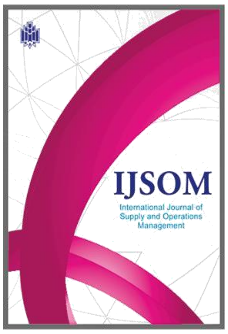

Emission Reduction Effort in a Low-Carbon Supply Chain: A Coordination Scheme

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Abstract

Sustainability and low-carbon manufacturing have been under the scrutiny of the academics and practitioners, along with the governmental and non-governmental organizations. Not to mention the growing awareness and concern of the consumers about the carbon footprint, leading the researchers to the joint problem of sustainable supply chain coordination and emission abatement. This study contributes to the current literature by developing a contract for a dyadic supply chain model under a manufacturer-led Stackelberg game where emission abatement is a key decision. Implementing a green-sensitive consumer preference and carbon abatement level into the demand function, a revenue-sharing contract is conducted to solve the channel conflict and double marginalization effect. The analytical results and numerical example prove the profit improvement of both channel members and validate the effectiveness and environmental-friendliness of the constructed supply chain structure.

Keywords: Low-carbon supply chain; Carbon tax; Revenue sharing contract; Supply chain coordination.

1. Introduction and Literature review

Sustainability is more like a mandatory requirement in today's competitive business world. Consumer environmental awareness, along with the governmental rules and regulations, has brought the business owners to consider the sustainability factors in their decisions. In comparison to the classic business models, carbon sensitive business owners achieve higher competitive advantages. Serious concerns are raised by both practitioners and academics regarding the necessity of sustainability. Global warming has attracted the attention of both the NGOs and governmental institutes on environmental issues; climate changes, wildlife patterns, and human health. Climate change is affecting the ecosystem and human-habitation life environments. Studies show that full alignment in supply chains could lead to lower levels of carbon emission and therefore, more eco-friendlier products. Unfortunately, supply chain members are often opposing one each other's interests. This issue is the key question in supply chain management and coordination literature; how could one reach coordination while the supply chain members tend to make their own decisions? Interestingly, centralized and integrated decision-making structure leads to higher supply chain performance. Throughout the recent decades, many authors have investigated the supply chain coordination problem. One can run the gamut from information sharing to the contract design. There are many pieces of evidence from the literature, proving the superior performance of a coordinated supply chain in comparison to a decentralized one [1]. Proper supply chain coordination scheme demands for a suitable motive to alter the supply chain member's independent behavior to a coherent decision-making structure. Optimal performance of the supply chain achieves through key decisions like marketing efforts, pricing, ordering, and material handling.

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Low-carbon policies as an important aspect of sustainability have attracted substantial interests of from the main members of a sustainable SC. Surprisingly, joint studies on carbon policies and supply chain coordination are scares. There are not enough efforts from academics on optimizing the SC decisions on joint SC coordination and sustainability. Low-carbon supply chains have been investigated in the scope of coordination in the very recent years (Nematollahi et al (2018), Sabzevar et al (2017), Madani et al (2017), Li et al (2020)). The background of these joint studies is rooted in production planning problems (Penkuhn (1997), Jones (2009)). Through time, this research avenue developed through more complex issues, lot sizing (Dai 2012), inventory control (Du et al (2015), Hua et al (2011), Song et al (2012), and production planning (Xu et al (2016). Developing through the years, today's business world requires joint optimizations on SC coordination and carbon legislations. As depicted in Figure 1, carbon tax, as one the widespread carbon legislations, helps corporates in emission reduction and also helps with energy consumption.

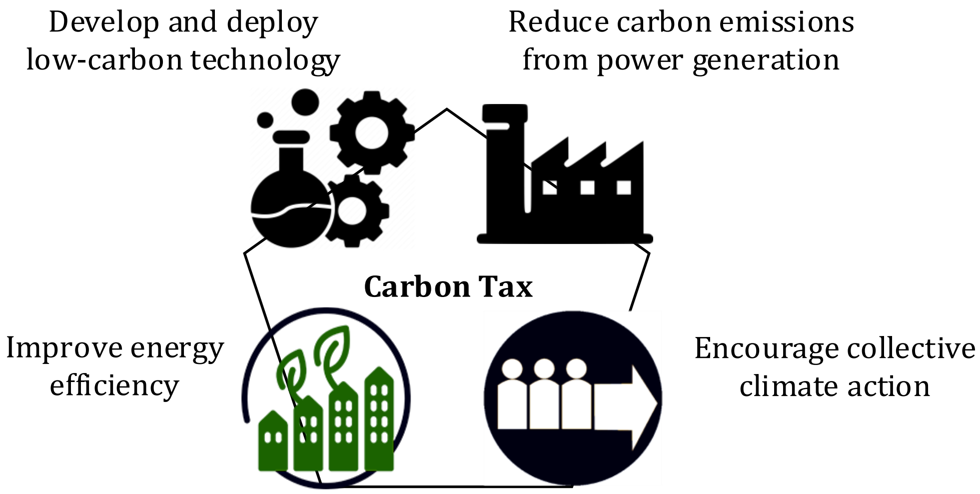

Figure 1. Carbon tax policy in Singapore's mitigation strategy [13]

Carbon legislations and policies are classified into three research streams in the literature, carbon tax (Du et al (2017), cap-and-trade (Du et al (2015),and emission constraints(Busch.et al(2007).The present study develops carbon-tax legislation in a dyadic supply chain. Among the three mentioned carbon policies, the carbon-tax is rarely investigated in the coordination literature. This study fills out the gap of proper mathematical modeling of carbon-tax in coordination problem. Finally, the proposed setting is concentrated on welfare rather than monetary profits. This study investigates channel decisions to resolve the supply chain entities conflict and avoid the double-marginalization effect, using a revenue sharing contract. As the body of the literature shows; coordination mechanisms are mainly subcategorized into four distinct areas (Arshinder et al (2008), Sabbaghnia (2018)). Fortunately, all the coordination schemes in traditional supply chains could be utilized in a sustainable supply chain system. In this study, CEA (consumer environmental awareness) and governmental restrictions, originating from global warming are considered as the moving engine of business-owners in being accountable for their business's environmental impact. In coordination problem studies like Li, et al. (2020), Hu, et al. (2018) and Ranjan and Jha (Ranjan et al(2019) explore the pricing issue in a dyadic supply chain structure.

The body of the literature is investigated in two different areas, supply chain coordination efforts and emission abatement studies. Sustainable supply chain coordination is an extension of classic supply chain coordination, which is thoroughly analyzed in this paper. Next, carbon policies are shortly discussed to point out the research gap and develop the model settings.

In particular, in the supply chain decision-making methods, there are two kinds of decision-making, decentralized and integrated (centralized).

The interactions between consumers' environmental awareness (CEA), and carbon regulations provides us a rich body of literature. One can run the gamut from different penalizing approaches on carbon emission to the different demand elevations extracted from the consumers' preferences. Studies like Hong et al (2019) and Zhou et al (2016) focus on the environmental awareness of the consumers and yet consider the carbon regulations as a mandatory requirement imposed by the government, while Yang, et al. (2017), Xu, et al. (2017) and Yang and Chen (2018) primarily study the carbon legislations in presence of environmentally aware consumers.

In an integrated mechanism, the supply chain entities accept a unified set of decisions, decided by the supply chain manager. This behavior leads to the global optimization of the supply chain, which not necessarily means the better performance for each supply chain's member. On the other hand, in the decentralized mechanism, the supply chain entities optimize their performance independently and in a decentralized structure. In this mechanism, the optimality of the whole supply chain is not necessarily promised. To motivate the members, engage in coordination decision-making mechanism, proper motivational schemes are required. In the literature of the coordination, several mechanisms are developed. One popular stream of these efforts is focused on coordinating contracts, namely; cost/revenue sharing, quantity discount, delay in payments, etc. (Arshinder(2008), Kabra(2015), Qian (2020)). Different studies have analyzed the different aspects of coordinating mechanisms and contracts. These efforts are developed under various business models. Some informative details could be found in (Cachon et al (2003), Modak et al (2016), Huang et al (2016), Sabbaghnia et al (2019)). Table 1 presents and compares the most related studies based on the applied contract, decision variables, and demand patterns. Most of the reviewed studies did not consider both environmental awareness of the consumers and carbon legislation at the same time. However, similar studies fail in providing a simple model in analyzing the behavior of the supply chain members. Carbon tax, is not been under investigations as much as the other two carbon regulations and needs to be explored for possible operational advantages over the cap-and-trade and emission constraints. Carbon tax promises a confidence level on emission prices, while cap-and-trade ensure emissions quantities. Addressing emission abatement costs, from the perspective of corporates, tax policy is favorable(Goulder (2013), He (2020)).

Supply chain coordination problem in context of the sustainability rarely combines the carbon regulations with the environmental preferences of the consumers, let alone the carbon tax regulation. To the best of our knowledge, there are few studies considering both CEA and carbon regulations. This study presents a dyadic supply chain structure where the manufacturer is the Stackelberg leader, determining wholesale price and emission abatement level. While the retailer, the Stackelberg follower, determines the retail price.

Table 1. Comparison of relevant studies with this paper.

Authors	Contract	Power structure	Sustainability aspects		Carbon regulation			Decision variables				
			Environmental	Economics	Tax	Cap-and-Trade	Emission constraints	Retail price	Wholesale price	Carbon emission	Greenness effort	Others
Wang, et al. [33]	WSP/CS	R	*	*				*			*	*
Zhou, et al. [21]	CS	M	*	*				*			*	
Ji, et al. [34]	-	M	*	*			*	*	*		*	
Yang and Chen [24]	RS/CS	-		*				*	*	*		
Ma and Gao [35]	WSP	M	*			*	*	*	*	*		
Liu, et al. [36]	RS	M	*					*	*	*		
Xu, et al. [23]	WSP/CS	M		*		*		*		*		
Yang, et al. [22]	RS/WSP	R			*					*		*
Peng, et al. [37]	RS/QD	S				*		*		*		*
Xu, et al. [38]	RS	M	*	*		*		*	*	*		
This study	**RS**	**M**	*	*	*			*	*	*		

Abbreviations:
WSP: wholesale price contract; **CS**: cost sharing contract; **RS**: revenue sharing contract; **QD**: quantity discounts.
R: retailer; **M**: manufacturer; **S**: supplier.

The rest of the paper is structured as follows. In section 2, the investigated problem is described and required parameters are well defined. The proposed model is applied into three different decision-making structures, centralized, decentralized and coordinated. The specifications of a revenue-sharing contract are introduced and utilized to meet the scope of our problem. Next, test problems and numerical examples are executed to run the sensitivity analysis. Finally, future research avenues are introduced and managerial insights of the results are highlighted.

2. Problem description

In this paper, a two-echelon supply chain with a single retailer and manufacturer is considered. It is assumed that a green product is produced by single manufacturer. The green or emission level as a decision variable evaluated by carbon emission tax procedure.

The considered demand function for sustainable and green parts depends on the carbon emissions reduction level. To escape the unnecessary complexity of the nonlinear expressions, the demand function can be formulated as Equation (1). This form of demand function is popular in the literature (Heydari et al(2020), Ma et al (2017)).

$$D = a - bp + me \tag{1}$$

In Equation (1), *a, b,* and *m* are the potential size of the market, *b* and *m* represent the market sensitivity coefficients. Also, *e* and *p* are emission reduction and retail price, respectively. The parameters' and decision variables' correlations could be achieved by the presented demand linear formation nature and running analytical investigations on them (Babazadeh et al (2018). Following the literature, the CE reduction cost is considered as θe^2. Consideration of this structure defines the investment of carbon reduction too. This approach of addressing the carbon emission cost structure is a common method as the body of the literature reveals (Aljazzar et al (2018), Bazan et al (2017)). Leading energy companies are facing a dilemma regarding the emission abatement. Emissions pose costs including tax, environmental fines and penalties, on the other hand, technological investments demand huge amount of capital to be spend on reducing the emission rates of the fuels to be used in the business process. Hopefully, the green preferences of the consumers come in favor of the investments to be spent on this regard. Nevertheless, corporations and business owners are compelled to follow the carbon regulations imposed by the governments.

The framework of this paper is as follows: the decentralized decision-making scenario is carried out first. Afterward, the centralized decision-making scenario is expanded by developing the model. Then, a coordinated decision-making procedure is presented to obtain a win-win solution, motivating both members to decide in a coordinated mechanism. The decisions are determined in the following order, first, the supply chain leader determines the emission abatement level and wholesale price (in the decentralized structure), and then the retailer determines the retail price. However, as the Stackelberg model is handled by the backward induction, this is the retailer who optimizes its own decision variable(s) and then the leader (manufacturer) determines its decision variables. The intended decision variables and parameters of the developed models are as follows:

Decision variables

e	The effort of Emission reduction
w	The wholesale price of the manufacturer
p	The selling price of the retailer

Parameters

D	The demand of consumer
a	The size of the market
b	The sensitivity coefficient of the retail price
m	The sensitivity coefficient of emission
e_0	The initial production emission
c	The production cost of the manufacturer
t	The carbon tax of government
θ	The cost coefficient of emission reduction

2.1. Decentralized decision-making process

In this instance, there is a Stackelberg game procedure. The leader of the channel plays the manufacturer or the upper stream role of the supply chain, while the follower of the channel plays the retailer or the lower stream of the supply chain. The upper stream tries to maximize profit. On the other hand, the lower stream follows his own maximum profit. One of the popular approaches to solve the Stackelberg game procedure is backward induction. Equations (2) and (3) represents the profit functions of the upper stream and the lower stream, respectively. These Equations are developed based on the consumer's demand function.

$$\pi_m^d = [w - c - t(e_0 - e)](a - bp + me) - \theta e^2 \tag{2}$$

$$\pi_r^d = (p-w)(a-bp+me) \tag{3}$$

By the maximization of Equation (3), the movement of the retailer and his own price can be determined. Afterward, by the maximization of Equation (2), the decision variables of the manufacturer can be determined.

Theorem 1. *By backward induction and under decentralized decision-making scenario the optimal closed-form of decision variables for the retailer and the upstream manufacturer can be calculated as follows:*

$$p^{d*} = \frac{(m+bt)\left(cm+t\left(a+me_0\right)\right)-2\theta\left(3a+b\left(c+te_0\right)\right)}{(m+bt)^2-8b\theta} \tag{4}$$

$$w^{d*} = \frac{(m+bt)\left(cm+t\left(a+me_0\right)\right)-4\theta\left(a+b\left(c+te_0\right)\right)}{(m+bt)^2-8b\theta} \tag{5}$$

$$e^{d*} = \frac{(m+bt)\left(-a+b\left(c+te_0\right)\right)}{(m+bt)^2-8b\theta} \tag{6}$$

Proof. Since $\frac{\partial^2 \pi_r^d}{\partial p^2} = -2b < 0$ *, the profit function of the retailer in p is concave for each e and w.* $p(w,e) = \frac{a+em+bw}{2b}$ *can be achieved by the application of the first order optimality condition (* $\frac{\partial \pi_r^d}{\partial p} = 0$ *). Also, the manufacturer's best response can be calculated by some calculations and the application of the best response of the retailer into the profit function of the manufacturer. The proof is complete.* ■

The supply chain's and its members' optimal profit function by applying Equations (2)-(6) can be calculated as:

$$\pi_r^{d*} = \frac{4b\theta^2\left(a-b\left(c+te_0\right)\right)^2}{\left((m+bt)^2-8b\theta\right)^2} \tag{7}$$

$$\pi_m^{d*} = \frac{\theta\left(a-b\left(c+te_0\right)\right)^2}{8b\theta-(m+bt)^2} \tag{8}$$

$$\pi_{sc}^{d*} = \frac{\theta\left(a-b\left(c+te_0\right)\right)^2\left(12b\theta-(m+bt)^2\right)}{\left((m+bt)^2-8b\theta\right)^2} \tag{9}$$

2.2. Centralized decision-making process

In this instance, the decisions of all supply chain members will be done as an integrated approach with the goal of increasing the channel's total profit, not their own profits. The optimal values of e and p are obtained through the optimizing the profit function of the supply chain. This is the main difference between decentralized and centralized process considering the mathematical point of view.

Equation (10) demonstrates the supply chain's profit function under the centralized decision-making scenario and the formulation is performed as the summation of the retailer and the manufacturer profit functions.

$$\pi_{sc}^{c} = [p - c - t(e_0 - e)](a - bp + me) - \theta e^2 \tag{10}$$

Theorem 2. The decision variables' optimal closed-form of the channel under the centralized decision-making scenario can be calculated as follows:

$$p^{sc*} = \frac{(m+bt)\left(cm + t\left(a + me_0\right)\right) - 2\theta\left(a + b\left(c + t_0\right)\right)}{\left(m+bt\right)^2 - 4b\theta} \tag{11}$$

$$e^{sc*} = \frac{(m+bt)\left(-a + b\left(c + te_0\right)\right)}{\left(m+bt\right)^2 - 4b\theta} \tag{12}$$

Proof: Since $\frac{\partial^2 \pi^{sc}}{\partial p^2} = -2b < 0$*, the profit function of the supply chain in p is concave for each e. In addition, the Hessian matrix is also numerically checked and we observed the concavity of the profit function in both decision variables. The channel's decisions can be achieved by the application of the first order optimality condition* $\frac{\partial \pi^{sc}}{\partial p} = 0,\ \frac{\partial \pi^{sc}}{\partial e} = 0$ *and some straightforward calculations. The proof is complete.* ■

The supply chain's optimal profit in the centralized decision-making process can be achieved as Equation (13).

$$\pi_{sc}^{c*} = \frac{\theta\left(a - b\left(c + te_0\right)\right)^2}{4b\theta - \left(m+bt\right)^2} \tag{13}$$

The profit can be reached a high value of the supply chain channel for the centralized solution against the decentralized scenario. However, this solution for all members cannot accept participating in the centralized decision-making procedure. Because the solution may not be appropriate for some members of the supply chain regarding the earned revenue of them. To coping with this issue, a coordinated decision-making process will be expanded to guarantee further profit for both supply chain members in comparison with the decentralized decision-making. By this way, the results of profit for the whole supply chain will be optimized.

2.3. Channel Coordination

To determine the confliction of the channel, a mechanism is proposed in the Stackelberg model to set the manufacturer (the upstream of the supply chain) for making a division of the profits as known, revenue sharing contract.

In an RS contract, the items are sold by the manufacturer at a unit cost ($w_{RS} < c$) and also, a fraction α of the total revenue of retailer is received. The constraint $w_{RS} < c$ guarantees the coordination of channel. Furthermore, the distribution of profit among the supply chain members will be resolved by α according to Cachon (2003). By considering the RS contract, the profit functions are as follows:

$$\pi_{m}^{RS} = [(1-\alpha)p + w_{RS} - c - t(e_0 - e)](a - bp + me) - \theta e^2 \tag{14}$$

$$\pi_{r}^{RS} = (\alpha p - w_{RS})(a - bp + me) \tag{15}$$

Necessary optimality condition $\frac{\partial \pi_m^{RS}}{\partial w} = 0, \frac{\partial \pi_m^{RS}}{\partial e} = 0,\ \frac{\partial \pi_r^{RS}}{\partial p} = 0$ yields:

$$p_r^{RS*} = \frac{(m+bt)(cm+t(a+me_0)) - 2\theta(a+b(c+te_0)+2a\alpha)}{(m+bt)^2 - 4b\theta(1+\alpha)} \quad (16)$$

$$w_m^{RS*} = \frac{\alpha(m+bt)(cm+t(a+me_0)) - 4\alpha\theta(b(c+te_0)+a\alpha)}{(m+bt)^2 - 4b\theta(1+\alpha)} \quad (17)$$

$$e_m^{RS*} = \frac{(m+bt)(b(c+te_0)-a)}{(m+bt)^2 - 4b\theta(1+\alpha)} \quad (18)$$

Implementing the optimal values of the decision variables from equations (16)-(18) into the equations (2) and (3) we have the optimal values for the retailer, the manufacturer, and the SC in overall, respectively:

$$\pi_r^{RS*} = \frac{4b\alpha\theta^2(a-b(c+te_0))^2}{\left((m+bt)^2 - 4b(1+\alpha)\theta\right)^2} \quad (19)$$

$$\pi_m^{RS*} = \frac{\theta(a-b(c+te_0))^2}{4b\theta(1+\alpha) - (m+bt)^2} \quad (20)$$

$$\pi_{sc}^{RS*} = \frac{\theta(a-b(c+te_0))^2\left(4b\theta(1+2\alpha) - (m+bt)^2\right)}{\left((m+bt)^2 - 4b(1+\alpha)\theta\right)^2} \quad (21)$$

3. Numerical results

Different parameter values are considered as $a=10$, $b=1$, $m=2$, $\theta=50$, $e_0= 3.5$, $c=5$, $t=3$ to achieve efficient insights on the coordination of the channel and also the behavior of the supply chain entities. The test problem parameters are extracted based on the similar problems in the literature. For more detailed arguments one may refer to (Li et al (2020), Sabbaghnia et al; (2019), Modak et al (2016), Panda et al (2016), Panda et al (2017), Panda et al (2015)). Afterward, the tax rate consequence on key decision variables such as abatements, the profits of supply chain and the prices of retailers are examined.

As mentioned, in this paper, three decision-making scenarios are considered; Centralized, Decentralized, and Coordination with RS contract. The quantities of emission reduction for these scenarios are shown in Figure 2. Without considering the decision modes, the abatements are growing increasingly and then they get smooth. The results show a high performance of RS contract in comparison with the centralized scenario in emission abatement. In addition, the minimum emission reduction happens under the decentralized scenario. One of the important insights is the increasing coverage of the emission reduction levels under centralized and coordinated scenarios by increasing the carbon tax. Thus, an appropriate carbon tax is of most important.

Figure 3 illustrates changes in the optimal retail price when tax rate is changed. More environmentally conscious costumers are eager to pay more for low-carbon sectors. It is interesting that the tendency of prices gets more converge as the carbon tax is grown.

Figure 4 shows the effect of the carbon tax on channel profits. The figure shows the reducing impact of the total profit of the supply chain by increasing the carbon tax. Note that double-marginalization effect consequences decentralized supply chain to the lowest profit quantities among other schemes. It is interesting that the centralized and coordinated scenario get converge by increasing carbon tax while the decentralized scenario is decreasing faster than two others are.

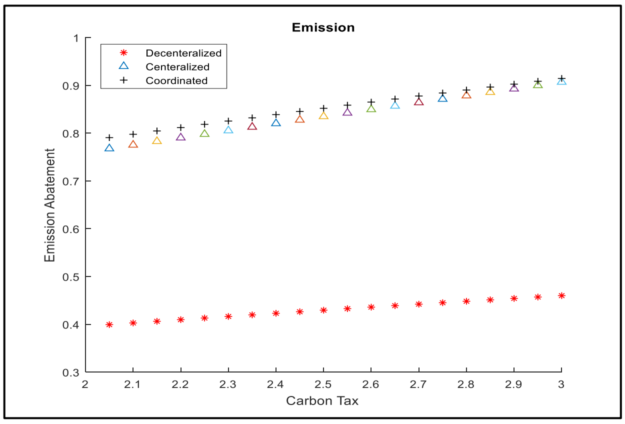

Figure 2. The effect of the carbon tax on carbon emission level

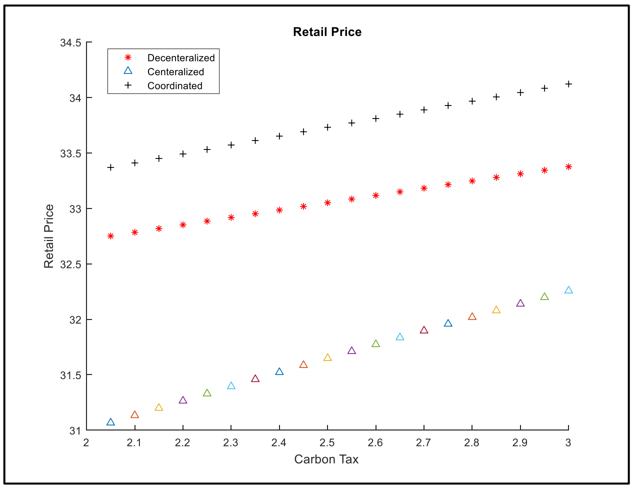

Figure 3. Carbon tax impact on retail price

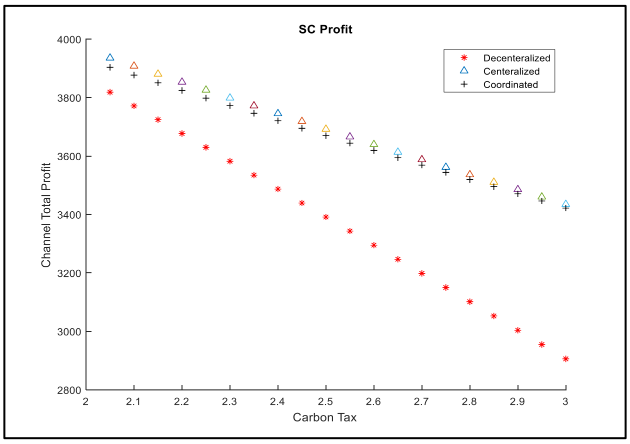

Figure 4. Carbon tax impact on channel profits

Interesting behavior is observable on emission abatement, recall equations (6), (12) and (18), the emission reduction effort on decentralized scenario is always less than the centralized scenario, $e^{d*} < e^{c*}$. Similarly, if the contract controlling parameter α is set to zero, the value of emission abatement in the centralized scenario equals to the value of the contract-based coordinated scenario. However, as α raises, and the profit gained from the integrated decision-making is dividing, the value of emission reduction effort drops in comparison to the centralized decision-making scenario, thus, $e^{con*} < e^{c*}$.

If the controlling parameter sets to its extreme value (α=1), all the possible extra profits are allocated to the manufacturer, thus no coordination occurs.

4. Managerial insights

Two main conclusions could be driven out from the results discussed: (1) carbon-tax can leads to carbon abatement, and (2) revenue-sharing contract could resolve the channel conflict with green sensitive consumers and carbon regulations imposed by the authorities. Manufacturer-led power structure is a common business relation. Major manufacturers around the globe develop their relations with their downstream supply chain members based on their huge bargaining power, Coca-Cola, Apple, Fiat, Toyota etc., are just some examples from various industries. Implementing carbon-tax is easier and thus the corporates tend to apply this regulation in comparison to the cap-and-trade and carbon emission constraints. The manufacturer's sustainability level is positively related with carbon tax. Further, business owners are affected with the revenue-sharing contract coefficient as they need to motivate the supply chain members to participate in an aligned decision-making procedure. As the carbon tax directly affects firm's carbon abatement effort; thus, it affects profit of the company. Consumers' low-carbon and green preference also affect the supply chain members' sustainability effort and pricing decisions.

5. Discussion and concluding remarks

In this study, the coordination problem is investigated in a dyadic sustainable supply chain. Sustainability considerations are mostly concentrated on the product's carbon footprint. The total performance of the supply chain is elevated through a revenue-sharing contract, resolving channel conflict. Carbon tax and CEA are used to investigate the supply chain's optimal decisions. Consumers' green preferences force the business owners to apply more sustainable methods into their business process. A single manufacturer and a single retailer under the carbon-tax policy and consumers' environmental awareness is coordinated through a revenue-sharing contract. The obtained results show significant promise on sustainable supply chain coordination in the presence of environmentally aware consumers and carbon emission policies. To cope with the real-world business environment, a decentralized (independent) decision-making scheme is utilized, next, to depict the best possible benchmark, an integrated (centralized) decision-making approach is executed to determine the supply chain decisions. Finally, a revenue-sharing contract is proposed to fully coordinate and optimize the performance of different entities of the proposed two-echelon supply chain. In a coordinated decision-making scenario, the upper stream of the supply chain (manufacturer) agrees to set a new lower wholesale price, to earn a specific share of the retailer's revenue in return. The applicability of the proposed revenue-sharing contract is proven through analytical results and sensitivity analysis. Further, numerical examples result in significant emission abatement level.

Finally, future research avenues and directions could be summarized as follows:
-Developing coordination models under uncertainty considerations,
-Studying supply chain networks with more complex relations,

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