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Pricing strategies in a dual-channel green supply chain with cannibalization and risk aversion

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ABSTRACT

This paper investigates a dual-channel supply chain in which a single manufacturer offers the standard product through a direct online channel and an inaugural green product through a traditional physical store (regular) channel. The manufacturer invests in a greening effort to produce green products by incorporating environment friendly features. These green products are offered to customers at a higher price in coordination with a downstream retailer. Standard (non-green) products, however, do not possess the enhanced green features and are offered by the manufacturer at a discounted price to customers using a direct channel. In this paper, we develop dual-channel supply chain (DCSC) coordination models for a more generalized case where the manufacturer and retailer are assumed to be risk averse. The risk aversion is modeled using a popular measure, namely, the mean-variance criterion. Further, the proposed DCSC coordination models enhance the existing DCSC coordination models in the literature, by allowing varying proportions of the market share associated with the traditional regular and online channels in lieu of fixed proportions. This is achieved by utilizing the price differentiation tool from revenue management for effectively segmenting the proportion of expected market share of the regular and online channels as a variable instead of a fixed value. In the proposed model for decentralized channel coordination, the manufacturer decision variables include price differentiation, wholesale price for greening products, and pricing in the direct channel along with the greening effort investment. Unlike manufacturer, the retailer plays the role of the follower within a leader-follower framework and decides on the retail price of the green products sold through the regular channel. For the integrated channel, the manufacturer determines the pricing for green and standard products in addition to the greening effort in a monopoly. The study also explores the supply chain coordination under revenue- and cost-sharing contracts for the dual channel supply chain. The models are unique since they capture the effects of demand cannibalization or demand leakage, which affects the supply chain revenue maximization due to price differentiation. A detailed numerical experimentation is carried out to investigate the impact of the risk-aversion, demand leakage, and market uncertainty on the performance of supply chain coordination.

1. Introduction

The majority of the global manufacturers including Samsung, Apple, Hewlett Packard and Lenovo are selling products through the direct online channel in addition to the traditional retail or regular channel [25,88]. The direct online selling allows the producing firms to build a superior customer relationship management and obtain vital demand information [18,85]. Thus, the dual channel structure of regular and direct online channels, enhances the outreach and may yield higher bargaining power to manufacturers. From the customer perspective, a dual channel structure can be an attractive proposition because of the greater degree of shopping choices, enhanced service experience,

greater convenience, and reduced transactional cost. From the manufacturer and retailer perspectives, however, the direct online selling by manufacturers can result in a number of supply chain coordination issues between the two in terms of competition, pricing, degree of interdependence, promotions and operations [14,49]. Depending on the coordination choices, the outcomes can be mixed for different supply chain partners, and the supply chain relationships can be characterized by a greater degree of competition or cooperation. Owing to a channel conflict between the two, the operation of a direct channel by the manufacturer may be perceived as a threat by the retailer and can lead to risk aversion [20,55]. Recently, the dual channel supply chain coordination problem, where one or more supply chain members

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undertake a greening effort has received much attention in the supply chain management literature [50,54].

Over the past decade, sustainability issues have gained momentum in supply chain coordination and an increasing preference of customers towards green products is observed [8,29,39,97]. A number of studies have appeared in the literature on supply chain coordination in green supply chains [3,36,42,80]. The green supply chain coordination involves coordination between supply chain members with respect to the greening decisions such as green pricing, greening effort, corporate social responsibility investment, product greenness and green quality, and inventory and routing decisions [13,15,61,70]. More recently, researchers have extended the research in the green supply chain coordination to dual channel supply chains (DCSC) [50,54]. The green supply chain problems in DCSC often deal with regular and direct online channels selling green and standard or non-green products. Many studies that discuss the coordination of green supply chain in a dual channel structure assume cross price sensitivity to explain customer switching behavior between channels [53,54]. Each channel has a self-price and cross-price sensitivity coefficient where the self-price coefficient is assumed to be higher among the two [18]. However, the aforementioned studies assume that the proportion of customers who prefer a particular channel is predetermined and fixed. In most real-world supply chains, however, the proportion of customers that opt for the regular or direct online channel may not be fixed. Further, the tactical nature of the pricing decisions entails that the model allows more flexibility in determining the relative expected market share of each channel. The models proposed in the current study introduce a more flexible way of modeling the DCSC green supply chain coordination by utilizing the price differentiation tool from revenue management and incorporating the demand cannibalization concept in lieu of the cross-price sensitivity [63,68,71,98]. Price differentiation exploits the heterogeneity of the customer's willingness-to-pay to divide the market demand into two or more segments where each segment has a different price [30,63,82,92]. Price fencing is used to ensure that customers having a similar degree of willingness-to-pay typically buy from the same segment. Nevertheless, even the best price fencing schemes often fail to contain customers from buying from the lower priced segments. This leads to a demand cannibalization or demand leakage; that is, a decrease in the demand for the higher priced product or segment because of the fraction of customers deciding to buy the lower priced product. The segmentation is achieved using a differentiation price where the latter is defined as a random variable. In contrast to the self- and cross-price sensitivity models for DCSC coordination, the expected market share of each segment in this study is a variable that depends on the differentiation price and can be controlled [63]. The variable differentiation price allows modeling of the demand leakages in DCSC green supply chain coordination without the restrictive assumption of a fixed expected market share.

In addition to the utilization of the price differentiation tool, we also incorporate risk aversion in the proposed models. Typically, the majority of the studies in dual supply chain coordination and almost all studies in green supply chain DCSC assume risk neutral supply chain members. In a DCSC problem involving greening, the presence of risk aversion is a more reasonable assumption because of the channel conflict between the manufacturer and retailer. The sources of conflict can arise since the manufacturer may assign higher priority to one channel compared to another with regards to decisions such as inventory allocation, promotional deals and new product launches. The literature on DCSC coordination consists of several studies on involving risk averse supply chain members that employ risk aversion modeling using mean-variance [55] or Variance-at-Risk (VaR) and Conditional-Variance-at-Risk (CvaR) [53]. Our study investigates the problem of green supply chain coordination for the DCSC assuming risk aversion behaviors by the supply chain members. However, our investigation is different from other studies analyzing pricing and operational decisions of risk averse supply chain members in DCSC. The highlights are presented in the

following paragraph.

In this study, the manufacturer coordinates with a retailer (or seller) to sell a priced green product using a regular channel and a standard product at a relatively lower price through a direct online channel. The terms retailer and seller are used interchangeably in this paper. Models are proposed for pricing, inventory and greening effort decisions in green supply chain coordination for DCSC where the manufacturer and seller are assumed to be risk averse. Mean-variance modeling is employed to model the risk aversion which constrains the risk within a prespecified risk tolerance. The mean-variance framework introduced by Markowitz [56] has several advantages in modeling risk aversion [1,16,53,91] since it enables transforming a stochastic (probabilistic) problem to a deterministic approximation which is distribution-free in nature [32,65]. The mean-variance allows effective modeling of the risk aversion in dual supply chains. In order to replace the fixed proportions of expected market share of regular and direct online channel with variable proportions, the price differentiation tool from revenue management is employed. In this way, the proportions of expected market share of the two channels are not predetermined but controlled by the manufacturer through the differentiation price. This facilitates the modeling of the impact of cannibalization or demand leakages on pricing, greening effort, and inventory in the regular channel (green product) and direct online channel (standard product). Closed form solutions are obtained for the following decisions: wholesale price, differentiation price, regular channel price, direct online channel price, greening effort and inventory. To the best of authors' knowledge, the impact of cannibalization proportion or demand leakage proportion on supply chain coordination decisions including pricing, greening effort and revenue of manufacturer and seller, and overall revenue is investigated for the first time in the context of green DCSC coordination. Similar to most papers on supply chain coordination, the decentralized and integrated coordination between manufacturer and seller are investigated. Further, models are also developed to understand the impact of revenue-sharing and cost-sharing contracts on pricing, inventory and greening investment under risk aversion.

The remainder of the paper is structured as follows. A brief literature review is presented in Section 2. The motivation and contribution are presented in Section 3. The proposed supply chain coordination models are developed in Section 4. Section 5 discusses a numerical example. Finally, conclusions, managerial implications and future research are presented in Section 6.

2. Literature review

In this section, we discuss relevant literature in dual supply chains, risk aversion in supply chain coordination, green supply chains, and price differentiation and cannibalization in dual channel supply chains. Several studies in the supply chain coordination literature discuss decision making in dual channel supply chains. Chiang et al. [23] highlight the importance of a direct online channel in moderating retailer prices in monopolistic and oligopolistic settings and suggest that the profits of retailers can be higher post-introduction of a direct online channel. Chen et al. [19] analyze manufacturer-retailer interaction in a DCSC by integrating a consumer channel choice model with the operational decisions of manufacturer and retailer and validate their recommendations through field experiments. Dumrongsiri et al. [28] highlight the role of demand variability on the manufacturer's decision of adding a direct channel. Cai [12] define Pareto zones for deciding whether the supplier and retailer can benefit from adding a new channel or by entering into a contract. Xiao and Shi [89] propose game-theoretic models to handle the decisions related to pricing and supply priority. Chen et al. [17] investigate price and quality decisions in DCSCs, where the single product is delivered using three methods: a regular channel, a direct online channel, or a dual channel. They conclude that the dual channel structure provides highest quality level and sale price in a centralized coordination. For decentralized channel, the

price and quality depend on channel relative power, quality coefficient, and channel substitutability. Huang and Swaminathan [49] study the effect of alternative pricing strategies when the product is sold in a dual channel in monopolistic and duopolistic settings. Huang et al. [48] study the inventory and pricing policies for a DCSC under a stochastic demand. The duopolistic competition is considered for a pure e-tailer and e-tailer with traditional channels. Dan et al. [25] study the effect of retail services and customer loyalty on the pricing behaviors of supply chain members. Modak and Kelle [58] study the DCSC coordination assuming a stochastic demand where the information regarding the distribution of the demand may not be known. The demand is dependent on price and delivery lead time. At the same time, several studies investigate use of contracts in DCSC coordination [11]. For example, Geng and Malik [34] introduced a contract where the retailer is transferred a portion of the revenues earned by the manufacturer through the direct online channel [31]. They refer to the contract as a reverse revenue-sharing contract. Chiang [21] propose and implement a new type of contract “inventory and direct revenue-sharing contract” that reformulates the profit function of each player in DCSC. Finally, Chen et al. [18] propose contracts to achieve manufacturer-retailer coordination in DCSC.

However, the majority of these studies assume that the supply chain members are risk neutral. Recently, however, studies have been conducted with the underlying assumption that supply chain members are risk averse [90]. Xu et al. [91] employ the mean-variance model [57] to study the impact of risk tolerance on the manufacturer's and retailer's pricing decisions in decentralized and centralized supply chain coordination and propose a two-way revenue-sharing contract for effective coordination. Li et al. [53] consider the case of a risk neutral supplier and risk averse retailer using both Value-at-Risk (VaR) and CVaR measures within a DCSC context for uncertain demand and propose a risk sharing contract. Chen et al. [20] also employ CVaR to study risk aversion in DCSC in the context of manufacturer's encroachment. Some of the older studies have modeled the employed risk aversion using mean-variance modeling for a single channel supply chain [1,24,33]. Liu et al. [55] investigate pricing policies in DCSC where the supply chain members are risk averse and consider the case of information asymmetry assuming an unknown degree of risk aversion.

The domain of supply chain management today emphasizes Green Supply Chain Management (GSCM). The latter aims to reduce the impact of supply chain activities on environment and involves integration of green strategies in various facets of supply chain operations management including design, procurement, processing, delivery, end use and post-use [5,79,102,103]. For example, Ghosh and Shah [36,37], Swami and Shah [80] and Sinayi and Rasti-Barzoki [77] propose models to make decisions on pricing and greening effort in a single channel supply chain for different coordination schemes. Basiri and Heydari [4] study impact of the green quality and sales effort in GSCM. The GSCM literature also covers a range of contracts including cost-sharing contract [46,52,64,95], revenue-sharing contract [78,96], buyback contract [27], wholesale price contract [64], and two-part tariff [36,46,64]. In recent times, research in DCSC in the context of sustainability is gaining increasing attention. Li et al. [53] consider the pricing and greening strategies in DCSC coordination between a manufacturer and a retailer and establish conditions for the adding a direct channel by the manufacturer. They use a two-part tariff to coordinate the dual channel green supply chain. Chen et al. [17] compare the dynamics of price quality in single channel supply chains and DCSCs. Jamali and Barzoki [50] investigate the competition on the basis of green parameters between manufacturers and retailers in two DCSCs offering green and standard products. However, none of these studies assume risk aversion nor do they model the demand leakage between channels. Xu et al. [91] investigate the impact of risk tolerance on pricing in a risk averse DCSC and coordinate the DCSC by a two-way revenue-sharing contract. However, their study does not consider greening effort and assumes that the proportion of expected market

share split between the regular and direct online channels are exogenous. Li et al. [53,54] also base their study on the assumption that the proportion of expected market share of each channel is exogenous.

In order to model the splitting of the proportion of the expected market share between the regular and direct online in a more flexible manner such that the proportion is variable rather than exogenous and predetermined, we utilize differentiation pricing in this study. Phillips [63] uses differentiation price as a tool to control the expected market share of the different market segments. Phillips [63] and Talluri and Ryzin [82] show the effectiveness of price differentiation in market segmentation for improved profitability. Zhang and Bell [99] and Zhang et al. [101] enhanced the work by considering the effect of demand leakages between segments and proposed fencing schemes to mitigate demand leakages. The models proposed in this study not only assume risk-averse supply chain players in green DCSCs, but also consider cost-sharing and revenue-sharing contracts for green coordination of the DCSC that sells two products. Moreover, the defining feature of our study is the utilization of the price differentiation tool to allow variable in lieu of the fixed splitting of expected market share between the two channels and modeling the impact of demand leakage on pricing, greening effort, inventory (demand) and revenue.

Table 1 presents a summary of the important studies from the literature and compares the contribution of the current study with the previous studies in the table. The contribution of the this paper is to demonstrate the utilization of price differentiation tools from RM and developing efficient contracts (revenue-sharing, and cost-sharing) for DCSC involving greening.

3. Motivation and contribution

The current study is motivated by global consensus on greening and environmental safety concerns faced by most businesses worldwide [5,75,79]. At the same time, businesses adopt greening related activities for achieving improved profitability and performance [39]. Typically, businesses adopting greening activities are faced with market heterogeneity due to multiple market players including governments, manufacturers, retailers, consumers, and other stakeholders [74]. While heterogeneity can result cannibalization [59,63], it can also create profitability opportunities by offering products via distinct (distribution) channels or at differentiated prices [63]; Raza (2015); [68]. Revenue Management (RM), also known as the science of profitability [83] offers promising tools for price differentiation while taking into account demand leakages (cannibalization). Greening activities are perceived differently among the heterogenous customers; therefore, it may be worth exploring the DCSCs where both green and standard products are offered via differentiated price and distinct distribution channel. This work is motivated by considering several factors such as demand leakages, risk-aversion attitude on the supply chain players (manufacturer and retailer). Furthermore, the intent of this work is to exploit the price differentiation tools from Revenue Management (RM) for developing green dual-channel coordination models in the presence of risk aversion among the supply chain members. While exercising the price differentiation in DCSC, the manufacturer segments the expected market share between the two channels to maximize payoff. Existing research studies perform the segmentation by considering an exogenous predetermined market share splitting rule that divides the expected market share into two distribution channels [18,53,54]. Therefore, this study proposes a flexible market segmentation strategy for splitting the expected market share between the direct online and regular channels when the channels experience a price dependent demand and a buy-down cannibalization effect [63]. The objective is to address these complex issues by adopting simple yet elegant frameworks in order to achieve insightful closed-form solutions with managerial implications.

In addition to demonstrating the efficient use of price differentiation for market segmentation, the impact of green product offerings through the regular channel to green-sensitive customers and the direct online

Table 1
Literature comparison.

Literature	SC configuration (closed-loop, network, others)	SC coordination contracts (Revenue-sharing, Cost-sharing, others)	Environmental considerations (Greening investment, Carbon emission control, Govt. incentives, Remanufacturing, others)	Market demand behavior (Deterministic, Stochastic)	SC players attitude (risk-less, risk-neutral, risk-averse)	Decisions (Pricing, Inventory, others)	Others
Cachon and Fisher [10]	Standard	None	None	Stochastic	Risk-neutral	Inventory	Value of information sharing
Ghosh and Shah [37]	Standard	Cost-sharing	Greening investment	Deterministic	Risk-less	Pricing and greening effort investment	Cost-sharing contract
Li et al. (2016)	Channel selection	None	Greening investment	Deterministic	Risk-less	Pricing	Channel selection
He et al. [45]	Dual-channel closed loop	None	Carbon emission	Stochastic	Risk-neutral	Pricing	Free riding behavior
Saha et al. [73]	Dual-channel closed loop	Others	Remanufacturing	Deterministic	Risk-less	Pricing, Rewards	Rewards consideration
Liu et al. [55]	Dual-channel	None	None	Stochastic	Risk-averse	Pricing	Mean-variance analysis
Ji et al. [51]	Dual-channel	None	Carbon emission	Stochastic	Risk-neutral	Pricing, Emission	Customer preferences
Zhu and He [103]	Single-channel	None	Greening investment	Stochastic	Risk-neutral	Pricing, Greening effort investment	Product design
Yang and Xiao [94]	Single-channel	None	Government Interventions	Stochastic	Risk-neutral	Pricing, Greening effort investment	Fuzzy uncertainties
He et al. [44]	Single-channel	Risk-diversification	None	Stochastic	Risk-averse	Pricing, Capacity investment	Capacity investment, CVaR
Jamali and Rasti-Barzoki [50]	Dual-channel	None	Greening investment	Deterministic	Risk-less	Pricing, Greening effort investment	Chain-to-chain competition
Taleizadeh et al. [81]	Dual-channel closed loop	Two-part tariff	None	Deterministic	Risk-less	Pricing, Marketing investment	Marketing effort
Yan et al. [93]	Dual-channel	None	None	Stochastic	Risk-averse	Pricing, Inventory	Demand disruption
Alawneh and Zhang [2]	Dual-channel warehouse	None	None	Stochastic	Risk-neutral	Inventory, Reorder point,	Warehouse management
This paper	Dual-channel	Revenue-sharing, Cost-sharing	Greening investment	Stochastic	Risk-averse	Pricing, Greening effort investment	Market segmentation via price differentiation, Mean-variance analysis

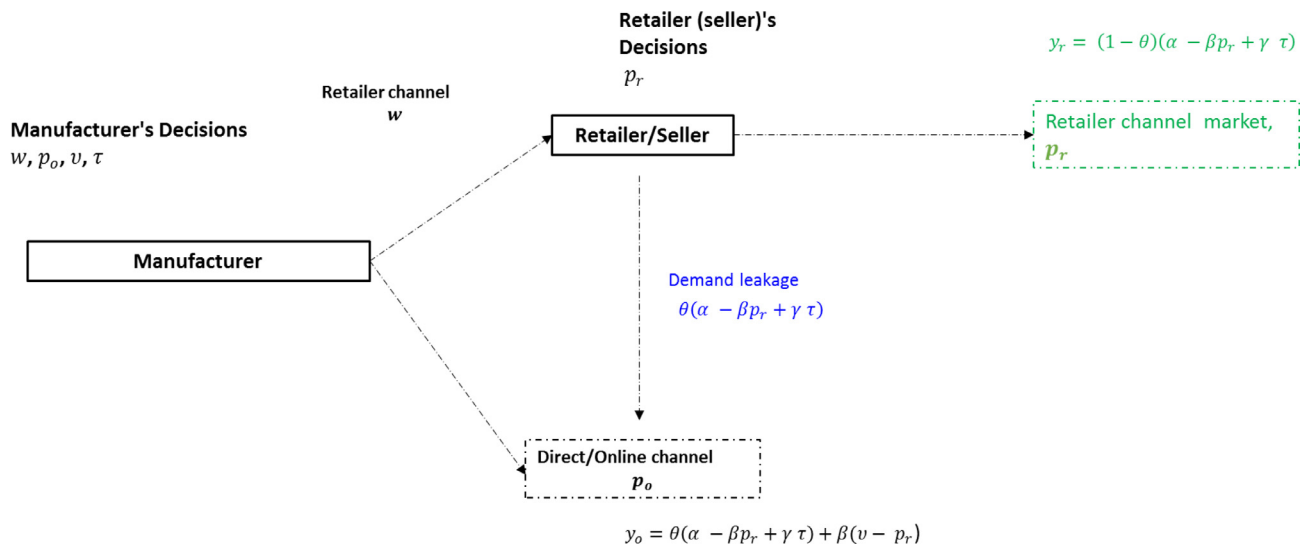


Fig. 1. Dual channel supply chain with greening.

channel is also studied. Due to the heterogeneity of the green sensitive customers, cannibalization is observed in the supply chain. The paper also seeks to develop a more comprehensive modeling framework by assuming the risk-aversion among the supply chain players (manufacturer and retailer) by pursuing a mean-variance analytical framework. This comprehensive framework considers models for (i) Decentralized channel; (ii) Integrated channel; (iii) Channel coordination through a greening cost-sharing contract; and (iv) Channel coordination through a revenue-sharing contract. The models are maintained simple and elegant by obtaining closed form solutions and proposing efficient solution methodologies to determine pricing and market segment decisions within the context of differentiation pricing.

4. The models

The coordination between a single manufacturer and a retailer (seller) offering two products in a DCSC is presented in Fig. 1. Table 2 lists the notation employed in the paper. The two products are sold at distinct prices using two separate channels in a single selling period. The manufacturer makes and sells green products at a wholesale price w per unit to the seller. The latter in turn offers the green product at a price p_r per unit to the customers. The manufacturer incurs a greening investment τ in order to augment the standard product with green attributes. In addition to the regular channel, the manufacturer also sells the standard (non-green) products through a direct online channel to the customers at a price p_o per unit. Fig. 1 illustrates the proposed Dual Channel Supply Chain (DCSC) model. The market share, a random parameter α_0 , may have followed an arbitrary probability distribution with expected value (mean) α and a standard deviation σ . In a closely related study, Liu et al. [55] assumed that α_0 is normally distributed such that, $\alpha_0 \sim N(\alpha, \sigma)$. However, similar to the work in Liu et al. [55], we used the mean-variance analysis which is deterministic approximation of a stochastic problem, and therefore it remains distribution-free (Gallego and Moon [32]; Raza [65]). Nevertheless, regardless of distribution related information, in most applications, $\alpha \gg \sigma > 0$, which largely guarantees a non-negative expected market share, α .

For purposes of analytical tractability and maintaining consistency with earlier studies, we postulate following assumptions

- 1 The manufacturer and the retailer (seller) coordinate in a single selling period with perfect information. In DCSC only a single product is offered through each channel. The inaugural green products are offered through the regular channel in coordination with a single downstream seller. The standard (non-green) products are offered

Table 2

Notations.

Parameters	
c_m	Cost of manufacturing per unit
α_0	Market share (random variable), α_0 with mean α and standard error, σ
α	Expected market share, $\alpha = E(\alpha_0) > 0$
β	Price sensitivity, $\alpha \gg \beta > 0$
σ	Market share variability, $\sigma > 0$
γ	Market greening responsiveness, $\gamma \geq 0$
δ	Greening effort cost efficiency, $\delta > 0$
θ	Cannibalization (demand leakage) proportion, $0 \leq \theta \leq 1$
k_s	Revenue variance tolerance of retailer (seller)
k_m	Revenue variance tolerance of manufacturer
y_r	Expected adjusted regular (green) channel demand
y_o	Expected adjusted direct online channel demand
π_m	Manufacturer's revenue (payoff)
π_s	Retailer (seller's) revenue (payoff)
π_{sc}	Supply chain (total) revenue (payoff)
Decisions	
p_r	price per unit for a green product in regular channel
w	Wholesale price per unit, $p_r \geq w > c_m$
p_o	Price per unit of standard product in direct online channel
v	Differentiation price, $v \geq 0$
τ	Greening effort, $\tau \geq 0$
ψ	Cost-sharing contract proportion, $0 \leq \psi \leq 1$
ρ	Revenue-sharing contract proportion, $0 \leq \rho \leq 1$
Scripts	
" ^d "	superscript for Decentralized channel, $(p_r^d, p_o^d, w^d, \tau^d, \pi_r^d, \pi_s^d, \pi_{sc}^d)$
" ^j "	superscript for Integrated (joint) channel, $(p_r^j, p_o^j, \tau^j, \pi_{sc}^j)$
" ^{cs} "	superscript for greening cost-sharing contract, $(p_r^{cs}, p_o^{cs}, w^{cs}, \tau^{cs}, \pi_r^{cs}, \pi_s^{cs}, \pi_{sc}^{cs})$
" ^{rs} "	superscript for a revenue-sharing contract, $(p_r^{rs}, p_o^{rs}, w^{rs}, \tau^{rs}, \pi_r^{rs}, \pi_s^{rs}, \pi_{sc}^{rs})$
$E(X)$	Expected value of random variable, X such that $X \in R$
$Var(X)$	Variance of random variable, X such that $X \in R$

directly by the manufacturer in the market using a direct online channel.

- 2 The manufacturer's plant has unlimited capacity and produces zero non-defective products.
- 3 Demand in the regular and direct online channels is simultaneously observed and are uncorrelated. Demand curve is assumed linear downward sloping in the prices in regular and direct online channels.
- 4 The setup cost of fencing the regular and direct online channels is negligible. The manufacturer splits her market share (a random

- variable) between the two channels using a differentiation price.
- 5 Demand cannibalization assumes a unidirectional movement of customers from the high-priced regular to the low-priced direct online channel.
- 6 The demand for regular channel products is linear upward sloping in manufacturer's greening effort.
- 7 The manufacturer's greening initiatives in the regular channel do not incur a marginal cost, but rather result in a one-time investment having a quadratic cost function of greening effort.

Assumptions 1 to 3 are widely observed in most dual-channel supply chain coordination models [22,23,25,55]. Assumption 4 is consistent with Liu et al. [55] whereas Assumption 5 is related to cannibalization [26,35,40]. The cannibalization is a result of segmenting markets using a differentiation price which splits the market share. One such way to achieve this is by using the dual-channel where the product or closely similar is offered through the two channels at different prices. Therefore, some customers originally expected to buy from the higher price segment are likely to move to a lower price market segment. A number of studies have considered the cannibalization effects in optimally splitting a firm's market share using a differentiation price [63,66,67,72]. In contrast to cannibalization, the economics literature has a rich history in analyzing the *cross-elasticity* effects between the two or more pre-existing market segments. Recently many studies in operation management have considered consideration of cross elasticities as demand leakages between the existing markets [60,62,98,100,101]. Raza [66] distinguishes between demand leakages resulted due to cannibalization versus demand cross-elasticity. Assumptions 6 and 7 are widely observed in developing models that interface traditional operations management studies with the greening initiatives [37,69,72,78,76].

Within a leader-follower setting, the manufacturer acts as the leader in the market and splits the expected market share $\alpha = E(\alpha_0)$ between the regular and direct online channels. Along the lines of Zhang et al. [101], Bell [6], Raza [66,57], and Raza and Turiac [71] a linear price sensitivity β is assumed. In order to segment the expected market share α among the two channels, the manufacturer uses a differentiation price v . Unlike most studies in dual-channel supply chain which assume an exogenous (fixed) market share for each of the two channels, the use of a price differentiation, v enables the players (primarily manufacturer) to optimally divide the expected market share among the two channels. The use of price differentiation for market segmentation first demonstrated in Philips [63] and later by several studies have successfully proved the benefits of controlling price differentiation optimally for enhanced profitability [66,67,71,72]. The manufacturer in the regular channel undertakes greening initiatives. A cumulative effort, τ , for the green products leads to an investment of $\delta \tau^2$ by the manufacturer [37,69,72,76]. The greening effort impacts positively the expected demand in the regular channel $u_r = \alpha - \beta p_r$, with an additional sales volume of $\gamma \tau$ observed by the retailer.

Researchers have shown that customers are heterogenous in their willingness-to-pay (WTP) and utilities [30,41,92]. Thus, any market segmentation often results in cannibalization [63,72] and demand leakages [98]. Although modeling a WTP can be complex, many researchers [30,84,87] devise simplified frameworks to model cannibalization in order to capture more realistic estimates for WTP. These enable researcher in finding implementable (preferably closed-form) solutions. The current study employs a simple approach to model cannibalization suggested by Philips [63], where a fraction θ ($0 \leq \theta \leq 1$) is cannibalized by the lower priced, direct online channel operated by the manufacturer. In this situation, the expected adjusted demand in the regular channel is, $y_r = (1 - \theta)(\alpha - \beta p_r + \gamma \tau)$. Consequently, the expected adjusted demand in the direct online channel is $y_0 = \theta (\alpha - \beta p_r + \gamma \tau) + (\beta v - \beta p_0)$. Of the expected adjusted demand observed in the direct online channel y_0 , the component $\theta (\alpha - \beta p_r + \gamma \tau)$ is the cannibalized demand because of customers who

switched from the regular channel to the low-priced, direct online channel. In addition, the direct online channel also experiences a demand $\beta v - \beta p_0$ as the manufacturer exercises a price differentiation, v .

In this section, a variety of models for supply chain coordination between the manufacturer and seller are presented. For example, decentralized channel (Section 4.1), integrated channel (Section 4.2), cost-sharing contract (Section 4.3) and revenue-sharing contract (Section 4.4). The manufacturer's decision variables are the wholesale price w , price of product in direct online channel p_0 per unit, differentiation price v , and the greening investment τ . On the other hand, the retailer's or seller's decision variables include the price of the product in the regular channel p_r .

4.1. Decentralized channel

In the decentralized channel, the manufacturer and the retailer make their decisions independently to maximize their revenues. To model the decentralized coordination, two models are considered; one for optimizing the manufacturer's expected revenue $E(\pi_m)$ and the other to optimize seller's expected revenue $E(\pi_s)$. The manufacturer's model seeks to determine the decision variables, whole sale price w , direct online price, p_0 , differentiation price v , and greening effort, τ that maximize the expected revenue $E(\pi_m)$. The risk is represented by the standard deviation, square root of the variance of revenue, $Var(\pi_m)$. Both the manufacturer and seller profit maximization problems maximize the revenue function, $E(\pi_m)$ or $E(\pi_s)$ subject to the constraint on the risk given by $\sqrt{Var(\pi_m)}$ or $\sqrt{Var(\pi_s)}$ along with the price differentiation related constraints. Recent studies that employ the mean-variance model for the decentralized coordination include [55,91]

The manufacturer earns a revenue from both the regular and the direct online channels. From regular channel, revenue (payoff) per unit is $w - c_m$, whereas from the direct online channel it is $p_0 - c_m$. Therefore, the total revenue (payoff) can be obtained by multiplying the corresponding expected adjusted demand of each channel. That is, the total revenue from regular is $y_r(w - c_m)$ and from direct is $y_0(p_0 - c_m)$. In order to compute the net revenue, the greening investment $\delta \tau^2$ is deducted. Hence the overall expected revenue for the manufacturer $E(\pi_m)$ is given by $E(\pi_m) = (w - c_m) y_r + (p_0 - c_m) y_0 - \delta \tau^2$. The standard deviation of π_m is $\sqrt{Var(\pi_m)} = (w - c_m)(1 - \theta) \sigma + (p_0 - c_m) \theta \sigma$. In a similar way, the seller revenue and risk can be given by $E(\pi_s) = (p_r - w) y_r$ and $\sqrt{Var(\pi_s)} = (p_r - (w + c_s))(1 - \theta) \sigma$ [55]. Now the manufacturer and seller optimization models for decentralized coordination can be formulated as follows. The manufacturer's revenue optimization model intends to determine decision variables w , p_0 , v and τ while maximizing $E(\pi_m)$ and can be written as

$$\max_{w, p_0, \tau, v} E(\pi_m) = (w - c_m) y_r + (p_0 - c_m) y_0 - \delta \tau^2 \tag{1}$$

subject to

$$p_r \geq v \tag{2}$$

$$v \geq p_0 \tag{3}$$

$$\sqrt{Var(\pi_m)} \leq k_m \tag{4}$$

$$v \geq 0$$

where $\sqrt{Var(\pi_m)} = (w - c_m)(1 - \theta) \sigma + (p_0 - c_m) \theta \sigma$.

In the model, Eq. (1) outlines the expected revenue to the manufacturer subject to the pricing related constraints in Eqs. (2) and (3). Given a non-negative differentiation price $v \geq 0$, the condition $p_r \geq p_0$ holds. The constraint, Eq. (4) ensures that variability associated with the payoff, $\sqrt{Var(\pi_m)}$, stays within the prespecified tolerance limit k_m . Similarly, the retailer optimization problem seeks to determine regular price p_r per unit that maximizes the retailer's revenue $E(\pi_s)$ subject to retailer's risk $\sqrt{Var(\pi_s)}$. The model can be written as follows:

$$\max_{p_r} E(\pi_s) = (p_r - w) y_r \tag{5}$$

subject to

$$\sqrt{\text{Var}(\pi_s)} \leq k_s \tag{6}$$

where $\sqrt{\text{Var}(\pi_s)} = (p_r - (w + c_s))(1 - \theta) \sigma$.

The analytical properties are further explored in Propositions 1 and 2 that provide mathematical expressions in closed-form for the seller's pricing decision and manufacturer's decisions with respect to pricing and greening effort. Script, "d" is used to distinguish the decentralized channel model from the rest of the channel coordination schemes forthcoming.

Proposition 1. For given manufacturer's decision (w, v, γ_m), the retailer decisions are

1 When the retailer's risk constraint is not binding

$$p_r^d = p_r(w, \tau) = \frac{\alpha + w\beta + \gamma\tau}{2\beta} \tag{7}$$

2 When the retailer's risk constraint is binding

$$p_r^d = p_r(w) = w + \frac{k_s}{\sigma - \theta\sigma} \tag{8}$$

Also, $v^d = p_r^d$

Proof. The proof is provided in Appendix.

Proposition 2. In the decentralized channel, the manufacturer's decisions are

1 Case (a): When both retailer's and manufacturer's risk aversion constraints are redundant

$$p_o^d = \frac{\alpha\delta(\theta + 3) - 2c_m(\gamma^2 - 2\beta\delta)}{\beta\delta(\theta + 7) - 2\gamma^2} \tag{9}$$

$$\tau^d = \frac{2\gamma(\alpha - \beta c_m)}{\beta\delta(\theta + 7) - 2\gamma^2} \tag{11}$$

2 Case (b): When only retailer's risk aversion constraint is redundant

$$p_o^d = \frac{k_m(4\beta\delta(\theta + 1) - \gamma^2(\theta - 1)) + (c_m(\gamma^2(\theta - 1) - 4\beta\delta(\theta - 3)) - 4\alpha\delta(\theta - 1))\sigma}{(\gamma^2(\theta - 1) - 8\beta\delta(\theta - 2))\sigma} \tag{12}$$

$$w^d = \frac{(c_m(\gamma^2(\theta - 1) - 4\beta\delta(\theta - 4)) - 4\alpha\delta\theta)\sigma - k_m(\gamma^2(\theta + 1) - 4\beta\delta(\theta + 4))}{(\gamma^2(\theta - 1) - 8\beta\delta(\theta - 2))\sigma} \tag{13}$$

$$\tau^d = \frac{\gamma(-k_m\beta(\theta - 5) - (\alpha - c_m\beta)(\theta - 1)\sigma)}{(\gamma^2(\theta - 1) - 8\beta\delta(\theta - 2))\sigma} \tag{14}$$

3 Case (c): When only manufacturer's risk aversion constraint is redundant

$$p_o^d = \frac{k_s(\gamma^2 - 2\beta\delta) - 2\sigma(\alpha\delta(\theta + 1) - c_m(\gamma^2 - 2\beta\delta))}{2\sigma(\gamma^2 - \beta\delta(\theta + 3))} \tag{15}$$

$$w^d = \frac{2(\theta - 1)\sigma(\alpha\delta(\theta + 2) + c_m(\beta\delta - \gamma^2)) + k_s(2\beta\delta(\theta + 1) - \gamma^2\theta)}{2(\theta - 1)\sigma(\beta\delta(\theta + 3) - \gamma^2)} \tag{16}$$

$$\tau^d = \frac{\gamma(-2\alpha\sigma + 2\beta c_m\sigma + \beta k_s)}{2\sigma(\gamma^2 - \beta\delta(\theta + 3))} \tag{17}$$

4 Case (d): When both retailer's and manufacturer's risk aversion constraints are active

$$p_o^d = c_m + \frac{k_m + k_s + k_m\theta}{2\sigma} \tag{18}$$

$$w^d = c_m + \frac{k_s\theta + k_m(-2 + \theta + \theta^2)}{2(-1 + \theta)\sigma} \tag{19}$$

$$\tau^d = \frac{k_m\gamma}{2\delta\sigma} \tag{20}$$

Proof. Provided in Appendix.

Using the results of Propositions 1 and 2, an efficient solution procedure is outlined for determining the decentralized control in the channel.

Solution procedure

- **Step 1:** Input parameters, $\alpha, \beta, c_m, \theta, k_m, k_s, \delta, \gamma, \sigma,$ and σ
- **Step 2:** Compute p_o^d, w^d, τ^d using Eqs. (9)–(11). Let, $w = w^d$, and $\tau = \tau^d$, then calculate, p_r^d from Eq. (7).
- **Step 3:** Estimate, $\text{Var}(\pi_m), \text{Var}(\pi_s)$, where, $\sqrt{\text{Var}(\pi_m)} = (w^d - c_m)(1 - \theta) \sigma + (p_o^d - c_m) \theta \sigma$, $\sqrt{\text{Var}(\pi_s)} = (p_r^d - (w^d + c_s))(1 - \theta) \sigma$.
- **Step 4:** Check feasibility
 - **Step 4a:** If $\sqrt{\text{Var}(\pi_m)} > k_m$ AND $\sqrt{\text{Var}(\pi_s)} > k_s$ then compute p_o^d, w^d, τ^d using Eqs. (18)–(20). Letting $w = w^d$ and $\tau = \tau^d$ calculate $p_r^d = p_r$ as given by Eq. (8). Go to Step 3.
 - **Step 4b:** If $\sqrt{\text{Var}(\pi_m)} > k_m$ AND $\sqrt{\text{Var}(\pi_s)} \leq k_s$ then compute p_o^d, w^d, τ^d using Eqs. (12)–(14). Letting $w = w^d$ and $\tau = \tau^d$ calculate p_r^d as given by Eq. (8). Go to Step 3.
 - **Step 4c:** If $\sqrt{\text{Var}(\pi_m)} \leq k_m$ AND $\sqrt{\text{Var}(\pi_s)} > k_s$ then compute p_o^d, w^d, τ^d using Eqs. (15)–(17). Letting $w = w^d$ and $\tau = \tau^d$ calculate p_r^d as given by Eq. (7). Go to Step 3.
- **Step 5:** Determine, $\pi_m^d = (w^d - c_m) y_r + (p_o^d - c_m) y_o - \delta (\tau^d)^2$ and $\pi_s^d = (p_r^d - w^d) y_r$, where $y_r = (1 - \theta)(\alpha - \beta p_r^d + \gamma \tau^d)$, $y_o = \theta(\alpha - \beta p_o^d + \gamma \tau^d) + (\beta v^d - \beta p_o^d)$, and $v^d = p_r^d$. Compute $\pi_{sc}^d = \pi_m^d + \pi_s^d$.

4.2. Integrated channel

In the integrated channel, the manufacturer and seller operate as a single system and make decisions on the green degree and the sale price simultaneously to maximize the system performance. In integrated channel coordination the optimization model for the supply chain seeks to determine w, p_o, τ and v . The model can be written as follows:

$$\max_{p_r, p_o, \tau, v} E(\pi_{sc}) = (p_r - c_m) y_r + (p_o - c_m) y_o - \delta \tau^2 \tag{21}$$

subject to

$$p_r \geq v \tag{22}$$

$$v \geq p_o \tag{23}$$

$$\sqrt{\text{Var}(\pi_{sc})} \leq k_{sc} \tag{24}$$

$$v \geq 0$$

where $\sqrt{\text{Var}(\pi_{sc})} = (p_r - c_m)(1 - \theta) \sigma + (p_o - c_m) \theta \sigma$

In Proposition 3, the Integrated channel is addressed to find centralized decisions by manufacturer. We solve the problem Eqs. (21)–(24) using the Karush Kuhn Tucker (KKT) optimality condition and have restored to the closed-form solution in Proposition 3 under both scenarios, i.e., when risk-aversion constraint is active and non-active.

Proposition 3. *In an integrated channel, the supply chain decisions are*

1 Case (a): When the risk-aversion constraint is redundant

$$p_r^j = \frac{c_m(-\gamma^2 + \beta\delta) + \alpha\delta(2 + \theta)}{-\gamma^2 + \beta\delta(3 + \theta)} \tag{25}$$

$$p_o^j = \frac{c_m(\gamma^2 - 2\beta\delta) - \alpha\delta(1 + \theta)}{\gamma^2 - \beta\delta(3 + \theta)} \tag{26}$$

$$\tau^j = \frac{(\alpha - c_m\beta)\gamma}{-\gamma^2 + \beta\delta(3 + \theta)} \tag{27}$$

2 Case (b): When the risk-aversion constraint is active

$$p_r^j = c_m + \frac{k_{sc}(2 + \theta)}{2\sigma} \tag{28}$$

$$p_o^j = c_m + \frac{k_{sc}(1 + \theta)}{2\sigma} \tag{29}$$

$$\tau^j = \frac{k_{sc} \gamma}{2\delta\sigma} \tag{30}$$

Also, $v^j = p_r^j$

Proof. The proof for Proposition 3 is provided in the appendix (online supplement).

Using the findings of Proposition 3, we outline an efficient solution procedure for the integrated channel coordination

Solution procedure

- **Step 1:** Input parameters, $\alpha, \beta, c_m, \theta, k_m, k_s, \delta, \gamma,$ and σ
- **Step 2:** Compute p_r^j, p_o^j, τ^j using Eqs. (25)–(27).
- **Step 3:** Estimate, $\text{Var}(\pi_{sc})$ given by $\sqrt{\text{Var}(\pi_{sc})} = (p_r^j - c_m)(1 - \theta) \sigma + (p_o^j - c_m) \theta \sigma$.
- **Step 4:** Check feasibility. If $\sqrt{\text{Var}(\pi_{sc})} > k_{sc}$, then compute p_r^j, p_o^j, τ^j using Eqs. (28)–(30).
- **Step 5:** Determine, $\pi_{sc}^j = (p_r^j - c_m) y_r + (p_o^j - c_m) y_o - \delta (\tau^j)^2$, where $y_r = (1 - \theta)(\alpha - \beta p_r^j + \gamma \tau^j)$, $y_o = \theta(\alpha - \beta p_r^j + \gamma \tau^j) + (\beta v^j - \beta p_o^j)$, and $v^j = p_r^j$.

4.3. Cost-sharing contract

The greening effort τ requires an investment cost $\delta \tau^2$ to the manufacturer. In the cost-sharing (CS) contract, the seller in the dual-channel supply chain offers to share a proportion ψ , where $0 \leq \psi \leq 1$. This helps the manufacturer to reduce the greening cost and improve the revenue [9,37]. Incorporating the cost-sharing contract, the manufacturer's revenue maximization problem is

$$\max_{w, p_o, \tau, v} \pi_m = (w - c_m) y_r + (p_o - c_m) y_o - (1 - \psi) \delta \tau^2 \tag{31}$$

subject to

$$p_r \geq v \tag{32}$$

$$v \geq p_o \tag{33}$$

$$\sqrt{\text{Var}(\pi_m)} \leq k_m \tag{34}$$

$$v \geq 0$$

where $\sqrt{\text{Var}(\pi_m)} = (w - c_m)(1 - \theta) \sigma + (p_o - c_m) \theta \sigma$

Similarly, the retailer's optimization problem is

$$\max_{p_r} E(\pi_s) = (p_r - w) y_r - \psi \delta \tau^2 \tag{35}$$

subject to

$$\sqrt{\text{Var}(\pi_s)} \leq k_s \tag{36}$$

where $\sqrt{\text{Var}(\pi_s)} = (p_r - w)(1 - \theta) \sigma$

In Propositions 4, the expressions for decision variables ($w^{cs}, p_r^{cs}, p_o^{cs}$ and τ^{cs}) when the manufacturer's and seller's risk constraints apply together, singly or none. The superscript ^{cs} denotes the cost-sharing contract.

Proposition 4. *In cost-sharing contract, for a given proportion for cost-sharing, ψ , we have*

1 Case (a): When both retailer's and manufacturer's risk aversion constraints are redundant

$$w^{cs} = w(\psi) = \frac{2\alpha\delta(-4 + \theta(5 + \theta))\psi + c_m(-2 + \theta)(\gamma^2(-1 + \theta) + 4\beta\delta\psi)}{(-1 + \theta)(\gamma^2(-2 + \theta) + 2\beta\delta(8 + \theta)\psi)} \tag{37}$$

$$p_o^{cs} = p_o(\psi) = \frac{c_m \gamma^2(-2 + \theta) + 2\delta(5c_m\beta + \alpha(3 + \theta))\psi}{\gamma^2(-2 + \theta) + 2\beta\delta(8 + \theta)\psi} \tag{38}$$

$$\tau^{cs} = \tau(\psi) = -\frac{(\alpha - c_m\beta)\gamma(-2 + \theta)}{\gamma^2(-2 + \theta) + 2\beta\delta(8 + \theta)\psi} \tag{39}$$

$$p_r^{cs} = p_r(\psi) = \frac{2\alpha\delta(-6 + \theta(6 + \theta))\psi + c_m(-2 + \theta)(\gamma^2(-1 + \theta) + 2\beta\delta\psi)}{(-1 + \theta)(\gamma^2(-2 + \theta) + 2\beta\delta(8 + \theta)\psi)} \tag{40}$$

2 Case (b): When only retailer's risk aversion constraint is redundant

$$w^{cs} = w(\psi) = \frac{k_m \gamma^2(-1 + \theta)\theta - 4k_m\beta\delta(-4 + \theta(4 + \theta))\psi + 4\delta}{4\beta\delta(-1 + \theta)(-4 + 3\theta)\psi} \tag{41}$$

$$p_o^{cs} = p_o(\psi) = \frac{k_m \gamma^2(-1 + \theta) - 4\delta(k_m\beta(1 + \theta) + (\alpha + c_m\beta(3 - 2\theta) - \alpha\theta)\sigma)\psi}{4\beta\delta(-4 + 3\theta)\sigma\psi} \tag{42}$$

$$\tau^{cs} = \tau(\psi) = \frac{k_m \gamma}{4\delta\sigma\psi} \tag{43}$$

$$p_r^{cs} = p_r(\psi) = \frac{k_m \gamma^2 (-1 + \theta)^2 - k_m \beta \delta (-4 + \theta(4 + \theta)) \psi + 2\delta}{2\beta \delta (-1 + \theta)(-4 + 3\theta) \sigma \psi} \quad (44)$$

3 Case (c): When only manufacturer's risk aversion constraint is redundant

$$w^{cs} = w(\psi) = \frac{-k_s \gamma^2 \theta + 2k_s \beta \delta (2 + \theta) \psi + 2\alpha \delta (-2 + \theta(2 + \theta)) \sigma \psi}{(-1 + \theta) \sigma (\gamma^2 (-2 + \theta) + 2\beta \delta (4 + \theta) \psi)} \quad (45)$$

$$p_o^{cs} = p_o(\psi) = \frac{-\gamma^2 (k_s - c_m (-2 + \theta) \sigma) + 2\delta (k_s \beta + (\alpha + 3c_m \beta + \alpha \theta) \sigma) \psi}{\gamma^2 (-2 + \theta) \sigma + 2\beta \delta (4 + \theta) \sigma \psi} \quad (46)$$

$$\tau^{cs} = \tau(\psi) = -\frac{2k_s \beta \gamma + (\alpha - c_m \beta) \gamma (-2 + \theta) \sigma}{\gamma^2 (-2 + \theta) \sigma + 2\beta \delta (4 + \theta) \sigma \psi} \quad (47)$$

$$p_r^{cs} = p_r(\psi) = \frac{\gamma^2 (-1 + \theta) (-2k_s + c_m (-2 + \theta) \sigma) + 2\delta}{(-1 + \theta) \sigma (\gamma^2 (-2 + \theta) + 2\beta \delta (4 + \theta) \psi)} \quad (48)$$

4 Case (d): When both retailer's and manufacturer's risk aversion constraints are active

$$w^{cs} = c_m - \frac{k_s \theta + k_m (-2 + \theta(2 + \theta))}{(-2 + \theta)(-1 + \theta) \sigma} \quad (49)$$

$$p_o^{cs} = c_m + \frac{k_m + k_s + k_m \theta}{2\sigma - \theta \sigma} \quad (50)$$

$$\tau^{cs} = \tau(\psi) = \frac{k_m \gamma}{2\delta \sigma \psi} \quad (51)$$

$$p_r^{cs} = p_r(\psi) = \frac{k_m \gamma^2 (-1 + \theta)^2 - k_m \beta \delta (-4 + \theta(4 + \theta)) \psi + 2\delta}{2\beta \delta (-1 + \theta)(-4 + 3\theta) \sigma \psi} \quad (52)$$

Using Proposition 4 an efficient solution procedure is developed along with a line search method (i.e., Golden Section search) for determining the optimal contract parameter, ψ [7,68].

Solution procedure

- **Step 1:** Input parameters, $\alpha, \beta, c_m, \theta, k_m, k_s, \delta, \gamma,$ and σ
- **Step 2:** Set $i = 0, \psi^{(i)} = 0, \bar{\psi}^{(i)} = 1, \psi^{(i)} \in U[0, 1], \psi = \psi^{(i)}, \Pi^{opt} = -10^6, \epsilon = 10^{-3}, \kappa = 0.618$
- **Step 2:** Given $\psi,$ compute $w^{cs}, p_o^{cs}, \tau^{cs},$ and p_r^{cs} using Eqs. (37)–(40).
- **Step 3:** Estimate, $Var(\pi_m), Var(\pi_s),$ where, $\sqrt{Var(\pi_m)} = (w^{cs} - c_m)(1 - \theta) \sigma + (p_o^{cs} - c_m) \theta \sigma,$ $\sqrt{Var(\pi_s)} = (p_r^{cs} - (w^{cs} + c_s))(1 - \theta) \sigma.$
- **Step 4:** Check feasibility
 - **Step 4a:** Case (b), If $\sqrt{Var(\pi_m)} > k_m$ AND $\sqrt{Var(\pi_s)} \leq k_s$ then compute $w^{cs}, p_o^{cs}, \tau^{cs},$ and p_r^{cs} using Eqs. (41)–(44). Go to Step 3.

- **Step 4b:** Case (c), If $\sqrt{Var(\pi_m)} \leq k_m$ AND $\sqrt{Var(\pi_s)} > k_s$ then compute $w^{cs}, p_o^{cs}, \tau^{cs},$ and p_r^{cs} using Eqs. (45)–(48). Go to Step 3.
- **Step 4c:** Case (d), If $\sqrt{Var(\pi_m)} > k_m$ AND $\sqrt{Var(\pi_s)} > k_s$ then compute $w^{cs}, p_o^{cs}, \tau^{cs},$ and p_r^{cs} using Eqs. (49)–(52). Go to Step 3.
- **Step 5:** Determine, $\pi_m^{cs} = (w^{cs} - c_m) y_r + (p_o^{cs} - c_m) y_o - (1 - \psi) \delta (\tau^{cs})^2,$ and $\pi_s^{cs} = (p_r^{cs} - w^{cs}) y_r - \psi \delta (\tau^{cs})^2,$ where $y_r = (1 - \theta)(\alpha - \beta p_r^{cs} + \gamma \tau^{cs}),$ and $y_o = \theta(\alpha - \beta p_r^{cs} + \gamma \tau^{cs}) + (\beta v^{cs} - \beta p_o^{cs}),$ also, $v^{cs} = p_r^{cs}.$ Compute, $\Pi^{(i)} = \pi_m^{cs} \times \pi_s^{cs}$
- **Step 6:** Check optimality
 - **Step 6a:** If $i = 0,$ then $\psi^{opt} = \psi^{(i)}, \Pi^{opt} = \Pi^{(i)}.$
 - **Step 6b:** $\psi^{(a)} = \underline{\psi}^{(i)} + (1 - \kappa)(\bar{\psi}^{(i)} - \underline{\psi}^{(i)}), \psi^{(b)} = \underline{\psi}^{(i)} + \kappa(\bar{\psi}^{(i)} - \underline{\psi}^{(i)}).$
 - **Step 6c:** Estimate $\Pi^{(a)}$ by setting $\psi = \psi^{(a)}$ and using Steps 2 through 5.
 - **Step 6d:** Estimate $\Pi^{(b)}$ by setting $\psi = \psi^{(b)}$ and using Steps 2 through 5.
 - **Step 6e:** If $\Pi^{(a)} > \Pi^{(b)},$ then $\underline{\psi}^{(i+1)} = \psi^{(a)}, \bar{\psi}^{(i+1)} = \bar{\psi}^{(i)}.$ Also, If $\Pi^{(a)} > \Pi^{opt},$ then $\Pi^{opt} = \Pi^{(a)}, \psi^{opt} = \psi^{(a)}.$
 - **Step 6f:** If $\Pi^{(a)} \leq \Pi^{(b)},$ then $\underline{\psi}^{(i+1)} = \underline{\psi}^{(i)}, \bar{\psi}^{(i+1)} = \psi^{(b)}.$ Also, If $\Pi^{(b)} > \Pi^{opt},$ then $\Pi^{opt} = \Pi^{(b)}, \psi^{opt} = \psi^{(b)}.$
- **Step 7:** If $|\bar{\psi}^{(i)} - \underline{\psi}^{(i)}| > \epsilon$ OR $|\Pi^{(i)} - \Pi^{opt}| > \epsilon,$ then $i = i + 1$ go to Step 6.
- **Step 8:** Let $\psi = \psi^{opt},$ compute $w^{cs}, p_o^{cs}, \tau^{cs},$ and p_r^{cs} Step 2, through 4.

4.4. Revenue-sharing contract

Revenue-sharing contracts are widely used for channel coordination Giri et al. [38]; Raza [68]; Song and Gao [78,86]. Earlier, Cachon and Lavriere [11] propose revenue-sharing contract where the manufacturer charges the seller a lower price in exchange for a portion of the seller's revenue. Hsueh [47] investigates a revenue-sharing contract where the retailer shares a proportion of revenue in response to the manufacturer's corporate social responsibility investment and wholesale price reduction. Xu et al. [91] discuss two-way revenue-sharing contract. Song and Gao [78] implement revenue-sharing contract as defined by Cachon and Lavriere [11]. In this paper we assume that the seller transfers a payment of ρp_r to the manufacturer per unit sold to the customer.

$$\max_{w, p_o, \tau, v} \pi_m = (\rho p_r + w - c_m) y_r + (p_o - c_m) y_o - \delta \tau^2 \quad (53)$$

Subject to

$$p_r \geq v \quad (54)$$

$$v \geq p_o \quad (55)$$

$$\sqrt{Var(\pi_m)} \leq k_m \quad (56)$$

$v \geq 0$

Where in Eq. (56), $\sqrt{Var(\pi_m)} = (\rho p_r + w - c_m)(1 - \theta) \sigma + (p_o - c_m) \theta \sigma$

Similarly, the retailer's optimization problem is

$$\max_{p_r} E(\pi_s) = ((1 - \rho) p_r - w) y_r \quad (57)$$

subject to

$$\sqrt{Var(\pi_s)} \leq k_s \quad (58)$$

where in Eq. (58), we have $\sqrt{Var(\pi_s)} = ((1 - \rho) p_r - w)(1 - \theta) \sigma.$

Proposition 5 enables determining the manufacturer and seller's decisions on wholesale price, pricing in the direct and retail channel along with the greening effort investment ($w^{cs}, p_o^{cs}, p_r^{cs},$ and τ^{cs}) for a proposition, $\rho.$

Proposition 5. In revenue-sharing contract, for a given proportion $\rho,$ we have

1 Case (a): When both retailer's and manufacturer's risk aversion constraints are redundant

$$w^{rs} = w(\rho) = -\frac{(c_m(2\beta\delta + \gamma^2(-2 + \rho)) + \alpha\delta(5 + \theta - 4\rho))(-1 + \rho)}{\beta\delta(7 + \theta - 4\rho) + \gamma^2(-2 + \rho)} \tag{59}$$

$$p_o^{rs} = p_o(\rho) = \frac{\alpha\delta(3 + \theta - 2\rho) + c_m(\gamma^2 - 2\beta\delta)(-2 + \rho)}{\beta\delta(7 + \theta - 4\rho) + \gamma^2(-2 + \rho)} \tag{60}$$

$$\tau^{rs} = \tau(\rho) = -\frac{(\alpha - c_m\beta)\gamma(-2 + \rho)}{\beta\delta(7 + \theta - 4\rho) + \gamma^2(-2 + \rho)} \tag{61}$$

$$p_r^{rs} = p_r(\rho) = \frac{c_m(\beta\delta + \gamma^2(-2 + \rho)) + \alpha\delta(6 + \theta - 4\rho)}{\beta\delta(7 + \theta - 4\rho) + \gamma^2(-2 + \rho)} \tag{62}$$

2 Case (b): When only retailer's risk aversion constraint is redundant

$$(1 - \theta)(\alpha - \beta p_r^{rs} + \gamma \tau^{rs}) - \lambda_m(1 - \theta)\sigma = 0 \tag{63}$$

$$\theta(\alpha - \beta p_r^{rs} + \gamma \tau^{rs}) + (\beta p_r^{rs} - \beta p_o^{rs}) - (p_o^{rs} - c_m)\beta - \lambda_m\theta \sigma = 0 \tag{64}$$

$$(\rho p_r^{rs} + w^{rs} - c_m)\gamma + (p_o^{rs} - c_m)\gamma = 0 \tag{65}$$

$$\lambda_m(k_m - (\rho p_r^{rs} + w^{rs} - c_m)(1 - \theta)\sigma - (p_o^{rs} - c_m)\theta\sigma) = 0 \tag{66}$$

$$p_r^{rs} - \frac{\alpha + \beta w^{rs} - \alpha\rho + \gamma\tau^{rs} - \gamma\rho\tau^{rs}}{2\beta - 2\beta\rho} = 0 \tag{67}$$

3 Case (c): When only manufacturer's risk aversion constraint is redundant

$$w^{rs} = w(\rho) = \frac{k_s(2\beta\delta(1 + \theta + 2\rho) + \gamma^2(-\theta + (-2 + \theta)\rho)) - 2(-1 + \theta)(c_m(-\gamma^2 + \beta\delta) + \alpha\delta(2 + \theta))(-1 + \rho)\sigma}{2(-1 + \theta)(-\gamma^2 + \beta\delta(3 + \theta))\sigma} \tag{68}$$

$$p_o^{rs} = \frac{k_s(\gamma^2 - 2\beta\delta) - 2(-c_m(\gamma^2 - 2\beta\delta) + \alpha\delta(1 + \theta))\sigma}{2(\gamma^2 - \beta\delta(3 + \theta))\sigma} \tag{69}$$

$$\tau^{rs} = \frac{\gamma(k_s\beta - 2\alpha\sigma + 2c_m\beta\sigma)}{2(\gamma^2 - \beta\delta(3 + \theta))\sigma} \tag{70}$$

$$p_r^{rs} = \frac{-k_s(4\beta\delta + \gamma^2(-2 + \theta)) + 2(-1 + \theta)(c_m(-\gamma^2 + \beta\delta) + \alpha\delta(2 + \theta))\sigma}{2(-1 + \theta)(-\gamma^2 + \beta\delta(3 + \theta))\sigma} \tag{71}$$

4 Case (d): When both retailer's and manufacturer's risk aversion constraints are active

$$w^{rs} = w(\rho) = \frac{-k_m(-2 + \theta + \theta^2)(-1 + \rho) + k_s(\theta + 2\rho - \theta\rho) - 2c_m(-1 + \theta)(-1 + \rho)\sigma}{2(-1 + \theta)\sigma} \tag{72}$$

$$p_o^{rs} = c_m + \frac{k_m + k_s + k_m\theta}{2\sigma} \tag{73}$$

$$\tau^{rs} = \frac{k_m\gamma}{2\delta\sigma} \tag{74}$$

$$p_r^{rs} = c_m + \frac{k_s(-2 + \theta) + k_m(-2 + \theta + \theta^2)}{2(-1 + \theta)\sigma} \tag{75}$$

Similar to the solution procedure developed earlier in the cost-sharing contract (see, Sec. 3.3), we also utilize the findings of Proposition 5 for laying out an efficient solution procedure for the revenue-sharing contract. The solution procedure for revenue sharing contract has similarity with the cost-sharing contract. The procedure is presented below.

Solution procedure

- **Step 1:** Input parameters $\alpha, \beta, c_m, \theta, k_m, k_s, \delta, \gamma$ and σ .
- **Step 2:** Set $i = 0, \underline{\rho}^{(i)} = 0, \bar{\rho}^{(i)} = 1, \rho^{(i)} \in U[0, 1], \rho = \rho^{(i)}, \Pi^{opt} = -10^6, \epsilon = 10^{-3}, \kappa = 0.618$.
- **Step 2:** Given ρ , compute $w^{rs}, p_o^{rs}, \tau^{rs}$, and p_r^{rs} using Eqs. (59)–(62).
- **Step 3:** Estimate $Var(\pi_m), Var(\pi_s)$, where, $\sqrt{Var(\pi_m)} = (\rho p_r^{rs} + w^{rs} - c_m)(1 - \theta)\sigma + (p_o^{rs} - c_m)\theta\sigma$, $\sqrt{Var(\pi_s)} = ((1 - \rho)p_r^{rs} - (w^{rs} + c_s))(1 - \theta)\sigma$.
- **Step 4:** Check feasibility
 - **Step 4a:** Case (b), If $\sqrt{Var(\pi_m)} > k_m$ AND $\sqrt{Var(\pi_s)} \leq k_s$ then compute $w^{rs}, p_o^{rs}, \tau^{rs}$, and p_r^{rs} using Eqs. (63)–(67). Go to Step 3.
 - **Step 4b:** Case (c), If $\sqrt{Var(\pi_m)} \leq k_m$ AND $\sqrt{Var(\pi_s)} > k_s$ then compute $w^{rs}, p_o^{rs}, \tau^{rs}$, and p_r^{rs} using Eqs. (68)–(71). Go to Step 3.
 - **Step 4c:** Case (d), If $\sqrt{Var(\pi_m)} > k_m$ AND $\sqrt{Var(\pi_s)} > k_s$ then compute $w^{rs}, p_o^{rs}, \tau^{rs}$, and p_r^{rs} using Eqs. (72)–(75). Go to Step 3.
- **Step 5:** Determine $\pi_m^{cs} = (\rho p_r^{rs} + w^{rs} - c_m)y_r + (p_o^{rs} - c_m)y_o - \delta(\tau^{rs})^2$ and $\pi_s^{cs} = ((1 - \rho)p_r^{rs} - w^{rs})y_r$, where $y_r = (1 - \theta)(\alpha - \beta p_r^{rs} + \gamma\tau^{rs}), y_o = \theta(\alpha - \beta p_r^{rs} + \gamma\tau^{rs}) + (\beta p_r^{rs} - \beta p_o^{rs})$, and $v^{rs} = p_r^{rs}$. Compute, $\Pi^{(i)} = \pi_m^{cs} \times \pi_s^{cs}$.
- **Step 6:** Check optimality
 - **Step 6a:** If $i = 0$, then $\rho^{opt} = \rho^{(i)}$ and $\Pi^{opt} = \Pi^{(i)}$.
 - **Step 6b:** $\rho^{(a)} = \underline{\rho}^{(i)} + (1 - \kappa)(\bar{\rho}^{(i)} - \underline{\rho}^{(i)})$, $\rho^{(b)} = \underline{\rho}^{(i)} + \kappa(\bar{\rho}^{(i)} - \underline{\rho}^{(i)})$
 - **Step 6c:** Estimate $\Pi^{(a)}$ by setting $\rho = \rho^{(a)}$ and using Steps 2 through 5.
 - **Step 6d:** Estimate $\Pi^{(b)}$ by setting $\rho = \rho^{(b)}$ and using Steps 2 through 5.
 - **Step 6e:** If $\Pi^{(a)} > \Pi^{(b)}$ then $\underline{\rho}^{(i+1)} = \rho^{(a)}, \bar{\rho}^{(i+1)} = \bar{\rho}^{(i)}$. Also, If $\Pi^{(a)} > \Pi^{opt}$, then $\Pi^{opt} = \Pi^{(a)}, \rho^{opt} = \rho^{(a)}$.
 - **Step 6f:** If $\Pi^{(a)} \leq \Pi^{(b)}$ then $\underline{\rho}^{(i+1)} = \underline{\rho}^{(i)}, \bar{\rho}^{(i+1)} = \rho^{(b)}$. Also, If $\Pi^{(b)} > \Pi^{opt}$, then $\Pi^{opt} = \Pi^{(b)}, \rho^{opt} = \rho^{(b)}$.
- **Step 7:** If $|\bar{\rho}^{(i)} - \underline{\rho}^{(i)}| > \epsilon$ OR $|\Pi^{(i)} - \Pi^{opt}| > \epsilon$ then $i = i + 1$ go to Step 6.
- **Step 8:** Let $\rho = \rho^{opt}$, compute $w^{rs}, p_o^{rs}, \tau^{rs}$, and p_r^{rs} Step 2, through 4

5. Numerical analysis

In this section, we present numerical experimentation with the models developed. The main objective of the numerical example is to demonstrate the proposed models and discuss the impact of

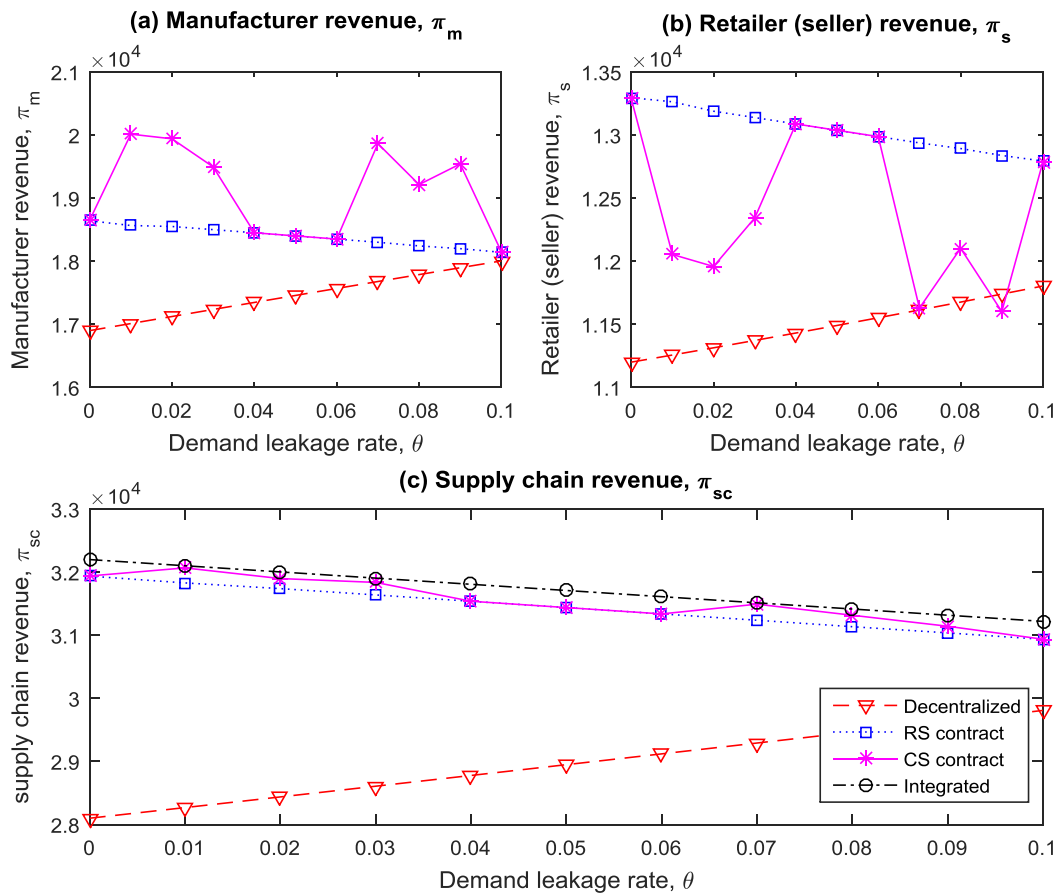


Fig. 2. Impact of demand leakage, θ , on supply chain revenues.

cannibalization rate or demand leakage proportion on the price, revenues and inventory. We have customized the data used earlier in Raza et al. [72]. Thus, we have $\alpha = 10000, \sigma = 1000, \beta = 800, c_m = 5, \gamma = 40, \delta = 1, k_s = 2000, k_m = 5000, k_{sc} = k_s + k_m = 7000$. A sensitivity analysis is presented for different parameter values of the demand leakage proportion, θ . For experimentation purposes, following values of θ are used: $\theta = \{0.0, 0.02, 0.04, 0.06, 0.08, 0.1\}$. First, the impact of the demand leakage θ on the revenues of the manufacturer, seller and the total revenue of the supply chain is shown by varying θ between 0 and 0.1 in steps of 0.02. From Fig. 2(a)–(c) the following can be noted regarding the behavior of these three revenues with respect to a change in demand leakage, θ . With an increase in θ , the manufacturer's revenue π_m for the current numerical example increases approximately in the range of 17000 to 18000 units. The increase in manufacturer's revenue π_m can be attributed to the increasing trend in the regular channel price p_r (see Fig. 5(a)) and direct online channel price p_o , and the increase in the direct online channel inventory y_o on an increase in θ (see Fig. 5(d)). On the other hand, π_m decreases under a revenue-sharing contract with an increase in θ . For lower values of θ , π_m are significantly higher in case of the revenue sharing contract compared to that of decentralized but the gap closes as θ increases. The reduction in the revenues can be explained by the decrease in the demand of the regular channel inventory y_r in case of the revenue-sharing contract (see Fig. 5(c)). In case of a cost-sharing contract, the effect of θ on the manufacturer revenues fluctuate; however, for the range of θ values considered, π_m tends to remain higher for the cost sharing contract compared to the decentralized coordination.

Figs. 3 and 4 further support the findings reported in Fig. 2 with regard to the seller's revenue π_s the effect of θ is almost similar to that of manufacturers revenue, which can be mainly attributed to the increase in p_r with respect to θ . The performance of π_s is the best in case of

revenue sharing contract although it shows a linearly decreasing trend with respect to θ . Once again, the seller's revenues are higher in case of revenue sharing and cost sharing contracts compared to decentralized channel. The total revenue of the supply chain π_{sc} decreases with an increase in θ for the integrated channel and the revenue-sharing contract whereas in the case of decentralized coordination π_{sc} increases with θ . For the cost-sharing contract the trend of the overall supply chain revenue is downward. However, the overall revenue of the supply chain is lower for decentralized compared to other three channel coordination, namely, revenue-sharing, integrated and cost-sharing for the range of θ considered in the study. This implies that practicing supply chain managers that the cooperation between the supply chain members can result in higher overall revenues for the supply chain in the case of integrated channel and revenue- and cost-sharing contracts.

The regular channel price p_r set by the seller increases steeply with respect to the proportion of demand leakage, θ for all types of coordination studied, i.e., decentralized, integrated, revenue-sharing and cost-sharing (see Fig. 5(a)). As θ increases the optimal course of action is to increase the prices of both the channels [67] when the channel is integrated or bargaining is exercised through revenue sharing or cost sharing contracts. In case of the decentralized channel, the price differential between p_r and p_o is maintained by the manufacturer to benefit at the cost of decrease in seller's revenues. Whereas the increase in p_r is to compensate the decrease in revenues due to demand leakage, the increase in p_o can be important to maintain the price differential. In the decentralized case, the increase in price compensates for the demand leakage and enhances the revenue for the seller. Further p_o is lower in the case of decentralized coordination compared to others and the gap increases with increase in the demand leakage. With regard to price, it may be observed that the direct online channel prices p_o are significantly lower compared to the regular channel prices (see Fig. 5(a))

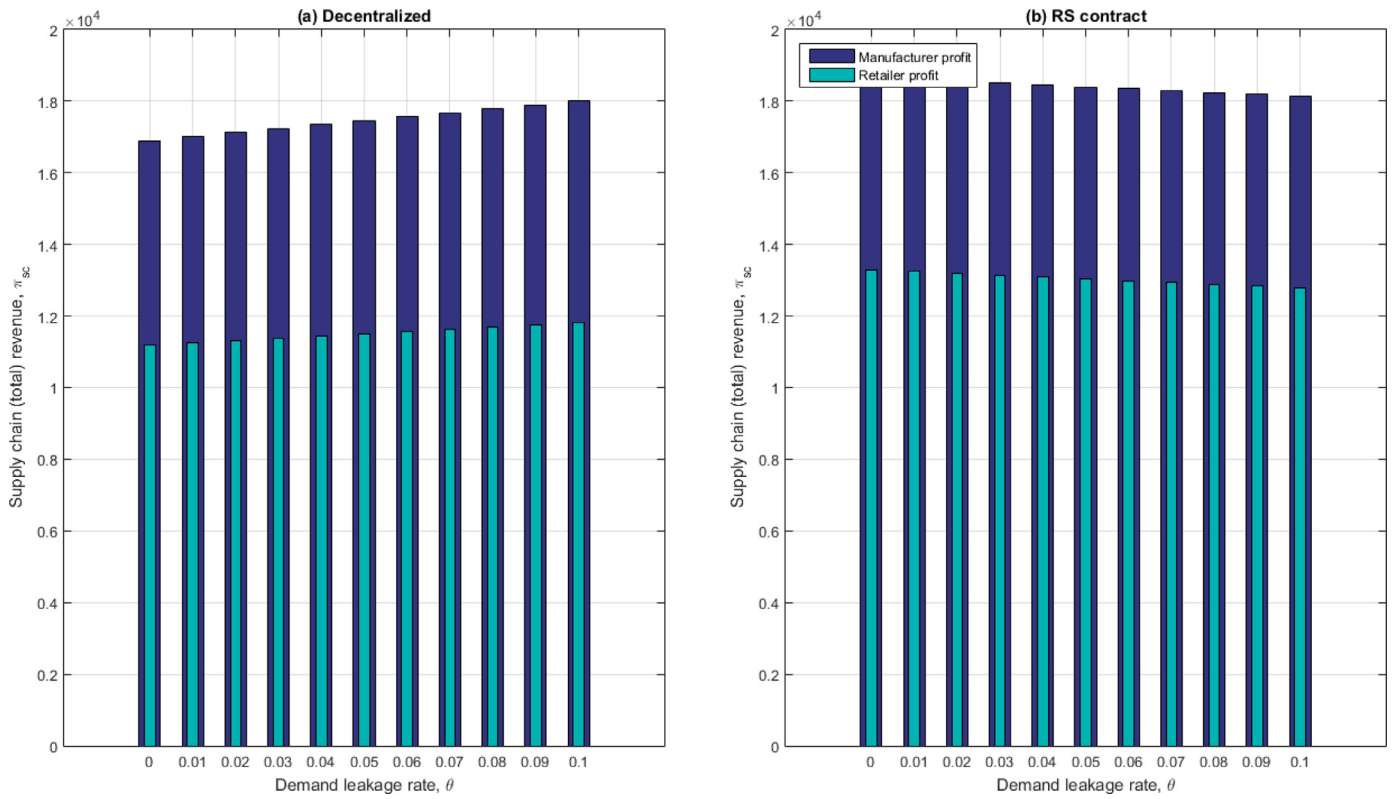


Fig. 3. Impact of demand leakage, θ , comparing decentralized and revenue-sharing contract.

and (b)).

It is observable from Fig. 5(c) and (d), the inventory carried by the regular channel y_r decreases with an increase in θ in case of integrated, revenue-sharing and cost-sharing contracts. The inventory is reduced to

lessen the chances of overstocking on account of increasing θ . For the decentralized channel however, the inventory in the regular channel, y_r remains flat with increase in the demand leakage proportion, θ . For the direct channel, the inventory held, y_o increases with θ for integrated,

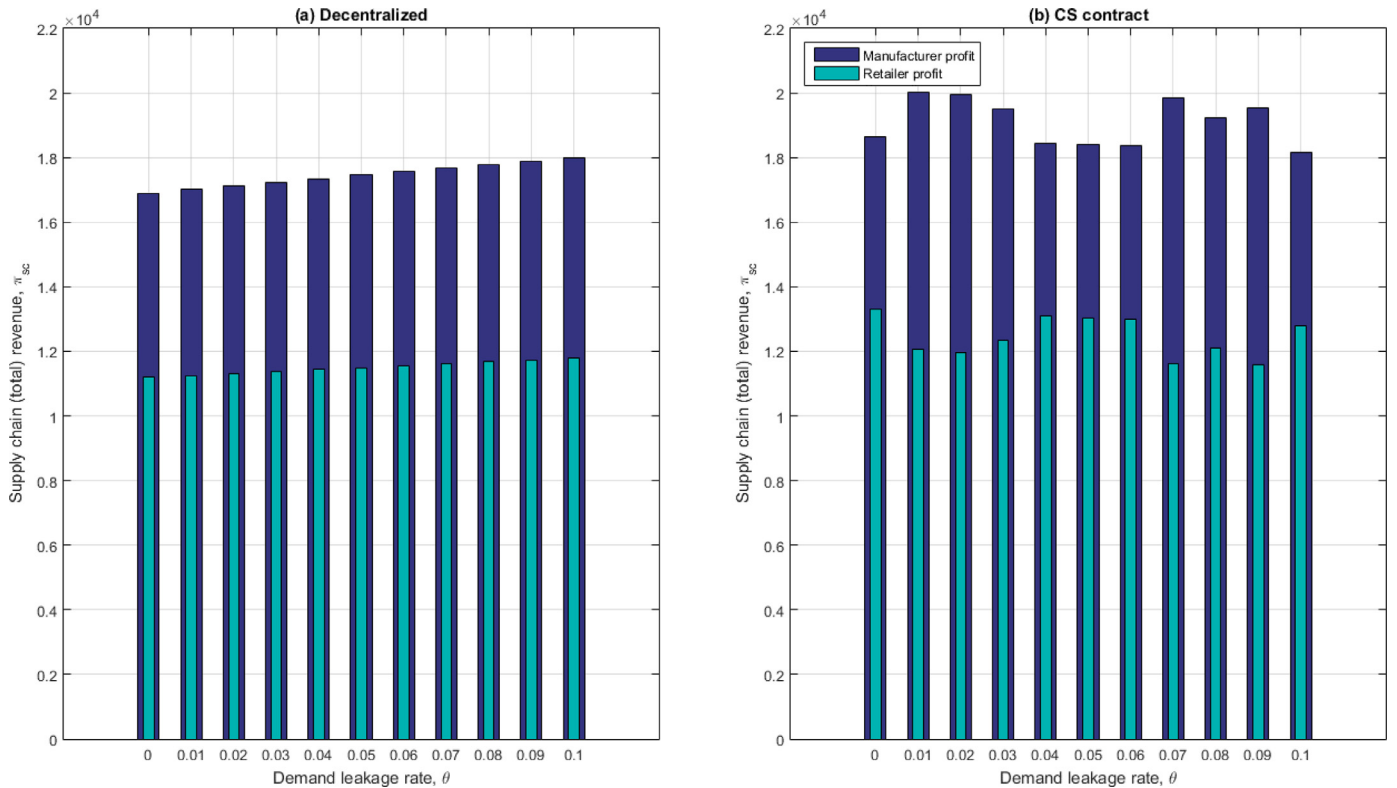


Fig. 4. Impact of demand leakage, θ , comparing decentralized and cost-sharing contract.

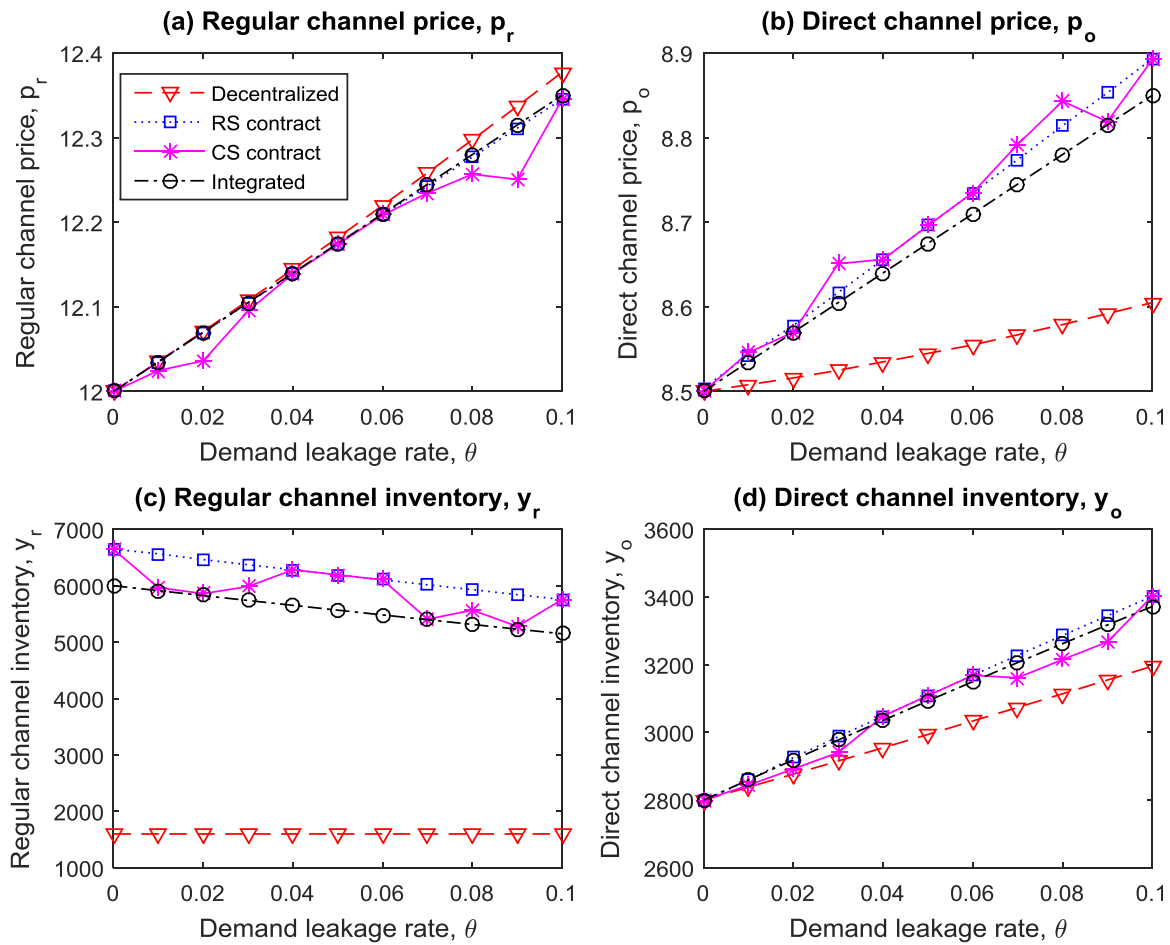


Fig. 5. Impact of demand leakage, θ , on supply chain decisions.

decentralized, revenue-sharing and cost-sharing scenarios. The increase in inventory is necessary to cover the extra demand due to demand leakage which is unidirectional from the high-priced green segment to the lower priced standard product segment. This however is not true for decentralized since the manufacturer acts independently.

The greening effort, τ is not particularly affected by changes in the proportion of demand leakage, θ regardless of the type of supply chain coordination or due to dual-channel (see Fig. 6(c)). For the decentralized coordination, the greening effort, τ is lower compared to integrated coordination, cost-sharing contract and revenue-sharing contracts. As mentioned in the model development, τ enhances the demand in the regular channel due to the term $\gamma \tau$ in the expression for demand $y_r = (1 - \theta)(\alpha - \beta p_r + \gamma \tau)$. In a decentralized coordination, the manufacturer may benefit higher due to less greening since more revenues may be obtained from the direct online channel sales.

The wholesale price w is higher for cost-sharing and decentralized coordination as compared to the revenue-sharing contract (see Fig. 6(a)). Thus, the optimal solution suggests that the manufacturer reduce the wholesale price in order to receive higher income from the seller by way of transfer price. The reduction in wholesale price improves the volume sold through the regular channel and hence the revenue shared ρp_r by the seller. Also, w is almost the same for cost-sharing and revenue-sharing contracts. At the same time, for the range of values of θ considered in the example, w does not behave regularly. However, it is lower at the extremes of the range over which the θ is varied. Fig. 3(a)–(d) show the total supply chain revenue and relative proportions of manufacturer and seller revenue for the decentralized versus the cost-sharing and revenue-sharing contracts. Finally, in Fig. 6(b) the variation in the optimal value of revenue sharing

proportion with respect to θ is studied and it is found that the relationship is not well behaved. The values of ρ are much higher for intermediate values of θ . In this numerical study, for the case of cost-sharing contract manufacturer bears the total investment incurred due to greening effort in return for a superior revenue.

6. Conclusions, managerial implications and future research directions

Two aspects are likely to become the permanent features of global supply chains: dual channel structure and greening. Most customers today expect manufacturers to provide a direct online channel [43]. The direct online channel introduces a conflict due to a perceived threat by the seller. The dual channel structure often results in an uncertainty in the form of a cross price elasticity or buy-down cannibalization. Nevertheless, the provision of direct online channel leading to a dual supply chain, has become a necessity owing to customer pressures and benefits from the operation of a direct online channel. The only option is to manage the coordination of the dual supply chain consisting of regular and direct online channels, considering the risk aversion in the supply chain. At the same time, regulatory pressures, external pressures from various groups and internal pressures to become environmentally responsive, requires that supply chain members adopt sustainable supply chain practices.

In this study, we have investigated the coordination in dual channel supply chain, selling a green product and a standard product through a regular channel and a direct online channel, respectively. The demand between the two channels is assigned using differentiation pricing approach to model buy-down cannibalization. Considering a risk averse

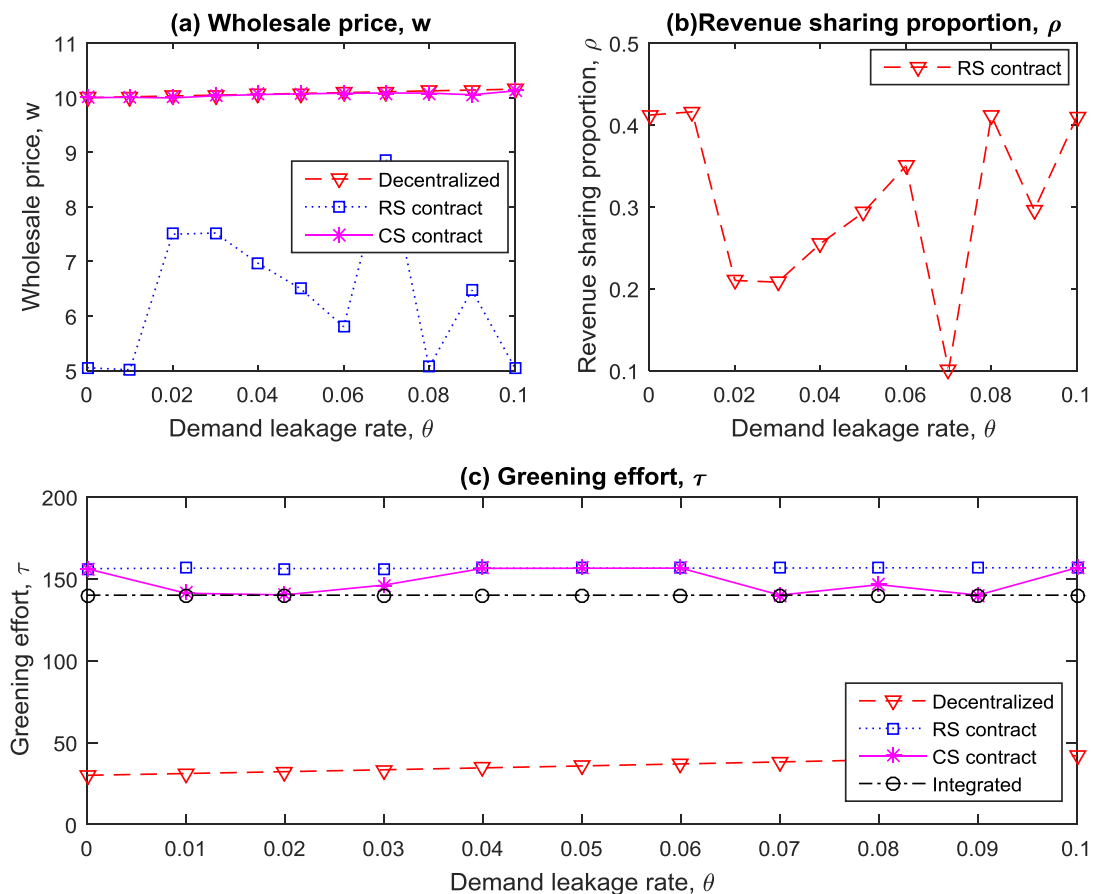


Fig. 6. Impact of demand leakage, θ , on greening effort, wholesale, and revenue-sharing.

manufacturer and seller, the impact of demand leakage on the pricing, inventory and profitability is established by closed form solutions and demonstrated through a detailed numerical example. The latter shows that an increase in demand leakage is associated with a deterioration in the overall profitability of the supply chain. As discussed in the previous section, the closed form solutions presented in the paper yield good insights into the dynamics of the demand and pricing in the presence of cannibalization and risk aversion. In general, the models proposed in the current study provide a comprehensive decision support to determine important decisions including pricing, differentiation price, greening effort and inventory in the presence of risk aversion in a dual supply chain context.

Assuming the supply chain to be risk averse, models consider integrated and decentralized decision making with regard to important decision variables. Further, cost-sharing and revenue-sharing contracts are also discussed. The most significant contribution of this study to the GSCM knowledge base is the utilization of price differentiation from revenue management to model the impact of cannibalization of regular channel demand by the direct online channel and investigating the impact of demand leakage proportion on pricing, inventory and greening effort. Meanwhile, the numerical example in the current study shows that the cooperation between supply chain members is beneficial since higher revenues are generated for all. Further, the greening effort suffers significantly in decentralized coordination within a DCSC. Conversely, this implies that a cooperative relationship between the manufacturer and the seller through integrated channel or contracts is important for greening. Typically, an increase in the demand leakage impacts the revenues of the manufacturer and seller positively when coordination is decentralized. The positive impact may be attributed to the increase in the regular channel price and direct online channel price and also the increase in the direct online channel sales. The opposite is

true for integrated channel coordination however. The integrated coordination generally outperforms the decentralized coordination in terms of the overall supply chain revenue. Both the seller and manufacturer are able to achieve higher revenues in a revenue sharing contract compared to the decentralized case. This implies that practicing supply chain managers can benefit from the cooperation between the supply chain members. Also, the best strategy in case of an increase in demand leakage is to increase the price regardless of the integrated, decentralized or the type of contract. The greening effort is lower in decentralized coordination compared to integrated coordination, cost-sharing contract and revenue-sharing contracts.

One of the limitations of the study is availability of full information about the risk aversion of one another to the manufacturer and seller. In real world however, the risk aversion information may not be always available. Hence the current study can be extended assuming asymmetry with regard to the risk aversion information among the supply chain members. Another limitation is the presence of a single manufacturer and retailer. Competing manufacturers and retailers might yield further insights into the nature of the conflict and cooperation between the multiple supply chain members. This study can be expanded also be generalized by considering stochastic demand, and other types of risk aversion modeling such as CVaR and VaR. Finally, from a sustainability perspective, additional future directions such as the incorporation of corporate social responsibility and reverse logistics considerations may be considered.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at [doi:10.1016/j.orp.2019.100118](https://doi.org/10.1016/j.orp.2019.100118).

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