Pricing and greening decisions in a three-tier dual channel supply chain

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Abstract

This paper addresses the problem of optimal and coordinated decision making for a three-tier dual-channel green supply chain (SC). In the investigated SC, the manufacturer produces a good with an arbitrarily green level and sells it to the distributor. The distributor has two choices: (1) selling product through a direct e-channel, or (2) selling product to a retailer. Demand in both e-channel and retail channel depends on price and green level of the product. The manufacturer, the distributor, and the retailer decide on the green level of product, the price in e-channel, and the retail price of the product, respectively. The problem is investigated in three different decision-making structures. At first, the open triad and the closed triad decision structures are analyzed and optimal decisions for all SC members are extracted. This study contributes to the literature by developing a coordinated, environmentally friendly decision model for a multi-tier dual-channel SC structure. According to the findings, compared to the open triad, the closed triad structure is profitable for the SC at the expense of one or more members, who will thus not adopt it. Secondly, a mathematical programming model, labeled as transitional model, is proposed to achieve coordination. The transitional triad guarantees the manufacturer’s profit, while keeping customer prices lower and greenness higher than the open triad. The numerical studies and sensitivity analyses show that the proposed model not only is profitable for all SC members, but also increases green level of the product and reduces prices in both the e-channel and retail channel.

Key words: Supply chain coordination; multi-tier supply chain management; dual-channel; pricing; green product.

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1. Introduction

A new phenomenon in contemporary supply systems is environmental compatibility. Sustainable development, comprising several aspects of the supply system such as production, distribution, and so on, is considered an important concept in modern supply chains. Green SC management (GSCM) reconsiders all aspects of the supply system such as SC design, decisions related to production, raw material procurement, etc. that are environmentally compatible (Li et al., 2016). GSCM is found not only as an environmentally useful procedure but also as a phenomenon that improves the economic performance of SCs, as well as manufacturer’s competitiveness (Porter and Van der Linde, 1995; Green et al., 2012). As a matter of fact, governmental and social pressure upon manufacturers and companies to follow the sustainable concepts has increased (Seuring, 2013; Lin and Tseng, 2016). Many companies in the world, such as Adidas, Pepsi Cola, and Wal-mart, have adopted their supply strategies based on environmental and green concerns, and the number of these companies is increasing rapidly (Wilkerson, 2005; Li et al., 2016). The significance of sustainable SCs and the increasing attention and investment on development of them throughout the world have made it essential for both academicians and industry managers to consider these issues in their research and decision making processes.

Adhering to sustainability standards becomes a more complicated task when we recognize that SC structures are more complex than ever. Modern SCs are increasingly complex, and each SC contains several independent parties, known as decision-makers. These SCs are called multi-tier SCs (MSCs) (Harland et al., 2005; Mena et al., 2013). In MSCs, structural issues, as well as behavioral issues like self-organization, have made it difficult to
implement a well-organized, coordinated SC; besides this, the number of beneficiaries is one of the other issues in these kinds of SCs. In order to conform to reality, restricting coordination methods to two-echelon SCs cannot reflect the problems found in real world encounters (Ding and Chen, 2008). Accordingly, enhanced solutions need to be devised to coordinate MSCs.

To become closer to their customers, most MSCs use the internet to sell their products. The growth of internet applications and the number of internet users worldwide has compelled many companies such as Nike, Hewlett-Packard (HP), and so on, to offer direct internet selling channels known as e-channels (Huang et al., 2012). Internet-based sales can benefit companies by decreasing the costs and providing greater market shares (Wu and Wu, 2015). It should be noted that in some cases, a distributor, not the manufacturer, owns the direct (internet) sale channel. This is mostly common for companies that import products from abroad. A good example of such a company is Digikala, the most famous and successful internet-based business in Iran ([www.Digikala.com](http://www.Digikala.com)). Digikala imports a wide variety of products from countries such as China, Korea, Netherlands, and so on; then, these products are sold to customers through an internet-based platform. Meanwhile, traditional physical channels are also maintained and, as a result, the SC reforms to a dual-channel structure. A dual-channel SC is defined as a network of selling products consisting of a direct sales channel through the internet and a traditional sales channel through retailers. The management and coordination of a dual channel is a crucial task in order to avoid raising conflicts between e-channels and traditional channels (Keenan, 1999; Xu et al., 2014).
Although MSCs are important and are a commonplace phenomenon in modern businesses, academic studies in the area of SC coordination have paid less attention to it compared to two-echelon traditional SCs. This is an important gap which is addressed in the current study. Moreover, despite the fact that dual-channel SCs are getting attention more than before, two important issues are missing in the literature: the first is that dual-channel SCs are always one part of a bigger system (MSCs), and the second is that more environmentally friendly decisions need to be made in such dual-channel MSCs.

In this paper, we develop a three-echelon dual-channel SC consisting of one manufacturer, one distributor, and one retailer. The distributor owns the direct sale channel (e-channel) and sells products through the internet along with the retail channel which is governed by the retailer. The manufacturer produces one type of green product with an arbitrarily selected level of greenness. The manufacturer should decide on the green level of the product while the distributor and the retailer decide on selling price of the product in their own channel. The aim is to optimize pricing decisions for both direct and traditional channels and for the green level of the product. The models are analyzed under three decision-making structures, namely the open triad, closed triad, and transitional triad decision structures. Under the open triad structure, all SC members try to make decisions that maximize their own profit. However, under the closed triad structure, the decisions are adopted in the SC with a holistic view. This means that the SC is considered as one entity and decisions are made to optimize the whole SC profit. Our analyses show that closed triad will be profitable for the SC compared to the open triad, at the expense of one or more members, who will thus not adopt the closed triad. In order to coordinate such a SC, we propose a transitional model which not only increases the profit of the SC compared
to the open triad structure, but also guarantees that all SC members will gain at least as much profit as they gain under the open triad structure. As a result, two main approaches are pursued in this study; first, by modelling the individual SC members’ profit, it is clear which members profit and which members incur losses by switching from open triad to closed triad structure. In the next approach, a coordination model, namely a transitional model, is proposed to ensure the profitability of members who were reluctant to adopt closed triad structure due to losses. In addition, members in a SC are willing to coordinate the SC so they can quickly respond to the customers (Xu et al., 2017).

The current paper is organized as follows. In Section 2, literature is reviewed and research gap is surveyed. Section 3 represents the problem statement. After that, the SC decision structure is modeled under closed triad, open triad, and transitional triad decision structures. In Section 4, numerical studies and sensitivity analyses are analyzed. Finally, in Section 5, conclusions and future research directions are stated.

2. Literature review

Because this paper addresses the issue of coordinated decision making in a multi-tier dual-channel SC for green products, in this section we review the related literature and draw insights in order to narrow the focus of the research gap.

2.1. Coordination of multi-tier supply chains

Basically, there are several studies in the literature for the issues of MSC coordination. Researchers have proposed MSCs with a wide variety of assumptions and settings and then have come up with traditional or heuristics methods to coordinate them. To provide some examples, Munson and Rosenblatt (2001) investigated a three-echelon SC including one...
supplier, one manufacturer, and one retailer. They pursued a quantity discount program to coordinate decisions in the investigated SC. Also, Jaber and Goyal (2008) investigated a three-level SC including multi retailers in the first level, one seller in the second level, and multi suppliers in the third level. The aim of this research is to coordinate order quantities decisions in the centralized structure. Ding and Chen (2008) surveyed a ‘flexible return policy’ in a three-echelon SC (supplier-manufacturer-retailer) in order to coordinate the SC decisions using a return policy between manufacturer and supplier, and an agreement for flexible pricing between the retailer and the manufacturer. Seifert et al. (2012) investigated the coordination and sub-coordination for a three-level SC. In that study, three decision structures are surveyed including the decentralized, coordination mechanism for two members, and full coordination. Recently, Aljazzar et al. (2016) introduced a permissible delay in payments contract to coordinate a three-echelon SC where the length of the delay is a decision variable. Also, Aljazzar et al. (2017) developed previous work and proposed delay in payments and price discount as two common strategies for this sake. Moreover, they applied a mechanism using both delay in payments and price discount, simultaneously. More recently, Lan et al. (2018) investigated a three-level SC consisting of one manufacturer, two distributors (channels) in the middle stage, and one retailer. In such SC, retailer’s ordering policies, manufacturer’s pricing strategies, and the distributors’ pricing equilibrium are considered decision variables. The described SC is then coordinated using the competition between two distribution channels. Several other research papers have observed problems with various settings and have examined them in the context of MSCs. Two important factors that have obtained less attention in the literature of MSCs are sustainability concepts and dual-channel systems in the retailing sector of MSCs.
2.2. Green supply chains

There are many studies in the area of green SCs; however, this concept in the context of MSCs needs much more attention. For instance, Barari et al. (2012) introduced an evolutionary game approach to achieve reconciliation between profitability and sustainability of a SC. As discussed previously, sustainability is a core issue that is vital to be investigated in MSCs. Zhang et al. (2014) investigated a SC consisting of two members where one kind of a green product coexists with one type of a non-green product. They introduced a pricing-based strategy for coordination of such a SC. Ghosh and Shah (2012) investigated a SC where members are seeking to initiate a green system. Problem modeling has been conducted through pricing procedures and level of greenness of products is considered as a decision variable. Furthermore, they proposed a two-part tariff contract to coordinate such a SC. In an effort to improve the literature of coordination in green MSCs, Huang (2016) surveyed coordination of a green three-level SC through pricing and remanufacturing decisions. In that study, concepts of channel selection and power structure are considered as well.

2.3. Dual-channel supply chains

Growth in the internet coverage and internet users has led to a market through direct sales. Therefore, many companies take advantage of dual-channel SCs. However, the literature of MSCs again has gained little attention regarding dual-channel supply systems. Works in the area of dual-channel SCs are mainly assigned to two echelon systems, not to more complex systems like multi-tier SCs. For example, Chen et al. (2012) investigated a manufacturer-led dual-channel SC under Stackelberg game. They utilized direct channel selling price and
wholesale price. For risk-averse dual-channel SCs, Xu et al. (2014) proposed a two-way revenue sharing mechanism to achieve full-coordination. Moreover, another work by Li et al. (2014) studied a dual-channel SC where the retailer is risk-averse. Xie et al. (2017) studied a dual-channel closed loop SC. In the mentioned work, SC coordination is conducted through a revenue sharing contract. There are other developments on the concepts of dual-channel SC such as considering disruptions (see Cao, 2014; Huang et al., 2013; Zhang et al., 2015). For instance, recently, Tang et al. (2018) investigated a dual-channel SC consisting of one retailer and one manufacturer with simultaneous cost and demand disruption. In this work, by using a developed revenue sharing contract, the SC is fully coordinated. Nevertheless, we cannot see a systematic development for dual channel SCs to consider them into more complex SCs.

2.4. Research gap

By now, we established that concepts of dual-channel SCs and greenness in SCs are frequently examined in the literature, but when it comes to multi-tier SCs, there are few studies. In one of them, Zhang and Liu (2013) introduced a coordination mechanism for a three-level SC including one supplier, one manufacturer, and a single retailer. The mechanism is based on non-cooperative games, and the decision variables are rates of a product’s greenness and retailing price. In another study conducted by Huang (2016), coordination of a green three-level SC through pricing and remanufacturing decisions are studied. In that study, concepts of channel selection and power structure are considered as well. Recently, Li et al. (2016) investigated a green dual channel SC in order to obtain pricing policies of direct channels and retail channels, and also to identify the level of
greenness for a manufacturer’s products. These three works are the main quantitative studies introduced in the literature to address problems somehow similar to our study. However, the lack of a thorough research including integrated concepts of multi-level SC, green SC, and dual-channel SC is evident. In this paper, we address this problem and propose a green three-level SC that considers two selling channels. The closest study to our work is the one done by Li et al. (2016). As we alluded to, that study considers a two-level dual-channel SC including one manufacturer and one retailer, and it addresses the issue of greenness and channels’ pricing in such a SC. In that work the manufacturer is considered the owner of the direct channel and the retailer governs the retail channel. There are several substantial contributions in our study that differ from the previous literature. First, we introduce a three-level, dual-channel SC including one manufacturer, one distributor, and one retailer, which is rarely investigated in the literature of SC coordination. Second, in our study the manufacturer only makes decisions about the green level of products and has nothing to do with selling channels. Instead, the distributor owns the direct e-channel (like the case of Digikala we mentioned in the Introduction), and the retailer governs the retail channel. Third, we also propose a coordination mechanism to lead the whole SC and each member toward a better situation for the mentioned SC, which has not been available in the literature even for simpler forms of such supply systems. It is worth mentioning that we develop a transitional model to coordinate the SC, which rarely has been used in previous studies (see Basiri and Heydari, 2017). The transitional model is based on the fundamental concepts introduced by Mena et al. (2013). In addition, compared to the most important paper in the literature which underscores the basis of our study, Li et al. (2016), we consider that the selling prices in e-channel and retail channel can be different; whereas
in the mentioned work these prices are assumed to be the same. Also it is substantial to point out that in the current study the value of price elasticity, cross price sensitivity, and extension effectiveness factor of greenness are assumed to be different between the direct and retail channels.

Here we explain the terminology adopted in this study. As we stated, the work by Li et al. (2016) is the basis of our study and we endeavor to embed the concepts proposed in that study in the literature of MSCs, along with other contributions. Moreover, in the numerical analyses, we use the study by Xu et al. (2014) to indicate the contributions and results of our work. Both of these studies are dyadic SCs. For the decision-making structure in which members decide independently, the term ‘decentralized’ is used by both studies. Also for the decisions structure in which decisions are adopted in the SC as a whole, the term ‘centralized’ is used. However, in our study, due to the multi-tier nature of the work, to better position our work in the MSCs literature, we use the terms ‘open triad’ and ‘closed triad,’ respectively. For the coordination model, we use the term ‘transitional triad.’ Using the term ‘triad’ is common in the literature of MSCs for describing the relationships in SCs that consist of three members. For instance, previously Mena et al. (2013), Choi and Wu (2009), and Peng et al. (2010) have used it. Thus, throughout the study, wherever the terms ‘open triad,’ ‘closed triad,’ and ‘transitional triad’ are used, they have the similar concepts as ‘decentralized,’ ‘centralized,’ and ‘coordinated,’ respectively.

3. Problem definition
In this paper, we address a green three-level SC with two selling channels, i.e. direct e-channel and traditional retail channel with one type of green product. First, the manufacturer produces a commodity in a given green level. The manufacturer has this
ability to increase/decrease green level of product if appropriate. The distributor, the owner of the direct e-channel, distributes the products via two available channels. The direct online channel is owned by the distributor itself, and the retail channel is owned by the third member of supply system, i.e., the retailer (see Figure 1). It is assumed that the demand is affected by selling prices and the green level of product, simultaneously. In addition, transaction cost is not considered in the investigated SC. In the investigated SC, the manufacturer has the authority to decide on the green level of the products. Furthermore, the distributor makes decision on selling price of product via direct e-channel, and the retailer decides on retailing price in the retail channel.

![Figure 1. Investigated multi-tier dual-channel SC overview](image)

The symbols and notations used in this study are as follows:

**Parameters**

- $a$: Primary potential demand
- $s$: Retail channel’s share from primary demand ($1 \leq s \leq 1$)
Demand attracted by the direct channel

Demand attracted by the retail channel

Price elasticity of demand for direct channel

Price elasticity of demand for retail channel

Cross-price sensitivity in direct channel (the effect of retail channel’s price on demand of direct channel); \( b_1 > b_1' \)

Cross-price sensitivity in retail channel (the effect of direct channel’s price on demand of retail channel); \( b_2 > b_2' \)

Green-level elasticity of demand for direct channel

Green-level elasticity of demand for retail channel

Production cost per unit of product incurred by the manufacturer

The price of each product sold by the manufacturer to the distributor

The wholesale price per unit of product sold by the distributor to the retailer

Cost factor for enhancing green level

Decision variables

Direct selling price per unit of product decided by the distributor

Retail price per unit of product decided by the retailer

Green level of product decided by the manufacturer

Subscripts \( d, r, m, \) and \( SC \) denote distributor, retailer, manufacturer, and whole supply chain, respectively. Superscripts \( OT, CT, \) and \( TT \) denote open triad, closed triad, and transitional triad scenarios, respectively.
In this paper, we use the demand functions of each channel similar to Li et al. (2016) and Kurata et al. (2007). Huang and Swaminathan (2009) and Xu et al. (2014) used demand functions in a dual-channel SC by considering price elasticity and cross price sensitivity. Similar to our study, in those functions, demand for a specific channel has a reverse relationship with the same channel’s price and at the same time has a direct relationship with the other channel’s price. Gosh and Shah (2012) also proposed a demand function for a SC with green considerations where the demand had an ascending relationship with the greenness of products. Other studies, like Li et al. (2016) and Kurata et al. (2007) also developed demand functions in dual-channel SCs and proposed functions by considering green level of products as well as price elasticity and cross price sensitivity. Accordingly, the demand function for direct channel and retail channel in this study can be expressed as follows, respectively:

\[ D_1 = (1 - s)a - b_1p_1 + b'_1p_2 + \gamma_1 \theta \]  \hspace{1cm} (1)

\[ D_2 = sa - b_2p_2 + b'_2p_1 + \gamma_2 \theta \]  \hspace{1cm} (2)

In Eqs. (1) and (2), the demand function of each channel is reversely affected by its own selling price and at the same time has a direct relationship with the other channel’s price. Also, the greenness of products, as a factor decided by the manufacturer, has a direct relationship with demand of both channels.

Based on the assumed demand functions in Eqs. (1) and (2), the problem will be modeled in three decision-making structures including open triad, closed triad, and transitional triad scenarios.

3.1. Open triad decision structure
When each member decides independently, we face three decision models for the players, i.e., manufacturer, distributor, and retailer. Under this scenario, called open triad decision structure, each player aims to maximize his own profit. Under the open triad structure, we follow the Stackelberg game to figure out the optimal value of decision variables. In this game, we consider the distributor as the leader, and other players as the followers.

Under the open triad decision-making structure, the profit functions of the retailer, the distributor, and the manufacturer in the investigated multi-tier dual-channel SC can be formulated as follows, respectively:

\[ \Pi_{OT}^{R} = (p_2 - w_2)(sa - b_2p_2 + b_2p_1 + \gamma_2 \theta) \]  
\[ \Pi_{OT}^{D} = (p_1 - w_1)((1 - s)a - b_1p_1 + b_1p_2 + \gamma_1 \theta) + (w_2 - w_1)(sa - b_2p_2 + b_2p_1 + \gamma_2 \theta) \]  
\[ \Pi_{OT}^{M} = (w_1 - c)(a - (b_1 - b_2)p_1 - (b_2 - b_1)p_2 + (\gamma_1 + \gamma_2)\theta) - e\frac{\theta^2}{2} \]

Eq. (3) illustrates the profit of the retailer where the first term indicates marginal profit from selling each item and second term denotes demand of retail channel. In Eq. (4), the first term indicates profit that the distributor earns from its own channel (e-channel) and the second term is the profit through selling products to the retailer. In Eq. (5), the first term shows the total profit of the manufacturer via selling products to the distributor and the second term indicates the investment cost of greening products.

Under the open triad structure, the aim of each member is to maximize his own profit regardless of other players. Theorem 1 gets the optimal value of decision variables under the open triad decision structure.

**Theorem 1.** Under a distributor-led Stackelberg game, the optimal decisions are:
\[ p_{\text{OT}1}^* = \frac{a e \left(2 b_2 (1 - s) + b_1 s\right) + (2 b_1 b_2 - b_1 b_2') w_1 e + (b_1 b_2 + b_2 b_1') w_2 e}{(4 b_1 b_2 - 2 b_1 b_2') e} \]

\[ p_{\text{OT}2}^* = \frac{e (s a + b_2 p_{\text{OT}1}^* + b_2 w_2) + \gamma_2 (w_1 - c) (\gamma_1 + \gamma_2)}{2 b_2 e} \]

\[ \theta_{\text{OT}1}^* = \frac{(w_1 - c) (\gamma_1 + \gamma_2)}{e} \]

**Proof.** Appendix 1. 

**Corollary 1.** Under distributor-led Stackelberg game, the green level of the product decided by the manufacturer is independent from the leader's decision.

**Proof.** First order optimality condition \( \frac{d(\Pi_{\text{OT}m}^*)}{d\theta} = 0 \) results in an optimal value for \( \theta \) which is independent from \( p_1 \).

### 3.2. Closed triad decision structure

We temporarily assume a central decision maker who aims to maximize the whole SC profit. Although there is not such a decision maker in the investigated SC, modeling such a decision model can help us to find the optimal solution from the entire SC.

Under the closed triad decision structure, the decisions are made in a way to maximize the profit of the entire SC as a whole. The total profit of the SC can be written as:

\[ \Pi_{\text{SC}}^{CT} = (p_1 - c) ((1 - s) a - b_1 p_1 + b_1' p_2 + \gamma_1 \theta) + (p_2 - c) (s a - b_2 p_2 + b_2' p_1 + \gamma_2 \theta) - e \theta^2 \]

In Eq. (9), the first term denotes the profit earned by selling products through the direct channel, the second term indicates the earned profit from selling products via retail channel, and finally, the third term is the investment cost for greening products with level \( \theta \).
**Theorem 2.** Under the closed triad decision structure, the optimal values of decision variables are:

\[ p_{CT_1}^* = \frac{(Ne + \gamma_1\gamma_2)(b_1' - b_2)e - a e s + cy_2(y_1 + y_2))}{(Ne + \gamma_1\gamma_2)^2 - (2b_1e - \gamma_1^2)(2b_2e - \gamma_2^2)} \]

\[ + (2b_2e - \gamma_2^2)(-ae(1 - s) + c(-b_1e + b_2e + \gamma_1(y_1 + y_2))) \]

\[ p_{CT_2}^* = \frac{a( - b_2'e - b_1'e(1 - s) + (b_2' - 2b_1)e s + s\gamma_1^2 - (1 - s)\gamma_1\gamma_2} + c[b_2\gamma_1^2 + b_2(Ne + \gamma_1^2) + (b_1' + b_2')\gamma_1\gamma_2}{M} + b_1((b_1' - 2b_2 - b_2')e + \gamma_2(y_1 + 2\gamma_2)) \]

\[ \theta_{CT}^* = \frac{\left(2b_1b_2 + (b_2' - b_1'b_2 - b_1N)c + a(-2b_2(1 - s) - Ns)\right)\gamma_1}{M} + \left[-aN + \left(b_1(b_1' + 2b_2 - b_2') - b_1'N\right)c + a(-2b_1 + Ns)\right]\gamma_2 \]

Where,

\[ M = (b_1')^2 e - 4b_1b_2e + 2b_1'b_2e + (b_2')^2 e + 2b_2\gamma_1^2 + 2(b_1' + b_2')\gamma_1\gamma_2 + 2b_1\gamma_2^2; \]

\[ N = b_1' + b_2' \]

**Proof.** Appendix 2. ■

### 3.3. Transitional triad decision structure

It is obvious and frequently emphasized in the literature that making decisions based on the result of the closed triad structure contributes to the best solution for the whole SC in terms of profitability. This means the profit of the SC under the closed triad structure will be higher than that under the open triad mode; in other words we have \( \Pi_{SC}^{CT} > \Pi_{r}^{OT} + \Pi_{d}^{OT} + \Pi_{m}^{OT}. \) However, switching from the open triad to the closed triad structure cannot guarantee that all the SC members will enjoy a higher profit than their profits in the open triad structure. To solve this problem, we will employ a transitional model. Referring to Mena et
transitional triad structure is a decision making structure between closed and open triad structures. This means that the supply chain decisions, and therefore optimality, will move from open triad structure toward closed triad structure under the transitional model. The objective of the proposed model is to maximize the whole SC profit. In addition, our proposed model guarantees more (or at least equal) profit for each SC member compared to open triad structure. It should be also mentioned that as an assumption, we do not consider transaction costs in coordinating the SC through the proposed transitional triad (for more information on transaction cost, refer to Mena et al. (2013)).

According to the depiction above, the transitional model is proposed as a non-linear programming model:

\[
\begin{align*}
\text{Max} & \quad p_1^{TT}, p_2^{TT}, \theta \\
\text{S.t.} & \quad \Pi_{r}^{TT} \geq \Pi_{r}^{OT} \\
& \quad \Pi_{d}^{TT} \geq \Pi_{d}^{OT} \\
& \quad \Pi_{m}^{TT} \geq \Pi_{m}^{OT} \\
& \quad p_1^{TT} \geq 0, \ p_2^{TT} \geq 0, \ \theta^{TT} \geq 0
\end{align*}
\]

Corollary 2. The proposed non-linear mathematical programming model has at least one feasible solution.

Proof. Solution of the open triad decision structure is a feasible solution for the proposed non-linear mathematical programming model which satisfies all the constraints.

4. Numerical experiments

To numerically test and validate the proposed models, we utilize a hypothetical dataset to calculate the optimal values of decision variables and profit functions. The used dataset satisfies our assumptions and is consistent with the previous literature. In the investigated
numerical study we consider \( a = 800; s = 0.7; c = 50; b_1 = 0.7; b_2 = 0.8; b_1' = 0.15; b_2' = 0.2; \)
\( w_1 = 300; w_2 = 330; \gamma_1 = 1.2; \gamma_2 = 1; e = 5. \)

4.1. Models evaluation

To evaluate the proposed triad models and also the efficacy of the transitional model, we conduct a set of numerical experiments. The optimal value of decision variables and corresponding profit function in three investigated scenarios are illustrated in Table 1.

Table 1. Optimal value of decision variables and profit functions in open triad, closed triad, and transitional triad decision structures

<table>
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<tr>
<th></th>
<th>( p_1 )</th>
<th>( p_2 )</th>
<th>( \theta )</th>
<th>( \Pi_r )</th>
<th>( \Pi_d )</th>
<th>( \Pi_m )</th>
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<td>Open triad Structure</td>
<td>489.495</td>
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<td>79348.2</td>
<td>31452.7</td>
<td>64260.9</td>
<td>175061.8</td>
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<td>641.325</td>
<td>239.427</td>
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<td>14801.3</td>
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</tbody>
</table>

As can be seen in Table 1, as expected, the profitability of the whole SC under the closed triad decision structure is higher than the open triad structure. However, the profitability of the manufacturer in the closed triad structure demonstrates a much worse value compared to that of the open triad structure. Therefore, the manufacturer refuses to switch from the open triad to the closed triad structure. In this situation, the proposed transitional model for the investigated dataset can be reformulated as

\[
\begin{align*}
\max_{p_1, p_2, \theta} & \quad \Pi_{TT}^{SC} \\
\text{s.t.} & \quad \Pi_{TT}^r \geq 79348.2 \\
& \quad \Pi_{TT}^d \geq 31452.7 \\
& \quad \Pi_{TT}^m \geq 64260.9 \\
& \quad p_{TT}^1 \geq 0, p_{TT}^2 \geq 0, \theta_{TT} \geq 0
\end{align*}
\]
Solving the transitional model using GAMS version 24.7 results in a much better situation for the whole SC and also enhances all members’ profit compared to the open triad structure. This means that the proposed model not only is attractive for all SC members, but also that it creates more profit for the whole SC. In addition, comparing values of decision variables from Table 1 illustrates that the proposed transitional model results in a more green product and, at the same time, lower prices in both e-channel and retail channels when compared to the open triad structure. This property of the proposed model means that the SC provides more green products with lower prices which, in turn, results in more satisfied customers.

4.2. Sensitivity analysis on greening cost, $e$

To create more insights toward creating greener SC, a set of sensitivity analyses on greening costs is conducted. In this regard, the impacts of change in greening cost factor $e$ on decision variables and profit functions are investigated. Figures 2 and 3 illustrate the effects of change in $e$ on e-channel and retail selling prices, respectively.

From Figures 2 and 3, it can be observed that once $e$ increases, both e-channel price and retail price decrease under all three decision structures. Figures 2 and 3 illustrate that the proposed transitional model results in lower prices than open triad structure for all values of $e$. While prices in closed triad structure are more sensitive to change in $e$, both prices under the open triad and transitional triad structures display similar patterns against change in $e$. 
Figure 2. Impact of change in $e$ on e-channel price

![Graph showing impact of $e$ on e-channel price]

Figure 3. Impact of change in $e$ on retail channel price

![Graph showing impact of $e$ on retail channel price]

Figure 4 illustrates the effects of change in $e$ on green level of product decided by the manufacturer. By increasing $e$, the green level of the product decreases; however, in all values of $e$, the proposed transitional model results in higher green levels than the open triad structure.
It should be noted that by exceeding the value of $e$ from 7, the green level of the product under the transitional triad scenario is as high as the closed triad scenario.

Figure 5 indicates how change in $e$ can impress the total profit of the whole SC.

Based on Figure 5, the total profit of the SC in transitional triad structure is always more than that under the open triad mode and equal or lower than that under the closed triad.
structure. As can be seen from Figure 5, the proposed model is more effective when $e$ is large enough. Indeed, when the cost of greening is higher than a threshold (which is true for real world cases) the proposed transitional model can achieve channel coordination. On the other hand, when the greening cost is low, the proposed model results in a Pareto improving situation where the SC profit is in a higher level compared to the open triad structure. (For definition of Pareto improving coordination, see Heydari et al. (2017))

Figures 6-8 illustrate the effects of change in $e$ on the profit of each individual SC member.

![Retailer's profit graph](image)

**Figure 6. Impact of change in $e$ on the retailer's profit**
According to Figures 6-8, should the members switch from open triad decisions structure to closed triad structure, the retailer and the distributor will profit from it; however, the manufacturer will be worse off. Therefore, all members are willing to participate in closed triad except the manufacturer. As a motivation, the transitional triad structure will be used.
to guarantee all members’ profitability. This means that all the members will gain the profit at least equal to what they gain in the open triad. According to Figures 6-8, increasing $e$ causes less profit for the retailer and the manufacturer while it increases the manufacturer’s profit. It is worth mentioning that, under the transitional triad, sensitivity of member’s profit on $e$ is negligible compared to it under the closed triad structure.

4.3. Sensitivity analysis on green-level elasticity of demand for direct channel, $\gamma_1$

To create more insights on the investigated problem, a set of sensitivity analyses on $\gamma_1$ is conducted.

Figures 9 and 10 illustrate the impact that green-level elasticity of demand for direct channel, i.e., $\gamma_1$, has on e-channel price and retail price, respectively.

![Figure 9. Impact of change in $\gamma_1$ on e-channel price](image-url)
As can be seen in Figure 9, in all decision making structures, e-channel price increases as $\gamma_1$ increases. According to Figure 10, retail price only in closed and open triad structures increases as $\gamma_1$ ascends. Moreover, one important implication is that both e-channel and retail prices in transitional model are constantly lower than those, respectively, in open triad. This, evidently, means that the proposed coordination method performs well from the customers’ perspective.

From Figure 11, it can be observed that when the SC transits from open triad toward closed triad via transitional triad, by increasing $\gamma_1$ the manufacturer produces greener products. This implicates that the proposed transitional model results in more environmentally friendly products compared to the open triad.
In the following, Figure 12 illustrates the impact of changes in $\gamma_1$ on the whole SC profit under different decision making structures. As expected and can be inferred from Figure 12, SC profit under the transitional decision structure is constantly greater than that under open triad structure. In total, Figure 12 shows the increase in SC profit by increasing $\gamma_1$ regardless of selected decision structure.

Figure 11. Impact of $\gamma_1$ on green level of products

Figure 12. Impact of $\gamma_1$ on the profit of the whole SC
According to our sensitivity analyses, as a general fact in nature of the proposed models, SC profitability in transitional model is always greater than that in open triad, and equal or less than that in closed triad structure, which means a better position for the whole SC under the proposed transitional triad.

In Figures 13-15, the effects of change in $\gamma_1$ on the profit of each individual SC member are illustrated.

![Graph showing retailer's profit for different triad structures](image)

Figure 13. Impact of change in $\gamma_1$ on the retailer's profit
As can be observed in Figures 13-15, by switching from open triad structure to the closed triad, as $\gamma_1$ increases, the retailer and the distributor will be better off in terms of profitability; the manufacturer, however, will be worse off. This means that the extra profit created via switching from the open triad to closed triad will be divided between the
retailer and the distributor, but the manufacturer is worse off compared to its profit under the closed triad. In such situation, by using the transitional triad structure, not only the SC profit will increase compared to that in the open triad, but also SC members’ profitability will be assured.

**Corollary 3.** The implications of Figures 5 and 12 are consistent with Mena et al. (2013) and Xu et al. (2104). In Mena et al. (2013) it is articulated that the goal of proposing a transitional model is to obtain results more desirable than open triad structure and also move toward the results of closed triad as much as possible. Also, in Xu et al. (2014), it is shown that SC profit under the coordinated model is always more than that in the decentralized model and it is equal to the centralized structure which is consistent with the results of our work. Although in the current study, in most cases, the closed triad results in a greater profit than the transitional model, the proposed transitional model always achieves a Pareto improving situation with respect to the open triad.

**Corollary 4.** One contradiction between the current study and the previous literature is that in the study by Li et al. (2016), which examines greening and pricing decisions in a dual-channel SC, selling prices in the centralized structure are always higher than in the decentralized structure. Meanwhile, regarding Figures 2, 3, 10, and 11 there is no clear connection between selling prices in closed and open triads in our model. Probably, this can be addressed by noting that in the work by Li et al. (2016), e-channel and retail channel prices are considered to be equal; hence, there will be no cross price sensitivity, and since closed triad always results in more profit than open triad, this can be achieved by higher selling price. However, in our study, selling prices are different and they affect each other
through cross-price sensitivity factors. As a result, sometimes profitability may require lower price under closed triad than the open triad.

**Corollary 5.** Another crucial comparison is about greenness of products. In Li et al. (2016), the green level of products under centralized structure is always higher than that under decentralized structure. This is the same result that we can conclude from Figures 4 and 11. We make an extension on this fact; the green level of products under transitional model obtains values between closed and open triads.

**5. Conclusion**

This paper addresses pricing and greening decisions in a three-tier dual-channel SC. In the investigated SC, the distributor can use a direct e-channel to sell products to the customers. In addition, the retailer uses a traditional retail channel. The manufacturer decides on the green level of the product while the distributor and the retailer decide on price of product in e-channel and retail channel, respectively. SC members’ decisions are modeled in the open triad and closed triad structures, and in the next step, a collaboration model is proposed in order to coordinate the SC decisions. The closed triad model profits the SC compared to the open triad. However, since this profit is obtained at the expense of one or more members, then the affected members will not take part in the closed triad structure. The proposed transitional model guarantees that all SC members’ profit will be greater than the open triad model. The numerical experiments results indicate the efficiency of the proposed model. An interesting implication of the proposed model is that the green level of the product is increased while both e-channel and retail prices are lower than the open triad structure. This property of the proposed model results in more satisfied customers under the proposed transitional model. As a limitation of this study, the developed models
do not consider transaction costs. In addition, although assuming a simple linear demand function is common for studies in this area (in order to avoid mathematical complexity), that is another limitation of this study. Furthermore, we assumed that participation of SC members in transitional triad structure is guaranteed subject to achieving more profit than the profit they obtained under open triad structure; this is not always true especially when the SC members are aware of the total gained profit. In that case, usually, each member asks a specified share of obtained profit. As a possible interesting future research, transaction costs in the coordination mechanism (i.e., transitional triad structure in our work) can be applied. Paying attention to it can improve the research applicability to the real problems. Moreover, in the transitional triad, it can be considered that each member not only must not be worse off compared to the open triad, but also it must obtain a certain percent of the extra profit which will be created through switching from the open triad to the closed triad structure. Establishing a mechanism potentially based on bargaining models in order to determine that “certain percent of extra profit” for each SC member is also another room for further studies.

Appendix 1.

Since we use a distributor-led Stackelberg game, at first the retailer and the manufacturer determine their decisions and then the distributor decides. It is obvious that $\Pi^{OT}_r$ and $\Pi^{OT}_m$ are both concave in $p_2$ and $\theta$, respectively. Therefore, the optimal value of the retailer’s decision variable $p_2$ and the manufacturer’s decision variable $\theta$ exists. The first order optimality condition for $\Pi^{OT}_r$ with respect to $p_2$ results in:
\[
\frac{d (\Pi_{OT}^r)}{dp_2} = b_2 p_1 - b_2 p_2 + as - b_2 (p_2 - w_2) + \gamma_2 \theta = 0
\]  
(A1)

Also, the first order optimality condition for \( \Pi_{OT}^m \) with respect to \( \theta \) results in:

\[
\frac{d (\Pi_{OT}^m)}{d\theta} = (w_1 - c)(\gamma_1 + \gamma_2) - e \theta = 0
\]  
(A2)

Solving Eqs. A1 and A2, we have:

\[
p_2^{OT} (p_1^{OT}, \theta^{OT}) = \frac{sa + b_2 p_1^{OT} + b_2 w_2 + \gamma_2 \theta^{OT}}{2b_2}
\]  
(A3)

\[
\theta^{OT} = \frac{(w_1 - c)(\gamma_1 + \gamma_2)}{e}
\]  
(A4)

Now, substituting A3 and A4 into Eq. 4, the second order derivative of \( \Pi_{OT}^d \) with respect to \( p_1 \) can be calculated as:

\[
\frac{\partial^2 (\Pi_{OT}^d)}{\partial p_1^2} = - 2b_1 + \frac{b_1 b_2}{b_2}
\]  
(A5)

Since \( 2b_1 b_2 > b_1^2 b_2 \), so \( \Pi_{OT}^d \) is concave in \( p_1 \). By \( \frac{\partial (\Pi_{OT}^d)}{\partial p_1} = 0 \) we have:

\[
p_1^{OT} = \frac{ae (2b_2 (1 - s) + b_1 s) + (2b_1 b_2 - b_1 b_2 - b_2^2) w_1 e + (b_1 b_2 + b_2 b_2) w_2 e + 2b_2 \gamma_2^2 (w_1 - c) - (b_1 + 2b_2) (w_1 - c) \gamma_1 \gamma_2 - b_1^2 (w_1 - c) \gamma_2^2}{(4b_1 b_2 - 2b_1 b_2) e}
\]  
(A6)

Now, by substituting A6 into A3 optimal value of \( p_2^{OT} \) can be calculated. Since \( \theta^{OT} \) is not dependent on other decision variables, we can substitute A4 into A3 and calculate \( p_2^{OT} \) only as a function of \( p_1^{OT} \). Therefore, Theorem 1 is proved.

Appendix 2.

Hessian matrix for \( \Pi_{SC}^{CT}(p_1^{OT}, p_2^{OT}, \theta) \) can be calculated as:
\[
H = \begin{bmatrix}
-2b_1 & b_1' + b_2' & \gamma_1 \\
b_1' + b_2' & -2b_2 & \gamma_2 \\
\gamma_1 & \gamma_2 & -e
\end{bmatrix}
\]  \tag{A7}

We have:
\[
|H_{1 \times 1}| = -2b_1 < 0
\]  \tag{A8}
\[
|H_{2 \times 2}| = 4b_1b_2 - (b_1' + b_2')^2
\]  \tag{A9}
\[
|H_{3 \times 3}| = 2\gamma_1\gamma_2(b_1' + b_2') + 2(\gamma_1^2b_2 + \gamma_2^2b_1) - \left[4b_1b_2 - (b_1' + b_2')^2\right]e < 0
\]  \tag{A10}

If the following condition is satisfied, then \(\Pi_{SC}^{CT}(p_1,p_2,\theta)\) will be concave in \(p_1,p_2,\theta\):
\[
4b_1b_2e > (b_1' + b_2')[2\gamma_1\gamma_2 + (b_1' + b_2')e] + 2(\gamma_1^2b_2 + \gamma_2^2b_1)
\]  \tag{A11}

The first order optimality condition for \(\Pi_{SC}^{CT}(p_1,p_2,\theta)\) results in:
\[
\frac{\partial \Pi_{SC}^{CT}(p_1,p_2,\theta)}{\partial p_1} = -b_1p_1 - b_1(p_1 - c) + b_1p_2 + b_2(p_2 - c) + a(1 - s) + \gamma_1\theta = 0 \tag{A12}
\]
\[
\frac{\partial \Pi_{SC}^{CT}(p_1,p_2,\theta)}{\partial p_2} = b_2p_1 + b_1(p_1 - c) - b_2p_2 - b_2(p_2 - c) + as + \gamma_2\theta = 0 \tag{A13}
\]
\[
\frac{\partial \Pi_{SC}^{CT}(p_1,p_2,\theta)}{\partial p_1} = (p_1 - c)\gamma_1 + (p_2 - c)\gamma_2 - e\theta = 0 \tag{A14}
\]

Solving A12-A14, the optimal solutions under the closed triad structure will be:
\[
p_{1}^{CT^*} = \frac{(Ne + \gamma_1\gamma_2)((b_1' - b_2)c) - a(e(1-s) + c(-b_1e + b_2e + \gamma_1(\gamma_1 + \gamma_2)))}{(Ne + \gamma_1\gamma_2)^2 - (2b_1e - \gamma_1^2)(2b_2e - \gamma_2^2)}
\]
\[
+ c[b_1^2\gamma_1^2 + b_2^2(Ne + \gamma_1^2) + (b_1' + b_2')\gamma_1\gamma_2 + b_1((b_1' - b_2) - (b_1' + b_2')\gamma_1\gamma_2)]
\]
\[
p_{2}^{CT^*} = \frac{M}{M}
\]
\[ \theta^{CT*} = \left( \left( 2b_1 b_2 + \left( b_2 - b_2' \right) b_2' - b_1 N \right) c + a \left( -2b_2 (1 - s) - Ns \right) \right) y_1 \]
\[ + \left[ -a N + \left( b_1 \left( b_1' + 2b_2 - b_2' \right) - b_1' N \right) c + + a \left( -2b_1 + N \right)s \right] y_2 \]
\[ M = \left( b_1' \right)^2 e - 4b_1 b_2 e + 2b_1 b_2 e + \left( b_2' \right)^2 e + 2b_2 y_1 \left( b_1' \right)^2 + 2 \left( b_1 + b_2 \right) y_1 y_2 + 2b_1 y_2^2 ; \]
\[ N = b_1' + b_2'. \]

Consequently, Theorem 2 is proved.

References


