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Pricing the Green Products in a Sustainable Supply Chain with Data Envelopment Analysis Approach (Case Study: Home Appliance Companies)

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Abstract

Today, most supply chains are moving towards green business with a greater focus on environmental protection as a competitive advantage. Among them, the design of a three-stage green supply chain with optimal allocation, a multiple supply chain that includes supplier (first stage), manufacturer (second stage) and distributor (third stage), based on maximum efficiency and considering the internal processes and products between these three levels, can be of special importance; because, it will increase the economic and environmental performance of the supply chain. One of the methods used to evaluate efficiency in Green Supply Chain Management (GSCM) is Data Envelopment Analysis (DEA). Therefore, performance evaluation is vital for companies to improve the effectiveness and efficiency of the supply chain. In this study, using the three-stage approach of DEA, the data collected in 2020 from 9 Selected home appliance companies have been analyzed. The results show that company 1 has the best efficiency and the greenest supply chain and company 7 has the worst value of efficiency, which makes it necessary to pay more attention to low performance companies. In order to show the capability of the proposed model, the developed model was compared with its equivalent base model, and companies 1 and 2 were identified as inefficient in the proposed model, but identified as efficient in the base model. Given that the efficiency score in the proposed model is always lower than the base model, so the accuracy of the developed model can be concluded.

Keywords: Green supply chain, Sustainable supply chain, Pricing, Data envelopment analysis approach, Efficiency.

1 | Introduction

Given the importance of environmental issues for countries, the concept of environmental protection has entered the supply chain and Green Supply Chain Management (GSCM) has become particularly important [1]. Globalization of sustainability concepts and determination of strict rules have made it very important to consider environmental issues at all stages of supply chain design. Companies have taken effective steps to preserve environmental standards to maintain a competitive advantage. Using GSCM will ultimately improve system performance. Supply chain managers, on the one hand, seek to minimize costs, and on the other hand, face government pressure to comply with environmental standards and the increase in customer demand for green products. Therefore, investment in

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improving the environmental aspects of the supply chain will reduce greenhouse gas emissions, eliminate waste, create value for customers, and ultimately increase productivity for companies.

The important point is that initial investment in technology and equipment for environmental protection should be considered at the design stage. This investment in the operational phase can affect environmental indicators. Therefore, in addition to making decisions on the location and capacity of facilities, decision-making for investing in environmentally friendly technologies is also essential. It is clear that making green eco-friendly products costs much more. In this regard, the government has a vital role in supporting manufacturers to reduce greenhouse gas emissions [2]. In fact, as an incentive strategy, the government can encourage manufacturers to produce less greenhouse gases [3] and [4]. Because many eco-friendly customers are willing to pay more for eco-friendly products, the government can also reassure manufacturers by paying green subsidies. GSCM has been considered and researched as a key role in improving environmental performance [5]. The green characteristics of the product not only attract more eco-friendly consumers but also affect the company's costs [5].

The supply chain is a set of organizations that are directly and indirectly connected and interacting to convert input into output [6]. Sustainable development is one of the most important issues from both theoretical and practical perspectives. Concepts and problems related to supply chain sustainability are applied in many manufacturing organizations [7]. Another important issue that has been considered in recent years is the study of multi-channel sales in the supply chain network. Nowadays, due to the speed of access to information and the growing importance of environmental issues, special attention has been paid to buying from direct channels through the Internet. In addition, because of the rapid change in living standards, customers are looking for higher quality products and services and prefer manufacturers who can offer different sales options. An increasing number of people are starting to shop online, although some still prefer the traditional way of shopping. As a result, many manufacturers consider different channels to sell products to customers. In the traditional channel (indirect channel), the retailer, as an intermediary, buys products from the manufacturer and sells them to customers. However, in an online channel (direct channel), manufacturers can sell products to their customers directly through the Internet. In the current state of globalization, dual-channel Supply Chain Management (SCM) is an important phenomenon between an online channel and traditional retail channels. Decision-making on greenness of a product toward a dual-channel supply chain is beneficial to a company's growing trend [8]. One of the most important factors of green activities is green production, which according to decision-making processes, plays an important role in the development of GSCM [9]. To achieve sustainable supply chains, the production of green products must be expanded [10]. Green products describe products that have fewer negative effects on human health and the environment. This concept includes sustainable supply chains, environmental sustainability and a green planet in which standardized technologies are used [11]. GSCM emerged as the activator of environmentally friendly supply chain after the 1990s [12]. GSCM has been widely considered by experts due to the deterioration of the environment and increasing awareness of environmental protection. Green supply chain studies focus primarily on supply chain operational decisions and coordination contracts [13]. Suppliers of companies benefit from green production in green investment [13]. Green products can be considered by suppliers and green strategy and pricing can be studied under centralized and decentralized decision-making [9]. The issue of product pricing has always been one of the most difficult decisions of a company, because it needs accurate knowledge of the important factors and characteristics affecting the demand of other companies, the cost of providing these factors, and the reaction of competitors. Success in pricing is a function of internal and external factors of the organization. In other words, in order to have a suitable pricing plan, not only internal factors such as organizational goals and policies must be considered, but also the situation and policies of the organization's competitors must be regarded. Determining the selling price of a product for each of the sales channels in the dual-channel supply chain is an important issue. In some studies, game theory has been used to deal with the pricing problem in the supply chain, which the result was that it cannot be used to solve this problem due to mathematical complexity [14]. However, some researchers, such as [15] and [16], examined the pricing problem with mathematical programming, which leads to

nonlinearity of the model. Huang and Swaminathan [17], proposed a model for designing a supply chain of introducing an online sales channel. They considered the effect of price on demand and profit. Jiang et al. [18], considered pricing policy in a dual-channel supply chain. Pricing in green supply chain is one of the factors that, if implemented properly, will have a surprising impact on consumer decision-making. But if the companies do not have the right strategy in this regard, they will either have to reduce the final price of their products or lose a lot of customers. It is best to cover the pricing of the products with important reasons for using these types of green products. Price should never be considered as a competitive factor. Those who only try to gain market share and outperform their competitors with a lower price often fail. This strategy can only be useful in the short term to save companies from the crisis, but in the long term, it will destroy the companies. The objective of this paper is to provide a model for pricing a three-stage supply chain with green structure in the presence of undesirable outputs using DEA technique. In DEA, the supply chain is considered as a profit box in which only its inputs and outputs are evaluated for efficiency. Therefore, intermediate products are ignored. Performance evaluation plays a vital role in achieving both goals of cost reduction and profit increase of the supply chain. Since an independent decision maker in each member of the supply chain only tries to maximize his or her technical work and ignores the other members and the whole chain, it is therefore necessary to use network models for paying attention to the whole supply chain, or more simply, paying attention to inside the black box. In network models, the supply chain includes suppliers, manufacturers and distributors. The relationship is such that supplier outputs are considered as manufacturer inputs and also, manufacturer outputs are considered as distributer inputs. Since the supplier intends to maximize efficiency by increasing outputs and prices, it leads to increased input and consequently reduced manufacturer efficiency, so it is necessary to consider the integrity of the model. Therefore, in this study, the application of the proposed model is implemented in a three-stage supply chain with a green structure. In this study, the green supply chain of nine home appliance companies has been evaluated.

Therefore, the objectives of this research are as follows:

- *Provide a model for pricing a three-step supply chain with a green structure.*
- *Calculate the efficiency score of the green supply chain.*
- *Presenting a three-step supply chain model using a data envelopment analytical approach.*
- *Comparison of the performance score of the proposed model (CRS) with the base model (CCR).*

The researcher faces obstacles and limitations in conducting research. This research is no exception to this rule. Some of these limitations are mentioned below:

- *Research results may be different in other statistical communities, so generalizing the results to other organizations and companies should be done with caution.*
- *Resistance of some companies in providing financial information and access to statistics and information.*
- *The results and findings of the research may change if the data collection tool changes.*

The rest of this article will be organized as specified. In the second part, a literature review is presented, in the third part, the research method is presented, which includes supply chain structure and mathematical modeling. In the fourth section, a practical example is provided. Finally, the fifth section provides a conclusion and suggestions for future research.

The following is a conceptual model of the research shown in *Fig. 1*:

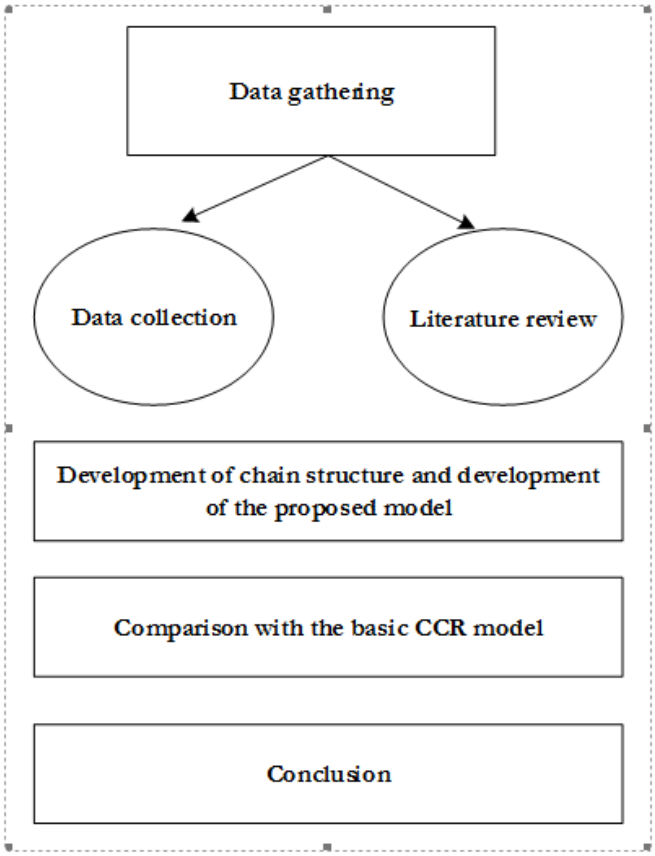

Fig. 1. Conceptual model of research.

2 | Literature Review

In this section, the most important domestic and foreign studies on pricing of green products in a sustainable supply chain with a DEA approach are reviewed.

Barman et al. [8], stated that the objective of their study was optimal decision-making and optimal pricing in a dual-channel supply chain. Demand was sensitive to the price and greenness level of the product, both in the retail channel and in the online channel. The supply chain model examined maximum profit in both centralized and decentralized decision-making structures. The Stackelberg game method was used to solve the scenarios. According to the numerical findings and sensitivity analysis, the centralized scenario was more profitable than the decentralized scenario. Kang et al. [12], examined the pricing and financing strategies of a green product in optimal decision-making. The results showed that high risk behavior of the supplier is not beneficial for the green supply chain. When the supplier has less initial capital, the down payment strategy presented by the retailer is of priority in the supplier's financial constraints. When the initial capital of the supplier is more, it must use the initial capital for manufacturing. Considering the greenness level of supply chain as an endogenous variable along with risk-taking of the supplier have a role in its novelty. Li et al. [19], stated that pricing strategy has a clear effect on the profit level of supply chain members but has no effect on the green degree of product. Both the manufacturer and the retailer with higher market potential tend to choose the consistent wholesale price, while the retailer with the lower market potential prefers the inconsistent wholesale price. In addition, the green degree which reflects the product's environmental protection degree of the manufacturer is positively related to environmental consciousness of customers and negatively correlated with green degree cost coefficient. Furthermore, an improved coordination model based on two-part tariff can not only reach the profit level under the centralized scenario, but also make the retailers benefit from the profit increasing. The results showed that the equilibrium profits of supply chain members are obviously affected by uncertain demand and asymmetric information. Shamsi Jamkhaneh et al. [20], stated in their study using a three-stage approach to DEA, this paper analyzed the data collected from 16 power companies, which included three sectors of manufacturing, transmission

and distribution for the year 2017. The results showed that power companies in Tehran, Khuzestan and Semnan provinces have a total efficiency of one and Yazd, Guilan and Sistan and Baluchestan provinces have the lowest efficiency, which makes it necessary to pay more attention to low-efficient companies. Rahmani and Yavari [21], in a study entitled Pricing policies for a dual-channel green supply chain under demand disruptions, stated that a dual-channel green supply chain was considered in two decision-making models. Pricing, landscaping and production were calculated under demand disruption. The original production quantity had some robustness with disruptions. Given the growing trend of companies towards electronic commerce as well as green production, disruption management in such a chain needs more attention from the academic community. This paper examined the management of demand disruption in a dual-channel supply chain and the sale of green products for the first time. Amini and Alinezhad [22], stated that the objective of this paper was to provide a model of network DEA to evaluate the management of green supply chain with undesirable outputs. Finally, the application of the proposed model was shown with a four-stage green supply chain. By increasing environmental laws and regulations and raising public awareness of environmental protection, companies cannot easily ignore environmental issues if they want to work in global markets and compete with other companies. GSCM has become an approach to enhance environmental performance. Under stakeholder pressures and regulations, firms need to enhance their environmental performance which includes practices such as green purchasing, green design, and product recovery. Considering environmental criteria will give companies a competitive advantage and improve their economic and environmental performance. Hence, GSCM evaluation is very important for any company. One of the techniques that can be used for evaluating GSCM is DEA. Traditional models of DEA are based upon thinking about production as a "black box". One of the drawbacks of traditional models of DEA is to omit linking activities of internal parts of the units. Mohebbi et al. [23], stated that the objective of their paper was to design a mathematical model of optimum assignment in the two-stage green supply chain using Network Data Envelopment Analysis (NDEA) and electrical circuits. Nowadays, most supply chains are starting to move towards green business by paying more attention to environmental protection as a competitive advantage. Therefore, designing a two-stage green supply chain for optimum assignment of a green supplier to a green producer based on maximum efficiency and considering intermediate products and processes is essential, because, economic performance and environmental performance of the supply chain will increase. One of the methods used to evaluating efficiency in the GSCM is DEA. The traditional DEA methods do not work properly for evaluating efficiency of supply chain processes and multi-stage systems, because, each decision making units is assumed as a black box and its internal processes are ignored. In order to overcome this deficiency, a novel two-stage network DEA was presented based on the concepts of electrical engineering that was able to consider all inputs, intermediate products, desirable and undesirable outputs between supplier and producer in the green supply chain for optimum assignment of a supplier to the producer based on maximum efficiency. The proposed model was described by a practical example and its reliability was confirmed. Hosseinzadeh Saljooghi and Rahimi [24], stated that the objective of their paper was to evaluate the efficiency and returns to scale of Iran's Resin Chemical Industry supply chain using crisp and fuzzy DEA model. SCM is a suitable tool to improve economic, social and environmental performance and its assessment is an important task. The DEA method has been widely used to evaluate SCM. By considering supply chain as network DEA, the efficiency of supply chain with multiple stages is calculated. This study examined the efficiency and Returns to Scale (RTS) of SCM of resin manufacturing companies based on network DEA models. Returns to scale was investigated in both modes of crisp and fuzzy data and a model for evaluating SCM ent using a network DEA model with fuzzy data was proposed. Fuzzy DEA model was based on α-cut approach to measure the efficiency and returns to scale of supply chain. The proposed models were used to evaluate the efficiency and returns to scale of supply chain of 27 resin production companies. The six companies were network efficient in the investigation with crisp data, while there were three network efficient companies with fuzzy data. These companies managed and coordinated the flow of materials between several organizations and within the organization in the most optimal way regarding environmental issues. Karimi and Rasti-Barzoki [25], stated that their study investigated pricing, advertising, and service level decisions simultaneously in a supply chain with dual distribution channels with a centralized game theoretic approach. The chain in this study included a manufacturer and a retailer in which the sales were carried out through the direct channel. Zhu and He [26], proposed a multi-objective optimization model for

GSCM design that minimized the risk posed by hazardous materials, carbon emissions and its economic costs. In their research, they solved their model by considering different scenarios and used a case study to confirm their optimization model and the results. Honarvar et al. [27], stated that this study examined the effect of dual-channel sales on pricing in the supply chain. The objective of this paper was to find a proper strategy for pricing dual sales channels in a centralized supply chain in order to achieve maximum supply chain integrated profit. This paper presented two models based on continuous and discrete function of expected profit. The discrete model was scenario-based and was solved using GAMS software and its solution was considered as the initial solution to solve the continuous model. Mirhedayatian et al. [28], stated that the objective of their paper was to present a new network DEA model for evaluating GSCM in the presence of dual role factors, undesirable outputs, and fuzzy data. This study also showed that GSCM has become a way to improve environmental performance. Under pressure from stakeholders, authorities and regulations, companies need to improve GSCM performance, which is influenced by methods such as green purchasing, green design, product improvement, and cooperation with sponsors and suppliers. As companies upgrade GSCM, their economic performance and environmental performance will improve. Therefore, GSCM evaluation is very important for any company. One of the techniques that can be used to evaluate GSCM is DEA. Traditional DEA models are based on thinking of production as a "black box". One of the disadvantages of these models is the elimination of linking activities.

The following is a summary of the literature review in *Table 1*.

Table 1. Summary of literature review.

	Researchers	Results
1	Barman et al. [8]	The supply chain model examines the maximum profit in both centralized and decentralized decision-making structures. And the Stalkberg game method has been used to solve the scenarios. According to the numerical findings and sensitivity analysis, the centralized scenario is more profitable than the decentralized scenario.
2	Kang et al. [12]	The results show that high supplier risk is not beneficial for the green supply chain. When the supplier has less initial capital, the down payment strategy presented by the retailer takes precedence over the supplier's financial constraints. When the initial capital of the supplier is more, it must use the initial capital for production. Considering the green level of supply chain as an endogenous variable, as well as supplier risk-taking, play a role in its novelty.
3	Li et al. [19]	The results show that the equilibrium profit of supply chain members is clearly affected by uncertain demand and asymmetric information.
4	Shamsi Jamkhane et al. [20]	This article has analyzed the data collected from 16 electricity companies, which includes three sectors of production, transmission and distribution, for the year 1396, using a three-step approach of DEA. The results show that electricity companies in Tehran, Khuzestan and Semnan provinces have a total efficiency of one and Yazd, Guilan and Sistan and Baluchestan provinces have the lowest efficiency, which makes it necessary to pay more attention to low efficiency companies.
5	Rahmani and Yavari [21]	They stated that a two-channel green supply chain is considered in two decision models. Pricing, landscaping and production are calculated under the disturbance of demand. The main production volume has good strength with disturbances. Given the growing trend of companies towards e-commerce as well as green production, disruptive management in such a chain needs more attention from the academic community.
6	Amini and Alinezhad [22]	They stated that the purpose of this paper is to provide a network DEA model to evaluate the management of green supply chain with undesirable outputs. Finally, the application of the proposed model with a four-stage green supply chain is shown. With increasing environmental laws and regulations and public awareness of environmental protection, companies can no longer easily ignore environmental issues if they continue to want to compete in global markets and compete with other companies.

Table 1. Continued.

	Researchers	Results
7	Mohebbi et al. [23]	The purpose of this paper is to design a mathematical model of optimal allocation in a two-stage green supply chain using NDEA and electrical circuits. One of the methods used to evaluate efficiency in GSCM is DEA. Traditional DEA methods for evaluating supply chain performance and multi-stage systems do not work well; Because, each decision-making unit is considered as a black box and neglects its internal structures. Therefore, in order to eliminate this shortcoming, a two-stage network DEA method based on electrical engineering concepts will be presented that is capable to consider the total desirable and undesirable inputs, intermediate products and outputs between supplier and manufacturer in the green supply chain for optimal allocation of supply units to production based on maximum efficiency.
8	Hosseinzadeh Saljooghi and Rahimi [24]	The purpose of this paper is to evaluate the efficiency and efficiency of the supply chain scale of Iranian resin industries with the model of definitive and fuzzy DEA. SCM is a good tool for improving economic, social and environmental performance at the same time, and evaluating its efficiency is very important. The DEA method is one of the suitable methods for SCM evaluation. Considering the supply chain as a model of NDEA, the supply chain efficiency is calculated in several steps. This study calculates the efficiency and efficiency scale (RTS) of SCM of resin companies in the framework of DEA network models. Scale efficiencies in both definite and fuzzy data modes are studied and a model for evaluating SCM using a network DEA model with fuzzy data is proposed. The DEA model is used based on the cut-off approach to measure efficiency and determine the supply chain scale efficiency.
9	Karimi and Rasti-Barzoki [25]	They stated that in this paper, the issue of pricing, determining the level of advertising and determining the level of service simultaneously in a supply chain with dual distribution channels with a centralized game approach has been studied. The chain in this article includes a manufacturer and retailer, as well as direct sales.
10	Zhu and He [26]	They have proposed a multi-objective optimization model for GSCM plan that minimizes the risk posed by hazardous materials, carbon emissions and its economic costs. In their research, they solved their model by considering different scenarios and used a case study to confirm their optimization model and the results.
11	Honarvar et al. [27]	The purpose of this paper is to find a suitable strategy for pricing dual sales channels in a centralized supply chain in order to achieve maximum integrated supply chain profit. This paper presents two models based on continuous and discrete function of expected profit that the discrete model is based on scenario and its solution is considered as the initial solution of continuous model.
12	Mir Hedayatian [28]	This study showed that GSCM has become a way to improve environmental performance. Under pressure from stakeholders, forces and regulations, companies need to improve GSCM performance, which is influenced by methods such as green purchasing, green design, product improvement, and partnerships with sponsors and suppliers. As companies upgrade GSCMs, their economic performance and environmental performance will improve. Therefore, GSCM evaluation is very important for any company. One of the techniques that can be used to evaluate GSCM is DEA. Traditional DEA models are based on thinking of production as a "black box". One of the disadvantages of these models is the elimination of linking activities.

As mentioned in the background, most supply chain processes are modeled with a two-stage DEA model. However, the study of the three-stage supply chain by considering the three fields of supplier, manufacturer and distributor has not been evaluated with a two-stage envelopment analysis model to determine whether the entire supply chain is moving in the direction of a single strategy that serves the interests of all areas or not. Therefore, in this study, it has been tried to evaluate and analyze a three-level green supply chain.

3 | Research Methodology

Among the branches of operations research science is the branch of linear programming, which due to its very high capabilities, a lot of effective studies has been done on it and it has found many applications. The applications of linear programming are such that it includes several sub-branches. One of these sub-branches is DEA, which aims to use scientific methods to evaluate the performance of Decision-Making Units (DMUs). In other words, it is a managerial approach that has been widely used to analyze performance in the public and private sectors. DEA has also been made available to economics as a mathematical tool in this collective effort to examine economic costs, revenues and benefits. When a

person needs a behavioral goal with price information, overall efficiency is defined and measured, which these goals are to maximize revenue, minimize costs, and maximize profits.

To calculate the chain efficiency, the model presented in the set of *Eq. (1)* has been used. *Fig. 2* shows a type of a chain. For modeling, it is assumed that there is a set of n DMU_j of $j = 1,\ldots,n$ whose notation is defined as follows.

x_i: The input to the whole chain which its weight is shown by $v_i = 1,\ldots,I.$

x_i^1: Input vector of the first stage which its weight is shown by $w_{i'}, i' = 1,\ldots,I'.$

x_p^2: The input vector of the second stage which its weight is shown by $w'_p, p = 1,\ldots,P.$

z_{nk}^1: The output vector that exits the first stage and enters the second stage. And its weight is shown by η_n, $n = 1,\ldots,N.$

z_{kh}^2: The output vector that exits the second stage and enters the third stage. And its weight is shown by μ_K, $k = 1,\ldots,K.$

y_{1r}^j, y_{2r}^j and y_{3r}^j are the specific outputs of the first, second and third stages, which their weights are shown by u'_r.

Y_r: The output vector of the whole chain which its weight is shown by u_r, $r = 1,\ldots,S.$

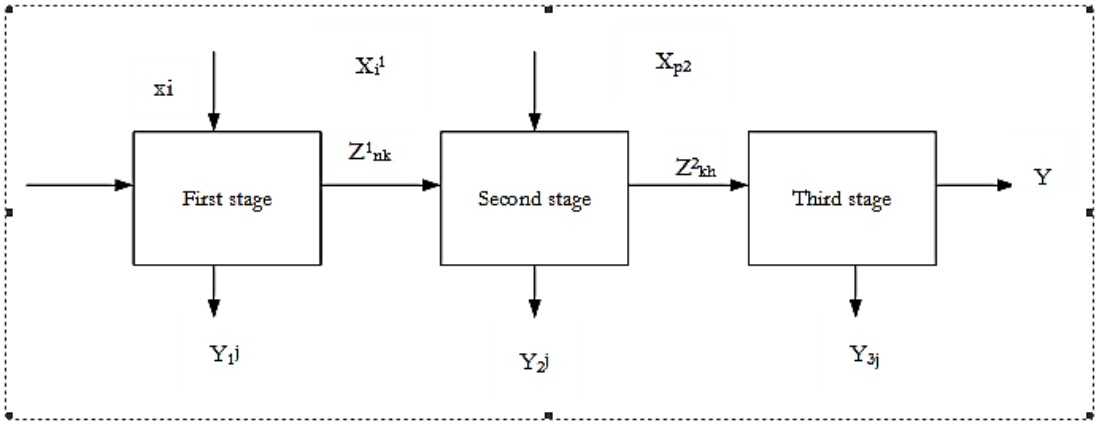

Fig. 2. Multi-stage chain.

Finally, the proposed model is defined as a set of *Eq. (1)* as follows.

$$\max\theta=\sum_{r=1}^{s}u_r y_r+\sum_{k=1}^{k}\mu_k z_{kh}^{2}+\sum_{n=1}^{N}\eta_n z_{nk}^{1}+\sum_{r=1}^{s}u'_r y_{3r}^{j}+\sum_{r=1}^{s}u'_r y_{2r}^{j}+\sum_{r=1}^{s}u'_r y_{1r}^{j},$$

$$\text{subject to}:\quad \sum_{i=1}^{I}v_i x_i+\sum_{i'=1}^{I'}w_{i'}x_i^{1}+\sum_{p=1}^{P}w'_p x_p^{2}+\sum_{k=1}^{k}\mu_k z_{kh}^{2}+\sum_{n=1}^{N}\eta_n z_{nk}^{1}=1,$$

$$\begin{aligned}
&\sum_{n=1}^{N}\eta_n z_{nk}^{1}+\sum_{r=1}^{s}u'_r y_{1r}^{j}-\Big(\sum_{i=1}^{I}v_i x_i+\sum_{i'=1}^{I'}w_{i'}x_i^{1}+\sum_{p=1}^{P}\eta_n z_{nk}^{1}\Big)\le 0,\\
&\sum_{k=1}^{k}\mu_k z_{kh}^{2}+\sum_{r=1}^{s}u'_r y_{2r}^{j}-\Big(\sum_{p=1}^{P}w'_p x_p^{2}+\sum_{n=1}^{N}\eta_n z_{nk}^{1}\Big)\le 0,\\
&\sum_{r=1}^{s}u_r y_r+\sum_{r=1}^{s}u'_r y_{3r}^{j}-\sum_{k=1}^{k}\mu_k z_{kh}^{2}\le 0,\\
&u_r, v_i, \mu_k, \eta_n, u'_r, w_i, w'_p \ge 0.
\end{aligned}\qquad (1)$$

Definition 1. A DMU such as *K* is called efficient if and only if, the objective function θ for *Model (1)* has an optimal solution equal to one. Otherwise, it is inefficient.

Definition 2. If in the set of *Eq. (1)* all the variables have a completely positive value, or all the shortage variables are equal to zero, the DMU under evaluation, such as*K*, has a Pareto solution.

3.1 | Case Study: Home Appliance Companies

In this section, the green supply chain of 9 selected home appliance companies[1] has been evaluated. *Table 2* shows the factors and symbols that are considered. Factors are determined through interviews with experts active in the field of home appliance manufacturers. The supply chain structure is shown in *Fig. 3*. According to this structure, there is a multiple supply chain that includes supplier (first stage), manufacturer (second stage) and distributor (third stage). The first stage inputs are environmental management costs and green parts supply costs. The first stage inputs are also considered as the overall input of the chain. In the considered structure, the inputs that enter the first stage are shown with x_i^1 for $i = 1, 2$. z_1^1 is the output that exits the first stage and enters the second stage. x_i^2 for $i = 1, 2$ are the second stage inputs, which are green design and green innovation. These variables are considered qualitatively that have been converted to quantitative values to perform calculations using the bipolar spectrum scale. z_1^2 is the output that exits the second stage and enters the third stage. Finally, *Y* is the output of the third stage. It should be noted that the output of the last stage is considered as the overall output of the chain. The collected data is related to the year 2020, which is shown in *Table 3*. Also, the considered network structure has been obtained through interviews with home appliance companies.

Table 2. Factors used in green supply chain evaluation.

Stage	Symbol	Definition
Supplier	x_1^1	Environmental management costs.
	x_2^1	Green parts supply costs.
Anufacturer	x_1^2	Green design.
	x_2^2	Green innovation.
Distributor	Y	Green distribution.
Intermediate	z_1^1	Number of products supplied by suppliers for factories.
	z_1^2	Number of green products made in factories.

[1] The names of these companies were reserved for the researchers

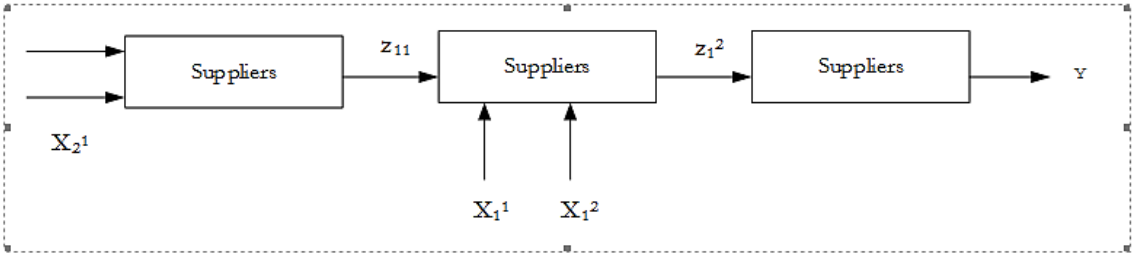

Fig. 3. Supply chain structure.

Table 3. Data.

DMUs	Inputs				Intermediate		Output
	x_1^1	x_2^1	x_1^2	x_2^2	z_1^1	z_1^2	Y
1	400	30	9	9	320	315	9
2	360	60	7	5	295	290	5
3	330	55	7	7	290	282	7
4	455	25	5	7	310	312	5
5	370	37	9	9	280	270	7
6	332	80	5	5	210	200	5
7	355	87	7	7	235	220	5
8	300	95	7	7	255	235	5
9	295	50	9	9	315	318	9

Environmental costs as costs associated with the supply of green parts and environmental management with natural value are determined through economic activities. Therefore, these costs are considered as the input of the first stage. Intermediate inputs/outputs consist of two stages, the second and the third. The intermediate input/output between the supplier and manufacturer stages is the number of products that are transferred from the supplier to the manufacturer. Also, the intermediate input/output between the manufacturer and distributor is the number of green products. To evaluate the efficiency of the green supply chain, each supply chain is considered as the DMU in *Model (1)* to calculate the efficiency score for each of them. Using *Model (1)*, the efficiency boundary and the maximum efficiency score of the units under evaluation can be calculated. Efficiency boundary emphasizes that the supply chain is green. To measure the total efficiency and finally the ranking of the supply chains of the units under evaluation, the relation $e_o = \theta_o^* / \sum_{j=1}^{n} \theta_j^{r^2}$ is calculated. In *Table 4*, the efficiency scores for DMU1 and DMU7 are 0.89 and 0.69, respectively, which are the best and the worst green supply chains.

Table 4. Calculation of chain efficiency score with the proposed model.

DMU	Chain efficiency
1	0.89
2	0.73
3	0.80
4	0.79
5	0.82
6	0.71
7	0.69
8	0.75
9	0.88

Table 5 shows the total efficiency of supply chains calculated using the e_o relation. In calculating the total efficiency, the interactions within the chain are not considered, only the inputs and outputs entered and exited from the chain are considered. As can be seen, the DMU1 has the best efficiency score. In other words, it is the greenest supply chain. It should be noted that because the calculation of efficiency score does not consider the internal interactions of the chain, the efficiency score decreases. Another noteworthy point about the proposed model is that, there is no equality between the scores obtained

for DMUs and the model can rank the DMUs completely. This means the high strength of DMUs in the proposed approach.

Table 5. Total efficiency of the chain with the proposed model.

DMU	Chain efficiency	Rank
1	0.38	1
2	0.31	7
3	0.34	4
4	0.33	5
5	0.35	3
6	0.30	8
7	0.29	9
8	0.32	6
9	0.37	2

The basis of CCR model is the definition of efficiency as the ratio of one output to one input. In other words, in the CCR model, instead of using the ratio of one output to one input, the ratio of the weighted sum of outputs (virtual output) to the weighted sum of inputs (virtual input) is used to calculate technical efficiency. One of the most important subjects in DEA is determining the kind of efficiency on a scale. Efficiency on a scale shows the relationship between changes in system inputs and outputs. One of the capabilities of the DEA method is to determine efficiencies at different scales in system units. In Constant Return to Scale (CRS), each multiple of inputs produces the same multiple of outputs. Assuming a constant scale return, small and large units are compared. In variable-scale returns, any multiple of inputs can produce the same multiple of outputs, or more or less, in the outputs. In order to show the capability of the proposed model, the developed model is compared with its equivalent base model. Given that the proposed model is a CRS model, it is compared to the base CCR model, which is also a CRS model. Since the base models of DEA do not deal with the internal interactions of the system, and are considered only on the basis of inputs and outputs, so, intermediate variables are ignored. The system structure for the base models will be converted to *Fig. 4*. Given that the inputs of the first stage in *Fig. 3* is regarded as the overall inputs of the system and the output of the last stage is considered as the overall output of the system, so the intermediate elements and specific inputs of the second stage are not considered in this analysis.

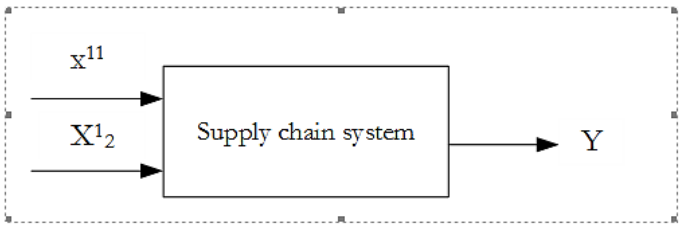

Fig. 4. Supply chain system.

Table 6 shows the factors considered to evaluate the supply chain system when using the CCR model.

Table 6. Factors related to supply chain system.

Supply Chain System	Symbol	Definition
	x_1^1	Environmental management costs.
	x_2^1	Green parts supply costs.
	Y	Green distribution.

By running the CCR model in GAMS software, which its mathematical model is shown in the set of *Eq. (2)*, the efficiency results of DMUs have been calculated according to *Table 7*.

$$\begin{aligned} &\text{Max}\theta = \sum_{r=1}^{s} u_r y_{ro}, \\ &\text{s.t} \\ &\sum_{i=1}^{m} v_i x_{io} = 1, \\ &\sum_{r=1}^{} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \le 0, \\ &u_r, v_i \ge 0. \end{aligned} \quad (2)$$

Table 7. Calculation of supply chain system efficiency score with CCR.

DMU	Chain efficiency
1	1
2	0.46
3	0.70
4	0.67
5	0.77
6	0.49
7	0.46
8	0.55
9	1

According to *Table 6*, beyond-estimation property in calculating the efficiency score of DMUs can be seen that in the case of using base models. Based on this property, the efficiency score of DMUs is always higher than the value of the proposed model. For example, DMU 1 and DMU 2 are identified as inefficient in the proposed model, but as efficient in the base model. *Fig. 5* shows the efficiency score chart of the proposed model and CCR. Based on this chart, considering that the efficiency score in the proposed model is always lower than the CCR model, the accuracy of the developed model can be concluded.

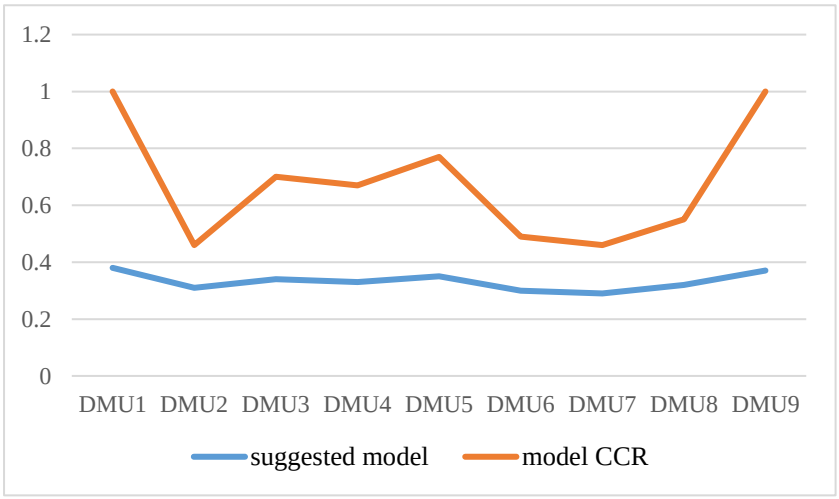

Fig. 5. Comparison of efficiency score of the proposed model and CCR.

4 | Discussion and Conclusion

Nowadays, GSCM, integrator of SCM with environmental requirements, has received much attention due to its important economic and environmental effects. By increasing environmental laws and regulations and raising public awareness of environmental protection, companies cannot easily ignore environmental issues if they want to work in global markets and compete with other companies. GSCM has become an approach to enhance environmental performance. Competitive advantage for them will

be GSCM in the form of networks with multiple connections and stages. This paper is presented to evaluate the efficiency of multi-stage units with the presence of undesirable output. This model is used to evaluate a three-stage green supply chain structure. The model is derived from the network DEA method. In this study, the data related to the year 2020 of 9 home appliance companies are evaluated and analyzed using the DEA three-stage method. Environmental costs as costs associated with the supply of green parts and environmental management with natural value are determined through economic activities. Therefore, these costs are considered as the input of the first stage. Intermediate inputs/outputs consist of two stages, the second and the third. The intermediate input/output between the supplier and manufacturer stages is the number of products that are transferred from the supplier to the manufacturer. Also, the intermediate input/output between the manufacturer and distributor is the number of green products. To evaluate the efficiency of a green supply chain, each supply chain is considered as a DMU to calculate the efficiency score for each of them. Efficiency scores for DMU1 and DMU7 are 0.89 and 0.69, respectively, which represent the best and the worst green supply chain, respectively. In order to show the capability of the proposed model, the developed model was compared with its equivalent base model. Given that the proposed model is a CRS model, it was compared with the CCR base model, which is also a CRS model. Given that the base models of DEA do not deal with the internal interactions of the system and are considered only on the basis of inputs and outputs, in this case, the intermediate variables were ignored. Given that the efficiency score in the proposed model is lower than the CCR model, so the accuracy of the developed model can be concluded. Therefore, if a chain is inefficient, this model can be used to identify which supply chain this inefficiency is related to. Finally, it can be emphasized that the use of NDEA method to evaluate companies that have several interrelated stages is very useful because managers will be aware of the problems that occur in different sections.

The following topics are suggested for future research:

– *Considering another supply chain similar to the considered supply chain and examining the competition between these two supply chains, which can be valuable points for manufacturers and other members of the supply chain.*
– *Consider dynamic and balanced pricing for the green product.*
– *Investigate the issue by considering other members of the supply chain as well as the four-step supply chain.*

The proposed model for managers in the field of supply chain is very efficient and practical. Because it is possible to model the supply chain with uncertain factors and very close to the real problem and experts can decide on a wide range of variables simultaneously. In addition, the possibility of considering several goals simultaneously as criteria for selecting the best scenario of the model features is provided for managers in the real world, which is very desirable, especially in the current situation where environmental issues are of particular importance and has been proposed as a determining factor in management decisions.

The researcher faces obstacles and limitations in conducting research. This research is no exception to this rule. Some of these limitations are mentioned below: Research results may be different in other statistical communities, so generalizing the results to other organizations and companies should be done with caution. Resistance of some companies in providing financial information and access to statistics and information. Differences in the quality of the reports of sample companies can affect the research results. Research data and findings may change if the data collection tool changes.

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