A THREE ECHELON REVENUE ORIENTED GREEN SUPPLY CHAIN NETWORK DESIGN

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Abstract. Green supply chain network designing has been studied during last decades. As carbon emissions considered as a major index in today’s activities around the world, here a three echelon-multi product network including manufacturer, distributor, retailer have been provided and tried to minimize the pollution gathered from manufacturing and distribution of products all over the chains which causes extra costs as penalty to the system.

As we faced with these penalties, the model determines selling prices of products for manufacturer and distribution center simultaneously by locating these centers in order to maximize the profits all around the network. Finally, the proposed model is solved through the numerical examples and the sensitivity analysis and important parameters are reported to find some management insights.

1. Introduction. Carbon dioxide emissions in recent years is one of the major problems for human life, which causes global temperature increasing that may lead to the extinction of the human species in the future (IPCC 2007). Most of the carbon dioxide emitted by industrial plants activities and transportations all around the network, and because of its importance, the green supply chain network designing has been studied in the literature. Organizations should be responsible in triple areas: economic, social and environmental.

Nowadays, carbon emissions come from manufacturing and transportation throughout all levels of the supply chain network causes penalties for producer, distributor, and retailers who their profits reduce based on it. As every echelon in a supply chain wants to increase profit by decreasing carbon pollution, price on the products in our chain should be calculated based on the mentioned costs.

2. Literature review. Here we considered some of the researches studies during the last decades (Abdallah et al., 2012; Cattani et al., 2006; Choudhary et al., 2015; Sarkar et al., 2016; Tseng and Hung, 2014), which have been related to our proposed model:

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The literature review of this research considers two main areas: (1) the advancement in research related to carbon emissions, environmental concerns and network design in the supply chain using quantitative models and (2) the research related to maximizing income by pricing for products in the supply chain.

2.1. Study on carbon emissions, environmental and network design. It is a global consensus that carbon emissions are the main reasons contributing to global warming. Industries and policy makers want to reduce the negative environmental impact on their supply chains continuously. There is a broad consensus that industry must reduce carbon emissions in order to mitigate global warming. It has been generally accepted that carbon emission trading is one of the most effective market-based mechanisms to curb environmental emissions. Hua et al. (2011) presented a model that shows how firms may be able to manage the carbon footprints in inventory management under the carbon emission trading mechanism and also, they illustrated the impacts of carbon trade, carbon price, and carbon cap on order decisions and total cost. Abdallah et al. (2012) developed a mixed integer program for the carbon-sensitive supply chain that minimizes emissions throughout the supply chain considering the green procurement which is known as environmental sourcing. Zhang and Xu (2013) investigated the multi-item production planning problem with carbon cap and trade mechanism, where firm uses a common capacity and carbon emissions quota to produce multiple products for fulfilling independent stochastic demands, and also can buy or sell the right to emit carbon on a trading market of carbon emission. They proposed a profit maximization model to characterize the optimization problem.

Stricter governmental regulations and rising public awareness on environmental issues pushed firms to develop their green supply chains. Partner selection is a critical activity in constructing a green supply chain because the environmental performance of the whole supply chain is significantly affected by all its constituents. Zhang et al. (2015) explored the supply chain coordination issues arising out of green supply chain initiatives and also they explored the impact of cost sharing contract on the key decisions of supply chain players undertaking green initiatives. Wu and Barnes (2016) presented a model for green partner selection and the supply chain construction by combining analytic network process and multi-objective programming methodologies.

It has been recognized that green marketing and sustainable supply chain management should be integrated, so that green customer’s needs can be better met by the supply chain capabilities. Liu et al.(2012) explored point-to-point integration approach. they proposed a new hub-and-spoke integration model to integrate green marketing and sustainable supply chain management from six dimensions: product, promotion, planning, process, people and project.

Supply chain network designing is one of the most important issues in environmental design so the environmental investments decisions in the design phase were studied and a multi-objective optimization model was proposed by Wang et al. (2011) that capture the trade-off between the total cost and the environment influence. Their model can be applied as a strategic planning tool for green supply chain. Harris et al.(2011) proposed a model to assess the impact of the traditional cost optimization approaches with regard to the strategic modeling on overall logistics costs and CO2 emissions by taking into account the supply chain structure (number of depots) and different transportation vehicle utilization ratios.
Tseng and Hung (2014) proposed a strategic decision-making model considering both the operational costs and social costs caused by the carbon dioxide emissions from operating such a supply chain network for sustainable supply chain management.

By apparent globalized supply chain network, carbon regulations and competitive marketing drive supply chain decision makers to reduce carbon emissions in their designs for environmental sustainability.

Attention to the forward-reverse logistics networks had been increased during the last decades since economic impact; air pollution and global warming have been focused increasingly.

El-Sayed et al. (2010) proposed a multi-period and multi-echelon forward-reverse logistics risky network design. They proposed network structure including three echelons in the forward direction, (suppliers, facilities and distribution centers) and two echelons, in the reverse direction (disassembly, and redistribution centers) where demands were stochastic in the first step (customer zone).

Chaabane et al. (2012) proposed a quantitative optimization model for integrated forward reverse logistics with carbon footprint considerations, by integrating the carbon emission into a quantitative operational decision-making model regarding layout facility decisions. Choudhary et al. (2015) presented a mixed-integer linear programming based framework for the sustainable supply chain design that considers life cycle assessment principles in addition to the traditional constraints of material balance which creates sustainability and minimization simultaneously at each node in the supply chain.

Sarkar et al. (2016) considered a three-echelon supply chain model where the supplier sends semi-finished products to manufacturer to complete. The manufacturer transports products by single-setup-multi-delivery policy to a multi-retailer. This model reduces the supply chain costs by considering variable transportation and carbon emission costs due to several shipments.

2.2. The study on pricing in supply chain. In recent decades, firms have been encountering new dimensions for competition in the supply chains. Therefore, they need more effective supply chain management. Pricing decisions by members of the supply chain are one of the critical factors in effective supply chain management since they are important in both operational and financial aspects. Members of the supply chain can manipulate their total demand by handling their pricing strategies. Hence, they can manage their operations to get profit.

When enterprises focus on social responsibilities, considering competitive pricing and manufacturing costs, then it will be often difficult to determine a long term strategy simultaneously. Product pricing and manufacturing costs often determine the firm’s profitability.

Manufacturers accrue their profits by setting the right pricing strategies with considerations for competitor responses and product characteristics (Reijnders, 2003).

Cattani et al. (2006) analyzed consistent pricing strategies between the manufacturer and the retailer. Specifically, the manufacturer and the retailer agreed with the results when the wholesale price and sale price were set by the manufacturer to maximize his profit.

Cruz (2008) investigates the optimality conditions of manufacturers and retailers based on the supply chain networks by considering their profits, the carbon emissions and the risk.
Chen and Sheu (2009) demonstrated that a proper designing of environmental-regulation pricing strategy will be able to promote extended product responsibility for the green supply chain firms in a competitive market.

Elhedhli and Merrick (2012) developed a supply chain network designing problem which notices CO2 emissions. Xu et al. (2015) presented a two echelon-supply chain with manufacturer and retailer, in which manufacturer produced two products based on make-to-order production. The manufacturer is regulated by a cap-and-trade regulation and determines the wholesale prices for the products. The retailer determines its order quantities in order to meet the price-sensitive demands. They derive the optimal total emissions and production quantities based on the two products. They analyzed the impact of emission trading price on the optimal production decisions and these two firms optimal profits.

Li et al. (2016) presented a dual-channel supply chain, in which the manufacturer produces green products for the environment. They discuss about the pricing and greening strategies for the chain members in both centralized and decentralized cases using the Stackelberg game model under a consistent pricing strategy.

As mentioned in our brief literature review, most of the published papers concern making strategic decisions on carbon emission and network design based on it, but here our network design has been conducted based on carbon emission and product prices as decision variables to control this emission. We proposed some innovations and contributions as follows, which distinguishes our study from the last ones:

- Designing a three echelon green supply chain regarding penalties for carbon emission
- Defining a profit maximization model, this determines sales price in manufacturer and distribution centers in addition to supply chain network designing.
- Determining distribution centers based on carbon emission penalties and the system costs.

Reminder of this paper is organized as follows: In section 3, problem description, assumptions, notations and mathematical model are described. A numerical example is presented to illustrate the effectiveness of the model in Section 4. Finally, conclusion from this research is discussed in Section 5.

3. Problem description. These days, organizations are faced with TBL (triple bottom line); social, environmental, and financial indexes. Carbon emissions control is one of these environmental indexes and countries consider an extra cost as a penalty for supply chains in order to overcome emissions. Here to overcome these penalties and being in the safe mode, companies needs to determine prices based on these penalties. We have studied in this paper such a problem in a three echelon multi product price based on green supply chain including producers, warehouses (distributor) and customers, where distribution centers have been selected based on these penalties during the problem solving.

3.1. Model assumptions. Assumptions are as follows:

1. Transfers in the supply chain are step by step, and direct connections are not permitted.
2. Distribution centers are limited.
3. Lack of inventory and lost sales is not permitted.
4. Demands and manufacturing capacities are not stochastic.
5. Carbon emissions for each product and every transportation vehicle are different and known.

3.2. **Model definition.** The following notations are used in the formulation:

**Sets:**
- $I$: set of customers
- $J$: set of distribution centers (warehouses)
- $M$: set of manufacturers
- $K$: set of products

**Parameters:**
- $f_j$: Fixed cost (In dollar) of establishing a warehouse at candidate $j$
- $C_{mk}$: Cost of production (In dollar) $k$ in the manufacturer $m$
- $T_{mjk}$: Transferring cost (In dollar) of product $k$ from manufacturer $m$ to the warehouse $j$
- $d_{ij}$: Distance (In km) between warehouse $j$ and customer $i$
- $d_{mj}$: Distance between (In km) manufacturer $m$ and warehouse $j$
- $P$: Cost of carbon dioxide (In dollar) emissions per ton
- $\alpha_{mj}$: Carbon dioxide emissions (In ton) from trucks between manufacturer $m$ and warehouse $j$ per kilometer
- $\alpha_{ij}$: Carbon dioxide emissions (In ton) from trucks between warehouses $j$ to customer $i$ per kilometer
- $\alpha_k$: Capacity for product $k$ in truck
- $\gamma_{mk}$: Carbon dioxide emissions (In ton) from manufacture $m$ for product $k$
- $\nu_{jk}$: Storage and maintenance costs (In dollar) for product $k$ in distribution center (warehouse) $j$
- $T_{jik}$: Transferring Cost (In dollar) for product $k$ from the warehouse $j$ to the customer $i$
- $T_{mjk}$: Transferring Cost (In dollar) for product $k$ from the manufacturer $m$ to the
Variables: $U_{mj}$: Order quantity from warehouse $j$ for product $k$ to manufacturer $m$

$X_{ijk}$: Order quantity of customer $i$ for product $k$ to warehouse $j$

$S_{mk}$: Sale price (In dollar) of product $k$ from manufacturer $m$

$S'_{jk}$: Sale price (In dollar) of product $k$ from warehouse $j$

$$y_j = \begin{cases} 1 & \text{if warehouse located in } j \\ 0 & \text{elsewhere} \end{cases}$$

Objective function

$$\max \left( \sum_{m} \sum_{j} \sum_{k} S_{mk} \cdot U_{mj} + \sum_{i} \sum_{j} \sum_{k} S_{jk} \cdot X_{ijk} - \left( \sum_{j} f_{j} \cdot y_{j} + \sum_{m} \sum_{j} \sum_{k} (C_{mk} + T_{mjk} \cdot U_{mj}) + \left( \sum_{j} f_{j} \cdot y_{j} + \sum_{m} \sum_{j} \sum_{k} p_{mk} \cdot U_{mj} + \sum_{m} \sum_{j} \sum_{k} \frac{U_{mj}}{\alpha_{k}} \cdot d_{mj} \cdot \alpha_{m} \cdot p + \sum_{i} \sum_{j} \sum_{k} T_{ijk} \cdot X_{ijk} + \sum_{i} \sum_{j} \sum_{k} X_{ijk} \cdot d_{ij} \cdot \alpha_{ij} \cdot p + \sum_{i} \sum_{j} \sum_{k} U_{mj} \cdot v_{jk} \right) \right) \right)$$

Objective function maximizes total profit of the supply chain. The first section represents incomes from sales by manufacturer. The second section represents the incomes from product sale by warehouse (distribution center) and the third section shows fixed establishment cost of the warehouse (distribution center). Fourth section defines production and transportation costs in warehouse (distribution center), fifth section shows carbon dioxide emissions cost, released from production in the manufacturer. The Sixth section explains the carbon dioxide emissions cost for products transportation from a manufacturer to a warehouse (distribution center), Which is equal to the multiplication the number of trucks required on the distance, in the amount of carbon dioxide released at the expense of carbon dioxide emissions. The Seventh section represents transportation cost from warehouse (distribution center) to customer, while the eighth section explains the carbon dioxide emissions cost of product transportation from warehouse (distribution center) to customers and finally the ninth section represents the storage cost in warehouse (distribution center).

Subject to the following constraints:
\[
\sum_{m}^{M} \sum_{j}^{J} \sum_{k}^{K} \gamma_{mk} U_{mjk} + \sum_{m}^{M} \sum_{j}^{J} \sum_{k}^{K} U_{mjk} \alpha_{mj} d_{mj} + \sum_{i}^{I} \sum_{j}^{J} \sum_{k}^{K} \frac{X_{ijk}}{a_{ik}} \alpha_{ij} + \sum_{j}^{J} \sum_{k}^{K} S_{mk} U_{mjk} + \sum_{i}^{I} \sum_{j}^{J} \sum_{k}^{K} S'_{jk} X_{ijk} \geq b,
\]

\[
\leq CO_{2},
\]

\[
\sum_{k}^{K} \sum_{m}^{M} U_{mjk} \leq N \cdot y_{j} \quad \forall j \in J,
\]

\[
\sum_{i}^{I} \sum_{k}^{K} X_{ijk} \leq N \cdot y_{j} \quad \forall j \in J,
\]

\[
\sum_{m}^{M} \sum_{j}^{J} \sum_{k}^{K} S_{mk} U_{mjk} + \sum_{i}^{I} \sum_{j}^{J} \sum_{k}^{K} S'_{jk} X_{ijk} \geq b,
\]

\[
\sum_{m}^{M} U_{mjk} \leq R_{m}^{k} \quad \forall k \in K, m \in M,
\]

\[
\sum_{j}^{J} X_{ijk} \geq w_{k} \quad \forall i \in I, k \in K,
\]

\[
\sum_{m}^{M} U_{mjk} = \sum_{i}^{I} X_{ijk} \quad \forall j \in J,
\]

\[
c_{mk} \leq S_{mk},
\]

\[
v_{jk} \leq S'_{jk},
\]

\[
S_{mk} \leq S'_{jk},
\]

\[
\sum_{m}^{M} \sum_{k}^{K} U_{mjk} l_{k} \leq q_{j} \cdot y_{j} \quad \forall j \in J,
\]

\[
U_{mjk} \geq 0, X_{ijk} \geq 0, S_{mk} \geq 0, S'_{jk} \geq 0, y_{j} \in \{0, 1\},
\]

Equation (2) is related to the maximum carbon dioxide emissions from transportation and production. Eqn.(3) represents feasibility of the warehouse order (distribution center) \( j \) for product \( k \) from manufacturer \( m \). Eqn. (4) furthermore represents feasibility of the customer order \( i \) for product \( k \) from warehouse (distribution center) \( j \). Eqn. 5 shows that the income from selling product \( e \) must be greater than a predefined value. Eqn. (6) is related to production capacity. Eqn. (7) shows that all the demands must be satiated. Eqn. (8) shows the balance between demands and capacities, where Eqn. (9) describes that sales price must be greater than manufacturing costs. Eqn. (10) shows superiority of the sale prices to the storage and maintenance costs. Eqn. (11) confirms that sales price in the warehouse must be greater than manufacturing price. Finally, Eqn. (12) refers to maximum available space in warehouse, while Eqn. (13) ensures binary and no negativity restrictions on corresponding decision variables.

4. **Numerical analysis.** Our proposed model in form of a random numerical example is shown in Table.1 which has been solved by GAMS. As here, we are faced with a nonlinear problem; we will change it into a linear equation as bellows:
4.1. Model Linearization. Here, linearization method which was presented by Vidal and Goetschalckx (2001) has been used in the following steps:

- **Step1**: For any of Continuous variables, we determine upper and lower bounds, which are defined as follows:
  
  \[
  \begin{align*}
  lb_{1_{mjk}} & \leq U_{mjk} \leq up_{1_{mjk}} & m \in M, j \in J, k \in K \\
  lb_{2_{ijk}} & \leq X_{ijk} \leq up_{2_{ijk}} & \forall i \in I, j \in J, k \in K \\
  lb_{3_{mk}} & \leq S_{mk} \leq up_{3_{mk}} & \forall m \in M, k \in K \\
  lb_{4_{jk}} & \leq S'_{jk} \leq up_{4_{jk}} & j \in J, k \in K
  \end{align*}
  \]

- **Step2**: Multiplication of each variable constitutes by another continuous variable, and we address these new variables in the model, instead of multiplication of continuous variable.

  \[
  g_{ijk} = S'_{jk}X_{ijk} \quad \forall i \in I, k \in K, j \in J
  \]

- **Step3**: Insert this limitation to the model:

  \[
  \begin{align*}
  lb_{2_{ijk}} \times S'_{jk} & \leq g_{ijk} \leq ub_{2_{ijk}} \times S'_{jk} & \forall i \in I, k \in K, j \in J \\
  lb_{4_{ijk}} \times S'_{jk} & \leq g_{ijk} \leq ub_{4_{ijk}} \times S'_{jk} & \forall i \in I, k \in K, j \in J \\
  lb_{1_{mjk}}^{'} \times S_{mk} & \leq g_{mjk}^{'} \leq ub_{1_{mjk}}^{'} \times S_{mk} & \forall m \in M, k \in K, j \in J \\
  lb_{3} \times U_{mjk} & \leq g_{mjk}^{'} \leq ub_{3} \times U_{mjk} & \forall m \in M, k \in K, j \in J
  \end{align*}
  \]

The Parameters in our example are as follows:

| Parameter | Random between | Random between | Random between |
|-----------|----------------|----------------|----------------|
| $f_j$     | [2000000, 3000000] | [10000, 10100] | [10000, 20000] |
| $m_{mk}$  | [1000, 1100] | [10000, 12000] | [450000000, 500000000] |
| $T_{mjk}$ | [500, 600] | [200, 300] | [10000, 10100] |
| $d_{ij}$  | [50, 60] | [500, 600] | [400, 450] |
| $d_{mjk}$ | [50, 60] | [500000000, 600000000] | [400, 450] |
| $P$       | [6000, 7000] | [100000000, 101000000] | [10000, 20000] |

The values of important decision variables in our example are as below, and all decision variables value is given in Appendix:

Sets: $I, J, M, K = 5$

**Table 1.** Data for numerical example

**Table 2.** The decision variables value

| $X_{mk}$ | $U_{mjk}$ | Objective function |
|----------|-----------|-------------------|
| $X_{111}$ = 0 | $U_{111}$ = 9575 | $5.6 \times 10^{15}$ |
| $X_{112}$ = 0 | $U_{112}$ = 25289 |          |
| $X_{113}$ = 0 | $U_{113}$ = 1657 |          |
As it is obvious from the results in table 2, from five potential locations for warehouse, there are warehouses located in locations of 1, 2 and 3 and also we have no warehouses in locations of 4 and 5. The value of objective function is equal to $5.6 \times 10^{14}$.

The presented model was solved in different sizes; the objective function and binary variable are mentioned in table below:

| Problem size(I*J*M*K) | Optimal value of binary decision variable | Objective function |
|-----------------------|-----------------------------------------|--------------------|
| 5*5*5*5              | $y_j = [111100]$                       | $5.6 \times 10^{14}$ |
| 15*15*15*15*15       | $y_j = [110111110011111]$              | $5.1 \times 10^{15}$ |
| 20*20*20*20*20       | $y_j = [11101101011011111]$            | $9.2 \times 10^{15}$ |
| 25*25*25*25*25       | $y_j = [111101111111111011010111]$     | $1.4 \times 10^{16}$ |

The problem model has been solved in different sizes and according to above table, the values of objective function and the construction locations of the warehouse are specified. Increasing the dimensions of the problem increases the value of objective function and also increases potential locations for warehouse construction.

4.2. Sensitivity analysis. In order to verify our model, the sensitivity analysis was performed on a fixed cost of established distribution centers. By significantly reducing the initial cost (one-thousandth of times) all potential points were activated, with data in table 1, 3 distribution centers were activated from 5 potential points and a significant increase in initial cost of establishment (1000 times) of distribution centers reached its minimum number. After this increase in initial cost, foundation of distribution centers had no impact on active or inactive potential points. Because of inaccuracy of demand, sensitivity analysis has been done on it. As it is obvious in figure 2 increasing in demands causes increasing in sales price in the supply chain, which is logical.

![Figure 2. The impact of demands on selling price](image-url)
selling price (In dollar), by increasing demand to 20% and, the prices (Sale price of product \(k\) from manufacturer \(m\) and sale price of product \(k\) from warehouse \(j\)) have grown between 90% to 100% substantially and after that growth at the price follows a lower slope, which means by increasing demands in above area, the supply chain has encountered with initial costs that actually made the prices higher. This will increase the amount of income, because both demand and price rise.

![Graph](https://via.placeholder.com/150)

**Figure 3.** The impact of carbon dioxide emissions on selling price

According to the above diagram (Fig.3), which the horizontal axis represents the amount of released carbon dioxide (In ton) and the vertical axis indicates the values of the selling price (In dollar), if we can reduce the amount of carbon dioxide productions, due to the reduction of carbon dioxide emissions penalty, the cost to the product will be reduced and consequently, the price (Sale price of product \(k\) from manufacturer \(m\) and sale price of product \(k\) from warehouse \(j\)) of the final product can be reduced which this can be assumed as a competitive advantage for the company in the competition. This reduces the price and increases demand, so it can be concluded that reducing carbon dioxide emissions will increase demand.

5. **Conclusion.** Carbon dioxide emissions increased the temperature on the earth and had important impacts on human life. Some of the most important factors in these emissions are manufacturers and transportations through the supply chains. Here, we studied on designing a three echelon green supply chain regarding penalties for carbon emission that the objective function of this model is profit maximization, which it considers distribution center establishment as a decision variable when it deals with fixed construction costs and carbon emission release during transportation.

We presented the model that pricing and Carbon dioxide emissions have considered, for satisfaction of customers in each chain all the amounts of orders must be met between chains. Finally, we transformed the non-linear model into linear model and solved it, and the sensitivity analysis has been done based on it. As it is obvious in our sensitivity analysis, by reducing carbon dioxide emissions, we faced with fewer penalties in our model that cause lower prices for final products. These therefore, give us more abilities to stay in today’s competitive markets and result
in carbon dioxide emissions (in manufacturers and transportation) that have major impact on pricing and supply chain profit and carbon dioxide emissions which should be controlled.

Appendix. values of all decision variables in our example are as below:

Sets:  $i,j,m,k = 5$.

Table 4. The optimal value of binary decision variable and objective function

| Variable | Value |
|----------|-------|
| $s_{ij}$ | $i = 1, j = 1, s_{ij} = 0$ |
| $s_{ij}$ | $i = 2, j = 1, s_{ij} = 1$ |
| $s_{ij}$ | $i = 1, j = 2, s_{ij} = 0$ |
| $s_{ij}$ | $i = 2, j = 2, s_{ij} = 0$ |
| $S_{ijk}$ | $i = 1, j = 1, k = 1, S_{ijk} = 1$ |
| $S_{ijk}$ | $i = 2, j = 1, k = 2, S_{ijk} = 0$ |
| $S_{ijk}$ | $i = 1, j = 2, k = 2, S_{ijk} = 0$ |
| $S_{ijk}$ | $i = 2, j = 2, k = 1, S_{ijk} = 0$ |
| $X_{gijk}$ | $g = 1, i = 1, j = 1, k = 1, X_{gijk} = 1$ |
| $X_{gijk}$ | $g = 2, i = 2, j = 1, k = 2, X_{gijk} = 0$ |
| $X_{gijk}$ | $g = 3, i = 1, j = 2, k = 2, X_{gijk} = 0$ |
| $X_{gijk}$ | $g = 4, i = 2, j = 2, k = 1, X_{gijk} = 0$ |

Objective function: $5.6 \times 10^6$

REFERENCES

[1] T. Abdallah, A. Farhat, A. Diabat and S. Kennedy, Green supply chains with carbon trading and environmental sourcing: Formulation and life cycle assessment, *Applied Mathematical Modelling*, 36 (2012), 4271–4285.

[2] K. Cattani, W. Gilland, H. S. Heese and J. Swaminathan, Boiling frogs: pricing strategies for a manufacturer adding a direct channel that competes with the traditional channel, *Production and Operations Management*, 15 (2006), 40–56.

[3] A. Chaabane, A. Ramudhin and M. Paquet, Design of sustainable supply chains under the emission trading scheme, *International Journal of Production Economics*, 135 (2012), 37–49.

[4] Y. J. Chen and J. B. Sheu, Environmental-regulation pricing strategies for green supply chain management, *Transportation Research Part E*, 45 (2009), 667–677.

[5] A. Choudhary, S. Sarkar, S. Settur and M. K. Tiwari, A carbon market sensitive optimization model for integrated forward-reverse logistics, *International Journal of Production Economics*, 164 (2015), 433–444.

[6] J. M. Cruz, Dynamics of supply chain networks with corporate social responsibility through integrated environmental decision-making, *European Journal of Operational Research*, 184 (2008), 1005–1031.

[7] S. Elhedhil and R. Merrick, Green supply chain network design to reduce carbon emissions, *Transportation Research Part D*, 17 (2012), 370–379.

[8] M. El-Sayed, N. Afia and A. El-Kharbotly, A stochastic model for forward-reverse logistics network design under risk, *Computers & Industrial Engineering*, 58 (2010), 423–431.
[9] I. Harris, M. Naim, A. Palmer, A. Potter and C. Mumford, Assessing the impact of cost optimization based on infrastructure modelling on CO₂ emissions, *International Journal of Production Economics*, 131 (2011), 313–321.

[10] G. Hua, T. C. E. Cheng and S. Wang, Managing carbon footprints in inventory management, *International Journal of Production Economics*, 132 (2011), 178–185.

[11] IPCC, 2007. Climate Change. In The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (eds. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor and H. L. Miller). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[12] B. Li, M. Zhu, Y. Jiang and Z. Li, Pricing policies of a competitive dual-channel green supply chain, *Journal of Cleaner Production*, 112 (2016), 2029–2042.

[13] S. Liu, D. Kasturiratne and J. Moizer, A hub-and-spoke model for multi-dimensional integration of green marketing and sustainable supply chain management, *Industrial Marketing Management*, 41 (2012), 333–338.

[14] L. Reijnders, Policies influencing cleaner production: the role of prices and regulation, *Journal of Cleaner Production*, 11 (2003), 333–338.

[15] B. Sarkar, B. Ganguly, M. Sarkar and S. Pareek, Effect of variable transportation and carbon emission in a three-echelon supply chain model, *Transportation Research Part E: Logistics and Transportation Review*, 91 (2016), 112–128.

[16] S. C. Tseng and S. W. Hung, A strategic decision-making model considering the social costs of carbon dioxide emissions for sustainable supply chain management, *Journal of Environmental Management*, 133 (2014), 315–322.

[17] C. J. Vidal and M. Goetschalckx, A global supply chain model with transfer pricing and transportation cost allocation, *European Journal of Operational Research*, 129 (2001), 134–158.

[18] F. Wang, X. Lai and N. Shi, A multi-objective optimization for green supply chain network design, *Decision Support Systems*, 51 (2011), 262–269.

[19] C. Wu and D. Barnes, An integrated model for green partner selection and supply chain construction, *Journal of Cleaner Production*, 112 (2016), 2114–2132.

[20] X. Xu, W. Zhang, P. He and X. Xu, Production and pricing problems in make-to-order supply chain with cap-and-trade regulation, *Omega*, 112 (2017), 248–257.

[21] B. Zhang and L. Xu, Multi-item production planning with carbon cap and trade mechanism, *International Journal of Production Economics*, 144 (2013), 118–127.

[22] Q. Zhang, W. Tang and J. Zhang, Green supply chain performance with cost learning and operational inefficiency effects, *Journal of Cleaner Production*, 112 (2015), 1–18.

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