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Collaboration on Corporate Social Responsibility between Suppliers and a Retailer

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***Abstract*—This paper proposes a bilevel programming model to formulate a corporate social responsibility (CSR) collaboration problem in a supply chain, in which the supply chain director determines optimal CSR performance levels and compensation for all the supply chain actors, such that the total supply chain profit is maximized. Given the fixed CSR performance levels and compensation, the equilibrium product quantities are determined in the lower-level model, in which the individual supply chain actor's behavior that maximizes its own profit is considered, and formulated as a variational inequality model. A gradient-based algorithm is proposed, and numerical examples are also provided for validating the model.**

***Index Terms*—corporate social responsibility, supply chain, bilevel programming, variational inequality.**

I. Introduction

With the continued trend of globalization, corporate social responsibility (CSR) is increasingly becoming a popular business concept. More and more companies voluntarily choose to behave in a more responsible manner to increase corporate goodwill. There are many available definitions of CSR in literature. Dahlsrud (2008) analyzed 37 definitions of CSR and developed five dimensions of CSR: environmental, social, economic, stakeholder, and voluntariness dimensions [1]. Unfortunately, Porter and Kramer (2006) pointed out that the prevailing approaches to CSR are so disconnected from business as to obscure many of the greatest opportunities for companies to benefit society. Managers without a strategic understanding of CSR are prone to postpone CSR costs, which can lead to far greater costs when the company is later judged to have violated its social obligation [2].

Many international enterprises outsource their manufacturing activities to developing countries or purchase materials from those areas to lower their cost. However, the companies in developing countries usually pay little attention to environment protection and workers' rights. Many leading global brands such as Nike, GAP, Adidas and McDonalds are often under intense pressure from groups working for socially responsible supply chain management [3]. The conditions of the supplier's CSR activities will eventually influence corporate image, goodwill, and the sales of the downstream company. Therefore, it is necessary to expand CSR activities to the partners in a supply chain (SC). Through collaborative CSR activities, the environment and the workers' rights can be protected. Unfortunately, the sole moral motivation for CSR is usually not enough; it does not provide incentives for suppliers to comply with the codes of conduct from the downstream company. A SC leader must ensure that each partner in the supply chain can benefit from CSR activities.

A supply chain consists of several actors that usually have different and sometimes conflicting objectives, which need to be coordinated. In most cases, each SC actor tries to maximize its own profit, leading to a different direction from the system objective, such as maximizing total SC profits or improving CSR performance level.

As to our knowledge, few studies have considered CSR in SC collaboration. Therefore, in this study we consider a CSR collaboration problem (CSRC), formulated as a bilevel programming model. In CSRC, the SC director determines optimal CSR performance levels and compensation for all SC actors such that the total SC profit is maximized; meanwhile, the individual SC actor's behavior that maximizes its own profit is also considered in the lower-level model of CSRC given the fixed CSR performance levels and compensation. The objectives of CSRC model are threefold: (1) maximizing total SC profits; (2) improving CSR performance level; (3) ensuring that each SC actor can benefit from CSR collaboration.

The remainder of the paper is organized as follows. Section 2 presents literature review, and Section 3 describes the problem and the model. Section 4 introduces the solution algorithms. In Section 5, numerical examples are provided. Conclusions are made in Section 6.

II. Literature Review

Many studies have pointed out the advantages of CSR. Companies engage in CSR activities as a way to enhance their reputation [4], preempt legal sanction [5], respond to non-governmental organization (NGO) action [6], manage their risk [7]–[8], and generate customer loyalty [9]–[10]. Companies increasingly realize that CSR activities offer opportunities to create value [2]. CSR can potentially decrease production inefficiencies, reduce cost and risk and at the same time allow companies to increase sales, increase access to capital, new markets, and brand recognition [11].

Literature about integrating CSR into SC has only emerged in the last few years [12]–[15]. Studies about adoption of CSR in SC are still in the beginning stage [16]–[18]. Amaeshi et al. (2008) suggests that the more powerful member in the supply chain has a responsibility to exert some moral influence on the weaker members [3]. Cramer (2008) proposed a step-by-step plan to offer guidance to companies

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in choosing their own appropriate way of organizing chain responsibility [19]. Cruz (2009) developed a decision support framework for modeling and analysis of supply chain networks with CSR. He considered the multicriteria decision-making behavior of the various decision makers (manufacturers, retailers, and consumers), which includes the maximization of net return, the minimization of emission, and the minimization of risk. [20]

Recently, two international journals, Journal of Business Ethics and Supply Chain Management: An International Journal, published special issues about CSR implementation in 2009. The articles in these two special issues provide insightful thinking and the ways to implement CSR; however, most studies are qualitative discussions or empirical studies. Andersen and Skjoett-Larsen (2009) presented a conceptual framework for analyzing CSR practices in global supply chains and demonstrated how a pioneering Swedish company, IKEA, implements and manages CSR practices at its suppliers [21]. They found that practicing CSR in SC requires that CSR is embedded within the entire organization, including subsidiaries abroad and offshore suppliers. It includes employee training and sharing of experience, training of key personnel at the supplier level, positive incentives for suppliers in the form of long-term contracts and enlarged purchasing orders, and regular auditing of suppliers' performance. Eltantawy et al. (2009) performed a survey of 162 purchasing managers to investigate the impact of supply management ethical responsibility (SMER) on perceived reputation and performance [22]. They found that perceived reputation has a positive impact on performance and SMER has a positive impact on perceived reputation. Lee and Kim (2009) surveyed research on supply management and CSR reported over the past two decades, and carried out an empirical study of the current status in the Korean electronics industry [23]. Their results show that "environmental" pressures and standards are widely accepted and implemented for supply management in the Korean electronics industry. However, "social" pressures and standards are still not commonly used and there is a lack of implementation in the entire SC in the industry.

Both Pedersen (2009) and Ciliberti et al. (2009) studied CSR of small- and medium-sized enterprises (SMEs) in a SC [24], [25]. Reference [24] concluded that CSR activities directed towards the SC still remain the privilege of a small group of SMEs with quite advanced CSR systems, based on the data from a large-scale survey of 1,071 Danish SMEs carried out in 2005. He pointed out that there may be a need for more differentiated initiatives to promote CSR that will enable smaller enterprises to address CSR issues in the SC. Reference [25] found that codes facilitate coordination between immediate partners in a SC, especially when the most powerful one (i.e. the chain director) enforces the code. For examples, the chain director can impose Social Accountability 8000 (SA8000) certification in the SC, and its SC partners can benefit from reduced information asymmetry and transaction costs.

A solid mathematical model can usually provide an objective, accurate and reliable analysis. However, most studies addressing CSR in a SC are conceptual in nature or case based. Instead, this paper adopts variational inequalities, sensitivity analysis, and bilevel programming in searching of better collaboration on CSR between suppliers and a retailer.

III. Model Formulation

A. Problem description

A supply chain, consisting of multiple suppliers and a retailer, is considered in this paper. The supplier i sells q_i units of the product to the retailer at a wholesale price ρ_i. The retailer then sells these products to customers in a monopoly market. Suppose y_i^S and y^R refer to the CSR performance level of the supplier i and the retailer, respectively. Generally speaking, the SC's CSR performance level y^{SC} can be regarded as a function of y_i^S, y^R, and q_i. For example, let $y^{SC} = y^R + \sum_{i\in\mathbb{S}} \frac{q_i}{\sum_{j\in\mathbb{S}} q_j} y_i^S$, where $\mathbb{S}$ is the set of all suppliers. The general cost of production, transaction, and CSR cost of supplier i is denoted by $c_i(\mathbf{y},\mathbf{q})$, where $\mathbf{y}$ and $\mathbf{q}$ are vector forms of y_i^S, y^R, and q_i, respectively. The general cost of retailer is denoted by $c_R(\mathbf{y},\mathbf{q})$. We assume that the market demand D is relevant not only to the retail price but also to CSR performance level y^{SC}. The higher CSR performance level is, the higher market demand is expected. The retail price can thus be characterized by an inverse demand function $p(y^{SC}, D)$. Since the demand function is assumed deterministic, the supply quantity must equal the demand quantity for the retailer who aims to maximize its profit, i.e., $D = \sum_{i\in\mathbb{S}} q_i$. Therefore, the retail price can be expressed as $p(\mathbf{y},\mathbf{q})$. For easy reference, the notations used in this paper are summarized in the Appendix.

In order to increase the profits, the suppliers and the retailer intend to collaborate on improving CSR performance level. The director of the SC collaboration has to determine the optimal CSR performance level $y_i^{S^*}$ and y^{R^*}, which can result in the maximum profit of whole SC. The director also has to determine a possible compensation, T_i, transferred between the supplier i and the retailer, in order to ensure that the resulting individual profit of each SC actor is higher than that before collaboration. The compensation transferred from the retailer to the supplier i if T_i is positive, and from the supplier i to the retailer if T_i is negative. The vector form of T_i is $\mathbf{T}$. After $\mathbf{y}^*$ and $\mathbf{T}$ is determined, each SC actor tries to maximize its own profit, resulting in equilibrium product quantity $\mathbf{q}^*$

The proposed CSR collaboration problem is denoted as CSRC. In the following, we propose a bilevel programming model to determine $\mathbf{y}^*$ and $\mathbf{T}$. The product quantity $\mathbf{q}$ is obtained in the lower-level model, which is a variational inequality.

B. A bilevel programming model

The CSRC problem is formulated as a bilevel programming model in the following.

$$\max \ \pi = p(\mathbf{y},\mathbf{q}) \sum_{i\in\mathbb{S}} q_i - \sum_{i\in\mathbb{S}} c_i(\mathbf{y},\mathbf{q}) - c_R(\mathbf{y},\mathbf{q}) \quad (1)$$

$$\text{s.t.} \quad y^R \in [0, \bar{y}^R], \ y_i^S \in [0, \bar{y}_i^S], \ \forall i \in \mathbb{S}, \quad (2)$$

$$\mathbf{q} \text{ solves VI model (15) parameterized by } \mathbf{y}, \quad (3)$$

$$T_i \geq \bar{\pi}_i - \left(\rho_i q_i - c_i(\mathbf{y},\mathbf{q})\right), \ \forall i \in \mathbb{S}, \quad (4)$$

$$\sum_{i\in\mathbb{S}} T_i \leq p(\mathbf{y},\mathbf{q}) \sum_{i\in\mathbb{S}} q_i - \sum_{i\in\mathbb{S}} \rho_i q_i - c_R(\mathbf{y},\mathbf{q}) - \bar{\pi}_R \quad (5)$$

Eq. (1) states that the objective of collaboration is to maximize the total profit of the SC. Eq. (2) are range constraints for y^R and y_i^S. Eq. (3) is the lower-level model, which is presented in the following subsection. Eq. (4) requires that the profit of the supplier *i* after compensation transferred should be higher than that before collaboration, $\bar{\pi}_i$. Similarly, Eq. (5) requires that the profit of the retailer after compensation transferred should be higher than that before collaboration, $\bar{\pi}_R$.

C. Variational inequality model

After **y** and **T** is determined, all SC actors try to maximize their own profits. Therefore results of their behaviors are outcomes of equilibrium. In the following, we present individual profit-maximizing models of suppliers and the retailer, describe their first-order conditions, derive the equilibrium conditions of the SC, and then propose a variational inequality model that corresponds to the derived equilibrium conditions.

Supplier's profit-maximizing behavior

The profit function of supplier *i* is defined as

$$\pi_i = \rho_i q_i + T_i - c_i(\mathbf{y}, \mathbf{q}) \quad (6)$$

Since T_i is given by the upper-level model, it is regarded as a constant in the profit function (6). Therefore, the profit-maximizing problem of supplier *i* is modeled as

$$\max \ \rho_i q_i - c_i(\mathbf{y}, \mathbf{q}) \quad (7)$$

$$\text{s.t.} \ \ q_i \geq 0 \quad (8)$$

where the price ρ_i is determined when the whole supply chain network achieves equilibrium. In other words, the supplier *i* cannot make a price decision by itself, and $\rho_i$is just a parameter to the supplier *i*. Suppose q_i^* is the optimal solution. The first-order condition for the supplier's profit-maximizing model is then described as

$$\frac{\partial c_i(\mathbf{y},\mathbf{q}^*)}{\partial q_i} \begin{cases} = \rho_i & if \ q_i^* > 0 \\ \geq \rho_i & if \ q_i^* = 0 \end{cases} \quad (9)$$

Retailer's profit-maximizing behavior

The profit function of the retailer is defined as

$$\pi_R = p(\mathbf{y}, \mathbf{q}) \textstyle\sum_{i\in\mathbb{S}} q_i - c_R(\mathbf{y}, \mathbf{q}) - \sum_{i\in\mathbb{S}} (\rho_i q_i + T_i) \quad (10)$$

Similarly, T_i is given by the upper-level model and regarded as a constant in the profit function (10). Therefore, the profit-maximizing problem of the retailer is modeled as

$$\max \ p(\mathbf{y}, \mathbf{q}) \textstyle\sum_{i\in\mathbb{S}} q_i - \mathrm{c}_R(\mathbf{y}, \mathbf{q}) - \sum_{i\in\mathbb{S}} \rho_i q_i \quad (11)$$

$$\text{s.t.} \ \ q_i \geq 0 \quad \forall i \in \mathbb{S} \quad (12)$$

The first-order condition for the retailer's profit-maximizing model is expressed as

$$\frac{\partial c_R(\mathbf{y},\mathbf{q}^*)}{\partial q_i} + \rho_i \begin{cases} = \frac{\partial (p(\mathbf{y},\mathbf{q}^*) \sum_{i\in\mathbb{S}} q_i^*)}{\partial q_i} & if \ q_i^* > 0 \\ \geq \frac{\partial (p(\mathbf{y},\mathbf{q}^*) \sum_{i\in\mathbb{S}} q_i^*)}{\partial q_i} & if \ q_i^* = 0 \end{cases} \quad \forall i \in \mathbb{S} \quad (13)$$

Variational inequality model for SC equilibrium

When the SC achieves equilibrium, Eqs. (9) and (13) hold simultaneously at $\mathbf{q}^*$. Hence we can derive the equilibrium conditions as follows:

$$\frac{\partial c_R(\mathbf{y},\mathbf{q}^*)}{\partial q_i} + \frac{\partial c_i(\mathbf{y},\mathbf{q}^*)}{\partial q_i} \begin{cases} = \frac{\partial (p(\mathbf{y},\mathbf{q}^*) \sum_{i\in\mathbb{S}} q_i^*)}{\partial q_i} & if \ q_i^* > 0 \\ \geq \frac{\partial (p(\mathbf{y},\mathbf{q}^*) \sum_{i\in\mathbb{S}} q_i^*)}{\partial q_i} & if \ q_i^* = 0 \end{cases} \quad \forall i \in \mathbb{S} \quad (14)$$

Equilibrium conditions (14) can be transformed into the following variational inequality model:

$$\sum_{i\in\mathbb{S}} \left(\frac{\partial c_R(\mathbf{y},\mathbf{q}^*)}{\partial q_i} + \frac{\partial c_i(\mathbf{y},\mathbf{q}^*)}{\partial q_i} - \frac{\partial (p(\mathbf{y},\mathbf{q}^*) \sum_i q_i^*)}{\partial q_i} \right) (q_i - q_i^*) \geq 0 \quad \forall q_i \in \mathbb{R}^+ \quad (15)$$

For a given **y**, the lower-level problem of the bilevel programming model (3) is to find a nonnegative $\mathbf{q}^*$ such that (15) holds for any nonnegative **q**.

IV. Solution Algorithm

The solution algorithms for sensitivity analysis of VI models and bilevel programming are discussed in [26]–[28]. In the following, we will review basic knowledge about sensitivity analysis of variational inequality first, and present our solution algorithm thereafter.

A. Sensitivity analysis of variational inequality

The details about sensitivity analysis of variational inequality can be found in Tobin and Friesz (1988) [26]. Here we only present how to calculate $\nabla_{\mathbf{y}}\mathbf{q}$, the derivatives of **q** with respect to **y** in our proposed model.

Let **y** be a vector of perturbation parameters of dimension *m*, let $F: R^n \times R^m \to R^n$ and $g: R^n \times R^m \to R^l$ be continuously differentiable in $(\mathbf{q}, \mathbf{y})$. Consider the following perturbed variational inequality, denoted as $\mathrm{VI}(\mathbf{y})$: Find $\mathbf{q}^* \in K(\mathbf{y})$ such that

$$F(\mathbf{q}^*, \mathbf{y})^T (\mathbf{q} - \mathbf{q}^*) \geq 0 \quad \forall \mathbf{q} \in K(\mathbf{y}) \quad (16)$$

where

$$K(\mathbf{y}) = \{\mathbf{q} \mid g(\mathbf{q}, \mathbf{y}) \geq 0\}. \quad (17)$$

If $\mathbf{q}^0$ is a solution of $\mathrm{VI}(\mathbf{y}^0)$ and the gradients $\nabla g_i(\mathbf{q}, \mathbf{y}^0)$, *i* such that $\nabla g_i(\mathbf{q}^0, \mathbf{y}^0) = 0$, are linearly independent, then there exists $\boldsymbol{\mu} \in R^l$ such that

$$F(\mathbf{q}^0, \mathbf{y}^0) - \textstyle\sum_{i=1}^{l} \mu_i \nabla g_i(\mathbf{q}^0, \mathbf{y}^0)^T = 0 \quad (18)$$

$$\mu_i g_i(\mathbf{q}^0, \mathbf{y}^0) = 0 \quad \forall i = 1, \dots, l \quad (19)$$

Let the Jacobian matrix of the system (18) and (19) with respect to $\mathbf{x} = (\mathbf{q}, \boldsymbol{\mu})$ be denoted as $J_{\mathbf{x}}$ and with respect to **y** as $J_{\mathbf{y}}$. Then the derivatives of **x** with respect to **y** are given by

$$\nabla_{\mathbf{y}}\mathbf{x} = \begin{bmatrix} \nabla_{\mathbf{y}}\mathbf{q} \\ \nabla_{\mathbf{y}}\boldsymbol{\mu} \end{bmatrix} = J_{\mathbf{x}}^{-1} J_{\mathbf{y}} \quad (20)$$

B. Solution algorithm of the CSRC model

Although the decision variables in the bilevel programming model (1) – (5) include **y**, **q** and **T**, we found that **T** is neither in the objection function (1) nor in the lower-level model (15). Therefore, we can ignore (4) and (5) in the beginning and solve the simplified bilevel programming model (1) – (3). After $\mathbf{y}^*$ and $\mathbf{q}^*$ are obtained, a solution of **T** can then be chosen within the feasible region defined by (4) and (5). Note that the value of **T** will not change the maximum profit of the SC π^* nor the product quantity **q**. However, it does affect the individual profits of

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the suppliers and the retailer, i.e., Eqs. (6) and (10). The determination of **T** may depend on partnership, relative bargaining power, CSR cost, and others.

To solve the simplified model (1) – (3), we propose a gradient-based algorithm, in which sensitivity analysis for variational inequalities is adopted to obtain the derivatives of **q** with respect to **y**. The implementation steps are given as follows:

Step 1. Let initial CSR performance level $\mathbf{y}^0=\mathbf{0}$, implying the current status without collaboration on CSR.

Step 2. Given $\mathbf{y}^0$, solve lower-level model (15) using any existing method that solves variational inequality (c.f. Nagurney, 1999). The initial product quantity $\mathbf{q}^0$ is obtained. Since $\mathbf{q}^0$ is the equilibrium solution before collaboration on CSR, we can calculate profits $\bar{\pi}_i$ and $\bar{\pi}_R$ using (6) and (10). Let k=0.

Step 3. Apply sensitivity analysis to calculate $\nabla_{\mathbf{y}}\mathbf{q}$, the derivatives of **q** with respect to **y,** evaluated at point ($\mathbf{y}^k$,$\mathbf{q}^k$). After $\nabla_{\mathbf{y}}\mathbf{q}$ is obtained, calculate gradient $\nabla\pi(\mathbf{y}^k)$ at point ($\mathbf{y}^k$,$\mathbf{q}^k$).

Step 4. Determine search direction $\boldsymbol{d}^k$. If k=0, let $\boldsymbol{d}^k = \nabla\pi(\mathbf{y}^k)$. Otherwise, let

$$\boldsymbol{d}^k = \nabla\pi(\mathbf{y}^k) + w^k\boldsymbol{d}^{k-1} \tag{21}$$

where $w^k = \frac{\|\nabla\pi(\mathbf{y}^k)\|^2}{\|\nabla\pi(\mathbf{y}^{k-1})\|^2}$

Step 5. Find step size α_{opt} which maximize total SC profit $\pi(\mathbf{y}^k + \alpha\boldsymbol{d}^k)$ subject to $0 \le \alpha \le \alpha_{max}$, where **q** is approximated as $\mathbf{q}^k + \nabla_{\mathbf{y}}\mathbf{q}\alpha\boldsymbol{d}^k$.

Step 6. Set projection on the feasible set of **y** as

$$\mathbf{y}^{k+1} = \begin{bmatrix} min\left\{\bar{y}_1^k, max\{0, y_1^k + \alpha_{opt}d_1^k\}\right\} \\ \vdots \\ min\left\{\bar{y}_n^k, max\{0, y_n^k + \alpha_{opt}d_n^k\}\right\} \end{bmatrix} \tag{22}$$

where y_j^k and d_j^k denote the jth component of $\mathbf{y}^k$ and $\boldsymbol{d}^k$.

Then, Solve $\mathbf{q}^{k+1}$ in model (15) with the fixed $\mathbf{y}^{k+1}$.

Step 7. For a predetermined stopping tolerance $\varepsilon > 0$, if $\pi(\mathrm{y}^{k+1}) - \pi(\mathrm{y}^k) < \varepsilon$, then y^{k+1} is the best solution and go to Step 8. Otherwise, let k=k+1 and return to Step 3.

Step 8. According to (9), let $\rho_i = \frac{\partial c_i(\mathbf{y}^{k+1},\mathbf{q}^{k+1})}{\partial q_i}$ for the supplier with positive q_i^{k+1}. Given $\mathbf{y}^{k+1}$**,** $\mathbf{q}^{k+1}$, $\bar{\pi}_i$, $\bar{\pi}_R$, and ρ_i, a feasible set of **T** is obtained by (4) and (5). The director of CSR collaboration can determine a value of **T** within the feasible set.

V. NUMERICAL EXAMPLES

A supply chain, as illustrated in Fig. 1, is taken for testing. Suppose $y^{SC} = y^R + \sum_{i=1}^{3}\frac{q_i}{q_1+q_2+q_3}y_i^S$ and the inverse demand function: $p = 200 + 2y^{SC} - (q_{1+}q_{2+}q_3)$. The upper bounds of **y** are set as $\bar{y}^R = \bar{y}_1^S = \bar{y}_2^S = \bar{y}_3^S = 3$. Other cost functions and parameters are listed in the following.

$$c_1(\mathbf{y},\mathbf{q}) = 10 + 0.1q_1^2(1 + 0.5y_1^S) + 0.1q_2 + 0.1q_3 \tag{23}$$

$$c_2(\mathbf{y},\mathbf{q}) = 10 + 0.12q_2^2(1 + 0.4y_2^S) + 0.1q_1 + 0.1q_3 \tag{24}$$

$$c_3(\mathbf{y},\mathbf{q}) = 10 + 0.09q_3^2(1 + 0.6y_3^S) + 0.1q_1 + 0.1q_2 \tag{25}$$

$$c_R(\mathbf{y},\mathbf{q}) = 10 + 0.1(q_{1+}q_{2+}q_3)^2(1 + 0.5y^R) \tag{26}$$

As mentioned before, the cost function with $y_i^S = 0$ or $y^R = 0$ refers to the status without collaboration on CSR. Now we formulate the bilevel model as:

$$\begin{aligned} \max\ \pi = {} & (199.8 + 2y^R)(q_1 + q_2 + q_3) \\ & +2(q_1y_1^S + q_2y_2^S + q_3y_3^S) \\ & -(1.1 + 0.05y^R)(q_1 + q_2 + q_3)^2 \\ & -0.1q_1^2(1 + 0.5y_1^S) - 0.12q_2^2(1 + 0.4y_2^S) \\ & -0.09q_3^2(1 + 0.6y_3^S) - 40 \end{aligned} \tag{27}$$

$$\text{s.t.} \quad y^R, y_1^S, y_2^S, y_3^S \in [0,3] \tag{28}$$

$$\text{VI model (32)} \tag{29}$$

$$T_i \ge \bar{\pi}_i - \big(\rho_i q_i - c_i(\mathbf{y},\mathbf{q})\big),\ \ \forall i \in \mathbb{S}, \tag{30}$$

$$\textstyle\sum_{i\in\mathbb{S}} T_i \le p(\mathbf{y},\mathbf{q})\sum_{i\in\mathbb{S}} q_i - \sum_{i\in\mathbb{S}}\rho_i q_i - c_R(\mathbf{y},\mathbf{q}) - \bar{\pi}_R \tag{31}$$

From (15), we establish the following VI model:

$$\begin{aligned} & \begin{pmatrix} 0.2(1 + 0.5y_1^S)q_1^* + \\ (2.2 + 0.1y^R)(q_1^* + q_2^* + q_3^*) \\ -2y^R - 2y_1^S - 200 \end{pmatrix}(q_1 - q_1^*) \\ + & \begin{pmatrix} 0.24(1 + 0.4y_2^S)q_2^* + \\ (2.2 + 0.1y^R)(q_1^* + q_2^* + q_3^*) \\ -2y^R - 2y_2^S - 200 \end{pmatrix}(q_2 - q_2^*) \\ + & \begin{pmatrix} 0.18(1 + 0.6y_3^S)q_3^* + \\ (2.2 + 0.1y^R)(q_1^* + q_2^* + q_3^*) \\ -2y^R - 2y_3^S - 200 \end{pmatrix}(q_3 - q_3^*) \ge 0 \\ & \forall q_i \in \mathbb{R}^+ \end{aligned} \tag{32}$$

The testing results of the problem without collaboration on CSR (i.e., $y^R = y_i^S = 0$) are obtained in Step 2 and listed in Table I. Furthermore, the optimal solution of the CSRC problem is summarized in Table II. Through collaboration on CSR, we can see that both the CSR performance level and the total SC profit are improved. In addition, by determining proper compensations T_1, T_2, T_3, the individual profits of all suppliers and the retailer can also be guaranteed to improve. Note that in this case y^R is zero because the CSR cost of the retailer is too high. Therefore, the retailer gives compensations to help the suppliers improve their CSR performance level, resulting in the higher SC's CSR performance level and the higher revenue.

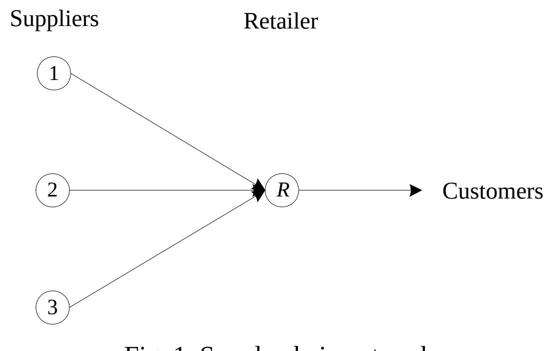

Fig. 1. Supply chain network

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TABLE I
TESTING RESULTS OF THE PROBLEM WITHOUT COLLABORATION ON CSR

	CSR performance level	Product quantity	Selling Price	Profit
Supplier 1	0	29.9501	5.99	73.8771
Supplier 2	0	24.9584	5.99	58.4278
Supplier 3	0	33.2779	5.99	84.1766
Retailer	0	N/A	111.8137	8544.5168
Total	N/A	88.1864	N/A	8760.9983

TABLE II
TESTING RESULTS OF THE CSRC PROBLEM

	CSR performance level	Product quantity	Selling Price	Profit*
Supplier 1	0.008970581	29.9385	5.9877	73.4049+T_1
Supplier 2	0.011913372	24.9662	2.4966	-29.1444+T_2
Supplier 3	0.004050129	33.2787	6.6557	106.0889+T_3
Retailer	0	N/A	111.8325	9007.8656 $-T_1 - T_2 - T_3$
Total	N/A	88.1834	N/A	9158.2150

*T_1, T_2, T_3 is subject to $T_1 \geq 0.4722$; $T_2 \geq 87.5722$; $T_3 \geq -21.9123$; $T_1 + T_2 + T_3 \leq 463.3488$

VI. CONCLUSIONS

This paper assumes a demand function that considers the influence of SC's CSR performance level on demands. Through CSR collaboration, the SC's profits can increase; meanwhile, the CSR performance can also improve. The CSRC problem is formulated as a bilevel programming model, and a solution algorithm is proposed along with numerical examples. The proposed model and algorithm can provide optimal suggesting values of CSR performance levels and compensations.

For the future research, multiple retailers and multi-echelon SC are suggested.

APPENDIX

The main notations in the model are listed in the following.

q_i	:	product quantity from supplier *i* to the retailer
$\mathbf{q}$	:	vector form of q_i
ρ_i	:	wholesale price of supplier *i*
y_i^S	:	CSR performance level of the supplier *i*
y^R	:	CSR performance level of the retailer
y^{SC}	:	CSR performance level of the supply chain
$\mathbf{y}$	:	vector form of y_i^S and y^R
$c_i(\mathbf{y}, \mathbf{q})$	:	general cost of production, transaction, and CSR cost of supplier *i*
$c_R(\mathbf{y}, \mathbf{q})$	:	general cost of retailer
D	:	market demand
$p(\mathbf{y}, \mathbf{q})$	:	retail price
T_i	:	compensation transferred between supplier *i* and the retailer
$\mathbf{T}$	:	vector form of T_i
π	:	total profit of the SC
π_i	:	profit of the supplier *i*
π_R	:	profit of the retailer
$\bar{\pi}_i$	:	profit of the supplier *i* without collaboration
$\bar{\pi}_R$	:	profit of the retailer without collaboration
$\mathbb{S}$	:	set of all suppliers
$\boldsymbol{d}^k$	:	search direction
α	:	step size

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