Must Pollution Abatement Harm the Supplier in a Multi-Echelon Supply Chain?

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Abstract. This paper studies the welfare effects of the abatement cost burden of a supplier in a multi-echelon supply chain. We theoretically show that the profits of all echelons other than the supplier become lower when the supplier contributes more to the abatement. Also, we computationally show that the profit of the supplier may be higher when it makes a small amount of contribution to the abatement provided that the demand curve faced by the retailer is sufficiently linear.

Keywords: Supply chain; multi-echelon; abatement cost.

1 Introduction

In this paper, we study whether pollution abatement must always reduce the supplier's profit in a multi-echelon supply chain where the prices are determined sequentially according to the generalized Nash bargaining process. Our paper can be related to the literature on sustainable (green) supply chain management. A substantial part of this literature deals with designing and analyzing models of supply chains that have environmental concerns, like minimizing emissions, in addition to the traditional objective of profit maximization or production cost minimization (e.g., Nagurney and Toyasaki, 2003; Sheu et al., 2005; Hugo and Pistikopoulos 2005, Lu et al., 2007; Neto et al., 2008, Das and Posinasetti, 2015; Wang et al., 2017, 2020; among others). A recent strand of the same literature develops models to explore the scope and effects of government intervention in centralized or decentralized markets involving green and/or non-green supply chains (e.g., Hafezalkotob, 2015, 2018; Madani and Rasti-Barzoki, 2017; Yang et al. 2019). In these models, the government usually imposes different tariffs for green and non-green products to induce better (or optimal) environmental impacts.

Our paper differs from the earlier works in several aspects: First, we deal with a single supply chain. Thus, we deal with the interaction among the members of a single supply channel instead of dealing with the price competition/coordination among the suppliers of two distinct channels. We borrow the price determination process in our supply chain from Zhong et al. (2016), who showed that the existence of intermediate levels in supply chains can be explained by the alleviating effect of bargaining on the multiple markups problem in channels with successive monopolies. Like Zhong et al. (2016), we consider a multi-echelon supply chain channel where all prices are uncoordinated and determined according to a cooperative bargaining system where negotiations take place between neighboring echelons sequentially. However, unlike Zhong et al. (2016), we also assume that our supply chain is non-green to investigate the effect of environmental sustainability on the welfare of channel members. In more detail, we consider a supply chain where the production of the supplier generates air pollution, and the cost of abatement is borne by the supplier and consumers. Following Nordhaus (2008) and Saglam (2023), we assume that this cost is an increasing non-linear function of the output of the supplier.

Given our model, one can easily predict that the contribution of the supplier to the abatement cost burden should directly affect the equilibrium price and profit of the supplier. The change in the supplier's price should, in turn, affect the prices and profits of all other channel members indirectly, since all prices in the channel are determined sequentially from the upstream (supplier) to the downstream (retailer). Calculating all equilibrium prices and profits, we theoretically show that the equilibrium prices of all channel members become higher when the supplier contributes more to the abatement. In consequence, the equilibrium profits of the retailer and the distributors become lower. However, this is not always true for the supplier's equilibrium profit. We computationally show that the supplier may benefit from making a positive, but sufficiently small, amount of contribution to the abatement if the demand curve facing the retailer is sufficiently linear.

The remainder of the paper is organized as follows. Section 2 presents the basic structures, Section 3 gives our theoretical results, and Section 4 gives our computational results. Finally, Section 5 concludes.

2 Basic Structures

We consider a supply chain with multiple echelons indexed by $i = 1, 2, \dots, n$. The first echelon, $i = 1$, is the retailer, the last echelon, $i = n$, is the supplier, and the remaining echelons are distributors. For convenience, we denote consumers as echelon $i = 0$.

The supplier produces a good at a constant marginal cost of c and at zero fixed cost. For each $i = 2, \dots, n$, we let p_i denote the wholesale price charged by echelon i to echelon $i-1$ and let p_1 denote the retail price charged by the retailer to consumers. Similarly, for each $i = 1, \dots, n-1$, we let q_i denote the order quantity of echelon i demanded via echelon $i+1$. For convenience, we let q_n denote the order of echelon i, the supplier, from itself. Borrowing from Zhong et al. (2016), we assume that the retailer faces a linear demand function given by

$$D(p_1) = (a - bp_1)^d, \tag{1}$$

where $b, d > 0$ and $a > bc$ ensure that the demand will be positive when the supplier produces at the marginal cost. Here, $D(p_1)$ denotes the quantity of goods the retailer orders from the supplier through $n-2$ distributors.

We assume that the production of the supplier generates pollution, and the cost of abatement is borne by the supplier and consumers. We let γ denote the amount of air pollution (CO_2) emitted by the supplier for each unit of goods. Borrowing from Nordhaus (2008) and Saglam (2023), we assume that the cost of abatement is given by

$$AC = \varphi \mu^{\epsilon} \tag{2}$$

where $\varphi > 0$ is a scale parameter, μ stands for the reduction in emissions from the baseline level to the zero level, and ϵ is a constant reflecting the non-linearity of costs for larger emission reductions. While Nordhaus (2008) sets ϵ at 2.8, we follow Saglam (2023) and set ϵ at 3 for tractability. Thus, we define for an output q produced by the supplier, the abatement cost of pollution $AC(q)$ as

$$AC(q) = \varphi \left[\gamma q\right]^3 = \varphi \gamma^3 q^3. \tag{3}$$

We assume that a fraction $\theta \in [0, 1]$ of the abatement cost $AC(q)$ at a given output level q is borne by the supplier and the remaining fraction $1-\theta$ of this cost is borne by consumers.

We denote the profit of any echelon $i = 1, \ldots, n$ by $\pi_i(p_i, p_{i+1}, q_i)$ where $p_{n+1} = c$ for convenience. The profit of the supplier is equal to its sales revenue net of the production and abatement costs whereas the profits of all other echelons are equal to their sales revenues. That is,

$$\pi_i(p_i, p_{i+1}, q_i) = (p_i - p_{i+1})q_i \text{ for all } i = 1, \ldots, n-1 \tag{4}$$

and

$$\pi_n(p_n, p_{n+1}, q_n) = (p_n - p_{n+1})q_n - \theta AC(q_n). \tag{5}$$

We assume that the retail price p_1 is determined individually by the retailer whereas the wholesale prices p_i ($i = 2, \ldots, n$) are determined by the generalized Nash bargaining process (Nash, 1950; Roth, 1979) between echelons i and $i-1$. For this process, the relative bargaining powers of echelon i and $i-1$ are λ_i and $1-\lambda_i$ respectively, and their disagreement payoff vector is $(0, 0)$. (Thus, the relative bargaining power of echelon $i = 1, \ldots, n-1$ when it negotiates with echelon $i+1$ on p_{i+1} is $1 - \lambda_{i+1}$.) We assume that $\lambda_1 = 1$, implying that the retailer (echelon 1) has the full bargaining power when negotiating with consumers (echelon 0) on the retail price p_1. After these descriptions, we let $(\lambda_1, \lambda_2, \ldots, \lambda_n)$ denote the bargaining power structure of the channel.

Negotiations in the channel proceed sequentially downwards, starting from the bargaining process between echelons n and $n-1$. Thus, for any $i = 2, \ldots, n-1$, when echelons i and $i-1$ bargain over the price p_i, they already know the agreement price p_{i+1} in the bargaining process between echelons $i+1$ and i. After the negotiation between echelons 2 and 1 over the wholesale price p_2 is complete, echelon 1, the retailer, knows p_2 and chooses p_1 to maximize its profit $\pi_1(p_1, p_2, q_1)$. Formally, for each $i = 2, 3, \ldots, n$, the bargaining problem of echelons i and $i-1$, whenever p_{i+1} is given to them, can be written as

$$\max_{p_i \geq 0} \left[\pi_i(p_i, p_{i+1}, q_i)\right]^{\lambda_i} \left[\pi_{i-1}(p_{i-1}, p_i, q_{i-1})\right]^{1-\lambda_i}. \tag{6}$$

Finally, since $\lambda_1 = 1$, we can write the bargaining problem between echelon 1 (the retailer) and echelon 0 (consumers), whenever p_2 is given to them, as an optimization problem for echelon 1:

$$\max_{p_1 \geq 0} \pi_1(p_1, p_2, q_1). \tag{7}$$

We assume that the cost information of the supplier, the demand information of the retailer, the number of echelons, the supply chain structure, the bargaining power structure and the timing of bargaining negotiations are common knowledge. Therefore, each echelon can correctly calculate the outcomes of all bargaining negotiations, i.e., the retail price p_1, the order q_i of each echelon $i = 1, 2, \ldots, n$, and the result that $D(p_1) = q_1 = q_2 = \ldots = q_n$.

3 Theoretical Results

We will first calculate the equilibrium price vector.

Theorem 1. *The sequential bargaining problems in the supply chain result in the price vector* $\mathbf{p}^* = (p_1^*, p_2^*, \ldots, p_n^*)$ *satisfying*

$$a - bp_i^* = \left(1 - \frac{\lambda_i}{d+1}\right)(a - bp_{i+1}^*) \quad \textit{for each } i = 1, 2, \ldots, n-1 \tag{8}$$

and

$$\frac{\lambda_n}{(p_n^* - c) - \theta\varphi\gamma^3(a - bp_n^*)^{2d}\prod_{i=1}^{n-1}\left(1 - \frac{\lambda_i}{d+1}\right)^{2d}} \times$$
$$\left(1 + 2bd\theta\varphi\gamma^3(a - bp_n^*)^{2d-1}\prod_{i=1}^{n-1}\left(1 - \frac{\lambda_i}{d+1}\right)^{2d}\right) - \frac{(1-\lambda_n)b}{(a - bp_n^*)} - \frac{bd}{(a - bp_n^*)} = 0. \tag{9}$$

Proof. We will first prove by induction that (8) holds for all $i = 1, 2, \ldots, n-1$. Let us first consider $i = 1$. The problem of echelon 1 in (7) can be rewritten as

$$\max_{p_1 \geq 0} (p_1 - p_2)(a - bp_1)^d. \tag{10}$$

The solution must satisfy the first-order condition

$$(a - bp_1)^d - db(p_1 - p_2)(a - bp_1)^{d-1} = 0, \tag{11}$$

implying

$$(a - bp_1) = \left(1 - \frac{\lambda_1}{d+1}\right)(a - bp_2), \tag{12}$$

where we have used the assumption that $\lambda_1 = 1$. Now, assume that (8) holds up to some integer $i = k$ where k is less then $n-1$. We will show that (8) holds for $i = k+1$, as well. Notice that the bargaining problem of echelon $k+1$ and k in (6) can be rewritten as

$$\max_{p_{k+1} \geq 0} \left[(p_{k+1} - p_{k+2})(a - bp_1)^d\right]^{\lambda_{k+1}} \left[(p_k - p_{k+1})(a - bp_1)^d)\right]^{1-\lambda_{k+1}} \tag{13}$$

using $q_{k+1} = q_k = q_1 = (a - bp_1)^d$. The solution must satisfy the first-order condition

$$\frac{\lambda_{k+1}}{(p_{k+1} - p_{k+2})} + \frac{1 - \lambda_{k+1}}{(p_k - p_{k+1})}\left(\frac{\partial p_k}{\partial p_{k+1}} - 1\right) - \frac{bd}{(a - bp_1)}\frac{\partial p_1}{\partial p_{k+1}} = 0. \tag{14}$$

Since (8) holds for all $i = 1, 2, \ldots, k$, we must have

$$a - bp_1 = (a - bp_{k+1}) \prod_{i=1}^{k} \left(1 - \frac{\lambda_i}{d+1}\right), \tag{15}$$

further implying

$$\frac{\partial p_1}{\partial p_{k+1}} = \prod_{i=1}^{k} \left(1 - \frac{\lambda_i}{d+1}\right). \tag{16}$$

Moreover, writing (8) for $i = k$, we can obtain

$$(p_k - p_{k+1}) = \frac{\lambda_k}{b(d+1)}(a - bp_{k+1}) \tag{17}$$

and

$$\frac{\partial p_k}{\partial p_{k+1}} = \left(1 - \frac{\lambda_k}{d+1}\right). \tag{18}$$

Using (15)-(18), we can rewrite (14) as

$$\frac{\lambda_{k+1}}{(p_{k+1} - p_{k+2})} - \frac{(1 - \lambda_{k+1})b}{(a - bp_{k+1})} - \frac{bd}{(a - bp_{k+1})} = 0, \tag{19}$$

implying after some rearrangements

$$a - bp_{k+1} = \left(1 - \frac{\lambda_{k+1}}{d+1}\right)(a - bp_{k+2}). \tag{20}$$

Therefore, (8) holds for $i = k+1$, as well. Since k was arbitrary, we have established that (8) holds for any $i = 1, 2, \ldots, n-1$.

Finally, we will show that (9) is true. The problem of echelons n and $n-1$ is to solve

$$\max_{p_n \geq 0} \left[(p_n - c)(a - bp_1)^d - \theta\varphi\gamma^3(a - bp_1)^{3d}\right]^{\lambda_n} \left[(p_{n-1} - p_n)(a - bp_1)^d)\right]^{1-\lambda_n}. \tag{21}$$

The solution must satisfy the first-order condition

$$\begin{aligned} &\frac{\lambda_n}{(p_n - c) - \theta\varphi\gamma^3(a - bp_1)^{2d}} \left(1 + 2bd\theta\varphi\gamma^3(a - bp_1)^{2d-1}\frac{\partial p_1}{\partial p_n}\right) \\ &+ \frac{1-\lambda_n}{(p_{n-1} - p_n)}\left(\frac{\partial p_{n-1}}{\partial p_n} - 1\right) - \frac{bd}{(a - bp_1)}\frac{\partial p_1}{\partial p_n} = 0. \end{aligned} \tag{22}$$

Using (8) we obtain

$$a - bp_1 = (a - bp_n)\prod_{i=1}^{n-1}\left(1 - \frac{\lambda_i}{d+1}\right), \tag{23}$$

$$\frac{\partial p_1}{\partial p_n} = \prod_{i=1}^{n-1}\left(1 - \frac{\lambda_i}{d+1}\right), \tag{24}$$

$$(p_{n-1} - p_n) = \frac{\lambda_{n-1}}{b(d+1)}(a - bp_n), \tag{25}$$

and

$$\frac{\partial p_{n-1}}{\partial p_n} = \left(1 - \frac{\lambda_{n-1}}{d+1}\right). \tag{26}$$

Next, using (23)-(26) we can rewrite (22) as

$$\begin{aligned} &\frac{\lambda_n}{(p_n - c) - \theta\varphi\gamma^3(a - bp_n)^{2d}\prod_{i=1}^{n-1}\left(1 - \frac{\lambda_i}{d+1}\right)^{2d}} \times \\ &\left(1 + 2bd\theta\varphi\gamma^3(a - bp_n)^{2d-1}\prod_{i=1}^{n-1}\left(1 - \frac{\lambda_i}{d+1}\right)^{2d}\right) - \frac{(1-\lambda_n)b}{(a - bp_n)} - \frac{bd}{(a - bp_n)} = 0. \end{aligned} \tag{27}$$

Thus, we have established that (9) is true. ■

In Theorem 1, we notice that if $\theta = 0$, $\varphi = 0$ or $\gamma = 0$, then equation (9) reduces to

$$a - bp_n^* = \left(1 - \frac{\lambda_n}{d+1}\right)(a - bp_{n+1}^*) \tag{28}$$

where $p_{n+1}^* = c$. Thus, in cases production does not generate any pollution, or the cost of pollution abatement is zero, or the supplier does not contribute to the burden of this cost whenever it is positive (each of which would imply $\theta AC(q_n) = 0$ in our model), equation (8) is satisfied for all echelons, including echelon n. In fact, this is what is shown by Zhong et al. (2016) in the absence of any environmental concern.

Trivially, we can rewrite equation (8) as

$$a - bp_i^* = (a - bp_n^*) \prod_{k=i}^{n-1} \left(1 - \frac{\lambda_k}{d+1}\right) \quad \text{for each } i = 1, 2, \ldots, n-1. \tag{29}$$

So, whenever $\theta AC(q_n) \neq 0$, it is true that not only the price p_n^* of the supplier, but the prices of all other echelons are affected by θ. This is because the negotiations that determine the prices of echelons occur sequentially, proceeding downwards starting with the bargaining of echelons n and $n-1$ resulting in the price p_n^*. Moreover, the sign of the effect of θ on the price p_i^* is the same for all $i = 1, 2, \ldots, n$, i.e., if a change in θ increases (decreases) p_n^*, then it increases (decreases) p_i^* for any $i \neq n$, as well. Below, we show the direction of these effects.

Corollary 1. *For any $i = 1, 2, \ldots, n$, the equilibrium price p_i^* is increasing in $\theta \in [0, 1]$.*

Proof. We can rewrite equation (9) as

$$K(p_n^*, \theta) = \frac{(1 - \lambda_n)b}{(a - bp_n^*)} + \frac{bd}{(a - bp_n^*)}, \tag{30}$$

where

$$\begin{aligned} K(p_n^*, \theta) \quad &= \quad \frac{\lambda_n}{(p_n^* - c) - \theta\varphi\gamma^3(a - bp_n^*)^{2d} \prod_{i=1}^{n-1} \left(1 - \frac{\lambda_i}{d+1}\right)^{2d}} \times \\ &\left(1 + 2bd\theta\varphi\gamma^3(a - bp_n^*)^{2d-1} \prod_{i=1}^{n-1} \left(1 - \frac{\lambda_i}{d+1}\right)^{2d}\right). \end{aligned} \tag{31}$$

Clearly, $K(p_n^*, \theta)$ is decreasing in p_n^* whereas the right-hand side of (31) is increasing. Now, consider an increase in θ. This will shift the function $K(p_n^*, \theta)$ upwards, while it will not affect the right-hand side of (31). Therefore, p_n^* will become higher. Since equation (29) shows that the price p_i^* is positively related to p_n^* for each $i = 1, 2, \ldots, n-1$, it is also true that the price of any echelon will become higher if θ is higher. ■

Now, we turn our attention to the profits generated in the channel. For each

$i = 1, 2, \ldots, n-1$, the profit of echelon i can be calculated as

$$\begin{aligned} \pi_i(p_i^*, p_{i+1}^*, q_i^*) &= (p_i^* - p_{i+1}^*)q_i^* = \frac{\lambda_i}{b(d+1)}(a - bp_{i+1}^*)(a - bp_1^*)^d \\ &= \frac{\lambda_i}{b(d+1)} \prod_{k=1}^{i} \left(1 - \frac{\lambda_k}{d+1}\right)^d Z(i)(a - bp_n^*)^{d+1}, \end{aligned} \tag{32}$$

where $Z(i) = \prod_{k=i+1}^{n-1} \left(1 - \frac{\lambda_k}{d+1}\right)^{d+1}$ if $i < n-1$ and $Z(i) = 1$ if $n-1$. Equation (32) shows that for any $i = 1, 2, \ldots, n-1$, the equilibrium profit π_i^* is decreasing in the equilibrium price of the supplier, p_n^*. Along with Corollary 1, this observation implies that the profit of any echelon other than the supplier becomes lower if the supplier's contribution to the abatement becomes higher.

Corollary 2. *For any $i = 1, 2, \ldots, n-1$, the equilibrium profit π_i^* is decreasing in $\theta \in [0, 1]$.*

Proof. Directly follows from (32) and Corollary 1. ■

Corollary 2 does not cover the supplier's profit, which can be calculated as

$$\begin{aligned} \pi_n^* &\equiv \pi_n(p_n^*, p_{n+1}^*, q_n^*) = (p_n^* - c)q_n^* - \theta AC(q_n^*) \\ &= (p_n^* - c)(a - bp_n^*)^d \prod_{k=1}^{n-1} \left(1 - \frac{\lambda_k}{d+1}\right)^d - \theta\varphi\gamma^3(a - bp_n^*)^{3d} \prod_{k=1}^{n-1} \left(1 - \frac{\lambda_k}{d+1}\right)^{3d}. \end{aligned} \tag{33}$$

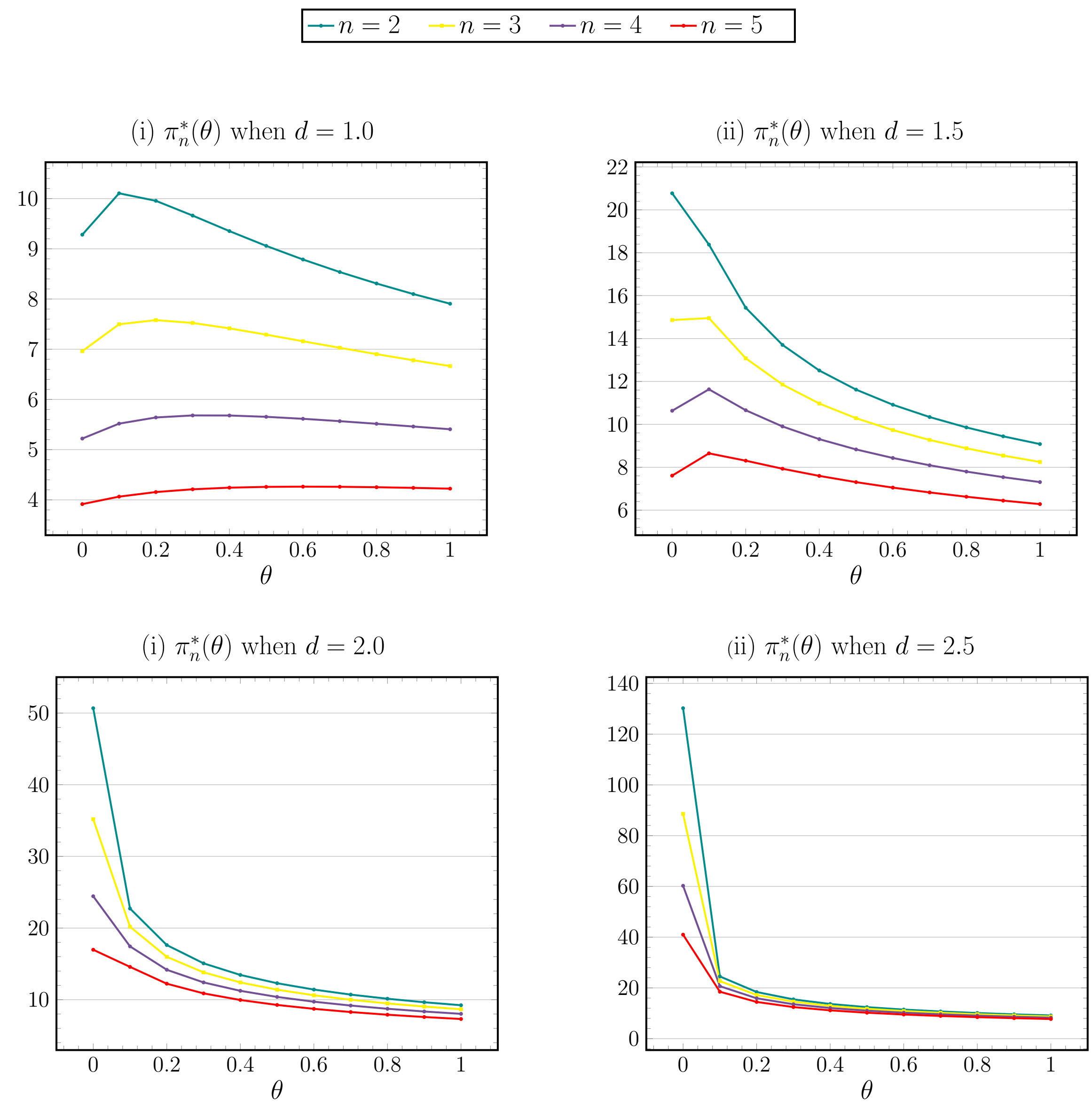
We should notice from above that the effect of p_n^* on π_n^* is ambiguous. Therefore, we cannot analytically answer how π_n^* is affected by θ, either. In Section 4, we will answer this question computationally.

4 Computational Results

The computations in this section are performed using MATLAB Software Version R2023a. The program codes and the resulting data are available upon request. For all computations, we set $a = 10$, $b = 1$, $c = 0.05$, $\gamma = 0.9$, $\varphi = 1$, and $\lambda_1 = 1$. We vary the demand parameter d in the set $\{1.0, 1.5, 2.0, 2.5\}$ and the channel length n in the set $\{2, 3, 4, 5\}$, and assume that the bargaining power distribution is always symmetric, i.e., $(\lambda_2, \ldots, \lambda_n) = (0.5, \ldots, 0.5)$ for each n. Given these settings, we calculate the supplier's equilibrium profit $\pi_n^*(\theta)$ as a function of the abatement contribution parameter θ that is varied in the set $\{0.0, 0.1, 0.2, \ldots, 1.0\}$.

We illustrate our result in Figure 1. Panel (i) shows that if the demand curve is linear ($d = 1$), then the supplier's equilibrium profit $\pi_n^*(\theta)$ is hump-shaped for all values of n and this is more visible when n is closer to 2 (since $\pi_n^*(\theta)$ becomes lower when n is higher, as expected). As the supplier's contribution rate to the abatement, θ, increases from zero to one, its equilibrium profit $\pi_n^*(\theta)$ first rises and then tends to fall. However, if the channel length is sufficiently high (e.g., $n = 4$ or $n = 5$), then the supplier may be still better off when it fully contributes to the abatement ($\theta = 1$) than when it makes no contribution ($\theta = 0$).

Figure 1. The Supplier's Equilibrium Profit $\pi_n^*(\theta)$ for Various Values of n and d



Panel (ii) of Figure 1 shows that some of the aforementioned results start to change if $d = 1.5$ and the demand is thus non-linear. In that case, the supplier's equilibrium profit $\pi_n^*(\theta)$ is hump-shaped only if the channel contains at least three members (i.e.,

$n \in \{3, 4, 5\}$). However, even in such a case, the supplier never prefers $\theta = 1$ to $\theta = 0$ as it would do when $d = 1$. Panels (iii) and (iv) show that if the demand is sufficiently non-linear (i.e., $d = 2.0$ or $d = 2.5$), then the supplier's equilibrium profit $\pi_n^*(\theta)$ is always decreasing in θ.

To understand the intuition underlying the above results, we should recall from Corollary 1 that an increase in θ raises the equilibrium prices of all echelons, and in particular the price p_1^* charged by the retailer. Since the equilibrium supply q_i^* of any echelon $i = 1, \ldots, n$ to echelon $i - 1$ is always equal to $q_1^* = (a - bp_1^*)^d$, an increase in θ then reduces q_i^*. This reduction tends to reduce the equilibrium profit of each non-supplier echelon, since $\pi_i^* = (p_i^* - p_{i+1}^*)q_i^*$ for all $i = 1, \ldots, n-1$. The increase in θ also compresses the markup $(p_i^* - p_{i+1}^*)$ charged by echelon i to echelon $i-1$ because this markup is equal to $\frac{\lambda_i}{b(d+1)} \prod_{k=i+1}^{n-1} \left(1 - \frac{\lambda_k}{d+1}\right) (a - bp_1^*)^d$, which is decreasing in p_1^* (hence decreasing in θ). As a result, the profit of each echelon other than the supplier is always decreasing in θ. However, this conclusion does not hold for the supplier. The reason is that the equilibrium markup of the supplier, $p_n^* - p_{n+1}^* = p_n^* - c$, is increasing in θ, unlike the markups of other echelons. The positive effect of θ on the supplier's equilibrium markup is countered by the negative effect on its equilibrium supply $q_n^* = q_1^* = (a - bp_1^*)^d$. If d is sufficiently high, then the aforementioned positive effect is outweighed by the negative effect, and thus the gross profit of the supplier $(p_n^* - c)q_1^*$ becomes smaller in equilibrium when θ becomes higher. Therefore, its net profit $\pi_n^* = (p_n^* - c)q_1^* - \theta AC(q_1^*)$ becomes smaller. Conversely, if demand is sufficiently linear (d is close to 1), then the positive effect of θ on the supplier's equilibrium markup more than offsets the negative effect on its equilibrium supply q_1^*. Thus, an increase in θ leads to a rise in the gross profit of the supplier $(p_n^* - c)q_1^*$ in equilibrium. However, this rise exceeds the rise in the supplier's contribution to the abatement, $\theta AC(q_1^*)$ if and only if θ is not too high. Therefore, we find that the net profit of the supplier π_n^* is increasing θ if and only if both d and θ are sufficiently low.

5 Conclusion

In this paper, we studied the effect of the abatement cost burden of a non-green supplier on the profits of the supplier, the retailer, and the distributors in a multi-echelon supply chain. We assumed that the price charged by each echelon maximizes the generalized Nash product of its profit gain and the profit gain of the next echelon from the bargaining agreement when the echelons in the channel negotiate sequentially downwards starting with the supplier located at the top of the channel. Calculating all equilibrium prices and profits analytically, we showed that when the supplier contributes more to the abatement, the equilibrium prices of all channel members become higher and consequently the equilibrium profits of all channel members other than the supplier become lower. Also, we computationally showed that in a supply chain with symmetric bargaining power distribution, the supplier may benefit from making a positive, but sufficiently small, amount of contribution to the abatement if the demand curve facing the retailer is sufficiently linear. Moreover, this result may be true even when there are no distributors in the supply chain. Our computations further revealed that when the retailer's demand curve is linear and the channel length is sufficiently large, the supplier may be better off even when it fully contributes to the abatement than when it does not contribute.

Our results imply that in an industry dominated by a single supply chain, the pollution abatement must not always harm the supplier. The existing literature on sustainable supply chain management often addresses environmental concerns in models where supply chains have multiple objectives, such as the maximization of profit and the minimization of emissions. As profitability and environmental concerns align very rarely, the reality of these models calls for a governmental authority that can successfully monitor, limit, or tax the emissions of supply chains. Our results show that there are industry structures where supply chains may adopt environmentally-friendly business practices even in the absence of governmental mandates.

The supply chain in our model involves a unique supplier and a unique retailer, in addition to an arbitrary number of distributors. Future research may extend our work to supply chains involving multiple suppliers and/or multiple retailers and explore whether contributing to pollution abatement must harm the suppliers in the presence of competition or collusion among suppliers and/or among retailers.

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