Impact of government subsidies on green supply chain operation under different power structures

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Abstract. Government subsidies play an important role in the operations of a green supply chain. However, the effectiveness of these subsidies under different power structures has rarely been examined. In this paper, we investigate a two-echelon green supply chain with a manufacturer who obtains government subsidies to develop and produce green products and a retailer who sells to consumers. We examine the impact of government subsidies on green product innovation, supply chain profits, and social welfare by focusing on five power structure models: centralized decision (C), manufacturer-Stackelberg (MS), retailer-Stackelberg (RS), vertical Nash (NL), and vertical Nash with bargaining mechanism (NB) models. The results show that government subsidies have a positive impact on the energy-saving level of green products, firms’ financial performance, and supply chain profits. We also find that the NB model is the optimal power structure of decentralized decision scenarios in terms of green product innovation, supply chain profits, and social welfare. Our findings indicate that if supply chain members have equal power and bargaining mechanisms the effectiveness of government subsidies will be enhanced. This study provides new theoretical insights for green supply chain research by revealing the interplay between the power structure of the green supply chain and government subsidies.

1. Introduction

Environmental pollution and natural resource shortages have led both the industry and academia to focus on green supply chain management [1-2]. As a novel management paradigm, the green supply chain aims to reduce the negative impact of supply chain members’ activities (e.g., material acquisition, R&D, manufacturing, and recycling) on the environment and promote the coordination of environmental protection and economic development [3]. To facilitate the implementation of green supply chains, government subsidies have been increasingly utilized in numerous countries to encourage suppliers, manufacturers, and retailers to improve the efficiency of resource utilization in their operations [4]. For example, the governments of the U.S., China, and the Netherlands have proposed specific subsidies and tax policies to encourage firms to implement green innovation or to produce energy-saving products [5]. However, as such practices is becoming popular, scholars have noted many challenges in green supply chain management. The power structure of a supply chain is critical to the efficiency of government subsidies and plays an important role in green supply chain management.
The power structure of a supply chain involves the allocation of leadership between suppliers, manufacturers, and retailers in terms of strategic decisions, resource sharing, and profit distribution [6], [7]. For example, Qualcomm controls the pricing power of baseband chips in the mobile communication industry, and thus achieves huge profits [8]. Intel, Microsoft, and Cisco have launched “platform leadership” strategies to strengthen their control over supply chains [9]. Suppliers, manufacturers, and retailers often have different motives and goals, and thus leaders and followers must establish common goals to improve the operational efficiency of the supply chain [10]. In practice, the power structure not only affects the value creation and value capture of the supply chain but also acts as an important factor that induces exchange hazards between firms [11]. The leader of a supply chain typically has extensive bargaining power and can gain from the distribution of profits between firms, which may reduce the value captured by their followers [12]. The power structure will also influence the pricing decisions and resource input of leaders and their followers. Unlike a leader, a follower must passively accept the pricing decisions and is vulnerable to the leader’s discriminatory pricing. The problems within the power structure of a supply chain have been analyzed from different perspectives (e.g., manufacturer–retailer [13-14], supplier–manufacturer [6], [15], and manufacturer–service operator [11]), and power structures have been found to have varying degrees of influence on product development, channel strategy, and supply chain profits [16]. However, few studies have focused on the power structure within a green supply chain. Although most researchers suggest that government subsidies can facilitate green supply chain management [5], [17], there are still some research gaps that limit our understanding of their management.

The contribution of government subsidies to the development and production of green products under different power structures remains unclear. Although these subsidies are essential in facilitating green supply chain management, they will not necessarily lead to satisfactory results in all power structure scenarios. The literature shows that government subsidies have a positive impact on the development and production of green products, but such studies only examine a single type of power structure with a manufacturer as the leader. They do not compare the effectiveness of government subsidies in different power structures [5], [18]. However, findings on the interactions between green supply chain power structures and social welfare are ambiguous. Some studies suggest that the government can effectively improve social welfare by providing direct or indirect assistance to the green supply chain, but do not compare the effects of government subsidies on social welfare under different power structures [17]. Identifying the type of power structure model that can maximize the effect of government subsidies on social welfare will therefore benefit managers and help them make more effective strategic decisions.

To address the above research gaps, we consider a two-echelon green supply chain with one manufacturer and one retailer and analyze how the power structure affects the effectiveness of government subsidies. We contribute to the literature on green supply chains by examining the relationships between government subsidies, the level of energy-saving in green products, and firms’ business performance under five power structure models: centralized decision, manufacturer-Stackelberg, retailer-Stackelberg, Vertical Nash, and Vertical Nash with bargaining mechanism models. We also extend power structure research by investigating the cooperative behavior of supply chain members under different power structures, and we identify the optimal power structure model for maximizing the profit and social welfare of a green supply chain.

The remainder of this paper is organized as follows. In Section 2, we review the related literature. The model and assumptions are described in Section 3. Section 4 presents the equilibrium solutions and propositions. A numerical analysis is provided in Section 5. Finally, in Section 6, we discuss the key findings, managerial implications, and future research directions.
2. Literature review

2.1. Green supply chain management

The literature on green supply chain management mainly focuses on designing benefit coordination mechanisms between supply chain members to reduce the negative environmental impact of supply chain operations. Game models have often been used to investigate the effects of revenue-sharing and cost-sharing contracts on the cooperative behaviors of supply chain members. Chen analyzed the effect of environmental standard implementation on the R&D efficiency of green products [19]. Ghosh and Shah assessed the effect that negotiations between suppliers and manufacturers have on the manufacturing efficiency of green products, and designed a benefit coordination mechanism for the supply chain [20]. Swami and Shah found a negative correlation between the cost sensitivity of supply chain members and the efficiency of the cooperative R&D of green products, and a positive correlation between members’ preference for green products and R&D efficiency [21]. Zhang et al. found that an increase in the level of competition improved the efficiency of supply chain operations [22]. Yenipazarli compared the effects of cost-sharing and revenue-sharing contracts between manufacturers and retailers on the efficiency of green product innovation and found that manufacturers’ profits were positively correlated with green product development efficiency [23]. Similarly, Hong and Guo found that sharing the manufacturing cost of green products between manufacturers and retailers is not only conducive to improving the greenness of the products, but also enhances the operational efficiency of the supply chain [2]. Song and Gao proposed that a revenue-sharing contract based on bargaining can positively affect the level of product greening and the profitability of the supply chain [24].

2.2. Government subsidies and supply chain management

In many studies of supply chain management, government subsidies are viewed as the most common and effective incentive approaches as they have a positive effect on the R&D, manufacturing, and marketing of supply chain members [17]. Mitra and Webster examined the impact of government subsidies on product recycling in closed-loop supply chains [18] and found that subsidies can incentivize remanufacturers’ product recycling efforts and enhance their profitability. Bi et al. analyzed the interplay of government subsidies, consumer environmental sensitivity, and green supply chains’ product development [25]. They showed that innovation ability, technical specialization level, and operating cost of supply chain members will influence the effectiveness of government subsidies. Similarly, Lu and Shao designed an optimal decision model for government subsidies and found that consumer price sensitivity can significantly reduce their effect [26]. Chen et al. found that subsidies aimed at innovation are more effective in promoting manufacturers’ product development than per-unit production subsidies [4]. However, they emphasized that neither type can effectively improve the operational efficiency of the retailer. Cohen et al. investigated optimal decisions concerning government subsidies when market demand is uncertain [27]. They proposed that providing subsidies to consumers rather than to manufacturers can more effectively promote technological innovation in the green supply chain. Heydari et al. found that government provides subsidies to the manufacturers can improve the efficiency of product recycling in closed-loop supply chains. [28]. Xue et al. investigated a two-echelon supply chain with a manufacturer and a retailer and found that government subsidies contribute to green product development [29]. Chen and Ivan examined the strategies of manufacturers and retailers who are concerned about fairness and found that government subsidies have a positive impact on supply chain operations [30].

2.3. The power structure of the supply chain

The Stackelberg game model is typically used in the supply chain literature to analyze the effect of power structures on firms’ profits, pricing decisions, and product development. Cox et al. examined a two-echelon supply chain with a manufacturer and a retailer and found that the supplier’s profit may be reduced when the manufacturer controls the distribution of benefits in the supply chain [31].
Ferguson et al. investigated the influence of power structure on retailers’ product sales [32]. They found that, unlike the manufacturer-Stackelberg model, the retailer-Stackelberg model can significantly enhance the sales of green products. Kolay and Shafer analyzed the relationship between power structure and channel coordination and found that the operational efficiency of the supply chain will increase when it is led by the retailer [33]. They also examined the problem of benefit coordination between supply chain members based on two-part tariff contracts. Shi et al. investigated the influence of power structure on supply chain management in the context of uncertain demand [34]. They found that the manufacturer-Stackelberg model is more conducive to improving the profitability of the supply chain than the retailer-Stackelberg model. Gao et al. analyzed the interaction between the change of channel power structure and optimal decision-making in a closed-loop supply chain and found that the performance of the supply chain improved when the leadership was transferred from the manufacturer to the retailer [16]. Luo et al. investigated a two-echelon supply chain with one retailer and two manufacturers and found that if the retailer played a leadership role in the supply chain, the conflicts between manufacturers were alleviated and the profitability of all supply chain members was enhanced [35].

The above literature offers important theoretical insights, but research gaps remain, which limit our understanding of green supply chain management. Few studies have focused on the interplay of government subsidies, power structure, and green supply chain management, even though a power structure can influence the effectiveness of government subsidies, product development, and supply chain profits. The type of power structure that can maximize the social welfare of the green supply chain should also be identified. Accordingly, we investigate the interaction between government subsidies and the operation of green supply chain under different power structures and discuss the optimal power structure for maximizing the social welfare benefits of this supply chain.

3. The model

3.1. Model descriptions

A two-echelon supply chain that consists of a manufacturer (m) and a retailer (r) is investigated. The manufacturer produces green products and sells them to the retailer at a wholesale price \( w \), and the unit cost of producing green products is \( c_m \). The retailer purchases green products and sells them to consumers at retail price \( p \), and the unit cost of selling green products is \( c_r \). We define green products as those that are more energy-saving and eco-friendly than traditional products. The energy-saving level of green products is denoted as \( x \). The greater the value of \( x \), the higher the energy-saving level of the products. The R&D cost of green products is \( \gamma x^2/2 \), where \( \gamma > 0 \) refers to the firm’s R&D ability [24], [36]. The market demand \( D(p,x) = \Lambda - bp + \beta x \) is a linear function of the product price and energy-saving level, where \( \Lambda > 0 \) refers to the market’s total potential demand for green products, the consumers’ sensitivity to price is \( b \), and the consumers’ sensitivity to the energy-saving level is \( \beta \) [37].

To encourage the production of green products, the government provides subsidies to the manufacturer, and the level of government subsidy is \( s \). The social welfare is a function of consumer surplus (CS), producer surplus (PS), and government subsidies: \( SW = CS + PS - sD(p,x) \) [30]. We assume \( \Lambda - b(c_m + c_r) > 0 \) and \( 2\gamma - \beta^2 > 0 \) to ensure that the game model is consistent with supply chain practice.

We can express the profits of the manufacturer (\( \pi_m \)) and the retailer (\( \pi_r \)) as:

\[
\pi_m(w,x) = (w + s - c_m)(\Lambda - bp + \beta x) - \frac{1}{2}\gamma x^2
\]

\[
\pi_r(p) = (p - w - c_r)(\Lambda - bp + \beta x)
\]
The supply chain’s profit ($\pi_c$) can be expressed as:

$$\pi_c(p, x) = (p + s - c_m - c_r)(\lambda - bp + \beta x) - \frac{1}{2}\gamma x^2.$$  \hspace{2cm} (3)

We can express the function of social welfare as:

$$SW = \frac{1}{2h}(\lambda - bp + \beta x)^2 + (p - c_m - c_r)(\lambda - bp + \beta x) - \frac{1}{2}\gamma x^2.$$ \hspace{2cm} (4)

We analyze the relationships between power structure, government subsidies, and supply chain profitability based on game theory. We consider five power structure models: centralized decision (C), manufacturer-Stackelberg (ML), retailer-Stackelberg (RL), vertical Nash (NL), and vertical Nash with bargaining mechanism (NB) models. Figure 1 shows the decision timelines of each model. First, the government announces the level of subsidies ($s$). Second, the manufacturer decides the energy-saving level of the product ($x$). Finally, supply chain members make their pricing decisions sequentially based on their relative market power.

**Figure 1.** The decision timelines.
In the following sections, the subscript \( i \in \{m, r, sc\} \) is used to denote the manufacturer, the retailer, and the supply chain, respectively. The superscript \( j \in \{C, ML, RL, NL, NB\} \) is used to represent the five power structure models.

3.2 Centralized decision model

In this section, we analyze the equilibrium solution of the centralized decision model (C). In this model, the supply chain is regarded as an integrated organization, and the focus is on maximizing the profit of the supply chain [24]. As shown in Figure 2, supply chain members make joint decisions about the retail price (\( p \)) and the energy-saving level of the product (\( x \)) to maximize the supply chain’s profit. Therefore, the game sequence of the C model can be expressed as:

\[
C : \max_{\pi} \pi_p \rightarrow \max_{\pi} \pi_{sc}.
\] (5)

We use the backward induction method to resolve Equation (5). For any given \( x \), the optimal retail price for \( \pi_{sc} \) can be expressed as:

\[
p = \frac{\Lambda + \beta x - bs + bc_m + bc_r}{2b}.
\] (6)

Substituting Equation (6) into Equation (3), the energy-saving level of the product (\( x \)) for \( \pi_{sc} \) can be expressed as:

\[
x = \frac{\beta(\Lambda - bs - bc_m - bc_r)}{2by - \beta^2}.
\]

The Hessian matrix of \( \pi_{sc} \) can be expressed as

\[
H = \begin{bmatrix}
\frac{\partial^2 \pi_{sc}}{\partial p^2} & \frac{\partial^2 \pi_{sc}}{\partial p \partial x} \\
\frac{\partial^2 \pi_{sc}}{\partial x \partial p} & \frac{\partial^2 \pi_{sc}}{\partial x^2}
\end{bmatrix} = \begin{bmatrix}
-2b & \beta \\
\beta & -\gamma
\end{bmatrix}.
\]

In Section 3.1, we assume \( 2by - \beta^2 > 0 \), meaning that the Hessian matrix of \( \pi_{sc} \) is negative definite. Therefore, the optimal retail price, energy-saving level, and market demand of green products can be expressed as:

\[
p^c = \frac{\gamma \Lambda + (by - \beta^2)c_m + (by - \beta^2)c_r - (by - \beta^2)s}{2by - \beta^2},
\] (7)

\[
x^c = \frac{\beta(\Lambda - bc_m - bc_r) + bs}{2by - \beta^2},
\] (8)

\[
D^c = \frac{by(\Lambda - bc_m - bc_r) + bs}{2by - \beta^2}.
\] (9)

By substituting Equations (7), (8), and (9) into Equations (3) and (4), we can obtain the profit of the green supply chain as:

\[
\pi_{sc}^c = \frac{\gamma(A + hs)^2}{2(2by - \beta^2)}.
\] (10)

The optimal social welfare of the C model is:
\[ SW^C = \gamma(A + bs) \frac{A(3by - \beta^2) - bs(b\gamma - \beta^2)}{2(2h\gamma - \beta^2)^2}. \]  

(11)

3.3. Decentralized decision models

In this section, we analyze the equilibrium solutions of the ML, RL, NL, and NB models. In the ML model, the manufacturer has greater power than the retailer, so the retailer will execute pricing decisions after the manufacturer. Thus, we can represent the game sequence of the ML model as:

\[ ML: \max_x \pi_m \rightarrow \max_w \pi_w \rightarrow \max_p \pi_r. \]  

(12)

According to the RL model in Figure 1, the manufacturer will execute pricing decisions after the retailer. Therefore, we can express the game sequence of the RL model as:

\[ RL: \max_x \pi_m \rightarrow \max_p \pi_r \rightarrow \max_w \pi_w. \]  

(13)

In the NL model, the manufacturer and the retailer have equal power, which means that the supply chain members make pricing decisions simultaneously, taking into consideration the other firm’s decision. Then, we can represent the game sequence of the NL model as:

\[ NL: \max_x \pi_m \rightarrow (\max_w \pi_w, \max_p \pi_p). \]  

(14)

To examine the effect of the bargaining mechanism, we propose a Nash bargaining model (NB) as an extension of the NL model. In the NB model, we assume that the supply chain members have equal power and make the pricing decisions through a bargaining mechanism. In line with Nash [38] and Wu et al. [39], we can express the game sequence of the NB model as:

\[ NB: \max_x \pi_m \rightarrow \max_{w, p} (\pi_m - \pi_{NL}^m)(\pi_p - \pi_{NL}^p). \]  

(15)

In Equation (15), \( \pi_{NL}^m \) and \( \pi_{NL}^p \) represent the supply chain members’ threat points [39]; they are the equilibrium solutions of Equations (14). We use the backward induction method to resolve Equations (12)-(15). Table 1 shows the equilibrium solutions of the decentralized decision models, where \( A = \Lambda - hc - be_c \), \( B_1 = b\gamma - \beta^2 \), \( B_2 = 2b\gamma - \beta^2 \), \( B_3 = 6b\gamma - \beta^2 \), \( B_4 = 3b\gamma - 2\beta^2 \), \( B_5 = 3b\gamma - \beta^2 \). The related proofs are illustrated in the Appendices. Table 2 presents the overall profit and social welfare levels of the green supply chain.

**Table 1. The equilibrium solutions.**

| Model | x | w | p | D |
|-------|---|---|---|---|
| C     | \( \frac{\beta(A + bs)}{2by - \beta^2} \) | - | \( \frac{\gamma A + B_1(c_m + c_e - s)}{2by - \beta^2} \) | \( \frac{by(A + bs)}{2by - \beta^2} \) |
| ML    | \( \frac{\beta(A + bs)}{4by - \beta^2} \) | \( \frac{2\gamma(A - hc)}{4by - \beta^2} + B_2(c_e - s) \) | \( \frac{3\gamma A + B_1(c_m + c_e - s)}{4by - \beta^2} \) | \( \frac{by(A + bs)}{4by - \beta^2} \) |
| RL    | \( \frac{\beta(A + bs)}{8by - \beta^2} \) | \( \frac{2\gamma(A - hc)}{8by - \beta^2} + B_2(c_e - s) \) | \( \frac{6\gamma A + B_1(c_m + c_e - s)}{8by - \beta^2} \) | \( \frac{by(A + bs)}{8by - \beta^2} \) |
| NL    | \( \frac{2\beta(A + bs)}{9by - 2\beta^2} \) | \( \frac{3\gamma(A - hc)}{9by - 2\beta^2} + B_2(c_e - s) \) | \( \frac{6\gamma A + B_1(c_m + c_e - s)}{9by - 2\beta^2} \) | \( \frac{3by(A + bs)}{9by - 2\beta^2} \) |
| NB    | \( \frac{\beta(A + bs)}{4by - \beta^2} \) | \( \frac{\gamma A - byc_e + B_1(c_m + s)}{4by - \beta^2} \) | \( \frac{2\gamma A + B_1(c_m + c_e - s)}{4by - \beta^2} \) | \( \frac{2by(A + bs)}{4by - \beta^2} \) |
Table 2. The profit and social welfare of the green supply chain.

| Model | $\pi_n$ | $\pi_r$ | $\pi_w$ | SW |
|-------|---------|---------|---------|----|
| C     | –       | –       | $\frac{\gamma(A + b_s)^2}{2(2b\gamma - \beta^2)}$ | $\frac{\gamma(A + b_s)(AB_s - bsB_s)}{2(2b\gamma - \beta^2)^2}$ |
| ML    | $\frac{\gamma(A + b_s)^2}{2(4b\gamma - \beta^2)}$ | $\frac{by^2(A + b_s)^2}{2(4b\gamma - \beta^2)^2}$ | $\frac{\gamma B_s(A + b_s)^2}{2(4b\gamma - \beta^2)^2}$ | $\frac{\gamma(A + b_s)(A(14B_s + 13\beta^2) - bs(2B_s - \beta^2))}{2(4b\gamma - \beta^2)^2}$ |
| RL    | $\frac{\gamma(A + b_s)^2}{2(8b\gamma - \beta^2)}$ | $\frac{8by^2(A + b_s)^2}{2(8b\gamma - \beta^2)^2}$ | $\frac{\gamma B_s(A + b_s)^2}{2(8b\gamma - \beta^2)^2}$ | $\frac{\gamma(A + b_s)(A(15B_s + 11\beta^2) - bs(3B_s - 5\beta^2))}{2(8b\gamma - \beta^2)^2}$ |
| NL    | $\frac{\gamma(A + b_s)^2}{(9b\gamma - 2\beta^2)}$ | $\frac{9by^2(3A + b_s)^2}{(9b\gamma - 2\beta^2)^2}$ | $\frac{2\gamma(3B_s + 2\beta^2)(A + b_s)^2}{(9b\gamma - 2\beta^2)^2}$ | $\frac{\gamma A(15B_s + 11\beta^2) - bs(3B_s - 5\beta^2)}{2(9b\gamma - 2\beta^2)^2}$ |
| NB    | $\frac{\gamma(A + b_s)^2}{2(4b\gamma - \beta^2)}$ | $\frac{2by^2(A + b_s)^2}{2(4b\gamma - \beta^2)^2}$ | $\frac{\gamma B_s(A + b_s)^2}{2(4b\gamma - \beta^2)^2}$ | $\frac{\gamma(A + b_s)(A(2B_s + \beta^2) - bs(2B_s - \beta^2))}{2(4b\gamma - \beta^2)^2}$ |

4. Model comparison

By comparing the equilibrium solutions in Table 1 and Table 2, the following propositions can be obtained.

**Proposition 1.** (1) The energy-saving levels of green products under different power structure models abide by the following order: $X^C > (X^N = X^{ML}) > X^{NL} > X^{RL}$.

(2) The relationship between government subsidies and the energy-saving level of green products is as follows: $\frac{\partial x^k}{\partial s} > 0$, where $k \in \{C, ML, RL, NL, NB\}$.

Proposition 1 reveals that green products’ energy-saving level in the C model is greater than that of any decentralized decision models, the levels in the NB and ML models are greater than in other decentralized decision models, and green products’ energy-saving levels will increase with the levels of government subsidies.

**Proposition 2.** (1) The manufacturer’s wholesale price under different power structure models abides by the following order: $w^{ML} > w^{NL} > w^{ML} > w^{ML}$. (2) We can obtain $D^C > D^{NL} > D^{ML} > D^{ML}$. (3) The impact of government subsidies on wholesale prices and market demand is as follows: $\frac{\partial D^k}{\partial s} > 0$, $\frac{\partial w^k}{\partial s} < 0$, where $k \in \{C, ML, RL, NL, NB\}$.

**Proposition 3.** The retail price of the green product abides by the following relationships: (1) $p^C > p^{ML} > p^{NL} > p^{NL} > p^{NL}$, if $by \in (\frac{\beta^2}{2}, \frac{\beta^2}{2})$; (2) $p^{ML} > p^C > p^{ML} > p^{ML} > p^{NL}$, if $by \in (\frac{\beta^2}{4}, \frac{5\beta^2}{4})$; (3) $p^{ML} > p^{NL} > p^C > p^{NL} > p^{NL}$, if $by \in (\frac{\beta^2}{4}, \frac{4\beta^2}{3})$; (4) $p^{ML} > p^{NL} > p^{NL} > p^C > p^{NL}$, if $by > \frac{4\beta^2}{3}$; (5) $\frac{\partial p^k}{\partial s} < 0$, where $k \in \{C, ML, RL, NL, NB\}$.
Propositions 2 and 3 show that the wholesale price of green products in the ML model is greater than in other decentralized decision models, indicating that the advantage of market power can help the manufacturer improve the wholesale price. In the ML model, the retail price of green products is greater than that of other decentralized decision models, which leads to a lower market demand in this model than in the NB and NL models. The retail price in the NB model is lower than in the other decentralized decision models. Thus, supply chain members can reduce the retail price of green products through the bargaining mechanism, then enhancing the market demand. In summary, Proposition 2 and 3 reveal that government subsidies can not only encourage supply chain members to reduce the price of green products, but also help improve the sales of green products.

**Proposition 4.** The profits of supply chain members under different power structure models abide by the following relationships: (1) \( \pi^M > \pi^N > \pi^L \); (2) \( \pi^N > \pi^R > \pi^M > \pi^L \).

**Proposition 5.** The profits of the green supply chain abide by the following order: \( \pi^C > \pi^N > \pi^L > \pi^M > \pi^R \).

**Proposition 6.** Social welfare under the five power structure models abides by the following order: \( SW^C > SW^N > SW^L > SW^M > SW^R \).

Proposition 4 compares supply chain members’ profits in the four decentralized decision models, suggesting that the supply chain members can benefit from the bargaining mechanism. The NB model is more profitable than the other decentralized decision models. Propositions 5 and 6 show that the profits and social welfare of the supply chain in the NB model are greater than in the other decentralized decision models. As discussed in Proposition 1, the bargaining mechanism increases the energy-saving level of the product. Thus, we propose that the NB model is the optimal power structure model for decentralized supply chain decisions in terms of profit, social welfare, and product innovation.

5. **Numerical analysis**

This section will conduct numerical analysis to examine the relationships between power structure, government subsidies, and supply chain profitability, thus providing insights for optimizing green supply chain management. Following previous studies, we suppose that \( \Lambda = 1000, b = 0.8, c_m = 30, c_r = 3, \beta = 0.5, \) and \( \gamma = 0.6 \) [37], [30]. The results of the numerical analysis are given in Figures 2-5.

5.1. **The relation between government subsidies and firms’ cooperative behaviors**

As shown in Figure 2, government subsidies have a positive impact on green products’ energy-saving level, the effect of the subsidies in the centralized decision model is greater than in the decentralized decision models, and the effect of government subsidies on green products’ energy-saving level is greater in the NB and ML models than in other decentralized decision models. It can be seen from Figure 3, government subsidies are positively correlated with the market demand, the market demand in the NB model is greater than in other decentralized decision models, and government subsidies have a more significant impact on the market demand in the NB model.
Figure 2. The impact of government subsidies on the energy-saving level of green products.

As shown in Figures 4 and 5, government subsidies are negatively correlated with the retail and wholesale prices of green products. Figure 4 indicates that the NB model generates the lowest retail price between the five power structure models, which reveals that the bargaining mechanism between supply chain members can effectively reduce green products’ market price.

Figure 3. The impact of government subsidies on market demand.

5.2. The relation between government subsidies and firms’ profits

As shown in Figures 6 and 7, the greater the government subsidy, the higher the profits of supply chain members. The equilibrium solutions of the NB model indicate that supply chain members with equal power can significantly enhance their financial performance through a bargaining mechanism and obtain the maximum profits. Figures 8 and 9 show that government subsidies are positively correlated with supply chain profits and social welfare. The social welfare and supply chain profit of the NB model are higher than those of other decentralized decision models. Figures 6-9 reveal that the NB model is the optimal power structure for the green supply chain in terms of the impact of government subsidies on supply chain profits, firms’ financial performance, and social welfare.
6. Conclusions
This study analyzes the interaction between government subsidies and the development of green supply chains under different power structures. We address the research gap by investigating a two-echelon supply chain that consists of one manufacturer and one retailer. We find that the power structure has an important influence on the effect of government subsidies. The vertical Nash bargaining model can significantly improve the effectiveness of government subsidies, that is, the greater the government subsidies offers, the greater the energy-saving level of green products, supply chain profits and the social welfare is, indicating that supply chain members with equal power can enhance the green supply chain’s operational efficiency through a bargaining mechanism. The results contribute to the green supply chain studies by revealing the interaction mechanism between the power structure of the supply chain and government subsidies.

Our findings offer several implications for managers and policymakers concerned with the green supply chain. First, managers should ensure that they establish close ties with business partners. The results indicate that if power is equally divided between supply chain members, the positive correlation between government subsidies and green supply chain operations will increase. Thus, managers should actively build a balanced power relationship with external partners and promote communication and interaction between supply chain members through mechanisms such as trust, reciprocity, and relational norms to facilitate green supply chains’ operational efficiency. Second, the policymakers should provide more support for green products’ development. Our results show that government subsidies are positively correlated with green products’ energy-saving level and social welfare, regardless of the power structure in the supply chain. Thus, managers should be encouraged to ensure that environmental protection and economic development are coordinated in terms of R&D,
production, sales, and service through financial subsidies or tax policies. Third, supply chain members should be actively engaged in protecting the environment. Government subsidy only represents an external intervention for enhancing green supply chain operations, and the sustainable development of a green supply chain depends more on the contribution of its members. In addition to improving the energy-saving aspects of green products and reducing the environmental pollution produced through the manufacturing and use of products, supply chain members should also fulfill their social responsibilities to promote green supply chain operation.

There are some limitations in this paper. First, we did not investigate the problem of contractual coordination between supply chain members. Future studies can analyze the effects of contractual coordination mechanisms on green supply chain profits under different power structures. Second, our study did not discuss the impact of asymmetric information on green supply chain operations. Thus, further research can examine the interplay of information asymmetry, firms’ pricing decisions, and the effect of government subsidies. Finally, investigating the relationships between consumer preferences, government subsidies, and green product development is valuable to offer a better understanding of the interaction between government subsidies and green supply chain operation.

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