

Citation is as follows: Tang, L., Li, E.Y., Wu, P., & Jiang, J. (2022) Optimal decisions for green supply chain with a risk-averse retailer under government intervention. *Environmental Science and Pollution Research* (Springer), forthcoming.

Optimal Decisions for Green Supply Chain with a Risk-Averse Retailer under Government Intervention

Li Tang[#]
*School of economics and management,
Tongji University, Shanghai, 200093,
China*

Eldon Y. Li[#]
*Department of Information Management,
National Chung Cheng University,
Chiayi, 621301, Taiwan*

Peipei Wu
*College of Business Administration,
Shanghai Business School, Shanghai
201400, China*

Jiang Jiang^{*}
*College of Business Administration,
Shanghai Business School, Shanghai
201400, China*



[#] Both authors are the first authors.

^{*}**Corresponding author:** Jiang Jiang, Ph.D.

E-mail: allenaji@126.com;

Tel: +8618721508207

Address: 123 Fengpu Avenue, Fengxian District, Shanghai

ABSTRACT

This paper investigates the effects of the financial subsidy and product access policies on the performance of green supply chains (GSCs). Based on the game theory and preference theory, we study a green supply chain consisting of a risk-neutral manufacturer and a risk-averse retailer under government interventions from different power structures. The result reveals that green production can be effectively promoted only when product access exceeds a certain threshold. The Nash equilibrium game has the highest greenness and expected utility of GSC. It also shows that regardless of the market structure and government intervention policy, the retailer's risk aversion is positively correlated with the highest level of product access. Moreover, once effective product access is implemented, the retailer's risk aversion does not affect the optimal greenness of manufacturer production. Besides, compared with other intervention policies, the highest optimal product greenness exists in the scenario of financial subsidy with effective product access. The study suggests that the government needs to set certain green standards when implementing subsidy policies and promoting the risk aversion of retailers.

KEYWORDS

green supply chain; risk aversion; government intervention; product access; financial subsidy; greenness

1. Introduction

With the rapid growth of industrialization, environmental problems such as water and air pollution, global warming, and changing biodiversity have intensified (Ahmad et al. 2021; Isik et al. 2019a; Isik et al. 2021b; Tseng et al. 2019). Facing the increasingly pressing issue of climate change, 177 out of 193 Parties of the United Nations adopted the "Paris Agreement" in 2016, expecting the parties' governments to enhance the implementation of sustainable development goals by providing the appropriate financing and other measures (Isik et al. 2021a; Ongan et al. 2022). In this context, green supply chains (GSCs) have become an effective and scientific way for those governments to promote manufacturing supply chain firms to reduce environmental pollution and improve energy efficiency (Isik et al. 2019b; Luthra et al. 2022; Rong and Xu 2022). Experience testifies that GSC management practices help to improve environmental performance (Khan et al. 2019; Khan et al. 2020; Tseng et al. 2019).

A financial subsidy is a policy tool commonly used by the government to promote the green production of GSCs (Barman et al. 2021; Bian and Guo 2021). For example, the Ministry of Finance of China issued the *Notice on the Financial Support Policy for the Promotion and Application of New Energy Vehicles in 2016-2020* (China-GOV 2015), which provides subsidies for manufacturers and consumers to stimulate the production and consumption of new energy vehicles. As an essential technique to solve supply chain (SC) problems, scholars (Barari et al. 2012; Chen et al. 2019) have used game theory to examine the impact of financial subsidies on GSCs from different perspectives. Bian et al. (2020) and Nielsen et al. (2020) discussed the impact of subsidy objects on GSCs' performance. Wu et al. (2019), Meng et al. (2021a), and Hadi et al. (2020) extended this issue to different power structure scenarios. Moreover, Ma et al. (2019) analyzed the difference between price subsidy and innovation subsidy in GSCs. With a subsidy policy, the government often sets a certain standard of product greenness, and only the product with a greenness exceeding the product access can be circulated in the market. This policy is referred to as the *product's market access* or simply the *product access*. For example, the Chinese government has promulgated the *Provisions on Administration of Access of New Energy Automobile Manufacturing Enterprises and Products* (China-MIIT 2020) to ensure that new energy vehicles meet energy-saving standards. These regulations require that the mass-energy density of the power battery system in a pure electric car must be at least 90Wh/kg. The only studies, such as Gao et al. (2021) and Gao et al. (2020), considered the scenarios where the government sets green standards and provides a financial subsidy. However, they do not answer for the specific design of these two policies.

In reality, risk aversion is pervasive in firms' management (Koller et al. 2012). Green production, which has high deployment costs, uncertain demand, and low market share, increases GSCs' risk (Huang et al. 2020b; Li et al. 2021; Wang et al. 2021). It hindered firms and governments from implementing and deploying GSCs (Agi et al. 2021; Tseng et al. 2019). Bai and Meng (2020), Raza and Govindaluri (2019), and Gao et al. (2018) take into account the risk appetite of the GSC members in their models. However, risk management in GSC remains under-discussed in the existing literature (Agi et al. 2021), especially under government intervention. Bian et al. (2020) show that risk-averse manufacturers make more conservative decisions and thus need more subsidies. In their model, the retailer is risk-neutral and the green standards have not been considered. Thus, this is still a research gap on how government intervention affects risk-averse GSCs towards sustainable goals.

Based on the above discussion, the main questions of this paper are as follows:

- (1) *How do the retailer's risk aversion and the power structures affect the performance of the GSCs under the financial subsidy and product access policies?*
- (2) *Compared to and combined with the financial subsidy policy, how does the product access policy affect the optimal decisions and performance of the GSCs?*
- (3) *To maximize product greenness and maintain the whole GSC's utility, what are the reasonable interval of green standards for governments to implement for manufacturers under different power structures?*

To shed light on the above questions, we research a two-stage supply chain consisting of a risk-neutral manufacturer and a risk-averse retailer to examine the effect of government intervention based on game theory and preference theory. First, we consider four possible intervention policies of the government: (1) no intervention; (2) product access; (3) financial subsidy; (4) financial subsidy with product access. Next, three power structures, i.e., Nash equilibrium, manufacturer Stackelberg game, and retailer Stackelberg game, are investigated. Finally, comparative analysis and numerical simulation are conducted to compare and verify the results. By solving these models, the comparisons of the equilibrium

outcomes of the above four possible intervention policies and three power structures are also examined to explore the effects of different government interventions, power structures, and the retailer's risk aversion.

The remaining content is organized as follows. In section 2, the relevant literature will be reviewed. Section 3 introduces the notations and assumptions underlying the proposed models are given. Section 4 describes the models' problem formulations under government intervention, and the optimal solutions are analyzed, compared, and simulated. In section 5, the results are discussed. Finally, policy suggestions and future work suggestions are presented in Section 6.

2. Literature Review

With the enormous attention of practice and academia to GSCM, it has become an important academic discipline and an independent branch of sustainable development (Huang et al. 2020a; Tseng et al. 2019). Here, we mainly discuss the three streams of literature that are highly relevant to our paper: financial subsidy policy, green standards, and GSCs members' risk aversion.

Key determinants of solving environmental problems are impartial government agencies and effective environmental policies (Godil et al. 2020; Sharif et al. 2021). With the development of GSCs, the government is playing an increasingly important role in green production (Gao et al. 2020; Isik et al. 2022). Different government policies, including green subsidy (Li et al. 2020; Raz and Ovchinnikov 2015), reward-penalty mechanism (Chen and Sheu 2009), tax and subsidy mechanism (Bian and Zhao 2020; Xu et al. 2020), green credit (He et al. 2019a; Zhang et al. 2011), and price regulation policy (Chen and Sheu 2009), have been widely explored within the GSC background. Among them, for the GSCs, subsidy policy is the most frequently studied measure used by the government. For example, Meng et al. (2021a) analyzed the effect of the financial subsidy on manufacturers' pricing strategies while considering the consumers' greenness and channel preferences. Bian et al. (2020) discussed whether it is better to subsidize consumers or manufacturers based on net emissions, government spending, manufacturer profits, and social welfare.

Similarly, Meng et al. (2021b) discussed whether environmental subsidies should be subsidized only to core manufacturers or to all firms in the GSCs. Moreover, Bian et al. (2020) and Meng et al. (2021b) showed that only subsidizing manufacturers have better performance with concentration and decentralization in reducing emissions and improving the efficiency of subsidies. Therefore, we mainly discuss the manufacturer subsidy and compare the effects under different power structures.

Regarding the effect of the green standard set by the government, Alberto Gomez-Luciano et al. (2018) exhibited that governments revise their environmental standards to encourage manufacturers to green production. Gao et al. (2018) further found that green standards set by the government promote rapid growth in profits and social welfare per unit green, which benefits society and consumers. Our work is closely related to Gao et al. (2021), which examined the impacts of financial subsidy and green standards in a decentralized and coordinated situation. They found that simultaneous implementation of green standards and subsidies improves GSCs' economic and environmental benefits but decreases manufacturers' tolerance of the associated cost. Thus, this study suggests that government needs to look for an appropriate balance between setting green standards and providing subsidies. Gao et al. (2020) further extended the discussion of these two policies to development-intensive green products and marginal cost-intensive green products. However, these studies do not answer how the government balances the green standard and the financial subsidy.

Considering demand uncertainty and financial risks in green supply chains (Bian et al. 2020), some scholars have also paid attention to the risk attitudes of GSC members. For example, Raza and Govindaluri (2019) investigated a dual-channel supply chain coordination model in which the manufacturer and the retailer are risk-averse. Furthermore, decentralized, centralized, and bargaining decision-making via contracts, revenue-sharing, and cost-sharing are explored. Bai and Meng (2020) studied the two-stage green supply chain's operational decision-making problems under the retailer-leader game in which manufacturers and retailers have different risk attitudes. Besides, some studies have considered the impact of risk aversion among the GSC members under government intervention. Gao et al. (2018) examined the government environment risk aversion in comparing the manufacturer or the government determining product green degree. Bian et al. (2020) investigated the role of financial subsidy by considering manufacturers' risk aversion. They found that risk aversion reduces the net emissions when subsidizing the manufacturer. Contrasted with the literature mentioned above, we believe that the financial subsidy can help manufacturers avoid risks to a certain extent. Thus, we mainly investigate the impact of different government interventions and power structures under considering the risk aversion of retailers.

The comparison of our work and previous literature is summarized in Table 1 below. As shown in the table, the existing literature focused mainly on the financial subsidy for the manufacturer's green production, but there is limited literature on both the impact of the member's risk attitude and product access. In addition, part of the literature focuses on decentralized and centralized decisions or only considers a specific power structure. Therefore, this study systematically examines and compares the financial subsidy and product access policies from different power structures. Specifically, we construct a two-stage supply chain consisting of a risk-neutral manufacturer and a risk-averse retailer, then compare four types of government policies (no intervention, product access, financial subsidy, and financial subsidy with product access) in three power structures (Nash equilibrium game, manufacturer Stackelberg game, and retailer Stackelberg game).

Table 1. Summary of the main related literature.

Publications	Government Interventions	Risk Attitude	Game Structure
Raza and Govindaluri (2019)	None	One risk-averse manufacturer with one risk-averse retailer	Decentralized; Centralized; Bargaining via contracts, revenue-sharing, and cost-sharing
Bian et al. (2020)	Subsidy	One risk-averse manufacturer	Government Stackelberg game
Bai and Meng (2020)	None	Two risk-neutral manufacturers with one risk-averse retailer; and two risk-averse manufacturers with one risk-neutral retailer.	Retailer Stackelberg game
Gao et al. (2018)	Subsidy and product access	Government with environmental risk aversion	Nash equilibrium game
Wang et al. (2021)	None	One risk-averse manufacturer with one risk-averse retailer	Retailer Stackelberg game
Gao et al. (2021)	Subsidy and product access	Risk-neutral	Decentralized; Centralized
Meng et al. (2021a)	Subsidy	Risk-neutral	Manufacturer Stackelberg game
Yang and Xiao (2017)	Subsidy and product access	Risk-neutral	Manufacturer Stackelberg game; Retailer Stackelberg game; Vertical Nash game
Sheu and Chen (2012)	Subsidy	Risk-neutral	Manufacturer Stackelberg game
Zhang and Yousaf (2020)	Subsidy	Risk-neutral	Decentralized; Centralized; Coordination contract
Zhao et al. (2012)	Subsidy	Risk-neutral	Manufacturer Stackelberg game; Retailer Stackelberg game
Cao et al. (2017)	Subsidy	Risk-neutral	Manufacturer Stackelberg game
This research	Subsidy and product access	One risk-neutral manufacturer with one risk-averse retailer	Manufacturer Stackelberg game; Retailer Stackelberg game; Nash equilibrium game

3. Methods

This study focuses on the influence of financial subsidy and product access on green production in supply chains. For this purpose, the assumptions and symbols are proposed as follows:

Assumption 1. Consider a GSC consisting of a risk-neutral manufacturer and a risk-averse retailer. In this two-echelon supply chain, the manufacturer produces a green product and sells the product with a greenness g to the retailer at wholesale price ω , and then the retailer sells the product to consumers at

retail price p . The difference between the wholesale price and the sales price is the sales premium $m(m > 0)$, where $p = \omega + m$.

Assumption 2. According to Wang et al. (2021) and Li et al. (2016), we assume the market demand for the green product is uncertain, the demand function is linear, the retail price (p) is decreasing, and the manufacturer's greenness (g) is increasing. Specifically, the demand function is expressed as $D = a - bp + kg + \varepsilon$, where $a(a > 0, \text{constant})$ indicates the total market potential; $\varepsilon \left[\varepsilon \in N(0, \sigma^2) \right]$ is the random noise; $b(b > 0)$ indicates the price sensitivity coefficient of consumer demand; $k(k > 0)$ indicates the consumer's green preference coefficient.

Assumption 3. The market demand uncertainty usually brings risks, and different members may have different risk attitudes toward the risks (Wang et al. 2021). As mentioned above, we assume the manufacturer is risk-neutral and the retailer is risk-averse. Following the studies of Choi et al. (2020), Raza and Govindaluri (2019), and Bian et al. (2020), the risk aversion of the manufacturer and retailer is measured by the mean-variance method based on preference theory. η_m and η_r represent the risk aversion degree of the manufacturer and retailer, respectively, where $\eta \geq 0$. $\eta_r > 0$ indicates that the retailer has a risk aversion attitude; the bigger η_r , the more risk-averse the retailer. Since this work assumes that the manufacturer is risk-neutral, then $\eta_m = 0$. Based on preference theory, the certainty utility of the retailer is expressed by the following equation:

$$U(\pi_r) = E(\pi_r) - \eta_r \text{Var}(\pi_r)$$

where $E(\pi_r)$ is the expected utility of the retailer, and $\text{Var}(\pi_r)$ is the variance of the utility. The variance of the retailer utility is $\sigma^2(p - \omega)^2$.

Assumption 4. The production of green products requires increased investment in green R&D, which does not affect the production costs of the manufacturer and the fixed and sales costs of the retailer. Therefore, the manufacturer's production costs and the retailer's fixed and sales costs are not considered, following the study of Huang *et al.* (2020).

Assumption 5. As one of the main bodies to promote green development, the government mainly regulates and guides the green market through product access and financial subsidy. Hence, this study assumes three ways for the government to influence GSCs. Firstly, set the product access; the government stipulates that the green degree of products entering the market must be greater than or equal to g_* . Otherwise, the product will be prohibited from entering the market. Secondly, give the financial subsidy. This study assumes that the financial subsidy object is the manufacturer; that is, the manufacturer is subsidized according to the product's greenness. Hence, according to Yi and Li (2018), the green subsidy per product is s_g , where $s > 0$ indicates the subsidy coefficient per product based on the greenness. Thirdly, only subsidize the manufacturer whose product's greenness is greater than or equal to the greenness of product access; the green subsidy per product is also s_g .

Assumption 6. According to D'Aspremont and Jacquemin (1988) and Swami and Shah (2013), the manufacturer's initial investment in green R&D costs $c(g)$ has a quadratic relationship with the product's greenness g ; that is $c(g) = zg^2 / 2$ where $z > 0$ is the coefficient of costs for R&D investment. Without loss of generality, we assume $bz - (k + bs)^2 > 0$ (Yang and Xiao 2017).

Assumption 7. This study assumes that GSC members play the Nash equilibrium game and Stackelberg game, respectively. The Nash equilibrium game refers to two firms making decisions simultaneously, and no firm can profit by unilaterally changing the price. The Stackelberg game is also called the "leader-follower model". In the non-cooperative game between the two players, the leader decides its pricing under the criterion of maximizing utility, and the followers make decisions that could maximize their utility according to the leader's pricing. In this GSC, both the manufacturer and retailer know the demand distribution and all other parameters (Hie et al. 2015; Wang et al. 2021).

Subscripts m , r , and sc denote the manufacturer, the retailer, and the whole GSC, respectively. Subscripts N , M , and R denote Nash Equilibrium, Manufacturer Stackelberg, and Retailer Stackelberg, respectively. Subscripts W , G , S , and GS denote four scenarios: no government intervention, product access, financial subsidy, and financial subsidy with product access, respectively. Finally, superscripts $*$,

min and max denote optimal, minimum, and maximum results, respectively. All the notations are defined in Table 2.

Table 2. Description of variables

Variables	Description
p	Retailer's retail price, the decision variable
ω	Manufacturer's wholesale price, the decision variable
g	The greenness of the product, the decision variable
m	Sales premium
a	Market potential
b	Price sensitivity coefficient of consumer demand
k	Green preference coefficient of consumers
ε	Random noises
η_r	Retailer's degree of risk aversion
η_m	Manufacturer's degree of risk aversion
$c(g)$	Manufacturer's initial investment in product green R&D costs
z	The coefficient of costs for R&D investment
g_*	Product access: the greenness requirement for products entering the market
s	Subsidy coefficient per product based on the greenness

4. Results

In this section, we establish and solve the models based on the above assumption and analyze the results for the four policies consecutively.

4.1 Results of no government intervention

This section presents a benchmark analysis of the scenario without government intervention. This benchmark enables us to evaluate the effects of three government policies on the GSC performance.

Without government intervention and consistent with the above assumptions and mean-variance method, we express the expected utility functions of the manufacturer $U(\pi_m)$ and retailer $U(\pi_r)$ as:

$$U(\pi_m) = E(\pi_m) = \omega(a - bp + kg) - zg^2 / 2 \quad (1)$$

$$U(\pi_r) = E(\pi_r) - \eta_r Var(\pi_r) = (p - \omega)(a - bp + kg) - \sigma^2 \eta_r (p - \omega)^2 \quad (2)$$

4.1.1 Nash equilibrium game model

In the Nash equilibrium game, the manufacturer and retailer make decisions simultaneously. From Eq.(1) to Eq.(2), using backward induction, we can derive Proposition 1. Proofs of all propositions are given in the Appendix.

Proposition 1. Under no government intervention, we have the following equilibrium decisions in the Nash equilibrium game model:

The manufacturer's wholesale price, greenness, and the retailer's retail price are:

$$\omega_{WN}^* = az(b + 2\sigma^2 \eta_r) / [bz(3b + 4\sigma^2 \eta_r) - k^2(b + 2\sigma^2 \eta_r)] \quad (3)$$

$$g_{WN}^* = ak(b + 2\sigma^2 \eta_r) / [bz(3b + 4\sigma^2 \eta_r) - k^2(b + 2\sigma^2 \eta_r)] \quad (4)$$

$$p_{WN}^* = 2az(b + \sigma^2 \eta_r) / [bz(3b + 4\sigma^2 \eta_r) - k^2(b + 2\sigma^2 \eta_r)] \quad (5)$$

The expected utility of the manufacturer, retailer, and the GSC are:

$$U(\pi_m)_{WN}^* = a^2 z (2bz - k^2) (b + 2\sigma^2 \eta_r)^2 / \left\{ 2 [bz(3b + 4\sigma^2 \eta_r) - k^2(b + 2\sigma^2 \eta_r)]^2 \right\} \quad (6)$$

$$U(\pi_r)_{WN}^* = a^2 b^2 z^2 (b + \sigma^2 \eta_r) / [bz(3b + 4\sigma^2 \eta_r) - k^2 (b + 2\sigma^2 \eta_r)]^2 \quad (7)$$

$$U(\pi_{sc})_{WN}^* = \frac{a^2 z [2bz(2b^2 + 5b\sigma^2 \eta_r + 4\sigma^4 \eta_r^2) - k^2 (b + 2\sigma^2 \eta_r)^2]}{2[bz(3b + 4\sigma^2 \eta_r) - k^2 (b + 2\sigma^2 \eta_r)]^2} \quad (8)$$

4.1.2 Manufacturer Stackelberg game model

In the manufacturer Stackelberg game model, the manufacturer is the leader while the retailer is the follower; thus, the sequence of the game is as follows:

- (i) The manufacturer first sets the wholesale price and greenness.
- (ii) After observing the manufacturer's decision, the retailer decides the retail price.

Following the principle of utility maximization, we adopt the backward induction method to solve Eqs. (1) and (2) in turn.

Proposition 2. Under no government intervention, we have the following equilibrium decisions in the manufacturer Stackelberg game model:

The manufacturer's wholesale price, greenness, and the retailer's retail price are:

$$\omega_{WM}^* = 2az(b + \sigma^2 \eta_r) / [4bz(b + \sigma^2 \eta_r) - k^2 (b + 2\sigma^2 \eta_r)] \quad (9)$$

$$g_{WM}^* = ak(b + 2\sigma^2 \eta_r) / [4bz(b + \sigma^2 \eta_r) - k^2 (b + 2\sigma^2 \eta_r)] \quad (10)$$

$$p_{WM}^* = az(3b + 2\sigma^2 \eta_r) / [4bz(b + \sigma^2 \eta_r) - k^2 (b + 2\sigma^2 \eta_r)] \quad (11)$$

The expected utility of the manufacturer, retailer, and the GSC are:

$$U(\pi_m)_{WM}^* = a^2 z (b + 2\sigma^2 \eta_r) / \{2[4bz(b + \sigma^2 \eta_r) - k^2 (b + 2\sigma^2 \eta_r)]\} \quad (12)$$

$$U(\pi_r)_{WM}^* = a^2 b^2 z^2 (b + \sigma^2 \eta_r) / [4bz(b + \sigma^2 \eta_r) - k^2 (b + 2\sigma^2 \eta_r)]^2 \quad (13)$$

$$U(\pi_{sc})_{WM}^* = \frac{a^2 z [2bz(3b + 4\sigma^2 \eta_r)(b + \sigma^2 \eta_r) - k^2 (b + 2\sigma^2 \eta_r)^2]}{2[4bz(b + \sigma^2 \eta_r) - k^2 (b + 2\sigma^2 \eta_r)]^2} \quad (14)$$

4.1.3 Retailer Stackelberg game model

In the retailer Stackelberg game, the retailer and the manufacturer are the leader and the follower, respectively. During the game, all parties aim to maximize utilities. The sequence of the game is as follows:

- (i) The retailer first sets the retail price.
- (ii) After observing the retailer's decision, the manufacturer decides the wholesale price and greenness.

From Eq.(1) to Eq.(2), we can derive Proposition 3 using backward induction.

Proposition 3. Under no government intervention, we have the following equilibrium decisions in the retailer Stackelberg game model:

The manufacturer's wholesale price, greenness, and the retailer's retail price are:

$$\omega_{WR}^* = az [bz(b + 4\sigma^2 \eta_r) - 2k^2 \sigma^2 \eta_r] / \{2(2bz - k^2)[bz(b + 2\sigma^2 \eta_r) - k^2 \sigma^2 \eta_r]\} \quad (15)$$

$$g_{WR}^* = ak [bz(b + 4\sigma^2 \eta_r) - 2k^2 \sigma^2 \eta_r] / \{2(2bz - k^2)[bz(b + 2\sigma^2 \eta_r) - k^2 \sigma^2 \eta_r]\} \quad (16)$$

$$p_{WR}^* = az [bz(3b + 4\sigma^2 \eta_r) - k^2 (b + 2\sigma^2 \eta_r)] / \{2(2bz - k^2)[bz(b + 2\sigma^2 \eta_r) - k^2 \sigma^2 \eta_r]\} \quad (17)$$

The expected utility of the manufacturer, retailer, and the GSC are:

$$U(\pi_m)_{WR}^* = a^2 z [bz(b + 4\sigma^2 \eta_r) - 2k^2 \sigma^2 \eta_r]^2 / \{8(2bz - k^2)[bz(b + 2\sigma^2 \eta_r) - k^2 \sigma^2 \eta_r]^2\} \quad (18)$$

$$U(\pi_r)_{WR}^* = a^2 b^2 z^2 / \{4(2bz - k^2)[bz(b + 2\sigma^2 \eta_r) - k^2 \sigma^2 \eta_r]\} \quad (19)$$

$$U(\pi_{sc})_{WR}^* = \frac{a^2 z \{3b^4 z^2 + 2(2bz - k^2)\sigma^2 \eta_r [3b^2 z + 2(2bz - k^2)\sigma^2 \eta_r]\}}{8(2bz - k^2)[bz(b + 2\sigma^2 \eta_r) - k^2 \sigma^2 \eta_r]^2} \quad (20)$$

4.2 Results of product access

When considering product access, the utility functions of both manufacturer and retailer need to meet product access condition $g \geq g_-$ based on no government intervention.

4.2.1 Nash equilibrium game model

In the Nash equilibrium model, the sequence of the game is as follows:

(i) The government firstly sets the lowest greenness g_- .

(ii) After observing the government's decision, the manufacturer and retailer make decisions at the same time. The manufacturer sets the wholesale price and greenness, and the retailer decides the retail price.

Proposition 4. Under the product access policy:

If $g_- \leq ak(b + 2\sigma^2 \eta_r) / [bz(3b + 4\sigma^2 \eta_r) - k^2(b + 2\sigma^2 \eta_r)]$, the equilibrium decisions and the utilities of the GSC in the Nash equilibrium game are the same as those in the Nash equilibrium game under no government intervention, which is $\omega_{GN}^* = \omega_{WN}^*$, $g_{GN}^* = g_{WN}^*$, $p_{GN}^* = p_{WN}^*$, $U(\pi_m)_{GN}^* = U(\pi_m)_{WN}^*$,

$$U(\pi_r)_{GN}^* = U(\pi_r)_{WN}^*, \quad U(\pi_{sc})_{GN}^* = U(\pi_{sc})_{WN}^* ;$$

if

$$\frac{ak(b + 2\sigma^2 \eta_r)}{bz(3b + 4\sigma^2 \eta_r) - k^2(b + 2\sigma^2 \eta_r)} < g_- < \frac{a(b + 2\sigma^2 \eta_r)[2k(b + 2\sigma^2 \eta_r) + \sqrt{2bz}(3b + 4\sigma^2 \eta_r)]}{bz(3b + 4\sigma^2 \eta_r)^2 - 2k^2(b + 2\sigma^2 \eta_r)^2}, \text{ then}$$

$$g_{GN}^* = g_- \quad (21)$$

$$\omega_{GN}^* = (a + kg_-)(b + 2\sigma^2 \eta_r) / [b(3b + 4\sigma^2 \eta_r)] \quad (22)$$

$$p_{GN}^* = 2(a + kg_-)(b + \sigma^2 \eta_r) / [b(3b + 4\sigma^2 \eta_r)] \quad (23)$$

$$U(\pi_m)_{GN}^* = (a + kg_-)^2 (b + 2\sigma^2 \eta_r)^2 / [b(3b + 4\sigma^2 \eta_r)^2] - zg_-^2 / 2 \quad (24)$$

$$U(\pi_r)_{GN}^* = (a + kg_-)^2 (b + \sigma^2 \eta_r) / [(3b + 4\sigma^2 \eta_r)^2] \quad (25)$$

$$U(\pi_{sc})_{GN}^* = (a + kg_-)^2 (2b^2 + 5b\sigma^2 \eta_r + 4\sigma^4 \eta_r^2) / [b(3b + 4\sigma^2 \eta_r)^2] - zg_-^2 / 2 \quad (26)$$

If $g_- \geq \frac{a(b + 2\sigma^2 \eta_r)[2k(b + 2\sigma^2 \eta_r) + \sqrt{2bz}(3b + 4\sigma^2 \eta_r)]}{bz(3b + 4\sigma^2 \eta_r)^2 - 2k^2(b + 2\sigma^2 \eta_r)^2}$, then $U(\pi_m)_{GN}^* \leq 0$. At this time,

the manufacturer chooses to withdraw from the market.

Corollary 1. Under the product access policy, the highest product access in the Nash equilibrium is:

$$g_{-GN}^{\max} = \frac{a(b + 2\sigma^2 \eta_r)[2k(b + 2\sigma^2 \eta_r) + \sqrt{2bz}(3b + 4\sigma^2 \eta_r)]}{bz(3b + 4\sigma^2 \eta_r)^2 - 2k^2(b + 2\sigma^2 \eta_r)^2} \quad (27)$$

4.2.2 Manufacturer Stackelberg game model

Under the manufacturer Stackelberg game model, the sequence of the game is as follows:

(i) The government first sets the lowest greenness g_- .

(ii) After observing the government's decision, the manufacturer sets the wholesale price and greenness. Then the retailer decides the retail price.

Proposition 5. Under the product access policy:

If $g_- \leq ak(b + 2\sigma^2\eta_r) / [4bz(b + \sigma^2\eta_r) - k^2(b + 2\sigma^2\eta_r)]$, the equilibrium decisions and the utilities of the GSC in the manufacturer Stackelberg game are the same as those in the manufacturer Stackelberg game under no government intervention, which is $\omega_{GM}^* = \omega_{WM}^*$, $g_{GM}^* = g_{WM}^*$, $p_{GM}^* = p_{WM}^*$, $U(\pi_m)_{GM}^* = U(\pi_m)_{WM}^*$, $U(\pi_r)_{GM}^* = U(\pi_r)_{WM}^*$, $U(\pi_{sc})_{GM}^* = U(\pi_{sc})_{WM}^*$;

$$\text{If } \frac{ak(b + 2\sigma^2\eta_r)}{4bz(b + \sigma^2\eta_r) - k^2(b + 2\sigma^2\eta_r)} < g_- < \frac{ak(b + 2\sigma^2\eta_r) + 2a\sqrt{bz(b + \sigma^2\eta_r)(b + 2\sigma^2\eta_r)}}{4bz(b + \sigma^2\eta_r) - k^2(b + 2\sigma^2\eta_r)},$$

then

$$g_{GM}^* = g_- \quad (28)$$

$$\omega_{GM}^* = (a + kg_-) / (2b) \quad (29)$$

$$p_{GM}^* = (a + kg_-)(3b + 2\sigma^2\eta_r) / [4b(b + \sigma^2\eta_r)] \quad (30)$$

$$U(\pi_m)_{GM}^* = (a + kg_-)^2(b + 2\sigma^2\eta_r) / [8b(b + \sigma^2\eta_r)] - zg_-^2 / 2 \quad (31)$$

$$U(\pi_r)_{GM}^* = (a + kg_-)^2 / [16(b + \sigma^2\eta_r)] \quad (32)$$

$$U(\pi_{sc})_{GM}^* = (a + kg_-)^2(3b + 4\sigma^2\eta_r) / [16b(b + \sigma^2\eta_r)] - zg_-^2 / 2 \quad (33)$$

If $g_- > \frac{ak(b + 2\sigma^2\eta_r) + 2a\sqrt{bz(b + \sigma^2\eta_r)(b + 2\sigma^2\eta_r)}}{4bz(b + \sigma^2\eta_r) - k^2(b + 2\sigma^2\eta_r)}$, then $U(\pi_m)_{GM}^* \leq 0$. At this time, the

manufacturer chooses to withdraw from the market.

Corollary 2. Under the product access policy, the highest product access in the manufacturer Stackelberg game model is:

$$g_{-GM}^{max} = \frac{ak(b + 2\sigma^2\eta_r) + 2a\sqrt{bz(b + \sigma^2\eta_r)(b + 2\sigma^2\eta_r)}}{4bz(b + \sigma^2\eta_r) - k^2(b + 2\sigma^2\eta_r)} \quad (34)$$

4.2.3 Retailer Stackelberg game model

Under the retailer Stackelberg game model, the sequence of the game is as follows:

(i) The government first sets the lowest greenness g_- .

(ii) After observing the government's decision, the retailer decides the retail price. Then the manufacturer sets the wholesale price and greenness.

Proposition 6. Under the product access policy:

If $g_- \leq ak[bz(b + 4\sigma^2\eta_r) - 2k^2\sigma^2\eta_r] / \{2(2bz - k^2)[bz(b + 2\sigma^2\eta_r) - k^2\sigma^2\eta_r]\}$, the equilibrium decisions and the utilities of the GSC in the retailer Stackelberg game are the same as those in the retailer Stackelberg game under no government intervention, which is $\omega_{GR}^* = \omega_{WR}^*$, $g_{GR}^* = g_{WR}^*$, $p_{GR}^* = p_{WR}^*$, $U(\pi_m)_{GR}^* = U(\pi_m)_{WR}^*$, $U(\pi_r)_{GR}^* = U(\pi_r)_{WR}^*$, $U(\pi_{sc})_{GR}^* = U(\pi_{sc})_{WR}^*$;

If

$$\frac{ak[bz(b + 4\sigma^2\eta_r) - 2k^2\sigma^2\eta_r]}{2(2bz - k^2)[bz(b + 2\sigma^2\eta_r) - k^2\sigma^2\eta_r]} < g_- < \frac{ak(b + 4\sigma^2\eta_r)^2 + 2a\sqrt{2bz}(b + 4\sigma^2\eta_r)(b + 2\sigma^2\eta_r)}{8bz(b + 2\sigma^2\eta_r)^2 - k^2(b + 4\sigma^2\eta_r)^2}$$

, then

$$g_{GR}^* = g_- \quad (35)$$

$$\omega_{GR}^* = (a + kg_-)(b + 4\sigma^2\eta_r) / [4b(b + 2\sigma^2\eta_r)] \quad (36)$$

$$p_{GR}^* = (a + kg_-)(3b + 4\sigma^2\eta_r) / [4b(b + 2\sigma^2\eta_r)] \quad (37)$$

$$U(\pi_m)_{GR}^* = (a + kg_-)^2 (b + 4\sigma^2\eta_r)^2 / [16b(b + 2\sigma^2\eta_r)^2] - zg_-^2 / 2 \quad (38)$$

$$U(\pi_r)_{GR}^* = (a + kg_-)^2 / [8(b + 2\sigma^2\eta_r)] \quad (39)$$

$$U(\pi_{sc})_{GR}^* = (a + kg_-)^2 (3b^2 + 12b\sigma^2\eta_r + 16\sigma^4\eta_r^2) / [16b(b + 2\sigma^2\eta_r)^2] - zg_-^2 / 2 \quad (40)$$

If $g_- \geq \frac{ak(b + 4\sigma^2\eta_r)^2 + 2a\sqrt{2bz}(b + 4\sigma^2\eta_r)(b + 2\sigma^2\eta_r)}{8bz(b + 2\sigma^2\eta_r)^2 - k^2(b + 4\sigma^2\eta_r)^2}$, then $U(\pi_m)_{GR}^* \leq 0$. At this time,

the manufacturer chooses to withdraw from the market.

Corollary 3. Under the product access policy, the highest product access in the retailer Stackelberg game model is:

$$g_{-GR}^{max} = \frac{a(b + 4\sigma^2\eta_r)[k(b + 4\sigma^2\eta_r) + 2\sqrt{2bz}(b + 2\sigma^2\eta_r)]}{8bz(b + 2\sigma^2\eta_r)^2 - k^2(b + 4\sigma^2\eta_r)^2} \quad (41)$$

Corollary 4. Under the product access policy, if $g_{-G} \leq g_w^*$, the optimal decisions with product access are consistent with the results under no government intervention; this situation is called the *ineffective product access policy*. On the other hand, if $g_{-G} > g_w^*$, product access can improve product greenness and impact corporate decision-making. This situation is called the *effective product access policy*.

4.3 Results of financial subsidy

Under the financial subsidy policy, consistent with the assumptions and mean-variance theory, we express the expected utility function of the manufacturer $U(\pi_m)$ as:

$$U(\pi_m) = E(\pi_m) = (\omega + sg)(a - bp + kg) - zg^2 / 2 \quad (42)$$

The expected utility function of the retailer is the same as Eq.(2).

4.3.1 Nash equilibrium game model

Under the Nash equilibrium model, the sequence of the game is as follows:

- (i) The government firstly decides the subsidy coefficient per product s .
- (ii) After observing the government's subsidy decision, the manufacturer and retailer make decisions at the same time. The manufacturer sets the wholesale price and greenness, and the retailer decides the retail price.

Proposition 7. Under the financial subsidy policy, we have the following equilibrium decisions in the Nash equilibrium model:

The manufacturer's wholesale price, greenness, and the retailer's retail price are:

$$\omega_{SN}^* = a[z - s(k + bs)](b + 2\sigma^2\eta_r) / [bz(3b + 4\sigma^2\eta_r) - (k + bs)^2(b + 2\sigma^2\eta_r)] \quad (43)$$

$$g_{SN}^* = a(k + bs)(b + 2\sigma^2\eta_r) / [bz(3b + 4\sigma^2\eta_r) - (k + bs)^2(b + 2\sigma^2\eta_r)] \quad (44)$$

$$p_{SN}^* = \frac{a[2z(b + \sigma^2\eta_r) - s(k + bs)(b + 2\sigma^2\eta_r)]}{bz(3b + 4\sigma^2\eta_r) - (k + bs)^2(b + 2\sigma^2\eta_r)} \quad (45)$$

The expected utility of the manufacturer, retailer, and the green supply chain are:

$$U(\pi_m)_{SN}^* = \frac{a^2z(b + 2\sigma^2\eta_r)^2[2bz - (k + bs)^2]}{2[bz(3b + 4\sigma^2\eta_r) - (k + bs)^2(b + 2\sigma^2\eta_r)]^2} \quad (46)$$

$$U(\pi_r)_{SN}^* = a^2b^2z^2(b + \sigma^2\eta_r) / [bz(3b + 4\sigma^2\eta_r) - (k + bs)^2(b + 2\sigma^2\eta_r)]^2 \quad (47)$$

$$U(\pi_{sc})_{SN}^* = \frac{a^2 z \left[2bz(2b^2 + 5b\sigma^2\eta_r + 4\sigma^4\eta_r^2) - (k+bs)^2(b+2\sigma^2\eta_r)^2 \right]}{2 \left[bz(3b+4\sigma^2\eta_r) - (k+bs)^2(b+2\sigma^2\eta_r) \right]^2} \quad (48)$$

4.3.2 Manufacturer Stackelberg game model

In the manufacturer Stackelberg game model, the sequence of the game is as follows:

- (i) The government decides the subsidy coefficient per product s .
- (ii) After observing the government's subsidy decision, the manufacturer first sets the wholesale price and greenness, and then the retailer decides the retail price.

Proposition 8. Under the financial subsidy policy, we have the following equilibrium decisions in the manufacturer Stackelberg game model:

The manufacturer's wholesale price, greenness, and the retailer's retail price are:

$$\omega_{SM}^* = \frac{a \left[2z(b + \sigma^2\eta_r) - s(k+bs)(b+2\sigma^2\eta_r) \right]}{4bz(b + \sigma^2\eta_r) - (k+bs)^2(b+2\sigma^2\eta_r)} \quad (49)$$

$$g_{SM}^* = a(k+bs)(b+2\sigma^2\eta_r) / \left[4bz(b + \sigma^2\eta_r) - (k+bs)^2(b+2\sigma^2\eta_r) \right] \quad (50)$$

$$p_{SM}^* = \frac{a \left[z(3b+2\sigma^2\eta_r) - s(k+bs)(b+2\sigma^2\eta_r) \right]}{4bz(b + \sigma^2\eta_r) - (k+bs)^2(b+2\sigma^2\eta_r)} \quad (51)$$

The expected utility of the manufacturer, retailer, and the green supply chain are:

$$U(\pi_m)_{SM}^* = a^2 z (b+2\sigma^2\eta_r)^2 / \left\{ 2 \left[4bz(b + \sigma^2\eta_r) - (k+bs)^2(b+2\sigma^2\eta_r) \right] \right\} \quad (52)$$

$$U(\pi_r)_{SM}^* = a^2 b^2 z^2 (b + \sigma^2\eta_r) / \left[4bz(b + \sigma^2\eta_r) - (k+bs)^2(b+2\sigma^2\eta_r) \right]^2 \quad (53)$$

$$U(\pi_{sc})_{SM}^* = \frac{a^2 z \left[2bz(b + \sigma^2\eta_r)(3b+4\sigma^2\eta_r) - (k+bs)^2(b+2\sigma^2\eta_r)^2 \right]}{2 \left[4bz(b + \sigma^2\eta_r) - (k+bs)^2(b+2\sigma^2\eta_r) \right]^2} \quad (54)$$

4.3.3 Retailer Stackelberg game model

In retailer Stackelberg game model, the sequence of the game is as follows:

- (i) The government firstly decides the subsidy coefficient per product s .
- (ii) After observing the government's subsidy decision, the retailer first decides the retail price, and then the manufacturer sets the wholesale price and greenness.

Proposition 9. Under the financial subsidy policy, we have the following equilibrium decisions in the retailer Stackelberg game model:

The manufacturer's wholesale price, greenness, and the retailer's retail price are:

$$\omega_{SR}^* = \frac{a \left[z - s(k+bs) \right] \left[bz(b+4\sigma^2\eta_r) - 2(k+bs)^2\sigma^2\eta_r \right]}{2 \left[2bz - (k+bs)^2 \right] \left[bz(b+2\sigma^2\eta_r) - (k+bs)^2\sigma^2\eta_r \right]} \quad (55)$$

$$g_{SR}^* = \frac{a(k+bs) \left[bz(b+4\sigma^2\eta_r) - 2(k+bs)^2\sigma^2\eta_r \right]}{2 \left[2bz - (k+bs)^2 \right] \left[bz(b+2\sigma^2\eta_r) - (k+bs)^2\sigma^2\eta_r \right]} \quad (56)$$

$$p_{SR}^* = \frac{a \left\langle \begin{aligned} & bz \left[3bz - (k+bs)(k+2bs) \right] + \\ & 2 \left\{ s(k+bs)^3 + z \left[2bz - (k+bs)(k+3bs) \right] \right\} \sigma^2\eta_r \end{aligned} \right\rangle}{2 \left[2bz - (k+bs)^2 \right] \left[bz(b+2\sigma^2\eta_r) - (k+bs)^2\sigma^2\eta_r \right]} \quad (57)$$

The expected utility of the manufacturer, retailer, and the green supply chain are:

$$U(\pi_m)_{SR}^* = \frac{a^2 z \left[bz(b + 4\sigma^2 \eta_r) - 2(k + bs)^2 \sigma^2 \eta_r \right]^2}{8 \left[2bz - (k + bs)^2 \right] \left[bz(b + 2\sigma^2 \eta_r) - (k + bs)^2 \sigma^2 \eta_r \right]^2} \quad (58)$$

$$U(\pi_r)_{SR}^* = a^2 b^2 z^2 / \left\{ 4 \left[2bz - (k + bs)^2 \right] \left[bz(b + 2\sigma^2 \eta_r) - (k + bs)^2 \sigma^2 \eta_r \right] \right\} \quad (59)$$

$$U(\pi_{sc})_{SR}^* = \frac{a^2 z \left\{ b^2 z^2 (3b^2 + 12b\sigma^2 \eta_r + 16\sigma^4 \eta_r^2) - 2(k + bs)^2 \sigma^2 \eta_r \left[bz(3b + 8\sigma^2 \eta_r) - 2(k + bs)^2 \sigma^2 \eta_r \right] \right\}}{8 \left[2bz - (k + bs)^2 \right] \left[bz(b + 2\sigma^2 \eta_r) - (k + bs)^2 \sigma^2 \eta_r \right]^2} \quad (60)$$

4.4 Results of financial subsidy with product access

When considering financial subsidy with product access, the greenness of the manufacturer's products needs to meet the condition for the subsidy, that is $g \geq g_-$.

4.4.1 Nash equilibrium game model

In the Nash equilibrium model, the sequence of the game is as follows:

(i) The government firstly sets the lowest greenness g_- and decides the subsidy coefficient per product s .

(ii) After observing the government's decisions, the manufacturer and the retailer make decisions at the same time. The manufacturer sets the wholesale price and greenness, and the retailer decides the retail price.

Proposition 10. Under the financial subsidy with a product access policy:

If $g_- \leq a(k + bs)(b + 2\sigma^2 \eta_r) / \left[bz(3b + 4\sigma^2 \eta_r) - (k + bs)^2 (b + 2\sigma^2 \eta_r) \right]$, then the equilibrium decisions and the utilities of the GSC in the Nash equilibrium are the same as those in the Nash equilibrium under the financial subsidy policy, which is $\omega_{GSN}^* = \omega_{SN}^*$, $g_{GSN}^* = g_{SN}^*$, $P_{GSN}^* = P_{SN}^*$,

$$U(\pi_m)_{GSN}^* = U(\pi_m)_{SN}^*, \quad U(\pi_r)_{GSN}^* = U(\pi_r)_{SN}^*, \quad U(\pi_{sc})_{GSN}^* = U(\pi_{sc})_{SN}^* ;$$

If

$$\frac{a(k + bs)(b + 2\sigma^2 \eta_r)}{bz(3b + 4\sigma^2 \eta_r) - (k + bs)^2 (b + 2\sigma^2 \eta_r)} < g_- < \frac{a(b + 2\sigma^2 \eta_r) \left[2(k + bs)(b + 2\sigma^2 \eta_r) + \sqrt{2bz} (3b + 4\sigma^2 \eta_r) \right]}{bz(3b + 4\sigma^2 \eta_r)^2 - 2(k + bs)^2 (b + 2\sigma^2 \eta_r)^2}$$

, then

$$g_{GSN}^* = g_- \quad (61)$$

$$\omega_{GSN}^* = \left[(a + kg_-)(b + 2\sigma^2 \eta_r) - 2bsg_-(b + \sigma^2 \eta_r) \right] / \left[b(3b + 4\sigma^2 \eta_r) \right] \quad (62)$$

$$P_{GSN}^* = \left[2(a + kg_-)(b + \sigma^2 \eta_r) - bsg_-(b + 2\sigma^2 \eta_r) \right] / \left[b(3b + 4\sigma^2 \eta_r) \right] \quad (63)$$

$$U(\pi_m)_{GSN}^* = \left[a + (k + bs)g_- \right]^2 (b + 2\sigma^2 \eta_r)^2 / \left[b(3b + 4\sigma^2 \eta_r)^2 \right] - zg_-^2 / 2 \quad (64)$$

$$U(\pi_r)_{GSN}^* = \left[a + (k + bs)g_- \right]^2 (b + \sigma^2 \eta_r) / \left[(3b + 4\sigma^2 \eta_r)^2 \right] \quad (65)$$

$$U(\pi_{sc})_{GSN}^* = \frac{\left[a + (k + bs)g_- \right]^2 (2b^2 + 5b\sigma^2 \eta_r + 4\sigma^4 \eta_r^2)}{b(3b + 4\sigma^2 \eta_r)^2} - zg_-^2 / 2 \quad (66)$$

If $g_- \geq \frac{a(b + 2\sigma^2 \eta_r) \left[2(k + bs)(b + 2\sigma^2 \eta_r) + \sqrt{2bz} (3b + 4\sigma^2 \eta_r) \right]}{bz(3b + 4\sigma^2 \eta_r)^2 - 2(k + bs)^2 (b + 2\sigma^2 \eta_r)^2}$, then $U(\pi_m)_{GSN}^* \leq 0$, the

manufacturer no longer produces green products.

Corollary 5. Under the financial subsidy with a product access policy, the highest product access in the Nash equilibrium model is:

$$g_{-GSM}^{max} \geq \frac{a(b+2\sigma^2\eta_r)\left[2(k+bs)(b+2\sigma^2\eta_r)+\sqrt{2bz}(3b+4\sigma^2\eta_r)\right]}{bz(3b+4\sigma^2\eta_r)^2-2(k+bs)^2(b+2\sigma^2\eta_r)^2} \quad (67)$$

4.4.2 Manufacturer Stackelberg game model

Under the manufacturer Stackelberg game model, the sequence of the game is as follows:

(i) The government sets the lowest greenness g_- and decides the subsidy coefficient per product s .

(ii) After observing the government's decision, the manufacturer sets the wholesale price and greenness. Then the retailer decides the retail price.

Proposition 11. Under the financial subsidy with a product access policy:

If $g_- \leq a(k+bs)(b+2\sigma^2\eta_r)/\left[4bz(b+\sigma^2\eta_r)-(k+bs)^2(b+2\sigma^2\eta_r)\right]$, then the equilibrium decisions and the utilities of the GSC in the manufacturer Stackelberg game are the same as those in the manufacturer Stackelberg game under the financial subsidy policy, which is $\omega_{GSM}^* = \omega_{SM}^*$, $g_{GSM}^* = g_{SM}^*$, $p_{GSM}^* = p_{SM}^*$, $U(\pi_m)_{GSM}^* = U(\pi_m)_{SM}^*$, $U(\pi_r)_{GSM}^* = U(\pi_r)_{SM}^*$, $U(\pi_{sc})_{GSM}^* = U(\pi_{sc})_{SM}^*$;

if

$$\frac{a(k+bs)(b+2\sigma^2\eta_r)}{4bz(b+\sigma^2\eta_r)-(k+bs)^2(b+2\sigma^2\eta_r)} < g_- < \frac{a(k+bs)(b+2\sigma^2\eta_r)+2a\sqrt{bz(b+\sigma^2\eta_r)(b+2\sigma^2\eta_r)}}{4bz(b+\sigma^2\eta_r)-(k+bs)^2(b+2\sigma^2\eta_r)}$$

, then

$$g_{GSM}^* = g_- \quad (68)$$

$$\omega_{GSM}^* = (a+kg_- - bsg_-)/(2b) \quad (69)$$

$$p_{GSM}^* = \left[\frac{(a+kg_-)(3b+2\sigma^2\eta_r)-bsg_-(b+2\sigma^2\eta_r)}{4b(b+\sigma^2\eta_r)}\right] \quad (70)$$

$$U(\pi_m)_{GSM}^* = \left[\frac{a+(k+bs)g_-}{8b(b+\sigma^2\eta_r)}\right]^2 (b+2\sigma^2\eta_r) - zg_-^2/2 \quad (71)$$

$$U(\pi_r)_{GSM}^* = \left[\frac{a+(k+bs)g_-}{16(b+\sigma^2\eta_r)}\right]^2 \quad (72)$$

$$U(\pi_{sc})_{GSM}^* = \left[\frac{a+(k+bs)g_-}{16b(b+\sigma^2\eta_r)}\right]^2 (3b+4\sigma^2\eta_r) - zg_-^2/2 \quad (73)$$

If $g_- \geq \frac{a(k+bs)(b+2\sigma^2\eta_r)+2a\sqrt{bz(b+\sigma^2\eta_r)(b+2\sigma^2\eta_r)}}{4bz(b+\sigma^2\eta_r)-(k+bs)^2(b+2\sigma^2\eta_r)}$, then $U(\pi_m)_{GSM}^* \leq 0$, the

manufacturer no longer produces green products.

Corollary 6. Under the financial subsidy with a product access policy, the highest product access in the manufacturer Stackelberg game model is:

$$g_{-GSM}^{max} = \frac{a(k+bs)(b+2\sigma^2\eta_r)+2a\sqrt{bz(b+\sigma^2\eta_r)(b+2\sigma^2\eta_r)}}{4bz(b+\sigma^2\eta_r)-(k+bs)^2(b+2\sigma^2\eta_r)} \quad (74)$$

4.4.3 Retailer Stackelberg game model

Under the retailer Stackelberg game model, the sequence of the game is as follows:

(i) The government sets the lowest greenness g_- and decides the subsidy coefficient per product s .

(ii) After observing the government's decision, the retailer determines the retail price. Then the manufacturer sets the wholesale price and greenness.

Proposition 12. Under the financial subsidy with a product access policy:

If $g_- \leq \frac{a(k+bs)\left[bz(b+4\sigma^2\eta_r)-2(k+bs)^2\sigma^2\eta_r\right]}{2\left[2bz-(k+bs)^2\right]\left[bz(b+2\sigma^2\eta_r)-(k+bs)^2\sigma^2\eta_r\right]}$, then the equilibrium decisions and

the utilities of the GSC in the retailer Stackelberg game model are the same as those in the retailer Stackelberg game model under the financial subsidy policy, which is $\omega_{GSR}^* = \omega_{SR}^*$, $g_{GSR}^* = g_{SR}^*$, $P_{GSR}^* = P_{SR}^*$,

$$U(\pi_m)_{GSR}^* = U(\pi_m)_{SR}^*, \quad U(\pi_r)_{GSR}^* = U(\pi_r)_{SR}^*, \quad U(\pi_{sc})_{GSR}^* = U(\pi_{sc})_{SR}^*;$$

If $\frac{a(k+bs)\left[bz(b+4\sigma^2\eta_r)-2(k+bs)^2\sigma^2\eta_r\right]}{2\left[2bz-(k+bs)^2\right]\left[bz(b+2\sigma^2\eta_r)-(k+bs)^2\sigma^2\eta_r\right]} < g_-$
 If $\frac{a(b+4\sigma^2\eta_r)\left[(k+bs)(b+4\sigma^2\eta_r)+2\sqrt{2bz}(b+2\sigma^2\eta_r)\right]}{8bz(b+2\sigma^2\eta_r)^2-(k+bs)^2(b+4\sigma^2\eta_r)^2} < g_-$, then

$$g_{GSR}^* = g_- \quad (75)$$

$$\omega_{GSR}^* = \left[(a+kg_-)(b+4\sigma^2\eta_r) - bsg_-(3b+4\sigma^2\eta_r) \right] / \left[4b(b+2\sigma^2\eta_r) \right] \quad (76)$$

$$P_{GSR}^* = \left[(a+kg_-)(3b+4\sigma^2\eta_r) - bsg_-(b+4\sigma^2\eta_r) \right] / \left[4b(b+2\sigma^2\eta_r) \right] \quad (77)$$

$$U(\pi_m)_{GSR}^* = \left[a + (k+bs)g_- \right]^2 (b+4\sigma^2\eta_r)^2 / \left[16b(b+2\sigma^2\eta_r)^2 \right] - zg_-^2 / 2 \quad (78)$$

$$U(\pi_r)_{GSR}^* = \left[a + (k+bs)g_- \right]^2 / \left[8(b+2\sigma^2\eta_r) \right] \quad (79)$$

$$U(\pi_{sc})_{GSR}^* = \frac{\left[a + (k+bs)g_- \right]^2 (3b^2 + 12b\sigma^2\eta_r + 16\sigma^4\eta_r^2)}{16b(b+2\sigma^2\eta_r)^2} - zg_-^2 / 2 \quad (80)$$

If $g_- \geq \frac{a(b+4\sigma^2\eta_r)\left[(k+bs)(b+4\sigma^2\eta_r)+2\sqrt{2bz}(b+2\sigma^2\eta_r)\right]}{8bz(b+2\sigma^2\eta_r)^2-(k+bs)^2(b+4\sigma^2\eta_r)^2}$, then $U(\pi_m)_{GSR}^* \leq 0$, so the

manufacturer no longer produces green products.

Corollary 7. Under the financial subsidy with a product access policy, the highest product access in the retailer Stackelberg game model is:

$$g_{-GSR}^{max} = \frac{a(b+4\sigma^2\eta_r)\left[(k+bs)(b+4\sigma^2\eta_r)+2\sqrt{2bz}(b+2\sigma^2\eta_r)\right]}{8bz(b+2\sigma^2\eta_r)^2-(k+bs)^2(b+4\sigma^2\eta_r)^2} \quad (81)$$

Corollary 8. Similar to corollary 4, under the financial subsidy with a product access policy, in the three different game structures, if $g_{-GS} \leq g_S^*$, this product access will not affect optimal decisions; this situation is also called *ineffective product access policy*. Only when $g_{-GS} > g_S^*$ can product access stimulate green production; this situation is called *financial subsidy with effective product access policy*.

4.5 Comparative Analysis

After the above calculation, we compare various equilibrium decisions, such as optimal greenness, wholesale price, retail price, and expected utility, among different power structures and policy scenarios.

4.5.1 Effect of the power structure

Corollary 9. The relationships of equilibrium results among three power structures under different types of government interventions are shown in Table 3. Proofs of this corollary are given in the Appendix.

Table 3. The relationships between variables among three power structures under different scenarios

Variab es	Scenario 1: Under no government intervention	Scenario 2: Under effective product access
g^*	$g_{WM}^* < g_{WR}^* < g_{WN}^*$	$g^* = g_-$

ω^*	$\omega_{WR}^* < \omega_{WN}^* < \omega_{WM}^*$	$\omega_{GR}^* < \omega_{GN}^* < \omega_{GM}^*$
p^*	$p_{WN}^* < p_{WR}^* < p_{WM}^*$	$p_{GN}^* < p_{GR}^* < p_{GM}^*$
$U(\pi_m)^*$	$U(\pi_m)_{WR}^* < U(\pi_m)_{WN}^* < U(\pi_m)_{WM}^*$	$U(\pi_m)_{GR}^* < U(\pi_m)_{GN}^* < U(\pi_m)_{GM}^*$
$U(\pi_r)^*$	$U(\pi_r)_{WM}^* < U(\pi_r)_{WN}^* < U(\pi_r)_{WR}^*$	$U(\pi_r)_{GM}^* < U(\pi_r)_{GN}^* < U(\pi_r)_{GR}^*$
$U(\pi_{sc})^*$	$U(\pi_{sc})_{WM}^* < U(\pi_{sc})_{WN}^*; U(\pi_{sc})_{WR}^* < U(\pi_{sc})_{WN}^*$	$U(\pi_{sc})_{GR}^* < U(\pi_{sc})_{GM}^* < U(\pi_{sc})_{GN}^*$
Variab les	Scenario 3: Under financial subsidy	Scenario 4: Under financial subsidy with effective product access
g^*	$g_{SM}^* < g_{SR}^* < g_{SN}^*$	$g^* = g_-$
ω^*	$\omega_{SR}^* < \omega_{SN}^* < \omega_{SM}^*$	$\omega_{GSR}^* < \omega_{GSN}^* < \omega_{GSM}^*$
p^*	$p_{SN}^* < p_{SR}^* < p_{SM}^*$	$p_{GSN}^* < p_{GSR}^* < p_{GSM}^*$
$U(\pi_m)^*$	$U(\pi_m)_{SR}^* < U(\pi_m)_{SN}^* < U(\pi_m)_{SM}^*$	$U(\pi_m)_{GSR}^* < U(\pi_m)_{GSN}^* < U(\pi_m)_{GSM}^*$
$U(\pi_r)^*$	$U(\pi_r)_{SM}^* < U(\pi_r)_{SN}^* < U(\pi_r)_{SR}^*$	$U(\pi_r)_{GSM}^* < U(\pi_r)_{GSN}^* < U(\pi_r)_{GSR}^*$
$U(\pi_{sc})^*$	$U(\pi_{sc})_{SM}^* < U(\pi_{sc})_{SN}^*; U(\pi_{sc})_{SR}^* < U(\pi_{sc})_{SN}^*$	$U(\pi_{sc})_{GSR}^* < U(\pi_{sc})_{GSM}^* < U(\pi_{sc})_{GSN}^*$

From Table 3, we can conclude that the whole GSC's expected utility is the highest in the Nash equilibrium game model regardless of the scenario. We also find that retailers and manufacturers have the highest expected utility only in the markets where they have a leadership position under any government policy. However, the wholesale and retail prices are the highest in the manufacturer Stackelberg game model. According to the competition theory, there is a "competitive" relationship between manufacturers and retailers (Hunt and Morgan 1995; Porter 1974, 2001). When a player occupies a dominant position in the power structure, its bargaining power is stronger. The dominant manufacturer will use its stronger bargaining power to get a higher wholesale price based on a lower greenness or just meet the green access set by the government. The retailer transfers this part of the cost to consumers by increasing the retail price.

Under no government intervention and only financial subsidy (scenarios 1 and 3), the Nash equilibrium game has the highest greenness. Under effective product access and financial subsidy with effective product access (scenarios 2 and 4), the optimal greenness under all power structures is the effective product access set by the government. This result is because high risks and high input costs characterize green production. According to behavioral decision-making theory, loss aversion leads manufacturers to make more conservative decisions (Kahneman et al. 1991). Therefore, they choose as lower greenness as possible.

4.5.2 Effect of risk aversion

Corollary 10. The impact of the retailer's risk aversion coefficient on the optimal decisions and expected utilities in different power structures and different scenarios are as Table 4. Proofs of this corollary are given in the Appendix.

From Table 4, we can find how the retailer's risk aversion coefficient impacts the optimal decisions and participants' expected utilities. Firstly, our findings show that no matter under any power structures and policy, retailers' risk aversion enhances product greenness and manufacturers' profits. However, it leads to lower profits for retailers. This is because the retailer always tends to expand the market scale by reducing retail prices to deal with risks, leading to weaker bargaining power and lower expected utility as the risk aversion degree increases; and the expanded market scale and stronger manufacturer's bargaining power will help promote the manufacturer's expected utility.

Secondly, regardless of government intervention, the expected utility of the GSC under the manufacturer Stackelberg game and the retailer Stackelberg game increases as the retailer's risk aversion coefficient increases. Furthermore, if the retailer's risk aversion coefficient satisfies given thresholds, the expected utility of the GSC under the Nash equilibrium game increases as the retailer's risk aversion coefficient increases. This indicates that when the cost coefficient of green R&D is relatively high (considered in this paper $z > (k + bs)^2 / b$), regardless of the power structure and government intervention, a moderate retailer's risk aversion is beneficial for the GSC.

1 **Table 4.** The impact of the retailer's risk aversion coefficient on the optimal decisions and expected utilities in different power structures and different scenarios

	Under no government intervention			Under effective product access			Under financial subsidy			Under financial subsidy with effective product access		
	ω_{WN}^*	ω_{WM}^*	ω_{WR}^*	ω_{GN}^*	ω_{GM}^*	ω_{GR}^*	ω_{SN}^*	ω_{SM}^*	ω_{SR}^*	ω_{GSN}^*	ω_{GSM}^*	ω_{GSR}^*
$\partial\omega^*/\partial\eta_r$	\nearrow	\nearrow	\nearrow	\nearrow	\rightarrow	\nearrow	\nearrow	\nearrow	\nearrow	\nearrow	\rightarrow	\nearrow
										$\nearrow s \leq \frac{k}{b}$; $\searrow s > \frac{k}{b}$		
$\partial g^*/\partial\eta_r, \partial g_-^{max}/\partial\eta_r$	g_{WN}^* \nearrow	g_{WM}^* \nearrow	g_{WR}^* \nearrow	g_{GN}^{max} \nearrow	g_{GM}^{max} \nearrow	g_{GR}^{max} \nearrow	g_{SN}^* \nearrow	g_{SM}^* \nearrow	g_{SR}^* \nearrow	g_{GSN}^{max} \nearrow	g_{GSM}^{max} \nearrow	g_{GSR}^{max} \nearrow
$\partial p^*/\partial\eta_r$	P_{WN}^* \searrow	P_{WM}^* \searrow	P_{WR}^* \searrow	P_{GN}^* \searrow	P_{GM}^* \searrow	P_{GR}^* \searrow	P_{SN}^* \searrow	P_{SM}^* \searrow	P_{SR}^* \searrow	P_{GSN}^* \searrow	P_{GSM}^* \searrow	P_{GSR}^* \searrow
$\partial U(\pi_m)^*/\partial\eta_r$	$U(\pi_m)_{WN}^*$ \nearrow	$U(\pi_m)_{WM}^*$ \nearrow	$U(\pi_m)_{WR}^*$ \nearrow	$U(\pi_m)_{GN}^*$ \nearrow	$U(\pi_m)_{GM}^*$ \nearrow	$U(\pi_m)_{GR}^*$ \nearrow	$U(\pi_m)_{SN}^*$ \nearrow	$U(\pi_m)_{SM}^*$ \nearrow	$U(\pi_m)_{SR}^*$ \nearrow	$U(\pi_m)_{GSN}^*$ \nearrow	$U(\pi_m)_{GSM}^*$ \nearrow	$U(\pi_m)_{GSR}^*$ \nearrow
$\partial U(\pi_r)^*/\partial\eta_r$	$U(\pi_r)_{WN}^*$ \searrow	$U(\pi_r)_{WM}^*$ \searrow	$U(\pi_r)_{WR}^*$ \searrow	$U(\pi_r)_{GN}^*$ \searrow	$U(\pi_r)_{GM}^*$ \searrow	$U(\pi_r)_{GR}^*$ \searrow	$U(\pi_r)_{SN}^*$ \searrow	$U(\pi_r)_{SM}^*$ \searrow	$U(\pi_r)_{SR}^*$ \searrow	$U(\pi_r)_{GSN}^*$ \searrow	$U(\pi_r)_{GSM}^*$ \searrow	$U(\pi_r)_{GSR}^*$ \searrow
	$U(\pi_{sc})_{WN}^*$	$U(\pi_{sc})_{WM}^*$	$U(\pi_{sc})_{WR}^*$	$U(\pi_{sc})_{GN}^*$	$U(\pi_{sc})_{GM}^*$	$U(\pi_{sc})_{GR}^*$	$U(\pi_{sc})_{SN}^*$	$U(\pi_{sc})_{SM}^*$	$U(\pi_{sc})_{SR}^*$	$U(\pi_{sc})_{GSN}^*$	$U(\pi_{sc})_{GSM}^*$	$U(\pi_{sc})_{GSR}^*$
$\partial U(\pi_{sc})^*/\partial\eta_r$	\nearrow $\eta_r > \frac{b(bz - k^2)}{2\sigma^2(2bz - k^2)}$ \searrow $\eta_r < \frac{b(bz - k^2)}{2\sigma^2(2bz - k^2)}$	\nearrow	\nearrow	\nearrow $\eta_r > \frac{b}{4\sigma^2}$ \searrow $\eta_r < \frac{b}{4\sigma^2}$	\nearrow	\nearrow	\nearrow	\nearrow $\eta_r > \frac{b[bz - (k + bs)^2]}{2\sigma^2[2bz - (k + bs)^2]}$ \searrow $\eta_r < \frac{b[bz - (k + bs)^2]}{2\sigma^2[2bz - (k + bs)^2]}$	\nearrow	\nearrow	\nearrow $\eta_r > \frac{b}{4\sigma^2}$ \searrow $\eta_r < \frac{b}{4\sigma^2}$	\nearrow

Notes: \nearrow : positive effect; \rightarrow : no effect; \searrow : negative effect

3 **Table 5.** Optimal decisions and expected utilities of the GSC when $\eta_r = 1$

Variables	Nash equilibrium						Manufacturer Stackelberg game						Retailer Stackelberg game					
	No intervention	Effective product access		Financial subsidy $s = 0.2$	Effective product access & financial subsidy $s = 0.2$		No intervention	Effective product access		Financial subsidy $s = 0.2$	Effective product access & financial subsidy $s = 0.2$		No intervention	Effective product access		financial subsidy $s = 0.2$	Effective product access & financial subsidy $s = 0.2$	
		$g_- = 3$	$g_- = 6$		$g_- = 6$	$g_- = 11$		$g_- = 3$	$g_- = 6$		$g_- = 6$	$g_- = 11$		$g_- = 3$	$g_- = 6$		$g_- = 6$	$g_- = 11$
ω^*	11.90	12.05	12.73	11.78	12.07	12.66	13.04	13.25	14.00	12.98	13.40	14.15	11.79	11.93	12.60	11.66	11.94	12.52
p^*	14.29	14.45	15.27	14.27	14.73	15.64	15.22	15.46	16.33	15.25	15.83	16.88	14.39	14.58	15.40	14.38	14.86	15.79
g^*	2.38	3.00	6.00	3.49	6.00	11.00	2.17	3.00	6.00	3.18	6.00	11.00	2.36	3.00	6.00	3.46	6.00	11.00
$U(\pi_m)^*$	269.27	267.69	233.97	280.75	262.33	139.36	271.74	270.10	236.67	283.58	265.27	143.04	263.99	261.91	227.52	275.35	255.32	130.56
$U(\pi_r)^*$	34.01	34.82	38.88	37.35	42.28	53.02	28.36	29.26	32.67	30.88	35.53	44.55	34.27	35.11	39.20	37.59	42.63	53.46
$U(\pi_w)^*$	303.29	302.51	272.84	318.10	304.61	192.38	300.10	299.37	269.33	314.46	300.79	187.59	298.25	297.02	266.72	312.94	297.95	184.03
(g_-^{min}, g_-^{max})	-	(2.38, 12.76)		-	(3.49, 14.21)		-	(2.17, 12.82)		-	(3.18, 14.29)		-	(2.36, 12.60)		-	(3.46, 14.01)	

4 **Table 6.** Optimal decisions and expected utilities of the GSC when $\eta_r = 2$

Variables	Nash equilibrium						Manufacturer Stackelberg game						Retailer Stackelberg game					
	No intervention	Effective product access		Financial subsidy $s = 0.2$	Effective product access & financial subsidy $s = 0.2$		No intervention	Effective product access		Financial subsidy $s = 0.2$	Effective product access & financial subsidy $s = 0.2$		No intervention	Effective product access		financial subsidy $s = 0.2$	Effective product access & financial subsidy $s = 0.2$	
		$g_- = 3$	$g_- = 6$		$g_- = 6$	$g_- = 11$		$g_- = 3$	$g_- = 6$		$g_- = 6$	$g_- = 11$		$g_- = 3$	$g_- = 6$		$g_- = 6$	$g_- = 11$
ω^*	12.43	12.55	13.26	12.32	12.63	13.29	13.09	13.25	14.00	13.02	13.40	14.15	12.39	12.51	13.22	12.29	12.59	13.24
p^*	13.81	13.95	14.74	13.77	14.17	15.01	14.40	14.56	15.40	14.39	14.86	15.79	13.85	13.99	14.78	13.81	14.21	15.06
g^*	2.49	3.00	6.00	3.66	6.00	11.00	2.36	3.00	6.00	3.45	6.00	11.00	2.48	3.00	6.00	3.64	6.00	11.00
$U(\pi_m)^*$	293.60	292.64	261.82	307.42	292.63	177.35	294.50	293.51	262.80	308.46	293.69	178.68	291.81	290.70	259.65	305.57	290.27	174.39
$U(\pi_r)^*$	19.08	19.45	21.72	21.04	23.62	29.62	17.13	17.56	19.60	18.79	21.32	26.73	19.12	19.51	21.78	21.08	23.68	29.70
$U(\pi_w)^*$	312.68	312.09	283.54	328.46	316.24	206.97	311.64	311.07	282.40	327.25	315.00	205.41	310.93	310.20	281.43	326.65	313.95	204.09
(g_-^{min}, g_-^{max})	-	(2.49, 13.44)		-	(3.66, 15.06)		-	(2.36, 13.46)		-	(3.45, 15.09)		-	(2.48, 13.39)		-	(3.64, 14.99)	

5

Thirdly, the optimal wholesale price positively correlates with the retailer's risk aversion without government intervention. Under a financial subsidy, the optimal wholesale price decreases as the retailer's risk aversion coefficient increases when the subsidy coefficient is large enough ($s > k/b$). Conversely, when the government sets effective product access and the manufacturer dominates the market, the retailer's risk aversion will affect neither wholesale price nor greenness.

4.6 Numerical Analysis

Some numerical examples are given below to examine the impact of the retailer's risk aversion and different types of government intervention and clarify and verify the results obtained in this study.

Without loss of generality, we suppose that $a = 50, b = 2, k = 1, z = 5, \sigma = 2, s \in (0, 1), g_- \in [0, 12]$. When illustrating the impact of excessive product access on the manufacturer's expected utility, we set the range of g_- as $[0, 20]$. It is easy to know that all the constraint conditions of the model are satisfied. Tables 5 and 6 show the specific numerical simulation results.

From Table 5 to Table 6, it can be seen that the results shown in Tables 3 and 4 are stable and right. Through numerical analysis, we also find that financial subsidy leads to the highest GSC utility and manufacturer utility. Besides, when the financial subsidy with effective product access policy is implemented, the GSC reaches the highest level of greenness. Finally, when the manufacturer and the retailer occupy an equal position in the market, they strive to provide consumers with more cost-effective green products resulting in the highest green performance-price ratio (g/p) and supply chain's expected utility.

To compare the effects of the government intervention on the optimal decisions and the expected utilities between different scenarios, we further make a sensitivity analysis. In this part, without loss of generality, we specifically set $\eta_r = 1$. Since the effects of the product access and subsidy coefficient are almost the same under different power structures, we only analyze the situation under the Nash equilibrium in this part. The results can be obtained in Figs 1, 2, 3, 4, 5, and 6.

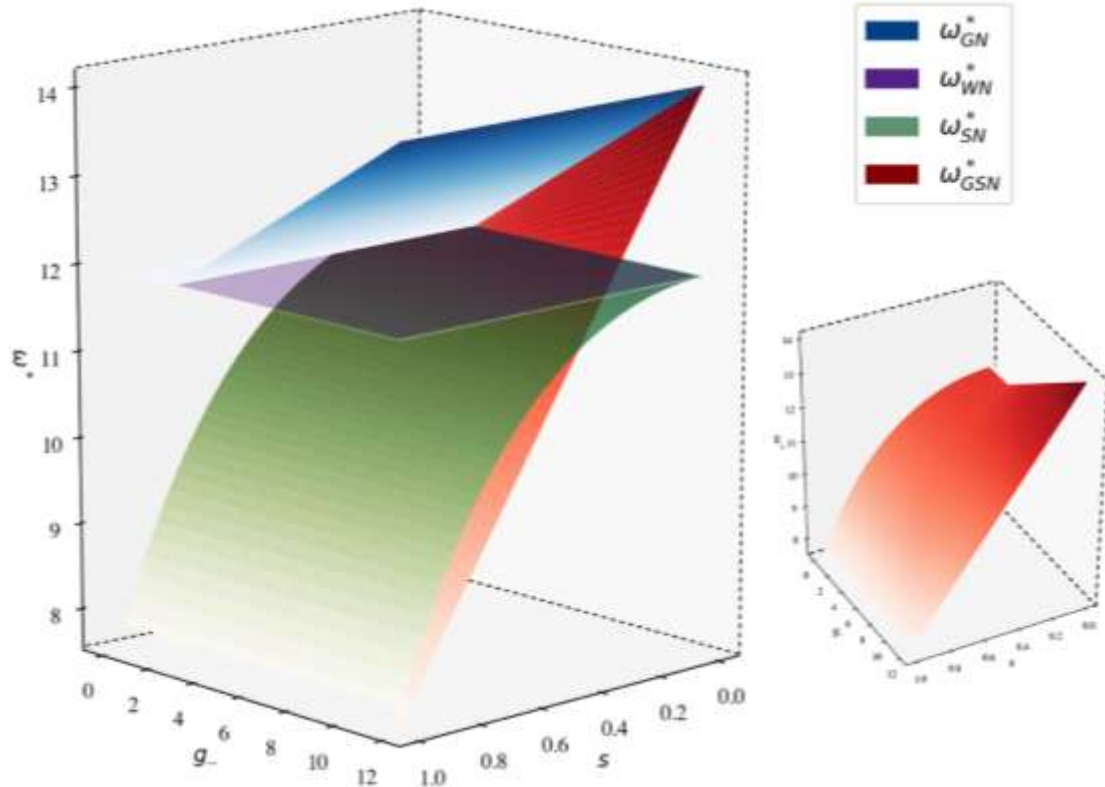


Fig. 1 The effects of product access and financial subsidy on the optimal wholesale price

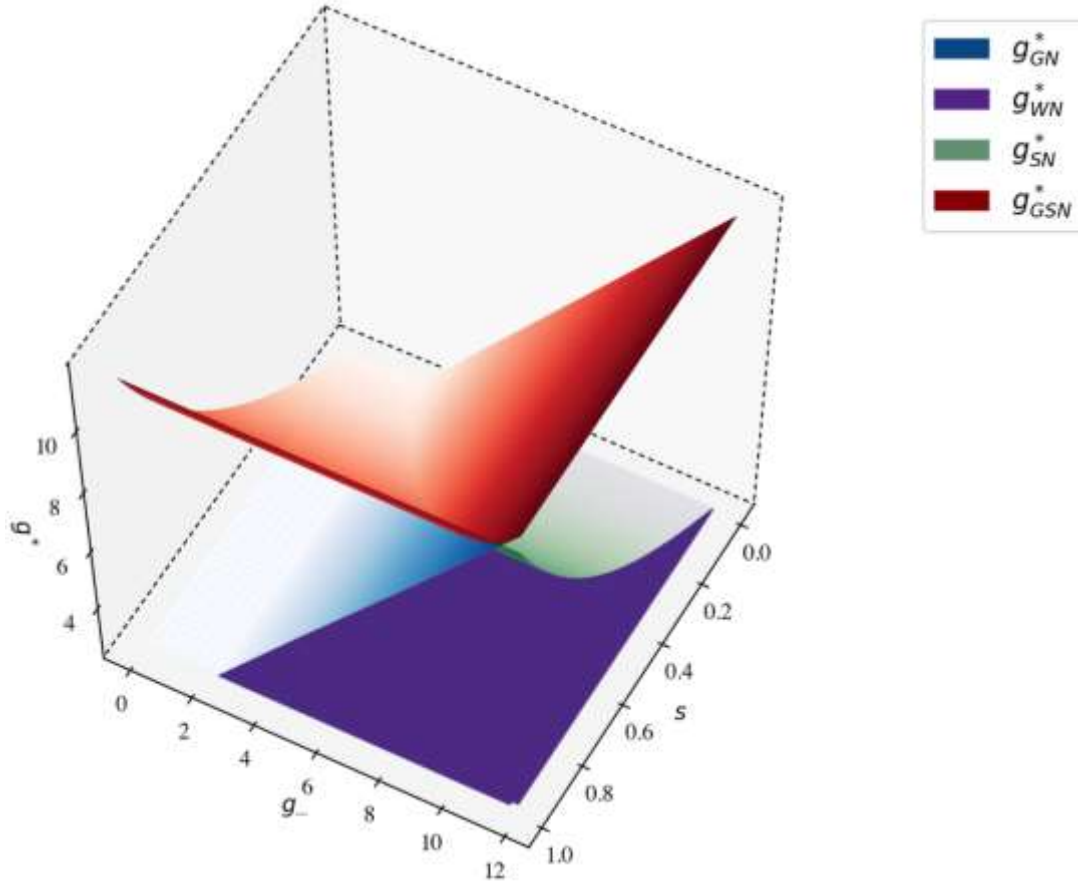


Fig. 2 The effects of product access and financial subsidy on the optimal greenness

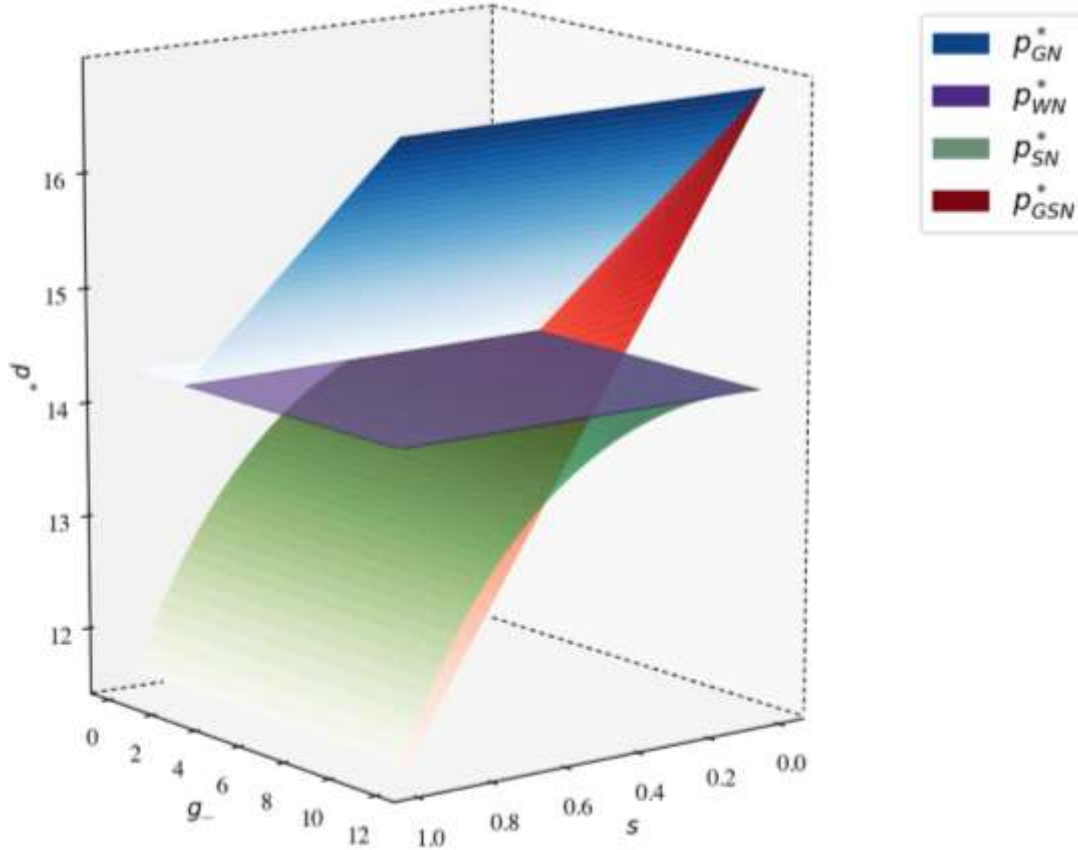


Fig. 3 The effects of product access and financial subsidy on the optimal retail price

It can be seen from Figs. 1, 2, and 3 that when the government aims to promote green production through setting product access, only when $g_G > g_W^*$ and $g_{GS} > g_S^*$ could the product access effectively affect the optimal wholesale price, retail price, and greenness. Moreover, under the scenario of financial subsidy with product access, the lowest effective product access increases as the financial subsidy increases. This pattern is because that g_- with product access being smaller than the optimal greenness without product access, the manufacturer will ignore the product access regulation to pursue the optimal results.

When the product access exceeds a certain value, regardless of financial subsidy, the optimal wholesale price, greenness, and retail price always positively relates to the product access. This is because higher product access means that the manufacturer needs to spend higher costs on R&D, prompting them to increase wholesale prices, leading to a higher retail price.

Regardless of product access, the optimal wholesale price and retail price are negatively associated with the financial subsidy coefficient; and the optimal greenness increases as the financial subsidy coefficient increases. These results are because the financial subsidy helps incentivize the manufacturer to develop greener products by reducing their costs, and the manufacturer passes on the benefits to the retailer, which in turn benefits consumers.

In addition, it can be seen from Fig. 2 that when product access and financial subsidy are implemented at the same time, the highest optimal greenness of the product exists in the scenario of financial subsidy with effective product access. Therefore, the government should implement a financial subsidy with product access when considering improving the greenness of products.

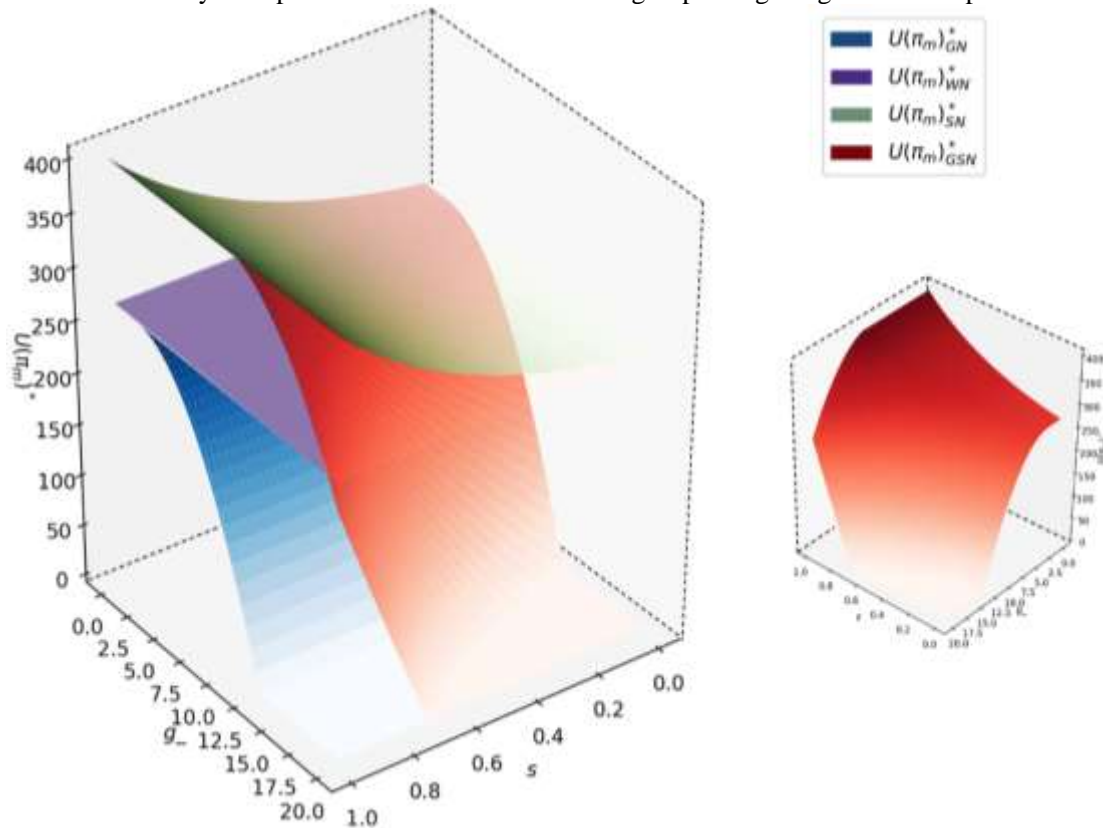


Fig. 4 The effects of product access and financial subsidy on the manufacturer's expected utility

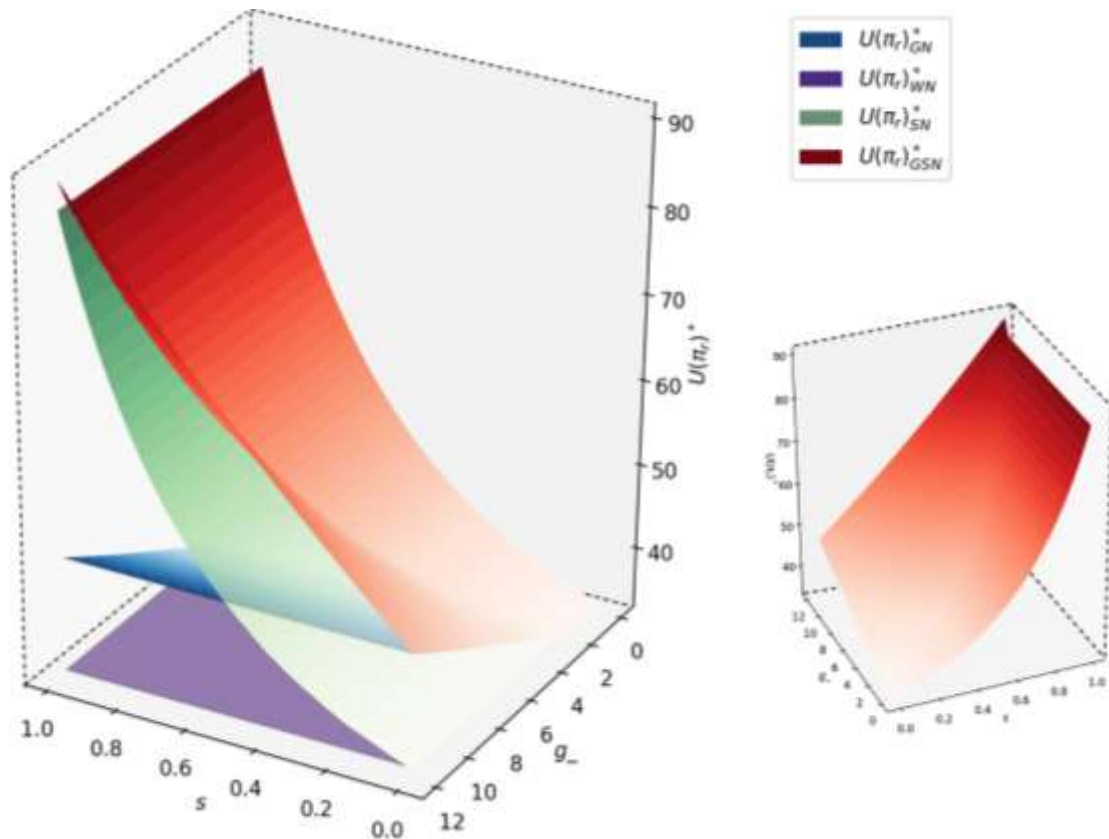


Fig. 5 The effects of product access and financial subsidy on the retailer's expected utility

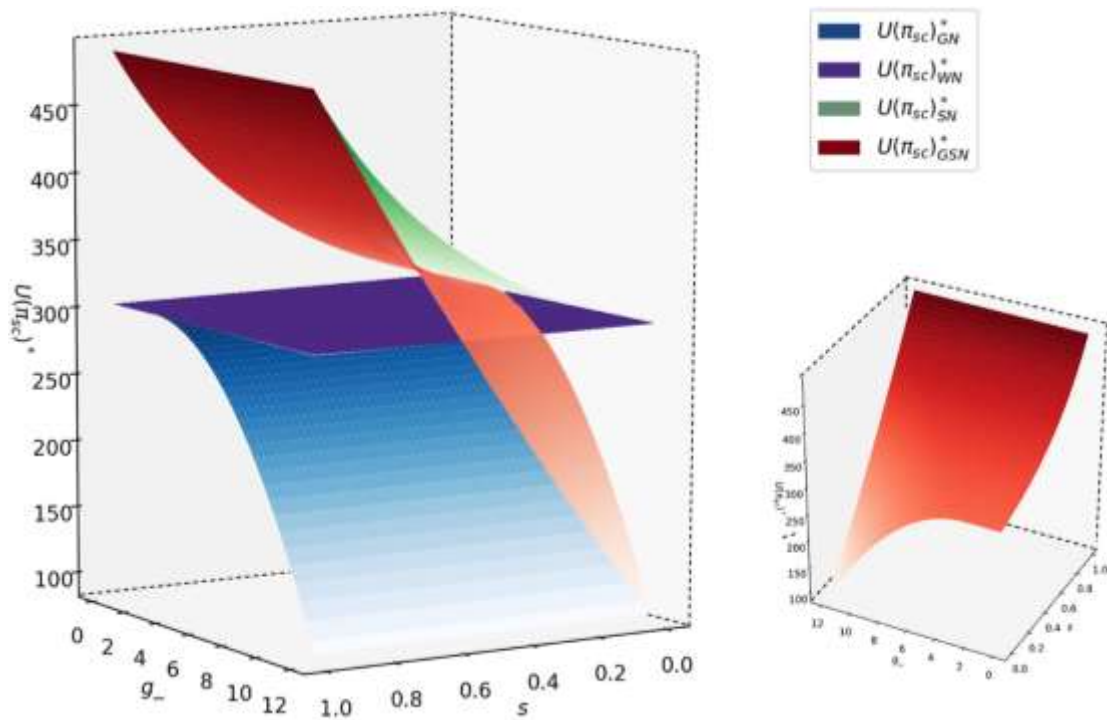


Fig. 6 The effects of product access and financial subsidy on the GSC's expected utility

It can be seen from Figs. 4, 5, and 6 that, similar to the above, only when the product access exceeds a certain threshold can the product access effectively affect the expected utility. When the product access exceeds a certain threshold, the manufacturer's and the GSC's expected utility is negatively related to the product access and positively relates to the financial subsidy. With the introduction and increase of effective product access, the manufacturer's expected utility drops sharply and may even go bankrupt. Furthermore, the higher the financial subsidy coefficient, the

weaker the negative effect of the product access on the manufacturer's and the GSC's expected utility is. The manufacturer and the GSC have the highest expected utility only when the financial subsidy policy is implemented. However, under this policy, the product's greenness cannot reach the highest level, and the high financial subsidy coefficient will be a great economic burden for the government. The retailer's expected utility is positively associated with product access and financial subsidy. The retailer has the highest expected utility when the policy of financial subsidy with product access is implemented. This finding implies that it is important for the government to set moderate product access with a certain level of financial subsidy.

5. Discussion

According to the above model and numerical analysis results, this section makes research discussion from the three perspectives of government subsidy and product access policies, retailer's risk aversion, and the market structure.

First, our findings confirm that the government subsidy positively promotes green production, which has been noted by Guo and Huang (2021) and Huang and Liang (2021). Specifically, the results indicate that the financial subsidy positively affects the optimal greenness, the member's and the GSC's expected utilities while having negative effects on the wholesale and retail prices. These findings are partially consistent with He et al. (2019b). Furthermore, although there is some research about government subsidy policy on the green supply chain (Guo and Huang 2021; Huang and Liang 2021), the accompanying conditions of subsidy policy in reality, such as government standards of subsidized green products, has been somewhat neglected. Our findings are consistent with Gao et al. (2021); their study shows that the simultaneous implementation of product access and financial subsidy improves GSC's economic and environmental benefits. However, this study further suggests that only when the product access conditions reach a certain threshold could the financial subsidy policy more powerfully affect the utility of the entire GSC. Moreover, our model also computes the interval for effective product access, which answers the balance of product access and financial subsidy not addressed in the study of Gao et al. (2021) and Gao et al. (2020).

Second, previous studies on green supply chains have mostly discussed supply chain member's characteristics, such as consumers' environmental awareness (Yang and Gong 2021; Zu et al. 2021) and retailers' reciprocal preferences (Yang and Gong 2021). Retailers' risk awareness has been considered only in a few studies on green supply chains (Bai and Meng 2020; Raza and Govindaluri 2019). Our results show that no matter what the market structure and government intervention type are, the retailer's risk aversion negatively affects the retail price and its utility, but it positively affects the manufacturer's utility, which is consistent with the research of Bai and Meng (2020). Different from the conclusions of Bai and Meng (2020), our study indicates that the wholesale price does not always increase according to the retailer's risk aversion. Specifically, when the manufacturer and the retailer are of equal status or the retailer leads the market, regardless of government intervention, the retailer's risk aversion positively affects the wholesale prices. When the manufacturer dominates the market, the retailer's risk aversion has a positive effect on the wholesale price only when the government does not intervene; when the government sets effective product access, regardless of whether there exists financial subsidy, the retailer's risk aversion has no effects on the wholesale prices; when the government intervenes with only a high level of financial subsidy, the retailer's risk aversion hurts the wholesale price. Furthermore, Xu and Zhan (2021) have noted that the optimal greenness of the manufacturer would increase as the degree of the retailer's risk aversion increases. However, our study finds that this conclusion only exists when effective product access is not implemented. Once the effective product access policy is implemented, the risk aversion of the retailer will not affect the optimal greenness of the manufacturer. Our research further finds that the highest effective product access increases as the retailer's risk aversion coefficient increases. In addition, when the retailer is risk-averse, the government can raise it appropriately. Moreover, only when the retailer has a relatively high level of risk aversion, the GSC's expected utilities will be positively associated with the retailer's risk aversion under the Nash equilibrium.

Third, our study focused on analyzing the influence of retailers' risk awareness on the effect of policy implementation under different power structures. We found that the retailer Stackelberg game has the lowest wholesale price and highest retailer's expected utility. This is consistent with the research conclusions of Yang and Xiao (2017) and Wang et al. (2019). In addition, Lan (2019) considered the same supply chain structure as our study, but they only discussed the manufacturer-

Stackelberg game scenario. We further extend the scenario to the Nash equilibrium and retailer-Stackelberg game and find that no matter what policy intervention, only in the manufacturer-Stackelberg and retailer-Stackelberg game, retailer risk aversion will increase the GSC's utility. In particular, a U-shaped relationship between retailer risk aversion and the GSC's utility occurs in the Nash equilibrium game.

6. Conclusions and policy implications

With the continuous development and maturity of behavioral decision-making theory, non-economic factors in decision-making have gradually been paid attention to, especially the impact of representative risk preference factors. To explore their effects on supply chain decision-making, this paper considers a GSC consisting of a risk-neutral manufacturer and a risk-averse retailer based on preference theory. We focused on the three possible decentralized power structures, i.e., Nash equilibrium game, manufacturer Stackelberg game, and retailer Stackelberg game. Specifically, we analyzed the equilibrium results of each member and the whole supply chain under four different policy backgrounds: no government intervention, product access, financial subsidy, and financial subsidy with product access. After examining the influences of different policies and power structures on the pricing, the member's utility, and supply chain utility, our main findings are as follows:

First, regardless of financial subsidy, only when the product access set by the government exceeds a certain threshold can the policy effectively impact the optimal decisions and expected utilities. Effective product access positively impacts the optimal greenness, wholesale price, retail price, and the retailer's expected utility. However, it negatively affects the manufacturer's and GSC's expected utilities. In addition, the highest effective product access increases as the retailer's risk aversion coefficient increases.

Second, the Nash equilibrium game model has the highest greenness and highest GSC's expected utility. These findings support that in the GSC, when the manufacturer and retailer make decentralized decisions, they are also in place to seek their interests. The manufacturer tries its best to raise the wholesale price with a lower or an established greenness. The retailer tries to lower the wholesale price with a higher or an established greenness. Besides, the manufacturer reaches the highest greenness under financial subsidy with product access.

Third, the effects of the retailer's risk aversion on the optimal retail price and the member's expected utilities are not influenced by the types of government intervention. Yet, the effects of the retailer's risk aversion on the optimal greenness and wholesale price are different because of the way the government intervenes.

The findings of this study proffer some implications. First, from the governments' perspective, our research findings provide strategic guidance on rationally designing the matching policy of financial subsidy and product access. For instance, our results show an effective interval for product access policies. Product access standards within this interval have an impact on the GSC. Therefore, the green standard of product access policy is not recommended to be set too high or too low. We also found that the highest product greenness is achieved when the financial subsidy with product access policy is implemented. However, similar to the product access policy, there is also an effective interval when the policy of financial subsidy with product access is implemented. Moreover, the product access standard is preferably increased according to the optimal greenness of the subsidy policy.

Second, the government should investigate the retailer's risk attitude toward promoted products. Our research found that regardless of the power structures and intervention policies, the retailer's risk aversion promotes greenness and manufacturer utility. Therefore, to improve the production greenness and the production enthusiasm of the manufacturers, the government should formulate corresponding strategies to enhance the risk aversion of retailers, thereby reversely promoting the green production of manufacturers from the demand side.

Finally, governments need to pay attention to the power structure between retailers and manufacturers. Our results show that the GSC utility under the Nash equilibrium game is the highest regardless of the government policy. Therefore, for the long-term healthy development of the GSC, the government needs to maintain the balance of power between retailers and manufacturers as much as possible.

Our research has some limitations, and future research can be engaged in the following directions. First, we only considered green products. However, their competition with ordinary

products is an important market environment. Therefore, considering the SC competition of green and non-green products is the direction of future research. Secondly, from the perspective of sensible policies, the government has implemented the policies in phases. Therefore, considering multi-period game models could be the next research direction. Finally, [globalized SCs have large and complex impacts on environmental issues](#) (Sharif et al. 2019). However, the COVID-19 pandemic has increased the operational risks of the global SC members and even resulted in the temporary suspension of global economic activities (Razzaq et al. 2020; Zambrano-Monserrate et al. 2020). Therefore, the resilience of GSCs is increasingly critical. In this context, our next research question should be how the government can help GSC members share risks without causing fiscal deficits.

Author Contributions

Model constructions, conceptualization, methodology, formal analysis, and data curation were performed by Li Tang, Eldon Y. Li, and Jiang Jiang. Peipei Wu participated in the methodology, formal analysis, and data curation of this paper. All authors read and approved the final manuscript.

Funding

This work was supported by 2021 plateau discipline and first-class undergraduate specialty project of Shanghai Business School (Grant number SHGDD-GSGL-2021-03-07) and the Ministry of Science and Technology in Taiwan (Grant No. 108-2410-H-194-106-MY3).

Availability of Data and Materials

All data and materials generated or analyzed during this study are included in this article.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Competing Interests The authors have no relevant financial or non-financial interests to disclose.

References

- Agi MAN, Faramarzi-Oghani S, Hazir O (2021) Game theory-based models in green supply chain management: a review of the literature. *Int J Prod Res* 59:4736-4755. <https://doi.org/10.1080/00207543.2020.1770893>
- Ahmad M, Isik C, Jabeen G, Ali T, Ozturk I, Atchike DW (2021) Heterogeneous links among urban concentration, non-renewable energy use intensity, economic development, and environmental emissions across regional development levels. *Sci Total Environ* 765 <https://doi.org/10.1016/j.scitotenv.2020.144527>
- Alberto Gomez-Luciano C, Rondon Dominguez FR, Gonzalez-Andres F, Urbano Lopez De Meneses B (2018) Sustainable supply chain management: Contributions of supplies markets. *J Clean Prod* 184:311-320. <https://doi.org/10.1016/j.jclepro.2018.02.233>
- Bai QG, Meng FW (2020) Impact of risk aversion on two-echelon supply chain systems with carbon emission reduction constraints. *J Ind Manag Optim* 16:1943-1965. <https://doi.org/10.3934/jimo.2019037>
- Barari S, Agarwal G, Zhang WJ, Mahanty B, Tiwari MK (2012) A decision framework for the analysis of green supply chain contracts: An evolutionary game approach. *Expert Syst Appl* 39:2965-2976. <https://doi.org/10.1016/j.eswa.2011.08.158>
- Barman A, Das R, De PK, Sana SS (2021) Optimal Pricing and Greening Strategy in a Competitive Green Supply Chain: Impact of Government Subsidy and Tax Policy. *Sustainability* 13 <https://doi.org/10.3390/su13169178>

- Bian J, Zhang G, Zhou G (2020) Manufacturer vs. Consumer Subsidy with Green Technology Investment and Environmental Concern. *Eur J Oper Res* 287:832-843. <https://doi.org/10.1016/j.ejor.2020.05.014>
- Bian J, Guo X (2021) Policy analysis for emission-reduction with green technology investment in manufacturing. *Ann Oper Res* <https://doi.org/10.1007/s10479-021-04071-7>
- Bian JS, Zhao X (2020) Tax or subsidy? An analysis of environmental policies in supply chains with retail competition. *Eur J Oper Res* 283:901-914. <https://doi.org/10.1016/j.ejor.2019.11.052>
- Cao KY, Xu XP, Wu Q, Zhang QP (2017) Optimal production and carbon emission reduction level under cap-and-trade and low carbon subsidy policies. *J Clean Prod* 167:505-513. <https://doi.org/10.1016/j.jclepro.2017.07.251>
- Chen D, Ignatius J, Sun D, Zhan S, Zhou C, Marra M, Demirbag M (2019) Reverse logistics pricing strategy for a green supply chain: A view of customers' environmental awareness. *Int J Product Econ* 217:197-210. <https://doi.org/10.1016/j.ijpe.2018.08.031>
- Chen YJ, Sheu JB (2009) Environmental-regulation pricing strategies for green supply chain management. *Transp Res Pt e-Logist Transp Rev* 45:667-677. <https://doi.org/10.1016/j.tre.2009.04.010>
- China-GOV (2015) Notice on the Financial Support Policy for the Promotion and Application of New Energy Vehicles in 2016-2020. Ministry of Finance, Ministry of Science and Technology, Ministry of Industry and Information Technology and National Development and Reform Commission of the People's Republic of China
- China-MIIT (2020) Provisions on Administration of Access of New Energy Automobile Manufacturing Enterprises and Products. Department of Industrial Policies, Laws & Regulations Ministry of Industry and Information Technology of the People's Republic of China
- Choi TM, Guo S, Liu N, Shi XT (2020) Optimal pricing in on-demand-service-platform-operations with hired agents and risk-sensitive customers in the blockchain era. *Eur J Oper Res* 284:1031-1042. <https://doi.org/10.1016/j.ejor.2020.01.049>
- D'Aspremont C, Jacquemin A (1988) Cooperative and noncooperative R&D in duopoly with spillovers. *Amer Econ Rev* 78:1133-1137.
- Gao J, Xiao Z, Wei H, Zhou G (2018) Active or passive? Sustainable manufacturing in the direct-channel green supply chain: A perspective of two types of green product designs. *Transp Res D: Transp Environ* 65:332-354. <https://doi.org/10.1016/j.trd.2018.09.007>
- Gao J, Xiao Z, Wei H, Zhou G (2020) Dual-channel green supply chain management with eco-label policy: A perspective of two types of green products. *Comput Ind Eng* 146 <https://doi.org/10.1016/j.cie.2020.106613>
- Gao J, Xiao Z, Wei H (2021) Competition and coordination in a dual-channel green supply chain with an eco-label policy. *Comput Ind Eng* 153 <https://doi.org/10.1016/j.cie.2020.107057>
- Godil DI, Sharif A, Agha H, Jermisittiparsert K (2020) The dynamic nonlinear influence of ICT, financial development, and institutional quality on CO2 emission in Pakistan: new insights from QARDL approach. *Environ Sci Pollut Res* 27:24190-24200. <https://doi.org/10.1007/s11356-020-08619-1>
- Guo J, Huang R (2021) A carbon tax or a subsidy? Policy choice when a green firm competes with a high carbon emitter. *Environ Sci Pollut Res*:1-8. <https://doi.org/10.1007/s11356-020->

[12324-4](#)

- Hadi T, Chaharsooghi SK, Sheikhmohammady M, Hafezalkotob A (2020) Pricing strategy for a green supply chain with hybrid production modes under government intervention. *J Clean Prod* 268 <https://doi.org/10.1016/j.jclepro.2020.121945>
- He LY, Zhang LH, Zhong ZQ, Wang DQ, Wang F (2019a) Green credit, renewable energy investment and green economy development: empirical analysis based on 150 listed companies of China. *J Clean Prod* 208:363-372. <https://doi.org/10.1016/j.jclepro.2018.10.119>
- He P, He Y, Xu H (2019b) Channel structure and pricing in a dual-channel closed-loop supply chain with government subsidy. *Int J Product Econ* 213:108-123. <https://doi.org/10.1016/j.ijpe.2019.03.013>
- Hie G, Yue W, Wang S (2015) Optimal selection of cleaner products in a green supply chain with risk aversion. *J Ind Manag Optim* 11:515-528. <https://doi.org/10.3934/jimo.2015.11.515>
- Huang L, Zhen L, Yin L (2020a) Waste material recycling and exchanging decisions for industrial symbiosis network optimization. *J Clean Prod* 276:124073. <https://doi.org/10.1016/j.jclepro.2020.124073>
- Huang S, Fan Z-P, Wang N (2020b) Green subsidy modes and pricing strategy in a capital-constrained supply chain. *Transp Res Pt e-Logist Transp Rev* 136:101885. <https://doi.org/10.1016/j.tre.2020.101885>
- Huang Y, Liang Y (2021) Exploring the strategies of online and offline recycling channels in closed-loop supply chain under government subsidy. *Environ Sci Pollut Res*:1-12. <https://doi.org/10.1007/s11356-021-17396-4>
- Hunt SD, Morgan RM (1995) The comparative advantage theory of competition. *J. Marketing* 59:1-15.
- Isik C, Ongan S, Ozdemir D (2019a) The economic growth/development and environmental degradation: evidence from the US state-level EKC hypothesis. *Environ Sci Pollut Res* 26:30772-30781. <https://doi.org/10.1007/s11356-019-06276-7>
- Isik C, Ongan S, Ozdemir D (2019b) Testing the EKC hypothesis for ten US states: an application of heterogeneous panel estimation method. *Environ Sci Pollut Res* 26:10846-10853. <https://doi.org/10.1007/s11356-019-04514-6>
- Isik C, Ahmad M, Ongan S, Ozdemir D, Irfan M, Alvarado R (2021a) Convergence analysis of the ecological footprint: theory and empirical evidence from the USMCA countries. *Environ Sci Pollut Res* 28:32648-32659. <https://doi.org/10.1007/s11356-021-12993-9>
- Isik C, Ongan S, Ozdemir D, Ahmad M, Irfan M, Alvarado R, Ongan A (2021b) The increases and decreases of the environment Kuznets curve (EKC) for 8 OECD countries. *Environ Sci Pollut Res* 28:28535-28543. <https://doi.org/10.1007/s11356-021-12637-y>
- Isik C, Ongan S, Bulut U, Karakaya S, Irfan M, Alvarado R, Ahmad M, Rehman A (2022) Reinvestigating the Environmental Kuznets Curve (EKC) hypothesis by a composite model constructed on the Armey curve hypothesis with government spending for the US States. *Environ Sci Pollut Res* 29:16472-16483. <https://doi.org/10.1007/s11356-021-16720-2>
- Kahneman D, Knetsch JL, Thaler RH (1991) Anomalies: The endowment effect, loss aversion, and status quo bias. *J Econ Perspect* 5:193-206.
- Khan SAR, Sharif A, Golpira H, Kumar A (2019) A green ideology in Asian emerging economies: From environmental policy and sustainable development. *Sustain Dev* 27:1063-1075.

- <https://doi.org/10.1002/sd.1958>
- Khan SAR, Yu Z, Sharif A, Golpira H (2020) Determinants of economic growth and environmental sustainability in South Asian Association for Regional Cooperation: evidence from panel ARDL. *Environ Sci Pollut Res* 27:45675-45687. <https://doi.org/10.1007/s11356-020-10410-1>
- Koller T, Lovallo D, Williams Z (2012) Overcoming a bias against risk. *McKinsey Q* 4:15-17.
- Lan CF (2019) A GREEN SUPPLY CHAIN COORDINATION CONTRACT CONSIDERING LOSS AVERSION AND CARBON EMISSIONS. *Appl Ecol Environ Res* 17:9333-9346. https://doi.org/10.15666/aeer/1704_93339346
- Li B, Hou P-W, Chen P, Li Q-H (2016) Pricing strategy and coordination in a dual channel supply chain with a risk-averse retailer. *Int J Product Econ* 178:154-168. <https://doi.org/10.1016/j.ijpe.2016.05.010>
- Li P, Rao C, Goh M, Yang Z (2021) Pricing strategies and profit coordination under a double echelon green supply chain. *J Clean Prod* 278 <https://doi.org/10.1016/j.jclepro.2020.123694>
- Li YN, Tong Y, Ye F, Song JJ (2020) The choice of the government green subsidy scheme: innovation subsidy vs. product subsidy. *Int J Prod Res* 58:4932-4946. <https://doi.org/10.1080/00207543.2020.1730466>
- Luthra S, Mangla SK, Sarkis J, Tseng M-L (2022) Resources melioration and the circular economy: Sustainability potentials for mineral, mining and extraction sector in emerging economies. *Resources Pol* 77:102652. <https://doi.org/10.1016/j.resourpol.2022.102652>
- Ma W, Zhang R, Chai S (2019) What Drives Green Innovation? A Game Theoretic Analysis of Government Subsidy and Cooperation Contract. *Sustainability* 11 <https://doi.org/10.3390/su11205584>
- Meng Q, Li M, Liu W, Li Z, Zhang J (2021a) Pricing policies of dual-channel green supply chain: Considering government subsidies and consumers' dual preferences. *Sustainable Production and Consumption* 26:1021-1030. <https://doi.org/10.1016/j.spc.2021.01.012>
- Meng Q, Wang Y, Zhang Z, He Y (2021b) Supply chain green innovation subsidy strategy considering consumer heterogeneity. *J Clean Prod* 281 <https://doi.org/10.1016/j.jclepro.2020.125199>
- Nielsen IE, Majumder S, Saha S (2020) Game-Theoretic Analysis to Examine How Government Subsidy Policies Affect a Closed-Loop Supply Chain Decision. *Appl Sci* 10 <https://doi.org/10.3390/app10010145>
- Ongan S, Isik C, Bulut U, Karakaya S, Alvarado R, Irfan M, Ahmad M, Rehman A, Hussain I (2022) Retesting the EKC hypothesis through transmission of the ARMEY curve model: an alternative composite model approach with theory and policy implications for NAFTA countries. *Environ Sci Pollut Res* <https://doi.org/10.1007/s11356-022-19106-0>
- Porter ME (1974) Consumer behavior, retailer power and market performance in consumer goods industries. *The Review of Economics and Statistics*:419-436.
- Porter ME (2001) The value chain and competitive advantage. *Understanding business processes* 2:50-66.
- Raz G, Ovchinnikov A (2015) Coordinating pricing and supply of public interest goods using government rebates and subsidies. *IEEE Trans Eng Manage* 62:65-79. <https://doi.org/10.1109/tem.2014.2380999>

- Raza SA, Govindaluri SM (2019) Pricing strategies in a dual-channel green supply chain with cannibalization and risk aversion. *Oper Res Perspect* 6:100118. <https://doi.org/10.1016/j.orp.2019.100118>
- Razzaq A, Sharif A, Aziz N, Irfan M, Jermstittiparsert K (2020) Asymmetric link between environmental pollution and COVID-19 in the top ten affected states of US: A novel estimations from quantile-on-quantile approach. *Environ Res* 191:110189. <https://doi.org/10.1016/j.envres.2020.110189>
- Rong L, Xu M (2022) Impact of Altruistic Preference and Government Subsidy on the Multinational Green Supply Chain under Dynamic Tariff. *Environ Dev Sustain* 24:1928–1958. <https://doi.org/10.1007/s10668-021-01514-w>
- Sharif A, Afshan S, Qureshi MA (2019) Idolization and ramification between globalization and ecological footprints: evidence from quantile-on-quantile approach. *Environ Sci Pollut Res* 26:11191-11211. <https://doi.org/10.1007/s11356-019-04351-7>
- Sharif A, Bhattacharya M, Afshan S, Shahbaz M (2021) Disaggregated renewable energy sources in mitigating CO2 emissions: new evidence from the USA using quantile regressions. *Environ Sci Pollut Res* 28:57582-57601. <https://doi.org/10.1007/s11356-021-13829-2>
- Sheu JB, Chen YMJ (2012) Impact of government financial intervention on competition among green supply chains. *Int J Product Econ* 138:201-213. <https://doi.org/10.1016/j.ijpe.2012.03.024>
- Swami S, Shah J (2013) Channel coordination in green supply chain management. *J Oper Res Soc* 64:336-351. <https://doi.org/10.1057/jors.2012.44>
- Tseng M-L, Islam MS, Karia N, Fauzi FA, Afrin S (2019) A literature review on green supply chain management: Trends and future challenges. *Resour Conserv Recycl* 141:145-162. <https://doi.org/10.1016/j.resconrec.2018.10.009>
- Wang LY, Ye MH, Ma SS, Sha YP (2019) Pricing and coordination strategy in a green supply chain with a risk-averse retailer. *Math Probl Eng* 2019:7482080. <https://doi.org/10.1155/2019/7482080>
- Wang W, Zhang Y, Zhang W, Gao G, Zhang H (2021) Incentive mechanisms in a green supply chain under demand uncertainty. *J Clean Prod* 279 <https://doi.org/10.1016/j.jclepro.2020.123636>
- Wu T, Zhang L-G, Ge T (2019) Managing financing risk in capacity investment under green supply chain competition. *Technol Forecast Soc Change* 143:37-44. <https://doi.org/10.1016/j.techfore.2019.03.005>
- Xu CY, Wang CX, Huang RB (2020) Impacts of horizontal integration on social welfare under the interaction of carbon tax and green subsidies. *Int J Product Econ* 222:107506. <https://doi.org/10.1016/j.ijpe.2019.09.027>
- Xu T, Zhan J (2021) Green Product Design and Pricing Decisions in a Risk-Averse Supply Chain under Alternative Power Structures. *Math Probl Eng* 2021 <https://doi.org/10.1155/2021/1946215>
- Yang DY, Xiao TJ (2017) Pricing and green level decisions of a green supply chain with governmental interventions under fuzzy uncertainties. *J Clean Prod* 149:1174-1187. <https://doi.org/10.1016/j.jclepro.2017.02.138>
- Yang M, Gong X-m (2021) Optimal decisions and Pareto improvement for green supply chain considering reciprocity and cost-sharing contract. *Environ Sci Pollut Res*:1-16.

<https://doi.org/10.1007/s11356-021-12752-w>

- Yi YY, Li JX (2018) The effect of governmental policies of carbon taxes and energy-saving subsidies on enterprise decisions in a two-echelon Supply chain. *J Clean Prod* 181:675-691. <https://doi.org/10.1016/j.jclepro.2018.01.188>
- Zambrano-Monserrate MA, Ruano MA, Sanchez-Alcalde L (2020) Indirect effects of COVID-19 on the environment. *Sci Total Environ* 728:138813. <https://doi.org/10.1016/j.scitotenv.2020.138813>
- Zhang B, Yang Y, Bi J (2011) Tracking the implementation of green credit policy in China: top-down perspective and bottom-up reform. *J Environ Manage* 92:1321-1327. <https://doi.org/10.1016/j.jenvman.2010.12.019>
- Zhang X, Yousaf H (2020) Green supply chain coordination considering government intervention, green investment, and customer green preferences in the petroleum industry. *J Clean Prod* 246:118984. <https://doi.org/10.1016/j.jclepro.2019.118984>
- Zhao R, Neighbour G, Han JJ, McGuire M, Deutz P (2012) Using game theory to describe strategy selection for environmental risk and carbon emissions reduction in the green supply chain. *J Loss Prev Process Ind* 25:927-936. <https://doi.org/10.1016/j.jlp.2012.05.004>
- Zu Y, Deng D, Chen L (2021) Optimal control of carbon emission reduction strategies in supply chain with wholesale price and consignment contract. *Environ Sci Pollut Res*:1-16. <https://doi.org/10.1007/s11356-021-15080-1>

Appendix

Proof of Proposition 1.

It can be checked that the first and the second-order partial differentiation to P of Eq.(2) are as follows:

$$\begin{aligned}\partial U(\pi_r) / \partial p &= a - 2bp + kg + \omega b - 2\sigma^2 \eta_r (p - \omega) \\ \partial^2 U(\pi_r) / \partial p^2 &= -2(b + \sigma^2 \eta_r) < 0\end{aligned}$$

So the retailer's expected utility function is concave with respect to production price P . The optimal solution of the retailer's second-period optimization problem defined in Eq.(2) is obtained by solving $\partial U(\pi_r) / \partial p = 0$. After simplification,

$p_{WN} = \left[a + \omega(b + 2\sigma^2 \eta_r) + kg \right] / \left[2(b + \sigma^2 \eta_r) \right]$. Then the first partial differentiation to ω, g of Eq.(1) are as follows (observing P is a function of ω , that is $p = \omega + m$):

$$\begin{aligned}\partial U(\pi_m) / \partial \omega &= a - b(2\omega + m) + kg \\ \partial U(\pi_m) / \partial g &= \omega k - zg\end{aligned}$$

Since we have assumed that $bz - (k + bs)^2 > 0$, then $2bz - k^2 > 0$ comes true. The Hessian matrix $H = \begin{bmatrix} -2b & k \\ k & -z \end{bmatrix}$ is negatively definite. So, the expected utility $U(\pi_m)$ is concave in (ω, g) . Setting $\partial U(\pi_m) / \partial \omega = 0$ and $\partial U(\pi_m) / \partial g = 0$, and solving them simultaneously, we can obtain the optimal reaction functions:

$$\begin{aligned}\omega_{WN} &= z(a - bm) / (2bz - k^2) \\ g_{WN} &= k(a - bm) / (2bz - k^2)\end{aligned}$$

Combining ω_{WN}, g_{WN} and p_{WN} , we can obtain Proposition 1.

Proof of Proposition 2.

It can be checked that the first and the second-order partial differentiation to P of Eq.(2) are as follows:

$$\begin{aligned}\partial U(\pi_r) / \partial p &= a - 2bp + kg + \omega b - 2\sigma^2\eta_r(p - \omega) \\ \partial^2 U(\pi_r) / \partial p^2 &= -2(b + \sigma^2\eta_r) < 0\end{aligned}$$

So the retailer's expected utility function is concave with respect to production price P . The optimal solution of the retailer's second-period optimization problem defined in Eq.(2) is obtained by solving $\partial U(\pi_r) / \partial p = 0$. After simplification,

$p_{WM} = \left[a + \omega(b + 2\sigma^2\eta_r) + kg \right] / \left[2(b + \sigma^2\eta_r) \right]$. Substitute p_{WM} into Eq.(1) and solve the

Hessian matrix. The Hessian matrix is $H = \begin{bmatrix} -\frac{b(b + 2\sigma^2\eta_r)}{(b + \sigma^2\eta_r)} & k - \frac{bk}{2(b + \sigma^2\eta_r)} \\ k - \frac{bk}{2(b + \sigma^2\eta_r)} & -z \end{bmatrix}$. Then we have

$$\partial^2 U(\pi_m) / \partial \omega^2 < 0, \partial^2 U(\pi_m) / \partial g^2 < 0, \text{ and}$$

$\det H(\omega, g) = bz(b + 2\sigma^2\eta_r) / (b + \sigma^2\eta_r) - \left\{ k - bk / [2(b + \sigma^2\eta_r)] \right\}^2$. Since we have assumed that $bz - (k + bs)^2 > 0$, $4bz(b + \sigma^2\eta_r) - k^2(b + 2\sigma^2\eta_r) > 0$ is true. Then, setting $\partial U(\pi_m) / \partial \omega = 0$ and $\partial U(\pi_m) / \partial g = 0$, and solving them simultaneously, we can obtain ω_{WM}^*, g_{WM}^* . Proposition 2 can be further obtained.

Proof of Proposition 3.

It can be checked that the first partial differentiation to ω, g of Eq.(1) are as follows (observing P is a function of ω , that is $p = \omega + m$):

$$\begin{aligned}\partial U(\pi_m) / \partial \omega &= a - b(2\omega + m) + kg \\ \partial U(\pi_m) / \partial g &= \omega k - zg\end{aligned}$$

Same with the above, the Hessian matrix $H = \begin{bmatrix} -2b & k \\ k & -z \end{bmatrix}$ is negatively definite. So, the expected utility $\partial U(\pi_m)$ is concave in (ω, g) . Setting $\partial U(\pi_m) / \partial \omega = 0$ and $\partial U(\pi_m) / \partial g = 0$, and solving them simultaneously, we can obtain the optimal reaction functions:

$$\begin{aligned}\omega_{WR} &= z(a - bm) / (2bz - k^2) \\ g_{WR} &= k(a - bm) / (2bz - k^2)\end{aligned}$$

Substituting ω_{WR}, g_{WR} into Eq.(2), we have

$U(\pi_r)_{WR} = m \left[bz(a - bm) - m\sigma^2\eta_r(2bz - k^2) \right] / (2bz - k^2)$. The first-order and the second-order derivatives of $U(\pi_r)_{WR}$ are:

$$\begin{aligned}\partial U(\pi_r)_{WR} / \partial m &= \left[bz(a - 2bm) - 2m\sigma^2\eta_r(2bz - k^2) \right] / (2bz - k^2) \\ \partial^2 U(\pi_r)_{WR} / \partial m^2 &= -2 \left[b^2z + \sigma^2\eta_r(2bz - k^2) \right] / (2bz - k^2) < 0\end{aligned}$$

By solving the first-order condition $\partial U(\pi_r)_{WR} / \partial m = 0$ for m , we obtain

$$m_{WR}^* = abz / \left\{ 2 \left[b^2z + \sigma^2\eta_r(2bz - k^2) \right] \right\}$$

Finally, substituting m_{WR}^* into ω_{WR}, g_{WR} and p_{WR} , Proposition 3 can be obtained.

Proof of Proposition 4.

It can be checked that the first and the second-order partial differentiation to P of Eq.(2) are as follows:

$$\begin{aligned}\partial U(\pi_r) / \partial p &= a - 2bp + kg + \omega b - 2\sigma^2 \eta_r (p - \omega) \\ \partial^2 U(\pi_r) / \partial p^2 &= -2(b + \sigma^2 \eta_r) < 0\end{aligned}$$

So the retailer's expected utility function is concave with respect to production price P . The optimal solution of the retailer's second-period optimization problem defined in Eq.(2) is obtained by solving $\partial U(\pi_r) / \partial p = 0$. After simplification,

$p_{GN} = \left[a + \omega(b + 2\sigma^2 \eta_r) + kg \right] / \left[2(b + \sigma^2 \eta_r) \right]$. Then the first partial differentiation to ω, g of Eq.(1) is as follows (observing P is a function of ω , that is $p = \omega + m$):

$$\begin{aligned}\partial U(\pi_m) / \partial \omega &= a - b(2\omega + m) + kg \\ \partial U(\pi_m) / \partial g &= \omega k - zg\end{aligned}$$

The Hessian matrix $H = \begin{bmatrix} -2b & k \\ k & -z \end{bmatrix}$ is negatively definite. So, the expected utility $U(\pi_m)$

is concave in (ω, g) . Then, since $g_- \leq g$ needs to be satisfied, the problem becomes:

$$\begin{cases} \max U(\pi_m) \\ \text{s.t. } g_- - g \leq 0 \end{cases}$$

For the above problem, we construct the Lagrangian function

$L(\omega, g, \lambda, v) = U(\pi_m) + \lambda(g_- - g + v^2)$. Setting

$$\begin{aligned}\partial L(\omega, g, \lambda, v) / \partial \omega &= a - b(2\omega + m) + kg = 0 \\ \partial L(\omega, g, \lambda, v) / \partial g &= \omega k - zg - \lambda = 0 \\ \partial L(\omega, g, \lambda, v) / \partial \lambda &= g_- - g + v^2 = 0 \\ \partial L(\omega, g, \lambda, v) / \partial v &= 2v\lambda = 0\end{aligned}$$

Then solving them simultaneously, we can obtain the optimal reaction functions

$$\begin{aligned}\omega_{GN1} = \omega_{GN3} &= z(a - bm) / (2bz - k^2), \omega_{GN2} = (a - bm + kg) / (2b) \\ g_{GN1} = g_{GN3} &= k(a - bm) / (2bz - k^2), g_{GN2} = g_- \\ \lambda_{GN1} = \lambda_{GN3} &= 0, \lambda_{GN2} = \left[k(a - bm) - g_-(2bz - k^2) \right] / (2b) \\ v_{GN1} &= \left\{ \left[k(a - bm) - g_-(2bz - k^2) \right] / (2bz - k^2) \right\}^{\frac{1}{2}}, \\ v_{GN2} = 0, v_{GN3} &= -\left\{ \left[k(a - bm) - g_-(2bz - k^2) \right] / (2bz - k^2) \right\}^{\frac{1}{2}}\end{aligned}$$

Besides, only when $g \leq \sqrt[2]{2\omega(a - bp + kg)} / z$, the manufacturer can achieve profitability.

Therefore, combining $\omega_{GN1}, g_{GN1}; \omega_{GN2}, g_{GN2}$ and p_{GN} , we can obtain Proposition 4.

Proof of Proposition 5.

It can be checked that the first and the second-order partial differentiation to P of Eq.(2) are as follows:

$$\begin{aligned}\partial U(\pi_r) / \partial p &= a - 2bp + kg + \omega b - 2\sigma^2 \eta_r (p - \omega) \\ \partial^2 U(\pi_r) / \partial p^2 &= -2(b + \sigma^2 \eta_r) < 0\end{aligned}$$

So the retailer's expected utility function is concave with respect to production price P . The optimal solution of the retailer's second-period optimization problem defined in Eq.(2) is obtained by solving $\partial U(\pi_r) / \partial p = 0$. After simplification,

$p_{GM} = \left[a + \omega(b + 2\sigma^2\eta_r) + kg \right] / \left[2(b + \sigma^2\eta_r) \right]$. Substitute p_{GM} into Eq.(1) and solve the Hessian matrix. The Hessian matrix is

$$H = \begin{bmatrix} -\frac{b(b + 2\sigma^2\eta_r)}{(b + \sigma^2\eta_r)} & k - \frac{bk}{2(b + \sigma^2\eta_r)} \\ k - \frac{bk}{2(b + \sigma^2\eta_r)} & -z \end{bmatrix}. \text{ Then we have } \partial^2 U(\pi_m) / \partial \omega^2 < 0, \partial^2 U(\pi_m) / \partial g^2 < 0,$$

and $\det H(\omega, g) = bz(b + 2\sigma^2\eta_r) / (b + \sigma^2\eta_r) - \left\{ k - bk / \left[2(b + \sigma^2\eta_r) \right] \right\}^2$. Since we have assumed that $bz - (k + bs)^2 > 0$, then $4bz(b + \sigma^2\eta_r) - k^2(b + 2\sigma^2\eta_r) > 0$ comes true. Then, since $g_- \leq g$ is to be satisfied, the problem becomes:

$$\begin{cases} \max U(\pi_m) \\ \text{s.t. } g_- - g \leq 0 \end{cases}$$

For the above problem, we construct the Lagrangian function

$$L(\omega, g, \lambda, v) = U(\pi_m) + \lambda(g_- - g + v^2). \text{ Setting}$$

$$\partial L(\omega, g, \lambda, v) / \partial \omega = (b + 2\sigma^2\eta_r)(a + kg - 2b\omega) / \left[2(b + \sigma^2\eta_r) \right] = 0$$

$$\partial L(\omega, g, \lambda, v) / \partial g = k\omega(b + 2\sigma^2\eta_r) / \left[2(b + \sigma^2\eta_r) \right] - zg - \lambda = 0$$

$$\partial L(\omega, g, \lambda, v) / \partial \lambda = g_- - g + v^2 = 0$$

$$\partial L(\omega, g, \lambda, v) / \partial v = 2v\lambda = 0$$

Then solving them simultaneously, we can obtain the optimal reaction functions

$$\omega_{GM1} = \omega_{GM3} = 2az(b + \sigma^2\eta_r) / \left[4bz(b + \sigma^2\eta_r) - k^2(b + 2\sigma^2\eta_r) \right], \omega_{GM2} = (a + kg_-) / (2b)$$

$$g_{GM1} = g_{GM3} = ak(b + 2\sigma^2\eta_r) / \left[4bz(b + \sigma^2\eta_r) - k^2(b + 2\sigma^2\eta_r) \right], g_{GM2} = g_-$$

$$\lambda_{GM1} = \lambda_{GM3} = 0, \lambda_{GM2} = \left[k(a + g_-k)(b + 2\sigma^2\eta_r) - 4g_-zb(b + \sigma^2\eta_r) \right] / \left[4b(b + \sigma^2\eta_r) \right]$$

$$v_{GM1} = \left\{ \left[k(a + g_-k)(b + 2\sigma^2\eta_r) - 4g_-zb(b + \sigma^2\eta_r) \right] / \left[4bz(b + \sigma^2\eta_r) - k^2(b + 2\sigma^2\eta_r) \right] \right\}^{\frac{1}{2}}, v_{GM2} = 0,$$

$$v_{GM3} = - \left\{ \left[k(a + g_-k)(b + 2\sigma^2\eta_r) - 4g_-zb(b + \sigma^2\eta_r) \right] / \left[4bz(b + \sigma^2\eta_r) - k^2(b + 2\sigma^2\eta_r) \right] \right\}^{\frac{1}{2}}$$

Besides, only when $g \leq \sqrt[3]{2\omega(a - bp + kg)} / z$, the manufacturer can achieve profitability.

Therefore, combining $\omega_{GM1}, g_{GM1}; \omega_{GM2}, g_{GM2}$ and p_{GM} , we can obtain proposition 5.

Proof of Proposition 6.

It can be checked that the first partial differentiation to ω, g of Eq.(1) is as follows (observing P is a function of ω , that is $p = \omega + m$):

$$\partial U(\pi_m) / \partial \omega = a - b(2\omega + m) + kg$$

$$\partial U(\pi_m) / \partial g = \omega k - zg$$

The Hessian matrix $H = \begin{bmatrix} -2b & k \\ k & -z \end{bmatrix}$ is negatively definite. Since $g_- \leq g$ needs to be

satisfied, the problem becomes

$$\begin{cases} \max U(\pi_m) \\ \text{s.t. } g_- - g \leq 0 \end{cases}$$

For the above problem, we construct the Lagrangian function

$$L(\omega, g, \lambda, v) = U(\pi_m) + \lambda(g_- - g + v^2). \text{ Setting}$$

$$\partial L(\omega, g, \lambda, v) / \partial \omega = a - b(2\omega + m) + kg = 0$$

$$\partial L(\omega, g, \lambda, v) / \partial g = \omega k - zg - \lambda = 0$$

$$\partial L(\omega, g, \lambda, v) / \partial \lambda = g_- - g + v^2 = 0$$

$$\partial L(\omega, g, \lambda, v) / \partial v = 2v\lambda = 0$$

Then solving them simultaneously, we can obtain the optimal reaction functions

$$\omega_{GR1} = \omega_{GR3} = z(a - bm) / (2bz - k^2), \omega_{GR2} = (a - bm + kg) / (2b)$$

$$g_{GR1} = g_{GR3} = k(a - bm) / (2bz - k^2), g_{GR2} = g_-$$

$$\lambda_{GR1} = \lambda_{GR3} = 0, \lambda_{GR2} = [k(a - bm) - g_-(2bz - k^2)] / (2b)$$

$$v_{GR1} = \left\{ [k(a - bm) - g_-(2bz - k^2)] / (2bz - k^2) \right\}^{\frac{1}{2}}, v_{GR2} = 0, v_{GR3} = -\left\{ [k(a - bm) - g_-(2bz - k^2)] / (2bz - k^2) \right\}^{\frac{1}{2}}$$

Substituting $\omega_{GR1}, \omega_{GR2}, g_{GR1}, g_{GR2}$ into Eq.(2), we have

$$U(\pi_r)_{GR1} = m \left[bz(a - bm) - m(2bz - k^2)\sigma^2\eta_r \right] / (2bz - k^2)$$

$$U(\pi_r)_{GR2} = m \left[(a + kg_-) - m(b + 2\sigma^2\eta_r) \right] / 2$$

The first-order and the second-order derivatives of $U(\pi_r)_{GR1}$ and $U(\pi_r)_{GR2}$ are

$$\partial U(\pi_r)_{GR1} / \partial m = [bz(a - 2bm) - 2m(2bz - k^2)\sigma^2\eta_r] / (2bz - k^2)$$

$$\partial U(\pi_r)_{GR2} / \partial m = (a + kg_-) / 2 - m(b + 2\sigma^2\eta_r)$$

$$\partial^2 U(\pi_r)_{GR1} / \partial m^2 = -[2b^2z + 2(2bz - k^2)\sigma^2\eta_r] / (2bz - k^2) < 0$$

$$\partial^2 U(\pi_r)_{GR2} / \partial m^2 = -(b + 2\sigma^2\eta_r) < 0$$

By solving the first-order condition $\partial U(\pi_r) / \partial m = 0$ for m , we obtain

$$m_{GR1} = abz / \left\{ 2[b^2z + (2bz - k^2)\sigma^2\eta_r] \right\}$$

$$m_{GR2} = (a + kg_-) / [2(b + 2\sigma^2\eta_r)]$$

Then, substituting m_{GR1}, m_{GR2} into $\omega_{GR1}, g_{GR1}, p_{GR1}$ and $\omega_{GR2}, g_{GR2}, p_{GR2}$. Besides, as the manufacturer's utility must be greater than or equal to 0, we have $g_- \leq g \leq \sqrt[2]{2\omega(a - bp + kg)} / z$.

Combined with the value of g , we can get Proposition 6.

The solution process of Proposition 7 is like Proposition 1.

The solution process of Proposition 8 is like Proposition 2.

The solution process of Proposition 9 is like Proposition 3.

The solution process of Proposition 10 is like Proposition 4.

The solution process of Proposition 11 is like Proposition 5.

The solution process of Proposition 12 is like Proposition 6.

Proof of Corollary 9.

The relationships between variables among three power structures under different scenarios can be obtained by subtracting the corresponding values. Here we take the proof of

$$g_{WM}^* < g_{WR}^* < g_{WN}^* \text{ as an example.}$$

Firstly, let's subtract g_{WR}^* from g_{WN}^* , we can obtain:

$$\begin{aligned}
g_{WN}^* - g_{WR}^* &= \frac{ak(b + 2\sigma^2\eta_r)}{bz(3b + 4\sigma^2\eta_r) - k^2(b + 2\sigma^2\eta_r)} - \frac{ak[bz(b + 4\sigma^2\eta_r) - 2k^2\sigma^2\eta_r]}{2(2bz - k^2)[bz(b + 2\sigma^2\eta_r) - k^2\sigma^2\eta_r]} \\
&= \frac{ab^3kz(bz - k^2)}{[bz(3b + 4\sigma^2\eta_r) - k^2(b + 2\sigma^2\eta_r)]\{2(2bz - k^2)[bz(b + 2\sigma^2\eta_r) - k^2\sigma^2\eta_r]\}}
\end{aligned}$$

Since we have assumed that $bz - (k + bs)^2 > 0$, $bz - k^2 > 0$ is true. We can conclude that

$$g_{WN}^* > g_{WR}^* ;$$

Secondly, let's subtract g_{WR}^* from g_{WM}^* , we can obtain:

$$\begin{aligned}
g_{WR}^* - g_{WM}^* &= \frac{ak[bz(b + 4\sigma^2\eta_r) - 2k^2\sigma^2\eta_r]}{2(2bz - k^2)[bz(b + 2\sigma^2\eta_r) - k^2\sigma^2\eta_r]} - \frac{ak(b + 2\sigma^2\eta_r)}{4bz(b + \sigma^2\eta_r) - k^2(b + 2\sigma^2\eta_r)} \\
&= \frac{ab^2kz[bk^2 + 2(2bz - k^2)\sigma^2\eta_r]}{[4bz(b + \sigma^2\eta_r) - k^2(b + 2\sigma^2\eta_r)]\{2(2bz - k^2)[bz(b + 2\sigma^2\eta_r) - k^2\sigma^2\eta_r]\}}
\end{aligned}$$

We also can conclude that $g_{WR}^* > g_{WM}^*$;

Finally, the result of $g_{WM}^* < g_{WR}^* < g_{WN}^*$ is proven.

Proof of Corollary 10.

The impact of the retailer's risk aversion coefficient on the optimal decisions and expected utilities in different power structures and different scenarios can be obtained through taking its first derivative of risk aversion. Here we take the proof of $\partial\omega_{WN}^* / \partial\eta_r > 0$ as an example.

$$\begin{aligned}
\frac{\partial\omega_{WN}^*}{\partial\eta_r} &= \frac{\partial\{az(b + 2\sigma^2\eta_r) / [bz(3b + 4\sigma^2\eta_r) - k^2(b + 2\sigma^2\eta_r)]\}}{\partial\eta_r} \\
&= \frac{2ab^2z^2\sigma^2}{[bz(3b + 4\sigma^2\eta_r) - k^2(b + 2\sigma^2\eta_r)]^2} > 0
\end{aligned}$$

We can conclude that $\partial\omega_{WN}^* / \partial\eta_r > 0$ is true.

BRIEF AUTHOR BIOGRAPHY:



Li Tang is a Ph.D. candidate in the Department of Business Administration at Tongji University. Her current research interests are green supply chain, online consumer behavior, and sharing economy (mmtangli@foxmail.com).



Eldon Y. Li is Chair Professor of Information Management in National Chung Cheng University in Taiwan and Emeritus Professor of MIS, Cal Poly, San Luis Obispo, USA. He has published over 300 papers on innovation and technology management, human factors in information technology (IT), strategic IT planning, software quality management, and information systems management (eli@calpoly.edu).



Peipei Wu is a lecturer in the College of Business Administration at Shanghai Business School. She received Ph.D. in Urban Economy and Management in 2017 from Tongji University. Her current research interests are green economy and green supply chain (wupp@sbs.edu.cn).



Jiang Jiang is a lecturer in the College of Business Administration at Shanghai Business School. She received her Ph.D. degree in Business Administration from Tongji University in 2020. Her current research interests are green supply chain, collaborative consumption, crowdsourcing, and online consumer behavior.

Optimal Decisions for Green Supply Chain with Risk-Averse Retailer under Government Intervention

Highlights

- Product access (i.e., the minimum greenness requirement for products entering the market) could be effective only if it exceeds a certain threshold.
- Government interventions in both effective product access and financial subsidy help incentivize sustainable production.
- A reasonable degree of risk aversion from the retailer is conducive to sustainable production.
- The risk-averse retailer tends to respond to uncertainty by lowering the retail price.
- When the government sets effective product access, the optimal greenness is only affected by the government intervention but not the retailer's risk aversion.