Government subsidy strategy selection in competing supply chains under green manufacturers’ risk aversion

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Abstract

Purpose – This paper investigates how the government selects demand-side promotional subsidy strategies in a market where a green supply chain competes with a conventional supply chain and the green manufacturer is risk-averse. It focuses on analyzing the government’s choice among no-subsidy, price-subsidy and the green-subsidy policies under different expenditure-benefit objectives.

Design/methodology/approach – This study develops a game-theoretic model of competing supply chains, in which inter-chain competition is modeled as Cournot competition and intra-chain interaction as a manufacturer-led Stackelberg game. The green manufacturer’s risk-averse behavior is characterized using a mean-variance model. A comparative policy analysis is conducted under equal-expenditure conditions and is further extended to a policy space with unequal expenditures.

Findings – Under equal subsidy expenditure, the green-subsidy policy yields the highest environmental benefit, whereas the no-subsidy policy performs best in terms of economic benefit. When the government’s comprehensive benefit is considered, the green-subsidy policy should be preferred at low subsidy levels. In contrast, the no-subsidy policy becomes more desirable at moderate or high subsidy levels. Under unequal subsidy expenditure, the optimal policy choice depends on the government’s expenditure-benefit objectives and is determined by a policy space partitioned by iso-expenditure curves and iso-benefit curves.

Originality/value – This study integrates competition between a green supply chain and a conventional supply chain, the green manufacturer’s risk-averse behavior and the selection of demand-side promotional subsidy strategies into a single theoretical framework. By distinguishing between equal and unequal subsidy expenditures, this study derives the policy selection rules under different objectives and provides a clear basis for designing government subsidy schemes under fiscal constraints and market uncertainty.

Keywords Competing supply chains, Green manufacturers, Risk aversion, Green promotional subsidy strategy

Paper type Research article

1. Introduction

As China’s economy transitions from rapid to high-quality growth, promoting green production and consumption has become central to sustainable economic and social development (Xi, 2022). To this end, the government has introduced policies to encourage green consumption and accelerate the manufacturing sector’s green transition. Yet enterprises still face volatile demand, market competition and high R&D costs for green technologies.

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Subsequently, policies such as the "Guidelines for Improving Supply Chain Management in Manufacturing Enterprises (Trial)" and the "Guiding Opinions on Accelerating the Green Development of the Manufacturing Sector" were introduced. Although these policies guide green production and consumption, enterprises still face multiple challenges in their green transition. Green production entails considerable uncertainty and investment risks: Mercedes-Benz's first pure electric vehicle, the EQC, sold fewer than 100 units per month for seven consecutive months following its 2023 launch, and in September 2024, Volvo abandoned its 2030 full-electrification target, opting to retain some hybrid models.

To this end, the government has introduced consumer-oriented green promotion policies to drive manufacturers' green transformation from the demand side. For instance, consumers purchasing green products receive price subsidies. In 2024, Shanghai issued the "Implementation Rules for the Subsidy Policy Supporting Green and Smart Home Appliance and Furnishing Consumption", which stipulate that consumers purchasing covered products receive a 15% subsidy on the sales price (Shanghai Municipal Commission of Commerce *et al.*, 2024).

Another common policy provides subsidies contingent on product greenness. For instance, the 2020 "Notice on Further Improving Fiscal Subsidy Policies for the Promotion and Application of New Energy Vehicles" stipulates subsidies of 8,500 yuan, 16,200 yuan and 22,500 yuan for purchasers of pure electric passenger vehicles, corresponding to driving ranges of 50 km $\leq R <$ 300 km, 300 km $\leq R <$ 400 km and $R \geq$ 400 km, respectively (Ministry of Finance of the People's Republic of China, 2020).

Although government subsidies have been widely used to promote green production and consumption, designing subsidy policies remains challenging. The price-subsidy policy lowers consumers' purchasing costs, whereas the green-subsidy policy ties the subsidy amount to product greenness. Both policies, however, require fiscal outlays and the additional environmental or economic benefits they generate may not fully cover the fiscal cost. Given fiscal constraints and market uncertainty, the government must determine which policy instrument more effectively achieves its stated objectives: typically economic benefit, environmental benefit, or comprehensive benefit. Thus, when fiscal resources are limited, the no-subsidy policy also remains a relevant option.

Meanwhile, green products in many markets must compete directly with conventional products that enjoy greater market acceptance. Green manufacturers may view government incentives with caution, as higher product greenness entails greater investment risk. Overlooking this characteristic may bias the estimation of government subsidy effectiveness. Therefore, it is crucial to explore how governments should choose among green promotion policies while considering both differentiated objectives and green manufacturers' risk-averse characteristics.

2. Literature review

2.1 Supply chain competition and decision-making

As market competition intensifies, rivalry extends from individual firms to entire supply chains. Hamidoğlu and Weber (2024) developed a Nash-based model for agricultural supply chain management. Jamali and Rasti-Barzoki (2018) examined market competition between green and non-green products. Liu and Ji (2017) analyzed how supply chain competition affects product selection and pricing in two competing supply chains. Chang *et al.* (2022) investigated the impact of inter-supply-chain competition on chain decisions and profits. Pal *et al.* (2025) studied optimal pricing and promotional effort strategies in a competitive live-streaming supply chain. These studies establish the foundational role of inter-chain rivalry in shaping operational decisions and market outcomes.

Another strand of research extends this perspective to broader sustainability-oriented strategic choices. Shi *et al.* (2020) explored the game-theoretic equilibrium of corporate social responsibility in competing supply chains. Deng *et al.* (2020) examined the interactive effects of supply chain competition on product sustainability strategies and profit objectives.

Recent studies have also explored strategic interactions involving information sharing, service competition and multi-agent coordination. Luo *et al.* (2023) examined the value transfer pathways of green service information sharing between manufacturers in competing green supply chains. Yang *et al.* (2025) developed a multi-agent dynamic game model incorporating dual competition in price and service level. Hamidoğlu *et al.* (2026) developed a game-theoretic framework for constructing a green and sustainable power grid, highlighting strategic interactions among multiple stakeholders in sustainable energy systems.

As the manufacturing sector undergoes a green transition, supply chain competition increasingly involves not only price and service but also environmental attributes. However, most existing studies focus on pricing strategies, service competition, or information sharing, with limited attention to the competition between a green supply chain and a conventional supply chain.

2.2 Risk aversion of green manufacturers in supply chains

Firms' risk-averse attitudes toward environmental policies are widely observed under uncertainty. Hamidoğlu *et al.* (2025) examined energy taxation policy for sustainable transitions in Canada using a dual cooperative game and stochastic frontier approach. Sana (2026) examined demand estimation in EOQ models using second-order difference equations with full backlogging, underscoring its relevance for modeling firm decisions under uncertain markets.

Uncertainty about consumer acceptance in green product markets induces risk-averse behavior among green manufacturers. Prior work has examined this issue extensively. Zou *et al.* (2022) studied how manufacturers' risk aversion affects emission reduction and pricing in low-carbon supply chains. Cai *et al.* (2026) analyzed the impact of both manufacturers' and retailers' risk aversion on optimal decisions and utility in green supply chains. Yang *et al.* (2018) and Wang and He (2018) explored the effects of risk aversion on supply chain benefits. Qin *et al.* (2025) further investigated how varying risk tolerance levels influence system operations under different insurance policies.

However, most of these studies focus on a single supply chain, with limited attention to the risk-averse behavior of green manufacturers in competitive supply chain settings.

2.3 Government green-subsidy policies and policy choice

A growing number of studies have examined how government green intervention policies affect supply chain decisions and policy outcomes. Chemama *et al.* (2019) found that variable subsidies are more effective than fixed subsidies in promoting green technology development. Zhang *et al.* (2020) compared carbon tax policies, subsidy policies and a mixed policy of carbon taxes and subsidies.

Another stream of research focuses on how subsidy forms or subsidy recipients affect supply chain decisions and strategy. Wang *et al.* (2024) compared the effects of subsidizing manufacturers versus subsidizing recyclers on decision-making, consumer surplus and social welfare in closed-loop supply chains. Shang *et al.* (2024) investigated the effectiveness of one-time and per-unit subsidies for green manufacturers. Tang *et al.* (2024) explored the impacts of trade-in subsidies and consumption subsidies on different stakeholders.

A growing body of literature has addressed uncertainty and environmental complexity. Soltani *et al.* (2024) suggested that strategic decisions should account for uncertainty, environmental complexity and future-oriented adaptability. Hamidoğlu and Wang (2026) proposed an efficiency-enhanced carbon tax rebate allocation framework based on a translog-evolutionary game approach, linking rebate allocation to firm-level efficiency, workforce performance and R&D-oriented indicators.

However, most extant policy literature adopts a single-objective framework. Limited research has focused on promotional subsidies for green products.

In summary, the existing literature has three limitations. First, most studies lack adequate incorporation of competition between green and conventional supply chains. Second, insufficient attention has been paid to green manufacturers' risk-averse behavior and its influence on equilibrium decisions in competing supply chains. Third, studies that simultaneously compare the no-subsidy policy, the price-subsidy policy and the green-subsidy policy, while accounting for both subsidy expenditure and multiple policy objectives, remain limited. To address these gaps, this paper investigates government subsidy strategy selection under competition between a green and a conventional supply chain, with a focus on the green manufacturer's risk-averse behavior. See Table 1.

3. Problem description and assumptions

3.1 Problem description

Consider a market with two supply chains: a conventional one and a green one. Each consists of a manufacturer and a retailer. Because the two chains offer functionally similar products, they compete in the market. This system features both inter-chain competition and intra-chain interaction. Inter-chain competition is modeled as a duopoly Cournot game with simultaneous decisions by the two chains. Intra-chain interaction is modeled as a manufacturer-led Stackelberg game, where the manufacturer first determines product greenness and wholesale price and the retailer then sets the retail price.

Green products are environmentally friendly and innovative products promoted by the government. Although consumers exhibit some green preference, demand for green products

Table 1. Comparison with existing literature and research gaps

Author(s)	Supply chain competition	Risk/ Uncertainty	Government policy	Policy comparison	Other
Jamali and Rasti-Barzoki (2018)	√				Green/non-green pricing
Liu and Ji (2017)	√				Green preference
Chang *et al.* (2022)	√				Green degree choice
Pal *et al.* (2025)	√				Pricing/promotional effort
Yang *et al.* (2025)	√	√			Price-service competition
Hamidoğlu and Weber (2024)	√		√		Low-carbon agricultural supply chain
Yang *et al.* (2018)		√			Push-pull model
Wang and He (2018)		√			Abatement outsourcing
Zou *et al.* (2022)		√			Carbon quota
Sana (2026)		√			Demand estimation
Cai *et al.* (2026)		√			Information sharing
Hamidoğlu *et al.* (2025)		√	√		Energy taxation
Chemama *et al.* (2019)		√	√	√	Consumer subsidy
Zhang *et al.* (2020)			√	√	Tax-subsidy policy
Wang *et al.* (2024)			√	√	CLSC subsidy
Tang *et al.* (2024)			√	√	Trade-in subsidy
This paper	√	√	√	√	Green subsidy selection

is more uncertain than that for conventional products with stronger market acceptance, owing to their innovativeness, high costs and insufficient market validation. Green manufacturers thus typically exhibit risk-averse attitudes toward producing green products. To encourage green production, the government provides demand-side promotional subsidies for green products. The available options include the price-subsidy policy (a discount based on retail price) and the green-subsidy policy (a subsidy based on product greenness). Alternatively, the government may choose not to subsidize.

Under multiple objectives that include limited fiscal expenditure, environmental benefit, economic benefit and comprehensive benefit, the government may pursue different goals, for instance, more benefit with more subsidies, lower benefit with fewer subsidies, more benefit with fewer subsidies, maximum benefit under equal expenditure, or minimum expenditure under equal benefit. Thus, given market and demand conditions, how the government selects from available promotional subsidy policies according to its objectives becomes a critical issue. Figure 1 illustrates the structure of supply chain competition under subsidy policies.

3.2 Parameters of the model

The parameters of the model are shown in Table 2.

3.3 Assumptions

Assumption 1. The government may adopt one of three promotional subsidy policies for the green product: the no-subsidy policy (O), the price-subsidy policy (P) and the green-subsidy policy (G). The price-subsidy policy is linked to the retail price of the green product, whereas the green-subsidy policy is linked to the greenness level of the green product. Under the price-subsidy policy, the subsidy amount per unit of product is μp_g^P. Under the green-subsidy policy, the subsidy amount per unit of product is $\tau\theta_g^G$ (Wu *et al.*, 2023). The demand for the conventional product and the green product are given by:

$$D_n^O = a - p_n^O + \beta p_g^O - \gamma\theta_g^O,$$

$$D_g^O = a - p_g^O + \beta p_n^O + \gamma\theta_g^O + \varepsilon.$$

Under the price-subsidy policy, consumers receive a subsidy of μp_g^P per unit of green product. The demand for the conventional product and the green product are given by:

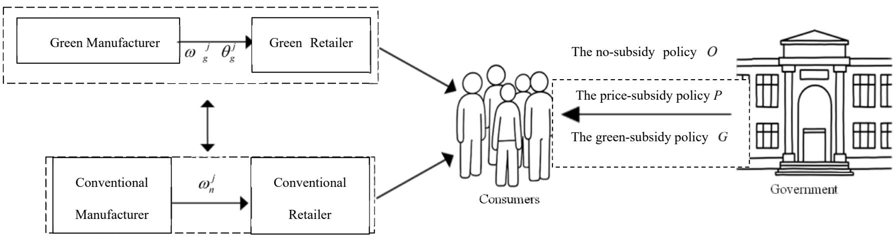

Figure 1. Competitive structure of green and conventional supply chains under green promotional subsidy policies

Table 2. Parameters of the model

Symbol	Definition	Symbol	Definition
a	Basic market demand, $a > 0$	τ	Subsidy amount per unit of product greenness
ε	Random demand caused by market uncertainty	$\pi_{M_i}^j$	Profit of the manufacturer in supply chain i under subsidy policy j
σ	Standard deviation of random market demand, $\sigma > 0$	$E(\pi_{M_i}^j)$	Expected profit of the green manufacturer in supply chain i under subsidy policy j
β	Competition intensity between supply chains, $0 < \beta < 1$	$U(\pi_{M_i}^j)$	Utility of the green manufacturer in supply chain i under subsidy policy j
γ	Consumers' green preference coefficient, $0 < \gamma < 1$	$\pi_{R_i}^j$	Profit of the retailer in supply chain i under subsidy policy j
D_i^j	Market demand of the product of supply chain i under subsidy policy j	$E(\pi_{R_i}^j)$	Expected profit of the green retailer in supply chain i under subsidy policy j
θ_g^j	Greenness level of the green product under subsidy policy j; decision variable	π_i^j	Profit of supply chain i under subsidy policy j
ω_i^j	Wholesale price of the product in supply chain i under subsidy policy j; decision variable	s^j	Government subsidy amount under subsidy policy j
p_i^j	Retail price of the product in supply chain i under subsidy policy j; decision variable	π_H^j	Environmental benefit under subsidy policy j
φ	Risk-aversion coefficient of the green manufacturer	π_J^j	Economic benefit under subsidy policy j
μ	Subsidy coefficient of the product retail price	π_Z^j	Comprehensive benefit under subsidy policy j

Note(s): $i = n, g$ denote the conventional supply chain and the green supply chain, respectively; $j = O, P, G$ denote the no-subsidy policy, the price-subsidy policy, and the green-subsidy policy, respectively

$$D_n^P = a - p_n^P + \beta\left(p_g^P - \mu p_g^P\right) - \gamma\theta_g^P,$$

$$D_g^P = a - \left(p_g^P - \mu p_g^P\right) + \beta p_n^P + \gamma\theta_g^P + \varepsilon.$$

Under the green-subsidy policy, consumers receive a subsidy of $\tau\theta_g^G$ per unit of green product. The demand for the conventional product and the green product are given by:

$$D_n^G = a - p_n^G + \beta\left(p_g^G - \tau\theta_g^G\right) - \gamma\theta_g^G,$$

$$D_g^G = a - \left(p_g^G - \tau\theta_g^G\right) + \beta p_n^G + \gamma\theta_g^G + \varepsilon.$$

Assumption 2. The green manufacturer enhances product greenness by investing in green technology. The investment cost of green technology is assumed to be $c = k\theta_g^2$ (Feng *et al.*, 2022), which is a one-time investment fully borne by the green manufacturer. Without affecting the results, let $k = 1$ (Cao *et al.*, 2019).

Assumption 3. Following Feng *et al.* (2022), the mean-variance framework is used to describe the risk-averse behavior of the green manufacturer. The utility of the green manufacturer is defined as:

$$U_M = E(\pi_M) - \varphi\sqrt{Var(\pi_M)}$$

Assumption 4. Without affecting the results, the manufacturer's unit production cost and the retailer's selling cost are both assumed to be 0 (Gao *et al.*, 2021; Arya *et al.*, 2007).

Assumption 5. The government's environmental benefit is defined as: $\pi_H^j = \theta_g^j D_g^j$ (setting the value of one unit of the greenness of the green product equal to 1). Economic benefit is defined as: $\pi_J^j = \pi_n^j + U(\pi_{Mg}^j) + E(\pi_{Rg}^j) - s^j$.

Under the no-subsidy policy, the government provides no subsidy and therefore $s^O = 0$. Under the price-subsidy policy, the total subsidy expenditure is the unit price subsidy multiplied by the expected demand for the green product:

$$s^P = \mu p_g^P \left(a - \left(p_g^P - \mu p_g^P\right) + \beta p_n^P + \gamma\theta_g^P\right)$$

Under the green-subsidy policy, the total subsidy expenditure is the unit green subsidy multiplied by the expected demand for the green product:

$$s^G = \tau\,\theta_g^G \left(a - \left(p_g^G - \tau\theta_g^G\right) + \beta p_n^G + \gamma\theta_g^G\right)$$

Comprehensive benefit is defined as $\pi_Z^j = \pi_H^j + \pi_J^j$ (Arya *et al.*, 2007).

Under supply chain competition, the manufacturer and retailer in the conventional supply chain both take profit maximization as their decision objective. In the green supply chain, the green manufacturer takes utility maximization as its decision objective, while the green retailer takes expected profit maximization as its decision objective. The green manufacturer's contribution to economic benefit is measured by its risk-adjusted utility.

4. Model construction and solution

4.1 The no-subsidy policy scenario (O)

The conventional manufacturer sells products to the conventional retailer at a wholesale price ω_n^O. In the green supply chain, the green manufacturer's payoff consists of wholesale revenue, green technology investment cost and risk cost. The green retailer's expected profit equals the unit profit margin $p_g^O - \omega_g^O$ multiplied by the expected demand for green products.

The profit functions of the conventional manufacturer and the conventional retailer, as well as the utility function of the green manufacturer and the expected profit function of the green retailer, are given as follows:

$$\pi_{M_n}^O = \omega_n^O * \left(a - p_n^O + \beta p_g^O - \gamma\theta_g^O\right)$$

$$\pi_{R_n}^O = \left(p_n^O - \omega_n^O\right) * \left(a - p_n^O + \beta p_g^O - \gamma\theta_g^O\right)$$

$$U\left(\pi_{M_g}^O\right) = \omega_g^O * \left(a - p_g^O + \beta p_n^O + \gamma\theta_g^O\right) - \left(\theta_g^O\right)^2 - \varphi\omega_g^O\sigma$$

$$E\left(\pi_{R_g}^{O}\right) = \left(p_g^O - \omega_g^O\right) * \left(a - p_g^O + \beta p_n^O + \gamma \theta_g^O\right)$$

Proposition 1. Under the no-subsidy policy scenario, when $4\beta^3 - \beta\gamma^2 + 8\beta^2 + 2\gamma^2 - 8\beta - 16 < 0$,

(1) The equilibrium decisions on the wholesale prices, retail prices and the greenness of the green product of the conventional and green products are as follows:

$$\omega_n^{O*} = \frac{(A_3)(\beta+2)}{A_1}$$

$$\omega_g^{O*} = \frac{\left(a\left(4\beta^2 - 2\beta - 8\right) + \sigma\varphi\left(4\beta^3 - 8\beta^2 - 8\beta + 16\right)\right)(\beta+2)^2}{A_1}$$

$$p_n^{O*} = \frac{2\left(3-\beta^2\right)(A_3)}{(2-\beta)A_1}$$

$$p_g^{O*} = \frac{\begin{array}{c} a\left(-8\beta^5 - 12\beta^4 + 48\beta^3 + 68\beta^2 - 72\beta - 96\right) \\ +\sigma\varphi\left(\left(-2\gamma^2+6\right)\beta^4 + 7\gamma^2\beta^3 - 40\beta^2 - 20\gamma^2\beta + \left(16\gamma^2 + 64\right)\right) \end{array}}{(2-\beta)A_1}$$

$$\theta_g^{O*} = \frac{\gamma\left(a\left(2\beta^3 + 3\beta^2 - 6\beta - 8\right) + \sigma\varphi\left(2\beta^4 - 12\beta^2 + 16\right)\right)}{A_1}$$

(2) The equilibrium profits of the conventional supply chain members, the utility of the green manufacturer and the expected profit of the green retailer, together with the equilibrium environmental benefit, are as follows:

$$\pi_{M_n}^{O\ *} = \frac{(\beta+2)\left(\beta^2-2\right)(A_3)^2}{(\beta-2)(A_1)^2}$$

$$\pi_{R_n}^{O\ *} = \frac{\left(\beta^2-2\right)^2(A_3)^2}{(\beta-2)^2(A_1)^2}$$

$$\pi_n^{O*} = \frac{8\left(\beta^2-3\right)\left(\beta^2-2\right)A_5^2}{(\beta-2)^2(A_1)^2}$$

$$U\left(\pi_{M_g}^{O}\right)^* = \frac{\begin{array}{c} (\beta+2)^2\left(a\left(2\beta^2 - \beta - 4\right) + \sigma\varphi\left(2\beta^3 - 4\beta^2 - 4\beta + 8\right)\right)^2 \\ *\left(4\beta^3 - \beta\gamma^2 + 8\beta^2 + 2\gamma^2 - 8\beta - 16\right) \end{array}}{(\beta-2)(A_1)^2}$$

$$E\left(\pi_{R_g}^{O}\right)^* = \frac{(A_4)^2}{(\beta-2)^2(A_1)^2}$$

$$E\left(\pi_g^O\right)^* = \frac{\begin{array}{c}(\beta+2)^2\left(a\left(2\beta^2-\beta-4\right)+\sigma\varphi\left(2\beta^3-4\beta^2-4\beta+8\right)\right)^2\\ *\left(4\beta^3-\beta\gamma^2+8\beta^2+2\gamma^2-8\beta-16\right)(\beta-2)+A_4^2\end{array}}{(\beta-2)^2(A_1)^2}$$

$$E\left(\pi_H^{O*}\right) = \frac{8\gamma(\beta+2)A_6A_7}{(\beta-2)(A_1)^2}$$

4.2 The price-subsidy policy scenario (P)

Under the price-subsidy policy scenario, the government subsidizes the retail price of green products. The price paid by consumers for green products is $p_g^P - \mu p_g^P$. The profit functions of the conventional manufacturer and the conventional retailer, as well as the utility function of the green manufacturer and the expected profit function of the green retailer, are given as follows:

$$\pi_{M_n}^P = \omega_n^P * \left(a - p_n^P + \beta\left(p_g^P - \mu p_g^P\right) - \gamma\theta_g^P\right)$$

$$\pi_{R_n}^P = \left(p_n^P - \omega_n^P\right) * \left(a - p_n^P + \beta\left(p_g^P - \mu p_g^P\right) - \gamma\theta_g^P\right)$$

$$U\left(\pi_{M_g}^P\right) = \omega_g^P * \left(a - \left(p_g^P - \mu p_g^P\right) + \beta p_n^P + \gamma\theta_g^P\right) - \left(\theta_g^P\right)^2 - \varphi\omega_g^P\sigma$$

$$E\left(\pi_{R_g}^P\right) = \left(p_g^P - \omega_g^P\right) * \left(a - \left(p_g^P - \mu p_g^P\right) + \beta p_n^P + \gamma\theta_g^P\right)$$

Proposition 2. Under the price-subsidy policy scenario, when $(\mu-1)\ (2\beta^3\ +8\beta^2\ -8\beta-16)+\gamma^2(\beta-2)\ >0$,

(1) The equilibrium decisions on the wholesale prices, retail prices and the greenness of the green product of the conventional and green products are as follows:

$$\omega_n^{P*} = \frac{-(\beta+2)(B_3)}{B_1}$$

$$\omega_g^{P*} = \frac{2(\beta+2)^2(B_2)}{B_1}$$

$$p_n^{P*} = \frac{-2\left(\beta^2-3\right)(B_3)}{(\beta-2)B_1}$$

$$p_g^{P*} = \frac{(B_4)}{(\mu-1)(\beta-2)B_1}$$

$$\theta_g^{P*} = \frac{\gamma\left(\sigma\varphi\left(2\beta^4-12\beta^2+16\right)+a\left(2\beta^3+3\beta^2-6\beta-8\right)\right)}{B_1}$$

(2) The equilibrium profits of the conventional supply chain members, the utility of the green manufacturer and the expected profit of the green retailer, together with the equilibrium environmental benefit, are as follows:

$$\pi_{M_n}^{P\ *} = \frac{(\beta+2)\left(\beta^2-2\right)(B_6)^2}{(\beta-2)\,(B_1)^2}$$

$$\pi_{R_n}^{P\ *} = \frac{\left(\beta^2-2\right)^2(B_6)^2}{(\beta-2)^2(B_1)^2}$$

$$\pi_n^{P*} = \frac{2\left(\beta^2-3\right)\left(\beta^2-2\right)B_9^2}{(\beta-2)^2\left(\beta^2+\frac{\beta}{2}-2\right)^2 B_8^2}$$

$$U\left(\pi_{M_g}^P\right)^* = \frac{-(\beta+2)^2(B_5)\left(\sigma\varphi\left(2\beta^3-4\beta^2-4\beta+8\right)+a\left(2\beta^2-\beta-4\right)\right)^2}{(\beta-2)(B_1)^2}$$

$$E\left(\pi_{R_g}^P\right)^* = \frac{(B_7)^2}{(1-\mu)(\beta-2)^2(B_1)^2}$$

$$E\left(\pi_g^P\right)^* = \frac{\left(\sigma\varphi\left(2\beta^3-4\beta^2-4\beta+8\right)+a\left(2\beta^2-\beta-4\right)\right)^2 *(\beta+2)^2(B_5)(\mu-1)(\beta-2)+B_7^2}{(1-\mu)(\beta-2)^2(B_1)^2}$$

$$E\left(\pi_H^P\right)^* = \frac{-2\gamma(\beta+2)B_{10}B_{11}}{(\beta-2)\left(\beta^2+\frac{\beta}{2}-2\right)B_8^2}$$

4.3 The green-subsidy policy scenario (G)

Under the green-subsidy policy scenario, the government subsidizes the greenness of green products. The price paid by consumers for green products is $p_g^G - \tau\theta_g^G$. The profit functions of the conventional manufacturer and the conventional retailer, as well as the utility function of the green manufacturer and the expected profit function of the green retailer, are given as follows:

$$\pi_{M_n}^G = \omega_n^G * \left(a - p_n^G + \beta\left(p_g^G - \tau\theta_g^G\right) - \gamma\theta_g^G\right)$$

$$\pi_{R_n}^G = \left(p_n^G - \omega_n^G\right) * \left(a - p_n^G + \beta\left(p_g^G - \tau\theta_g^G\right) - \gamma\theta_g^G\right)$$

$$U\left(\pi_{M_g}^G\right) = \omega_g^G * \left(a - \left(p_g^G - \tau\theta_g^G\right) + \beta p_n^G + \gamma\theta_g^G\right) - \left(\theta_g^G\right)^2 - \varphi\omega_g^G\sigma$$

$$E\left(\pi_{R_g}^G\right) = \left(p_g^G - \omega_g^G\right) * \left(a - \left(p_g^G - \tau\theta_g^G\right) + \beta p_n^G + \gamma\theta_g^G\right)$$

Proposition 3. Under the green-subsidy policy scenario, when $(-\tau^2 + 4)\beta^4 - 2\ \beta^3\gamma\,\tau + (4\,\gamma\,\tau + 4\,\tau^2 - 24)\beta^2 - (2(\tau+\gamma)\ -\gamma\beta)^2 + 32 > 0$,

(1) The equilibrium decisions on the wholesale prices, retail prices and the greenness of the green product of the conventional and green products are as follows:

$$\omega_n^{G*} = \frac{-\left(\beta^2 - 4\right)(C_2)}{C_1}$$

$$\omega_g^{G*} = \frac{2\,(\beta+2)^2\left(\sigma\,\varphi\left(2\beta^2 - 4\right)(\beta - 2) + a\left(2\beta^2 - \beta - 4\,\right)\right)(\beta - 2)}{C_1}$$

$$p_n^{G*} = \frac{2\left(3 - \beta^2\right)(C_2)}{C_1}$$

$$p_g^{G*} = \frac{a\left(8\,\beta^5 + 12\,\beta^4 - 48\,\beta^3 - 68\,\beta^2 + 72\,\beta + 96\right) + \sigma\varphi C_3}{C_1}$$

$$\theta_g^{G*} = \frac{\left(\beta^2\tau + \beta\gamma - 2\,\gamma - 2\,\tau\right)\left(\sigma\,\varphi\left(2\,\beta^2 - 4\right)\left(\beta^2 - 4\right) + a\left(2\beta^3 + 3\,\beta^2 - 6\,\beta - 8\right)\right)}{C_1}$$

(2) Under the green-subsidy policy scenario, the equilibrium profits of the conventional supply chain members, the utility of the green manufacturer and the expected profit of the green retailer, together with the equilibrium environmental benefit, are as follows:

$$\pi_{M_n}^{G\ *} = \frac{\left(\beta^2 - 2\right)\left(\beta^2 - 4\right)(C_2)^2}{(C_1)^2}$$

$$\pi_{R_n}^{G\ *} = \frac{\left(\beta^2 - 2\right)^2(C_2)^2}{(C_1)^2}$$

$$\pi_n^{G*} = \frac{8\left(\beta^2 - 2\right)\left(\beta^2 - 3\right)C_6^2}{C_1^2}$$

$$U\left(\pi_{M_g}^G\right)^* = \frac{(\beta+2)^2\left(\sigma\,\varphi\left(2\beta^2 - 4\right)(\beta - 2) + a\left(2\beta^2 - \beta - 4\right)\,\right)^2(C_4)}{(C_1)^2}$$

$$E\left(\pi_{R_g}^G\right)^* = \frac{\left(a\left(4\beta^5 + 6\,\beta^4 - 20\beta^3 - 28\,\beta^2 + 24\beta + 32\,\right) + \varphi\,\sigma C_5\right)^2}{(C_1)^2}$$

$$E\left(\pi_g^G\right)^* = \frac{(\beta+2)^2\left(\sigma\varphi\left(2\beta^2-4\right)(\beta-2)+a\left(2\beta^2-\beta-4\right)\right)^2(C_4) + \left(a\left(4\beta^5+6\beta^4-20\beta^3-28\beta^2+24\beta+32\right)+\varphi\sigma C_5\right)^2}{(C_1)^2}$$

$$E\left(\pi_H^{G*}\right) = \frac{8C_7C_8\left(\beta^2\tau+\beta\gamma-2\tau-2\gamma\right)(\beta+2)}{C_1^2}$$

5. Results and numerical analysis

To examine government subsidy strategy choice under green manufacturer risk aversion, this section conducts numerical analysis based on the equilibrium results derived in Section 4.

5.1 Data description and parameter settings

This section constructs a benchmark numerical model. Following Feng *et al.* (2022), the parameter values must meet model validity conditions, including $\tau\theta_g^G \le p_g^G$, $\theta_g^j \ge 0$, $D_i^j \ge 0$, $P_i^j \ge 0$, $\omega_i^j \ge 0$ and the equilibrium existence conditions under the three subsidy scenarios: $4\beta^3-\beta\gamma^2+8\beta^2+2\gamma^2-8\beta-16<0$, $(\mu-1)(2\beta^3+8\beta^2-8\beta-16)+\gamma^2(\beta-2)>0$ and $(-\tau^2+4)\beta^4-2\beta^3\gamma\tau+(4\gamma\tau+4\tau^2-24)\beta^2-(2(\tau+\gamma)-\gamma\beta)^2+32>0$.

Meanwhile, the parameter values should reflect an appropriate degree of inter-chain competition, consumer preference for green products, the green manufacturer's risk-averse tendency, and the uncertainty in green product demand.

Following these principles, the parameters are set as $a=10$, $\beta=0.7$, $\sigma=1.5$, $\varphi=0.8$, and $\gamma=0.5$. Thus, $\mu\in[0.000, 0.969]$ and $\tau\in[0.000, 2.327]$.

5.2 Implementation details

The parameter values from Section 5.1 are substituted into the equilibrium solutions in Section 4. The equilibrium decisions under the no-subsidy, price-subsidy and green-subsidy policies are then computed. Subsequently, the environmental, economic and comprehensive benefits under each policy scenario are obtained.

Following Wu *et al.* (2023), the equal-expenditure condition $D_g^P\mu p_g^P = D_g^G\tau\theta_g^G$ is employed to compare the price-subsidy and green-subsidy policies under equal expenditure.

To ensure that both μ and the corresponding τ lie within their feasible ranges, μ is restricted to [0.00, 0.901]. This interval is divided into 20 equal subintervals at a step size of 0.04505. For each positive grid value of μ, the corresponding τ is computed via the equal-expenditure condition. The results are reported in Table 3.

Based on these paired values of μ and τ, the subsequent analysis compares the environmental, economic and comprehensive benefits under the no-subsidy, price-subsidy and green-subsidy policies. In the unequal expenditure analysis, the two subsidy coefficients constitute a two-dimensional policy space. Within this space, iso-expenditure and iso-benefit curves are used to compare the effects of the price-subsidy and green-subsidy policies under different expenditure-benefit objectives.

5.3 Policy comparison under equal subsidy expenditure

The no-subsidy, price-subsidy and green-subsidy policies are compared under equal subsidy conditions for different objectives. Figures 2–4 illustrate the corresponding changes in benefits.

As shown in Figure 2, when total subsidy expenditure is equal, the environmental benefit of both the price-subsidy and green-subsidy policies increases with the subsidy coefficient and the green-subsidy policy consistently yields the highest benefit. The environmental benefit

Table 3. Mapping between the price-subsidy policy coefficient and the green-subsidy policy coefficient under equal subsidy expenditure

Policy coefficient	Coefficient values under equal subsidy expenditure									
μ	0.04505	0.09010	0.13515	0.18020	0.22525	0.27030	0.31535	0.36040	0.40545	0.45050
τ	0.38309	0.59379	0.75483	0.88943	1.00720	1.11327	1.21080	1.30193	1.38821	1.47085
μ	0.49555	0.54060	0.58565	0.63070	0.67575	0.72080	0.76585	0.81090	0.85595	0.90100
τ	1.55084	1.62906	1.70634	1.78351	1.86150	1.94142	2.02477	2.11372	2.21195	2.32694

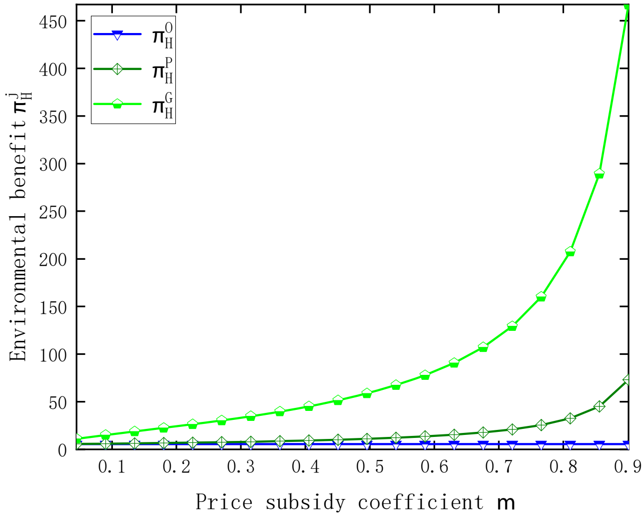

Figure 2. Environmental benefit comparison among the no-subsidy, price-subsidy and green-subsidy policies under equal subsidy expenditure

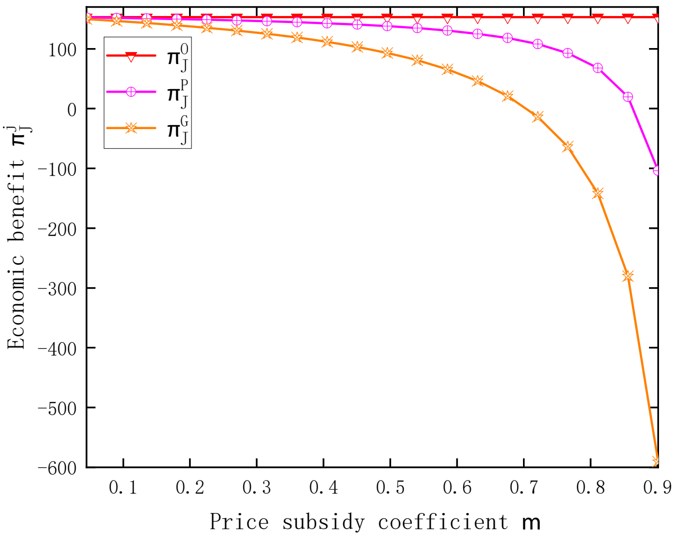

Figure 3. Economic benefit comparison among the no-subsidy, price-subsidy and green-subsidy policies under equal subsidy expenditure

under the no-subsidy policy stays constant at the lowest level, because green product demand receives no subsidy stimulus. While the price-subsidy policy encourages greenness improvement, the green-subsidy policy is more effective at doing so, ultimately delivering higher environmental benefit.

Figure 3 shows that when total subsidy expenditure is equal, the economic benefit of both the price-subsidy and green-subsidy policies decreases as the subsidy coefficient rises, whereas the no-subsidy policy yields the highest economic benefit. This occurs because higher

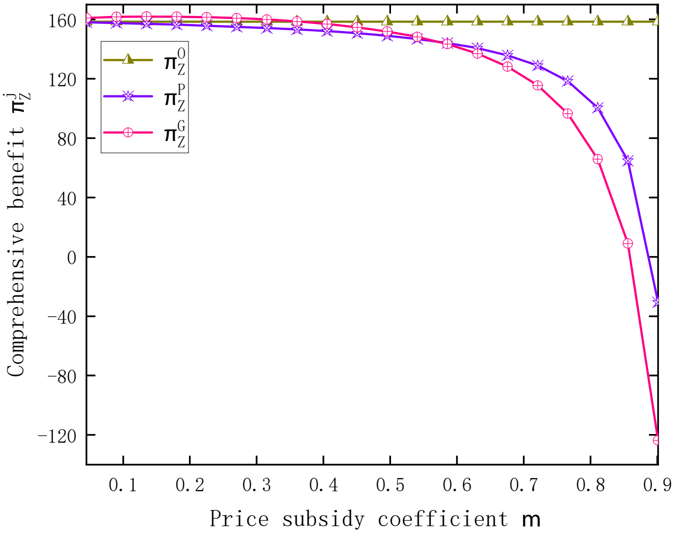

Figure 4. Comprehensive benefit comparison among the no-subsidy, price-subsidy and green-subsidy policies under equal subsidy expenditure

subsidy expenditure outweighs the benefit gain, reducing net economic benefit. The no-subsidy policy maintains unchanged economic benefit at the highest level. Under the green-subsidy policy, the increase in the green supply chain's economic return is smaller than the conventional chain's profit decrease, while under the price-subsidy policy, the increase in the green supply chain's economic return exceeds the conventional chain's decrease. Consequently, the economic benefit of the green-subsidy policy remains below that of the price-subsidy policy.

Figure 4 shows that under equal subsidy expenditure, the price-subsidy policy's comprehensive benefit decreases with the subsidy coefficient, whereas the green-subsidy policy's comprehensive benefit first increases and then decreases. The green-subsidy policy reaches its maximum comprehensive benefit around $\mu = 0.15(\tau = 0.79)$. When $\mu < 0.36(\tau < 1.31)$, the green-subsidy policy yields the highest comprehensive benefit among the three policies. When $\mu > 0.36(\tau > 1.31)$, the no-subsidy policy yields the highest comprehensive benefit. This is because, as the subsidy coefficient increases, the price-subsidy policy's economic benefit declines while its environmental benefit rises but the decline in economic benefit outweighs the rise in environmental benefit, leading to a continuous downward trend in its comprehensive benefit. For the green-subsidy policy, economic benefit also declines while environmental benefit rises with the subsidy coefficient. When $\mu < 0.15(\tau < 0.79)$, the environmental benefit increase exceeds the economic benefit decrease, so the comprehensive benefit rises. When $\mu > 0.15(\tau > 0.79)$, the environmental benefit increase falls short of the economic benefit decrease, so the comprehensive benefit declines. Around $\mu = 0.36(\tau = 1.31)$, the green-subsidy policy's comprehensive benefit becomes equal to that under the no-subsidy policy.

These results offer practical guidance for subsidy policy design under equal expenditure. If environmental benefit is prioritized, the green-subsidy policy is preferred for its consistently highest environmental benefit. If economic benefit is prioritized, the no-subsidy policy is more suitable, as subsidy expenditure reduces the net economic benefit. If comprehensive benefit is the objective, subsidy intensity should be kept within an appropriate range. The green-subsidy policy reaches its maximum comprehensive benefit around $\mu = 0.15(\tau = 0.79)$ and remains preferable when $\mu < 0.36(\tau < 1.31)$. When $\mu > 0.36(\tau > 1.31)$, the no-subsidy policy becomes the better choice. Thus, under a fixed subsidy budget, governments should align policy selection with environmental, economic, or comprehensive benefit objectives and avoid excessive subsidy intensity when pursuing comprehensive benefit.

5.4 Policy comparison under unequal subsidy expenditure

When the government offers demand-side promotional subsidies to foster green supply chain development, the price-subsidy and green-subsidy policies may entail different expenditure levels and yield different benefits. Policy selection should therefore account for both expenditure and benefit, rather than benefit alone.

To this end, a complete subsidy space is constructed in terms of the price-subsidy coefficient μ and the green-subsidy coefficient τ. Each feasible pair of policies (one of each type) corresponds to a point in this space, which covers all comparable price and green subsidy combinations.

Because subsidy strategy selection involves both expenditure and benefit, iso-expenditure lines $S^G = S^P$ and iso-benefit lines $\pi_H^G = \pi_H^P$、 $\pi_J^G = \pi_J^P$、 $\pi_Z^G = \pi_Z^P$ are plotted in the subsidy space, as shown in Figures 5–7. These lines divide the space into several regions. It is verified that the value of φ has limited effect on the regional patterns in each figure. Thus, the case of moderate risk aversion ($\varphi = 0.5$) serves as the benchmark for analysis.

Figure 5 shows that the iso-expenditure and iso-environmental-benefit lines divide the subsidy space into three regions. (1) In Region I, $S^G > S^P$ and $\pi_H^G > \pi_H^P$. The green-subsidy policy requires higher expenditure and yields greater environmental benefit. (2) In Region II, $S^G < S^P$ and $\pi_H^G > \pi_H^P$. The green-subsidy policy requires lower expenditure but yields greater environmental benefit. (3) In Region III, $S^P > S^G$ and $\pi_H^P > \pi_H^G$. The green-subsidy policy requires lower expenditure but yields lower environmental benefit. (4) On the iso-expenditure line, $S^G = S^P$ and $\pi_H^G > \pi_H^P$. Under equal expenditure, the green-subsidy policy yields greater environmental benefit. (5) On the iso-environmental-benefit line, $S^G < S^P$ and $\pi_H^G = \pi_H^P$. The green-subsidy policy achieves the same environmental benefit at lower expenditure.

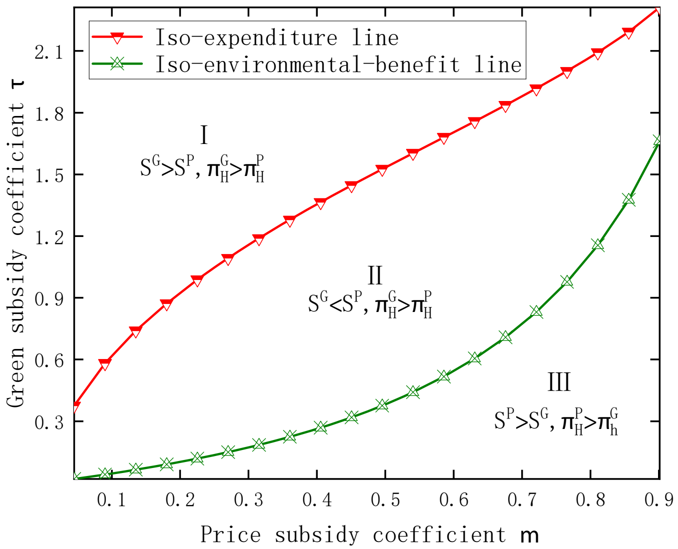

Figure 5. Policy-space comparison between the price-subsidy and green-subsidy policies based on subsidy expenditure and environmental benefit

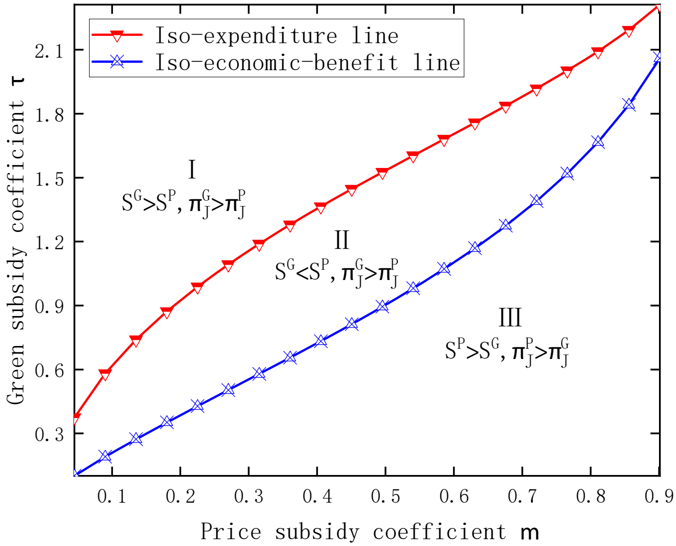

Figure 6. Policy-space comparison between the price-subsidy and green-subsidy policies based on subsidy expenditure and economic benefit

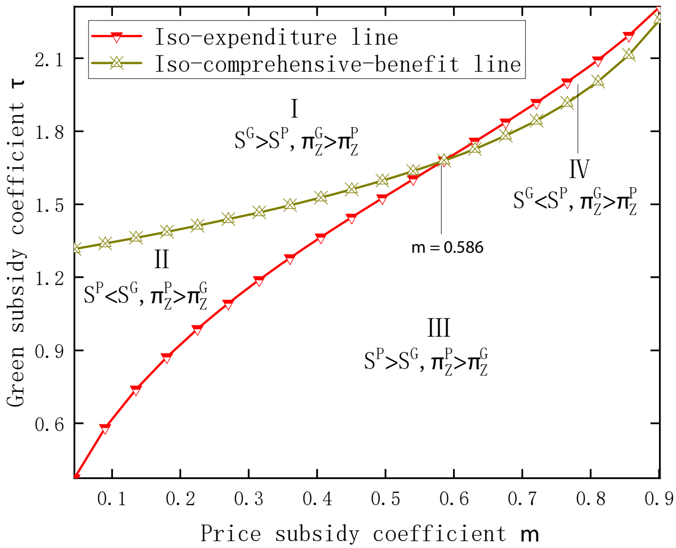

Figure 7. Policy-space comparison between the price-subsidy and green-subsidy policies based on subsidy expenditure and comprehensive benefit

Based on this, when environmental benefit is the objective with expenditure also considered, the optimal subsidy strategy is as follows. (1) For more benefit with more subsidy, choose the green-subsidy policy in Region I or the price-subsidy policy in Region III. (2) For less benefit with less subsidy, choose the price-subsidy policy in Region I or the green-subsidy policy in Region III. (3) For more benefit with less subsidy, choose the green-subsidy policy in

Region II. (4) To achieve greater environmental benefit under equal expenditure, choose the green-subsidy policy on the iso-expenditure line. (5) To achieve the same environmental benefit with less expenditure, choose the green-subsidy policy on the iso-environmental-benefit line.

Figure 6 shows that the iso-expenditure and iso-economic-benefit lines divide the subsidy space into three regions. (1) In Region I, $S^G > S^P$ and $\pi_J^G > \pi_J^P$. The green-subsidy policy requires higher expenditure and yields greater economic benefit. (2) In Region II, $S^G < S^P$ and $\pi_J^G > \pi_J^P$. The green-subsidy policy requires lower expenditure but yields greater economic benefit. (3) In Region III, $S^P > S^G$ and $\pi_J^P > \pi_J^G$. The green-subsidy policy requires lower expenditure but yields lower economic benefit. (4) On the iso-expenditure line, $S^G = S^P$ and $\pi_J^G > \pi_J^P$. Under equal expenditure, the green-subsidy policy yields greater economic benefit. (5) On the iso-economic-benefit line, $S^G < S^P$ and $\pi_J^G = \pi_J^P$. The green-subsidy policy achieves the same economic benefit at lower expenditure.

Based on this, when economic benefit is the objective with expenditure also considered, the optimal subsidy strategy is as follows. (1) For more benefit with more subsidy, choose the green-subsidy policy in Region I or the price-subsidy policy in Region III. (2) For less benefit with less subsidy, choose the price-subsidy policy in Region I or the green-subsidy policy in Region III. (3) For more benefit with less subsidy, choose the green-subsidy policy in Region II. (4) To achieve greater economic benefit under equal expenditure, choose the green-subsidy policy on the iso-expenditure line. (5) To achieve the same economic benefit with less expenditure, choose the green-subsidy policy on the iso-economic-benefit line.

Figure 7 shows that the iso-expenditure and iso-comprehensive-benefit lines divide the subsidy space into four regions. (1) In Region I, $S^G > S^P$ and $\pi_Z^G > \pi_Z^P$. The green-subsidy policy requires higher expenditure and yields greater comprehensive benefit. (2) In Region II, $S^P < S^G$ and $\pi_Z^P > \pi_Z^G$. The price-subsidy policy requires lower expenditure and yields greater comprehensive benefit. (3) In Region III, $S^P > S^G$ and $\pi_Z^P > \pi_Z^G$. The green-subsidy policy requires lower expenditure but yields lower comprehensive benefit. (4) In Region IV, $S^G < S^P$ and $\pi_Z^G > \pi_Z^P$. The green-subsidy policy requires lower expenditure and yields greater comprehensive benefit. (5) On the iso-expenditure line, when $\mu < 0.586$, $S^G = S^P$ and $\pi_Z^P > \pi_Z^G$. The green-subsidy policy yields lower comprehensive benefit under equal expenditure. When $\mu = 0.586$, $S^G = S^P$ and $\pi_Z^G = \pi_Z^P$. The two policies yield the same comprehensive benefit under equal expenditure. When $\mu > 0.586$, $S^G = S^P$ and $\pi_Z^G > \pi_Z^P$. The green-subsidy policy yields greater comprehensive benefit under equal expenditure. (6) On the iso-comprehensive-benefit line, when $\mu < 0.586$, $S^P < S^G$ and $\pi_Z^P = \pi_Z^G$. The green-subsidy policy requires higher expenditure for the same comprehensive benefit. When $\mu = 0.586$, $S^G = S^P$ and $\pi_Z^G = \pi_Z^P$. The two policies yield the same comprehensive benefit under equal expenditure. When $\mu > 0.586$, $S^G < S^P$ and $\pi_Z^G = \pi_Z^P$. The green-subsidy policy achieves the same comprehensive benefit at lower expenditure.

Based on this, when comprehensive benefit is the objective with expenditure also considered, the optimal subsidy strategy is as follows. (1) For more benefit with more subsidy, choose the green-subsidy policy in Region I or the price-subsidy policy in Region III. (2) For less benefit with less subsidy, choose the price-subsidy policy in Region I or the green-subsidy policy in Region III. (3) For more benefit with less subsidy, choose the price-subsidy policy in Region II or the green-subsidy policy in Region IV. (4) To achieve greater comprehensive benefit under equal expenditure: when $\mu < 0.586$, choose the price-subsidy policy on the iso-expenditure or iso-comprehensive-benefit line; when $\mu = 0.586$, choose either policy; when $\mu > 0.586$, choose the green-subsidy policy. (5) To achieve the same comprehensive benefit with less expenditure: when $\mu < 0.586$, choose the price-subsidy policy on the iso-expenditure or iso-comprehensive-benefit line; when $\mu = 0.586$, choose either policy; when $\mu > 0.586$, choose the green-subsidy policy.

The policy-space analysis helps governments align subsidy instruments with fiscal constraints and policy priorities. When environmental or economic benefit is the main objective, attention should be paid to regions where one policy achieves higher benefit at lower expenditure, indicating a more cost-efficient choice. For comprehensive benefit, the threshold $\mu = 0.586$ offers a useful reference: the price-subsidy policy is more suitable when $\mu < 0.586$ and the green-subsidy policy when $\mu > 0.586$, under equal-expenditure or equal-benefit comparisons. More broadly, this framework guides policy selection toward specific expenditure-benefit objectives, for example, maximizing benefit under a given expenditure or minimizing expenditure for a given benefit.

6. Conclusion

6.1 Conclusion

This paper integrates competition between a green and a conventional supply chain, green manufacturer risk aversion and the comparison of no-subsidy, price-subsidy and green-subsidy policies into a unified analytical framework.

The findings are as follows. (1) Under equal subsidy expenditure, the green-subsidy policy achieves optimal environmental benefit and the no-subsidy policy achieves optimal economic benefit. For comprehensive benefit, the green-subsidy policy is preferred when the subsidy coefficient is small and the no-subsidy policy is preferred when the subsidy coefficient is moderate or large. (2) When both expenditure and benefit are considered, the iso-expenditure and iso-benefit lines divide the subsidy space into several regions. The preferred policy can then be identified according to the expenditure-benefit relationship in each region.

Compared with existing studies, this paper provides more specific policy insights into government promotional subsidy selection. Tang *et al.* (2024) find that subsidy strategy choice should balance benefit improvement against fiscal costs. Chemama *et al.* (2019) show that under demand uncertainty, flexible consumer subsidies reduce technology adoption uncertainty but typically increase government expenditure. This finding highlights expenditure sensitivity in consumer subsidy design. Building on these, this paper demonstrates that when green products compete with conventional products and the green manufacturer is risk-averse, the optimal policy depends on subsidy form, subsidy level and government objective.

6.2 Management implications

Based on the above conclusions, this study provides several implications for government green promotional subsidy design.

First, policymakers should clarify whether the priority is environmental improvement or economic performance before selecting a subsidy policy. Governments should match subsidy policies with specific policy objectives under limited fiscal resources. When environmental benefit is the primary objective, the green-subsidy policy is more suitable because it performs best in improving environmental benefit under equal subsidy expenditure. When economic benefit is emphasized, the no-subsidy policy may be more appropriate, since subsidy expenditure can reduce the net economic gains generated by green-product promotion.

Second, when governments consider comprehensive benefits, subsidy intensity should be carefully controlled. The results show that the green-subsidy policy is preferable at a low subsidy level, while the no-subsidy policy becomes more suitable when the subsidy level increases. This indicates that moderate green subsidies can improve comprehensive benefit but excessive subsidy expenditure may weaken policy efficiency. Therefore, governments should avoid continuously increasing subsidy intensity and should instead identify an appropriate subsidy range according to comprehensive benefit performance.

Third, under unequal subsidy expenditure, governments should evaluate subsidy policies from an expenditure–benefit perspective. The policy-space analysis shows that iso-expenditure and iso-benefit lines can be used to identify the preferred policy under different objectives. Therefore, in practical policy design, governments can use the policy-space framework to compare the price-subsidy policy and the green-subsidy policy, and then select the policy that best matches their fiscal constraints and policy priorities.

6.3 Limitations and future research

Based on a competing supply chain framework with a risk-averse green manufacturer, this study compares the policy effects of no-subsidy, price-subsidy and green-subsidy strategies and identifies subsidy selection rules under different expenditure-benefit objectives.

The model assumes that each retailer sells only one type of product, which simplifies the channel structure in real markets. Behavioral uncertainty is mainly captured by the risk aversion of the green manufacturer, while other risk preferences are not considered. Building on this framework, future research could examine subsidy strategy selection in extended scenarios. First, future research could consider non-exclusive retailers or retailers offering both conventional and green products. Second, while this study focuses on the risk-averse green manufacturer, future research could explore the case of risk-seeking preferences to compare how different risk attitudes affect green technology investment, supply chain profits and government subsidy strategy selection.

Supplementary material

The supplementary material for this article can be found online

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