RESEARCH ARTICLE

Retailer-driven carbon emission reduction: contract design in the presence of information asymmetry and cap-and-trade

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Abstract
This study considers a supply chain consisting of a dominant brand-name retailer and a manufacturer in the presence of a cap-and-trade mechanism and consumers’ low-carbon preference. The retailer exerts advertising efforts, while lacks of the manufacturer’s private carbon emission reduction effort cost information. We construct the benchmark model with information symmetry and asymmetry respectively. We obtain all members’ equilibrium solutions and analytically examine the impact of the manufacturer’s carbon emission reduction effort cost, the retailer’s advertising effort cost, and consumers’ low-carbon preference on the supply chain members’ decisions. And then, we systematically compare two scenarios to obtain the condition in which the manufacturer would be willing to share the private information. With the aim of improving the manufacturer’s carbon emission reduction effort level and all members’ economic performance, we further propose a two-part tariff contract for information symmetry and asymmetry, respectively.

Keywords Cap-and-trade · Advertising · Information asymmetry · Consumers’ low-carbon preference · Two-part tariff contract

Introduction
Studies had showed that the rising global average temperature poses a huge threat to humans (Parry et al. 2007; Yang et al. 2020). Excessive carbon emission is one of the most key factors leading to global warming (Park et al. 2015; Zhang et al. 2019). Thus, more and more countries have devoted themselves to curb carbon emissions (Barrieu and Fehr 2014). For example, Sweden and Finland proposed carbon tax mechanisms in 1990, European Union proposed Emission Trading System in 2005, the USA granted a subsidy for consumers who purchase electronic vehicles in 2009 (Cohen et al. 2015), California enacted a cap-and-trade mechanism in 2011 (Wang et al. 2016), and China started the pilot carbon emission trading project in 2011 and became the number one in the world in 2017 (China Daily 2019). Cap-and-trade becomes one relatively effective mechanism. It has been extensively applied in many countries, such as North-eastern United States, Tokyo, Australia, and New Zealand (International Emission Trading Association 2013; Toptal and Çetinkaya 2017). With cap-and-trade, the government allocates a certain carbon cap for firms, and then, firms can buy the right or sell the credit according to their real carbon emission. Also, an increasing number of consumers begin to pursue a low-carbon life, and their perceived utility increases with the lower emission (Grimmer and Bingham 2013; Ngai et al. 2018; Ghosh et al. 2020). For example, studies had showed that consumers are becoming increasingly interested in the low-carbon product, such as the new energy vehicles, products with non-polluting, and recyclable raw materials (Ji et al. 2017). The BBMG Conscious Consumer Report showed that 51% of Americans have a higher willingness to pay for the low-carbon product (Yang et al. 2018).

With the low-carbon-oriented market in terms of government and consumers, brand-name retailers have begun to incorporate carbon emission reduction into business operations, which contribute to increase economic benefits, achieve sustainable development, and enhance brand...
reputation (Ma et al. 2017; Dawid et al. 2020). For example, Apple commits to become carbon-neutral for the entire product footprint by 2030 (Apple 2021). Walmart devotes to become zero-emission by 2040. Tesco, who pioneers carbon emission reduction management across the entire supply chain in the UK, commits to become zero-carbon by 2050. Gome actively combines energy-saving and emission reduction with strategic upgrading to respond to the dual-carbon targets. To disclose the carbon emission reduction measures and strengthen the carbon emission information transmission, advertising campaigns are indispensable, which devotes to improve consumers’ perception and thus promote a low-carbon product (Hong and Guo 2019). Driven by the triple pressure of the government, consumers, and brand-name retailers, low-carbon manufacturing has become an irreversible tendency. Generally, producing low-carbon products is relatively costly than traditional products (Conrad 2005; Wu et al. 2017). For example, Adidas’s manufacturer, the Yeh Group, spent $3.5 million on DyeCoo machines and $10 million on R&D to produce sustainable DryDye clothing (Hepburn 2015). Financial Times showed that the manufacturing cost of electronic vehicles increases by 45% compared with gasoline vehicles. The CDP report showed that about 60% of the 16 firms have invested in R&D for low-carbon production, such as biodegradable plastics and recyclable equipment, while most of them are unable to successfully transform a low-carbon product into a revenue-generating product. Hence, manufacturers lack of motivation to sufficiently invest in low-carbon production. To ensure economic performance from information advantage, manufacturers may do not completely disclose the carbon emission reduction effort cost information. Information asymmetry could increase brand-name retailers’ decision-making difficulty and induce the potential misreporting behavior, leading to the supply chain’s impairment. For example, Armani, Calvin Klein, Disney, and Zara were investigated by NGOs. The reason is that their products were unqualified due to that carbon emission information is concealed by their manufacturers, which severely damages their brand reputation (Genasci 2012). Based on the above discussion, there exists a tradeoff between manufacturers and brand-name retailers. Brand-name retailers prefer to sell products with a higher carbon emission reduction level and make advertising efforts for them, while manufacturers lack the motivation to improve the carbon emission reduction level and may conceal the carbon emission reduction effort cost information.

It is seen from the above industrial observations, that for the brand-name retailer with information asymmetry, how to motivate the manufacturer to improve the carbon emission reduction effort level so as to achieve a triple-win of economy, society, and environment has become an urgent issue. This is just the critical issue that this study attempts to shed light on by designing a new contract to formulate a mutually beneficial and efficient system. In this paper, we consider a low-carbon supply chain with consumers’ low-carbon preference and cap-and-trade mechanism, consisting of one dominant brand-name retailer with the advertising efforts and one manufacturer with the carbon emission reduction efforts. The brand-name retailer lacks full information about the manufacturer’s carbon emission reduction effort cost. We first establish the benchmark model under the information symmetry and asymmetric scenario and compare these two scenarios. And then, we respectively design a more effective two-part tariff contract under an information symmetry and asymmetry scenario to further enhance all members’ economic profits and improve the manufacturer’s carbon emission reduction effort level. A fundamental contribution of this study is to help the brand-name retailer design an effective contract to motivate the manufacturer to improve the carbon emission reduction effort level with information asymmetry and cap-and-trade, so as to achieve economic, social, and environmental performance simultaneously. This is a topic that has not been studied in the existing literature.

The rest of the paper is arranged as follows. Section 2 reviews the literature related to this paper. Section 3 formulates the model. Section 4 respectively constructs the benchmark model under information symmetry and asymmetry. Section 5 further designs a two-part tariff contract under information symmetry and asymmetry, respectively. Section 6 concludes the paper and proposes future directions. All proofs of the solutions are set in 12.

**Literature review**

This paper is closely related to three research streams. The first related research stream is the low-carbon supply chain. This research stream can be divided into two lines. The first line is to consider the equilibrium decisions under different carbon emission reduction policies. This line mainly focused on how to generate less emission. For example, Luo et al. (2016) investigated the carbon emission reduction decisions of two competitive manufacturers with different emission reduction efficiencies under the cap-and-trade mechanism. They found that co-opetition between two manufacturers leads to more profit and less emission. Meng et al. (2018) explored two competitive firms’ product selection in different power structures under the carbon tax mechanism. They found that two firms select a low-carbon product with a high-carbon tax rate, when two firms play the Nash/Stackelberg game in both product selection and pricing competition. Bian et al. (2020) investigated the impact of consumer subsidy and manufacturer subsidy on the manufacturer’s carbon emission reduction incentives. They found that manufacturer subsidy induces higher investments in carbon emission-reducing technology and
consumer subsidy induces the higher net emission. Liu et al. (2021a) studied three different carbon emission reduction modes under the cap-and-trade mechanism. They found that joint emission reduction mode by the manufacturer and the retailer leads to the highest emission reduction level, consumer surplus, and social welfare. Our paper focuses on the cap-and-trade mechanism. The second line is to consider the contract coordination issues under the cap-and-trade mechanism. For the contract offered by the manufacturer, Bai et al. (2017) studied a low-carbon supply chain including the manufacturer with carbon emission reduction efforts and the retailer with promoting efforts. They found that cooperation brings higher profits and lower emissions. Again, a two-part tariff contract is better. For the contract offered by the supplier, Bai et al. (2018) examined a low-carbon supply chain including a supplier providing two materials and a manufacturer producing two products. They found that the decreasing carbon emission and the increasing profit can be achieved, and revenue- and the investment-sharing contract can effectively achieve the supply chain coordination. For the contract offered by the retailer, Yang et al. (2017) showed that two competitive supply chains' vertical cooperation would induce a higher carbon emission reduction level. Again, revenue-sharing contracts can hinder manufacturers' horizontal cooperation incentive that is harmful to retailers and the environment. Wang et al. (2021) studied a low-carbon supply chain including the retailer with altruistic preference and the manufacturer with cost pressure. They found that the cost-sharing contract with altruistic preference can coordinate the supply chain. Yang et al. (2017) assumed the manufacturer is the leader, while Wang et al. (2021) assumed the retailer is the leader. Our paper focuses on the leading brand-name retailer and the contract offered by the brand-name retailer. As compared with the above literature, a fundamental difference lies in that our paper considers the impact of consumers' low-carbon preference and information structure. In this case, we devote to generate less emission and get more profit under information asymmetry by a two-part tariff contract.

The second related research stream concerns the studies about consumers' low-carbon preference. Many literatures demonstrate that consumers' low-carbon preference reduces carbon emission. For example, Xia et al. (2018a) studied the effect of reciprocal preference and consumers’ low-carbon preference on the carbon emission reduction decisions under the cap-and-trade mechanism. They found that the carbon emission reduction level increases with reciprocal preference and consumers’ low-carbon preference. Hammami et al. (2018) showed that consumers’ low-carbon preference leads to decreasing emission intensity and profit, and emission intensity depends on the carbon cap if consumers’ low-carbon preference is smaller than a threshold value. Cheng et al. (2022) considered gasoline vehicles and battery energy vehicles under the environmental tax mechanism and found that the BEV cost reduction strategy is optimal with high consumers’ low-carbon preference, while the GV emission reduction strategy is optimal with the low initial emission of GV and the high emission reduction efficiency. Literatures paying attention to consumers’ low-carbon preference have also begun to address the issue of contract coordination. For example, Du et al. (2017) found that a carbon-related price-discount sharing-like scheme can perfectly coordinate the supply chain. Yang and Chen (2018) found that the manufacturer and the retailer prefer the revenue-sharing scheme and both schemes over than cost-sharing scheme and neither scheme under the carbon tax mechanism, which can improve the system’s efficiency and the carbon emission reduction level while not coordinating with the supply chain. Peng et al. (2020) found that the unidirectional option contract (which is more beneficial to the manufacturer) and the bidirectional option contract (which is beneficial to the retailer, the whole supply chain, and the environment) can improve economic profit and reduce emission. Zhang and Yu (2022) found that the cost-sharing contract can coordinate the supply chain, and the ratio is related to altruism while is not related to the reference effect. Many literatures considering contract coordination issues focus on the cap-and-trade mechanism. For example, Xu et al. (2017) demonstrated that implementing the wholesale price and cost-sharing contract with a two-part tariff agreement can achieve Pareto improvement in the low-carbon supply chain. Wang et al. (2020) found that joint emission reduction is optimal, and the one-way cost-sharing contract is beneficial while the two-way cost-sharing contract is beneficial only with a small-sharing rate. Ghosh et al. (2020) found that the dual-channel strategy is profitable with high consumers’ low carbon preference and the low initial emission, and then buyback contract and reduction task-sharing contract can coordinate the supply chain. Liu et al. (2021b) found a coordinated cost-sharing for carbon emission reduction contract, which reduces the more carbon emission and promotes the more enthusiastic cooperation between members. Our paper also focuses on the cap-and-trade mechanism. As compared with the above literatures, a fundamental difference lies in that our paper considers the impact of information structure, and the brand-name retailer designs the new two-part tariff contract under information asymmetry.

The third related research stream concerns the studies that consider information asymmetry in a low-carbon supply chain. For example, Ma et al. (2018) investigated information asymmetry of the unit emission rate of raw materials between suppliers and the manufacturer under the emission trading mechanism. They found that if the manufacturer selects greener suppliers with enough emission allowances, suppliers would increase market share by providing raw materials with low emission rates. Some literatures focus
on the optimal carbon mechanism choice under information asymmetry. For example, Liu et al. (2015) studied information asymmetry of demand distribution between remanufacturers and consumers under mandatory carbon emission capacity, carbon tax, and cap-and-trade mechanism, respectively. They found that government should prefer a carbon tax, and a higher cap or lower penalty can promote remanufacturers’ development. D’Amato and Dijkstra (2015) examined the information asymmetry of the carbon emission reduction technology cost between the regulator and firms under tradable emission permits and emission taxation, respectively. They found that tradable permit brings less technology adoption under commitment, and the regulator can achieve the social optimum in the case of information symmetry under time consistency. Some literatures focus on information sharing under information asymmetry and consumers’ low-carbon preference. For example, Yu et al. (2020) studied the information asymmetry of demand between the retailer and the supplier under emission penalty. They showed that information sharing always reduces global emissions and reduces wasted emissions when consumers’ low-carbon preference is low or moderate. Ma et al. (2021) studied information asymmetry of the carbon emission reduction level under government subsidy. They found that the manufacturer would be willing to share information achieving less reduction if subsidy policy stimulates demand effectively. Some literatures focus on the issues concerning contract coordination. For example, Xia and Niu (2020) studied information asymmetry of the carbon emission reduction effort and capacity between the government and the firm under carbon contracting. They found that a carbon contract can positively promote the firm to reduce carbon emissions. Again, the government adjusts contractual terms to maximize the profit under single asymmetric information and offers a carbon contract menu to make extra information rent for the firm under dual asymmetric information. Xu et al. (2022) considered information asymmetry of financial status between two manufacturers under the carbon tax mechanism. They found that the sharing ratio of energy performance contracting and variable cost coefficient play the important role in providing contracts. As compared with the above literatures, a fundamental difference lies in that our paper considers consumers’ low-carbon preference and contract coordination under the cap-and-trade mechanism and information asymmetry of the carbon emission reduction effort cost between the brand-name retailer and the manufacturer. And then, the leading brand-name retailer designs a two-part tariff contract to achieve Pareto improvement for the brand-name retailer, the manufacturer, and the environment.

As compared with the above research streams, the fundamental differences of our paper lie in that (i) we consider a brand-name retailer as a Stackelberg leader, who makes advertising efforts for low-carbon products and designs an effective two-part tariff contract with the manufacturer; (ii) we address the manufacturer’s carbon emission reduction effort cost is the private information; and (iii) we integrate the effect of consumers’ low-carbon preference and cap-and-trade mechanism. The main aim of our work is to help the brand-name retailer without the carbon emission reduction effort cost information design a new contract to motivate the manufacturer to improve the carbon emission reduction effort level while ensuring all members’ profit maximization. This scenario is commonly observed in practice, but has not been studied till now.

Model formulation

We construct a low-carbon supply chain including a brand-name retailer and a manufacturer. With the government’s cap-and-trade mechanism and consumers’ low-carbon preference, the manufacturer makes carbon emission reduction efforts for producing a low-carbon product and the brand-name retailer makes advertising efforts for promoting a low-carbon product. However, the brand-name retailer may lack full information about the manufacturer’s carbon emission reduction effort cost. For clarity, the related parameters and definitions in this study are shown in Table 1. The necessary assumptions are made as follows.

Assumption 1 The game follows the Stackelberg game, and the brand-name retailer is the leader.

Assumption 2 The market demand function is characterized by $D = a - bp + ye + \lambda m$, which is a linear function of the selling price, the carbon emission reduction effort level, and the advertising effort level. To be specific, the market demand increases with the carbon emission reduction effort level and the advertising effort level, decreases with the selling price. $a > 0$ is the market potential, which is sufficiently large. $b > 0$ is a price-sensitive coefficient. $y > 0$ is consumers’ low-carbon preference, which indicates that the stronger consumers’ low-carbon preference is, the stronger willingness-to-pay for the low-carbon product is. $\lambda > 0$ is the effectiveness of advertising.

Assumption 3 The manufacturer’s carbon emission reduction can be achieved by technology, which is regarded as one-time investments and does not affect its unit production cost. In accordance with the model considered in D’Aspremont and Jacquemin (1988), José et al. (2005), and Jones and Mendelson (2011), the manufacturer’s carbon emission reduction effort cost is $\frac{ae^2}{2}$. $a > 0$ is the manufacturer’s carbon emission reduction effort cost coefficient, which is sufficiently large.
Assumption 4 In accordance with the model considered in Atasu et al. (2009), the brand-name retailer’s advertising effort cost is \( \frac{E_m^2}{2} \). \( \beta > 0 \) is the brand-name retailer’s advertising effort cost coefficient, which is sufficiently large.

Assumption 5 The manufacturer is regulated by a cap-and-trade mechanism. To be specific, the manufacturer is allocated a certain carbon cap by the government, while the manufacturer can purchase (sell) \((e_0 - e)D - E\) emission permit (credit) in the carbon trading market (Du et al. 2016; Yang et al. 2017).

The profit functions of the brand-name retailer and the manufacturer are as follows, respectively.

\[
P_R(s, m) = s(a - bs - bw + \gamma e + \lambda m) - \frac{\beta m^2}{2} \tag{1}
\]

\[
P_M(e, w) = (w - c)(a - bs - bw + \gamma e + \lambda m) - \frac{ae^2}{2} - p_e[(e_0 - e)(a - bs - bw + \gamma e + \lambda m) - E] \tag{2}
\]

Next, we will respectively discuss the benchmark model with information symmetry and information asymmetry. The manufacturer’s profit in the benchmark model provides the basis for a two-part tariff contract. Namely, if the profit in a two-part tariff contract is higher than that in the benchmark model, then the manufacturer will accept it. It is worth noting that \( a, a, \) and \( \beta \) are sufficiently large and are significantly larger than the other parameters, which implies that all models are solvable and all equilibrium decisions are positive and finite.

The benchmark model

Information symmetry

In this subsection, the retailer has full information about the manufacturer’s carbon emission reduction effort cost. As the leader, the brand-name retailer firstly determines the sales margin and the advertising effort level. The manufacturer then determines the wholesale price and the carbon emission reduction effort level. By backward induction, Proposition 1 shows the equilibrium solutions and profits.

Proposition 1 With information symmetry, the brand-name retailer’s equilibrium sales margin is \( s_{WS}^{W_M} = \frac{\beta[a - b(h + p, c_e)](2ab - (r + bp)^2)}{2b[2ab - (r + bp)^2] - a^2 - \alpha^2} \), the equilibrium advertising effort level is \( m_{WS}^{W_M} = \frac{1}{2b[2ab - (r + bp)^2] - a^2 - \alpha^2} \), the manufacturer’s equilibrium wholesale price is \( w_{WS}^{W_M} = \frac{\alpha^2[a - b(h + p, c_e)] + (r + bp)^2 + \alpha^2}{2b[2ab - (r + bp)^2] - a^2 - \alpha^2} \), the equilibrium carbon emission reduction effort level is \( e_{WS}^{W_M} = \frac{1}{2b[2ab - (r + bp)^2] - a^2 - \alpha^2} \), and the equilibrium profit is \( \Pi_{WS}^{W_M} = \frac{1}{2b[2ab - (r + bp)^2] - a^2 - \alpha^2} + p_eE. \)
Proof: See proof of proposition 1 in 12.

Remark 1

\begin{align}
(1) & \frac{d\pi_1^{WS}}{d\alpha} < 0, \quad \frac{d\pi_1^{WS}}{d\beta} < 0, \quad \frac{d\pi_1^{WS}}{d\gamma} < 0, \quad \frac{d\pi_1^{WS}}{d\theta} < 0, \quad \frac{d\pi_1^{WS}}{d\theta} < 0; \\
(2) & \frac{d\pi_1^{WS}}{d\theta} < 0, \quad \frac{d\pi_1^{WS}}{d\theta} < 0, \quad \frac{d\pi_1^{WS}}{d\theta} < 0, \quad \frac{d\pi_1^{WS}}{d\theta} < 0, \quad \frac{d\pi_1^{WS}}{d\theta} < 0; \\
(3) & \frac{d\pi_1^{WS}}{d\sigma} > 0, \quad \frac{d\pi_1^{WS}}{d\sigma} > 0, \quad \frac{d\pi_1^{WS}}{d\sigma} > 0, \quad \frac{d\pi_1^{WS}}{d\sigma} > 0, \quad \frac{d\pi_1^{WS}}{d\sigma} > 0.
\end{align}

Proof: See proof of remark 1 in 12.

Remark 1

(1) shows that the brand-name retailer’s sales margin, the advertising effort level, the profit, and the manufacturer’s carbon emission reduction effort level, the profit decreases while the manufacturer’s wholesale price increases, as the manufacturer’s carbon emission reduction effort cost increases. This implies that the high carbon emission reduction effort cost deter the manufacturer’s carbon emission reduction efforts. To offset fractional costs, the manufacturer will improve the wholesale price. However, the loss resulting from the high carbon emission reduction effort cost is still larger than the benefit resulting from the increasing wholesale price; thus, the manufacturer’s profit will decrease. The increasing wholesale price and the decreasing carbon emission reduction effort level hit the brand-name retailer’s advertising effort enthusiasm and then reduces its sales margin and profit resulting from the deviation of consumers’ low-carbon preference.

Remark 1

(2) shows that the brand-name retailer’s sales margin, the advertising effort level, the profit, the manufacturer’s wholesale price, and the carbon emission reduction effort level, the profit decrease as the brand-name retailer’s advertising cost increases. This implies that the high advertising cost deter the brand-name retailer’s advertising efforts. Without the motivation of the brand-name retailer as the leader, the manufacturer will decrease its carbon emission reduction effort level and further decrease the wholesale price to promote its product. In this case, the brand-name retailer’s sales margin, profit, and the manufacturer’s profit will decrease resulting from the deviation of consumers’ low-carbon preference.

Remark 1

(3) shows that the brand-name retailer’s sales margin, the advertising effort level, the profit, and the manufacturer’s carbon emission reduction effort level, the profit increases while the manufacturer’s wholesale price decreases, as consumers’ low-carbon preference increases. This implies that high consumers’ low-carbon preference spurs the brand-name retailer’s advertising efforts. With the motivation from both the brand-name retailer and consumers, the manufacturer will improve its carbon emission reduction effort level. To promote low-carbon products ensuring enough sales, the manufacturer would approximately decrease its wholesale price. In this case, the benefit resulting from the higher sales because of high consumers’ low-carbon preference is larger than the loss resulting from the increasing carbon emission reduction effort level and the decreasing wholesale price, the manufacturer’s profit will increase. The benefit resulting from the decreasing wholesale price and the increasing carbon emission reduction effort level is larger than the loss resulting from the increasing advertising effort level, the brand-name retailer’s sales margin and profit will increase.

Therefore, from the above discussions in Remark 1, we can see that with information symmetry, the high carbon emission reduction effort cost and the high advertising effort cost are certainly negative, while high consumers’ low-carbon preference is certainly positive to the brand-name retailer, the manufacturer, and environment.

Information asymmetry

In this subsection, the brand-name retailer lacks full information about the manufacturer’s carbon emission reduction effort cost. We assume that \( \alpha \) is uniformly distributed with \( g(\alpha) \) and \( G(\alpha) \), where \( \alpha \sim U(\bar{\alpha} - \varepsilon, \bar{\alpha} + \varepsilon) \), \( g(\alpha) = 1/2\varepsilon \), and \( 0 < \varepsilon < \bar{\alpha} \). The larger the value of \( \varepsilon \) is, the less certain the brand-name retailer for the manufacturer’s carbon emission reduction effort cost will be. Proposition 2 shows the equilibrium solutions and profits.

Proposition 2 With information asymmetry, the brand-name retailer’s equilibrium sales margin is \( s_{1, WA} = \frac{\rho(\alpha - b(s + \varepsilon))}{2\beta b - \alpha^2 h(\varepsilon)} \), the equilibrium advertising effort level is \( m_{1, WA} = \frac{\rho(\alpha - b(s + \varepsilon))}{2\beta b - \alpha^2 h(\varepsilon)} \), the equilibrium profit is \( E[\pi_{1, RA}]_{WA} = \frac{\rho(\alpha - b(s + \varepsilon))}{2\beta b - \alpha^2 h(\varepsilon)} \), the manufacturer’s equilibrium wholesale price is...
\( w_{WA} = \frac{ab(\gamma + \beta y) + \epsilon}{2ab(\gamma + \beta y)^2} \), the equilibrium carbon emission reduction effort level is
\( e_{WA} = \frac{\beta b(\gamma + \beta y) + \epsilon}{2ab(\gamma + \beta y)^2} \), and the equilibrium profit
\( E[\Pi_M]^{WA} = \frac{ab^2}{2[2\beta b + \epsilon]} \epsilon \), where
\( h(e) = \frac{1}{2} + \frac{(r+bp)^2}{8bc} \ln \left( \frac{2a(b+r+yp)^2}{2a(b+r+yp)^2} \right) \).

Proof: See proof of proposition 2 in 12.

Remark 2

(1) \( \frac{\partial w_{WA}}{\partial \epsilon} > 0 \), \( \frac{\partial w_{WA}}{\partial \gamma} > 0 \), \( \frac{\partial w_{WA}}{\partial \beta} > 0 \);

(2) \( \frac{\partial h(e)}{\partial \epsilon} < 0 \), \( \frac{\partial h(e)}{\partial \gamma} < 0 \), \( \frac{\partial h(e)}{\partial \beta} < 0 \);

(3) \( \frac{\partial E[\Pi_M]}{\partial \gamma} > 0 \), \( \frac{\partial E[\Pi_M]}{\partial \beta} > 0 \), \( \frac{\partial E[\Pi_M]}{\partial \epsilon} > 0 \).

Proof: See proof of remark 2 in 12.

Remark 2

(1) shows that the brand-name retailer’s sales margin, the advertising effort level, and the manufacturer’s wholesale price, the carbon emission reduction effort level increases as the manufacturer’s emission reduction effort cost variation increases. This indicates that when the uncertainty is relatively high, the brand-name retailer would make more advertising efforts. In this case, the manufacturer will improve the carbon emission reduction effort level and the wholesale price to get more profit. Due to the benefit resulting from the increasing carbon emission reduction effort level being larger than the loss resulting from the increasing wholesale price and advertising effort level, the brand-name retailer’s sales margin increases.

Remark 2

(2) shows that the brand-name retailer’s sales margin, the advertising effort level, and the manufacturer’s wholesale price, the carbon emission reduction effort level decrease as the brand-name retailer’s advertising effort cost increases. These are consistent with information symmetry in Remark 1 (2).

Remark 2

(3) shows that the brand-name retailer’s sales margin, the advertising effort level, and the manufacturer’s carbon emission reduction effort level increase while the manufacturer’s wholesale price decreases, as consumers’ low-carbon preference increases. These are consistent with information symmetry in Remark 1 (3).

Remark 3

(1) \( \frac{\partial \Pi_M}{\partial \epsilon} > 0 \) indicates that the brand-name retailer’s profit increases with \( \epsilon \); when \( \frac{\partial \Pi_M}{\partial \gamma} \), \( \frac{\partial \Pi_M}{\partial \beta} > 0 \) indicates that the brand-name retailer’s profit increases with \( \beta \). If \( \frac{\partial \Pi_M}{\partial \beta} < 0 \) indicates that the manufacturer’s profit always increases with \( \beta \).

(2) When
\( \frac{\partial \Pi_M}{\partial \epsilon} > 0 \) indicates that the brand-name retailer’s profit increases with \( \gamma \); when
\( \frac{\partial \Pi_M}{\partial \beta} < 0 \) indicates that the manufacturer’s profit always decreases with \( \beta \).

(3) When
\( \frac{\partial \Pi_M}{\partial \gamma} > 0 \) indicates that the brand-name retailer’s profit increases with \( \gamma \); when
\( \frac{\partial \Pi_M}{\partial \beta} > 0 \) indicates that the manufacturer’s profit always increases with \( \gamma \).

Proof: See proof of Remark 3 in 12.

Remark 3 shows that with information asymmetry, the manufacturer’s profit always increases as the manufacturer’s carbon emission reduction effort cost variation and consumers’ low-carbon preference, decreases as the brand-name retailer’s advertising effort cost. Interestingly, the brand-name retailer’s profit may increase or decrease as the manufacturer’s carbon emission reduction effort cost variation, the brand-name retailer’s advertising effort cost, and consumers’ low-carbon preference, depending on the value of \( h(e) \).
As the manufacturer’s carbon emission reduction effort cost variation increases, the brand-name retailer’s profit increases when $h(\varepsilon)$ is relatively low. However, when $h(\varepsilon)$ is relatively high, the benefit resulting from the increasing carbon emission reduction effort level is smaller than the loss resulting from the increasing wholesale price and advertising effort level, which decreases the brand-name retailer’s profit.

As the brand-name retailer’s advertising effort cost increases, the brand-name retailer’s profit decreases when $h(\varepsilon)$ is relatively low. However, when $h(\varepsilon)$ is relatively high, the benefit resulting from the decreasing wholesale price and advertising effort level is larger than the loss resulting from the decreasing carbon emission reduction effort level, which increases the brand-name retailer’s profit.

As consumers’ low-carbon preference increases, the brand-name retailer’s profit increases when $h(\varepsilon)$ is relatively low. Many literatures also found the same result, that is, consumers’ low-carbon preference is positively related to profits (Xia et al. 2018a, b; Ghosh et al. 2020; Yao et al. 2021). Interestingly, we further find that when $h(\varepsilon)$ is relatively high, the brand-name retailer’s profit would decrease. This implies that with information asymmetry, the high advertising efforts with high consumers’ carbon preference may be negative to the brand.

Therefore, from the above discussions in Remark 3, we can see that with information asymmetry, the high carbon emission reduction effort cost variation and high consumers’ low-carbon preference are certainly positive, while the high advertising effort cost is certainly negative to the manufacturer and environment. However, the brand-name retailer as the leader could strategically adjust decisions to achieve positive profit.

**Comparative analysis**

In this subsection, we compare the equilibrium solutions and profits under information symmetry with those under information asymmetry and explore the condition that the manufacturer should share the carbon emission reduction effort cost information with the brand-name retailer. Thus, we obtain some important managerial implications.

**Theorem 1**

\[
\begin{align*}
(1) \quad & s_{W^*} > s_{W^*} > m_{W^*} > m_{W^*}, \quad w_{WS^*} > w_{W^*} > e_{WS^*} > e_{W^*}, \\
& \text{when} \quad \frac{1}{2} < h(\varepsilon) < \min \left\{ \frac{ab}{2ab-(r+bp)^2}, \frac{2\lambda b}{\lambda^2} \right\}; \\
(2) \quad & s_{WS^*} < s_{W^*} < m_{WS^*} < m_{W^*}, \quad w_{WS^*} < w_{W^*} < e_{WS^*} < e_{W^*}, \\
& \text{when} \quad \frac{ab}{2ab-(r+bp)^2} < h(\varepsilon) < \frac{2\lambda b}{\lambda^2}.
\end{align*}
\]

Proof: See proof of Theorem 1 in 12.

Theorem 1 shows that the comparisons between information symmetry and information asymmetry in terms of the brand-name retailer’s sales margin, the advertising effort level, and the manufacturer’s wholesale price, the carbon emission reduction effort level depend on the value of $h(\varepsilon)$. When $h(\varepsilon)$ is relatively low, the brand-name retailer’s sales margin and the advertising effort level, the manufacturer’s wholesale price and the carbon emission reduction level under information symmetry are larger than those under information asymmetry. Interestingly, when $h(\varepsilon)$ is relatively high, the brand-name retailer’s sales margin and the advertising effort level, the manufacturer’s wholesale price and the carbon emission reduction level under information symmetry are smaller than those under information asymmetry. Xia and Niu (2020) demonstrate that information asymmetry increases emission, while carbon contracts devoting to information transparency can efficiently motivate the manufacturer to reduce emission. Different from Xia and Niu (2020), we find that when $h(\varepsilon)$ is relatively high, information asymmetry leads to a higher carbon emission reduction level.

**Theorem 2**

\[
(1) \quad E[\Pi_{W^*}] > E[\Pi_{W^*}], \quad (2) \quad E[\Pi_{W^*}] < E[\Pi_{W^*}] \quad \text{when} \quad 0 < \alpha < \alpha_1 \text{ or } \alpha > \alpha_2; \quad E[\Pi_{W^*}] > E[\Pi_{W^*}] \quad \text{when} \quad \alpha_1 < \alpha < \alpha_2.
\]

Proof: See proof of Remark 5 in 12, where

\[
\begin{align*}
\alpha_1 &= \frac{2\lambda^2 h(\varepsilon)(r+bp)^2 + 4\lambda h(\varepsilon)(r+bp)^2 - 8h(\varepsilon)(r+bp)^2}{b[c^2 h(\varepsilon) - 16h(\varepsilon)(r+bp)^2 - \lambda^2]} \quad ; \\
\alpha_2 &= \frac{2\lambda^2 h(\varepsilon)(r+bp)^2 - 8h(\varepsilon)(r+bp)^2 + 2\lambda h(\varepsilon)(r+bp)^2}{b[c^2 h(\varepsilon) - 16h(\varepsilon)(r+bp)^2 - \lambda^2]}
\end{align*}
\]

**Theorem 2**

(1) shows that the brand-name retailer always benefits from the manufacturer that shares the carbon emission reduction effort cost information. In the case of information symmetry, when $h(\varepsilon)$ is relatively low, the benefit resulting from the high carbon emission reduction effort level is larger than the loss resulting from the high wholesale price and advertising effort level. Thus, the brand-name retailer’s profit with information symmetry is larger than that with information asymmetry. When $h(\varepsilon)$ is relatively high, the benefit resulting from the low wholesale price and advertising effort level is larger than the loss resulting from the low carbon emission reduction effort level. Thus, the brand-name retailer’s profit with information symmetry is also larger than that with information asymmetry.
Theorem 2

(2) shows that the manufacturer could flexibly adjust the information-sharing strategy according to the carbon emission reduction effort cost. It follows a cut-off policy. Specifically, when the carbon emission reduction effort cost is moderate, the manufacturer is willing to share information. While hiding information is beneficial to the manufacturer when the carbon emission reduction effort cost is high or low enough. Remark 2 (1) shows that uncertainty leads the brand-name retailer to make more advertising efforts. In this case, with information asymmetry, the manufacturer with the low carbon emission reduction cost also increases the carbon emission reduction effort level so as to get more profit. And then, the manufacturer with the high carbon emission reduction cost approximately increases the carbon emission reduction effort level according to the brand-name retailer’s advertising effort level so as to get positive profit. Remark 1 (1) shows that the carbon emission reduction effort level and the advertising effort level decrease with the carbon emission reduction effort cost increases. In this case, with information symmetry, the manufacturer with the moderate carbon emission reduction cost could get positive profit by dynamically matching the carbon emission reduction level with the advertising effort level. In addition, when the manufacturer’s carbon emission reduction effort cost is moderate, information symmetry could make the brand-name retailer and the manufacturer achieve Pareto improvement.

Two-part tariff contract

Information symmetry

Many studies demonstrate that a two-part tariff contract is one of the most effective contracts in coordinating the low-carbon supply chain. For example, Bai et al. (2017) demonstrated that a two-part tariff contract is more robust than a revenue and promotional cost-sharing contract in coordinating the low-carbon supply chain. Xu et al. (2017) demonstrated that compared with a wholesale price contract and cost-sharing contract, a two-part tariff contract could further achieve Pareto improvement for the manufacturer and the retailer. Hence, we consider that the brand-name retailer designs a two-part tariff contract to motivate the manufacturer to improve the carbon emission reduction effort level. In this subsection, the sequence of events is as follows. Firstly, the brand-name retailer offers a contract including the per-unit payment w and the fixed transfer payment F. Secondly, the manufacturer chooses to accept or reject the contract. If the contract is accepted, in the case the manufacturer’s expected profit is higher than the reservation profit in the benchmark model, the manufacturer decides the carbon emission reduction effort level. And then, the brand-name retailer determines the selling price and the advertising effort level. Finally, the manufacturer delivers the low-carbon product to the brand-name retailer, and the demand is realized.

The profit functions of the brand-name retailer and the manufacturer are as follows, respectively.

$$\Pi_R(p, m) = (p - w)(a - bp + \gamma e + \lambda m) - \frac{\beta m^2}{2} - F$$

(3)

$$\Pi_M(e) = (w - c)(a - bp + \gamma e + \lambda m) - \frac{\alpha e^2}{2} - p_e[(e_0 - e)(a - bp + \gamma e + \lambda m) - F] + F$$

(4)

Proposition 3 With information symmetry, the brand-name retailer’s equilibrium contract parameters are as follows:

$$w^{TS} = \frac{\beta \alpha [(2b - \lambda^2)(y^2 - bp_\gamma c) - \beta bp_1(y^2 - bp_\gamma c - 2b^2p_\gamma c_\beta)] + \beta \alpha [(2b - \lambda^2)(y^2 - bp_\gamma c) - \beta bp_1(y^2 - bp_\gamma c - 2b^2p_\gamma c_\beta)]}{\beta \alpha [(2b - \lambda^2)(y^2 - bp_\gamma c) - \beta bp_1(y^2 - bp_\gamma c - 2b^2p_\gamma c_\beta)] + \beta \alpha [(2b - \lambda^2)(y^2 - bp_\gamma c) - \beta bp_1(y^2 - bp_\gamma c - 2b^2p_\gamma c_\beta)]}$$

$$F^{TS} = \frac{\beta \alpha [(2b - \lambda^2)(y^2 - bp_\gamma c) - \beta bp_1(y^2 - bp_\gamma c - 2b^2p_\gamma c_\beta)] + \beta \alpha [(2b - \lambda^2)(y^2 - bp_\gamma c) - \beta bp_1(y^2 - bp_\gamma c - 2b^2p_\gamma c_\beta)]}{\beta \alpha [(2b - \lambda^2)(y^2 - bp_\gamma c) - \beta bp_1(y^2 - bp_\gamma c - 2b^2p_\gamma c_\beta)] + \beta \alpha [(2b - \lambda^2)(y^2 - bp_\gamma c) - \beta bp_1(y^2 - bp_\gamma c - 2b^2p_\gamma c_\beta)]}$$

$$M^{TS} = \frac{\beta \alpha [(2b - \lambda^2)(y^2 - bp_\gamma c) - \beta bp_1(y^2 - bp_\gamma c - 2b^2p_\gamma c_\beta)] + \beta \alpha [(2b - \lambda^2)(y^2 - bp_\gamma c) - \beta bp_1(y^2 - bp_\gamma c - 2b^2p_\gamma c_\beta)]}{\beta \alpha [(2b - \lambda^2)(y^2 - bp_\gamma c) - \beta bp_1(y^2 - bp_\gamma c - 2b^2p_\gamma c_\beta)] + \beta \alpha [(2b - \lambda^2)(y^2 - bp_\gamma c) - \beta bp_1(y^2 - bp_\gamma c - 2b^2p_\gamma c_\beta)]}$$

$$e^{TS} = \frac{\beta \alpha [(2b - \lambda^2)(y^2 - bp_\gamma c) - \beta bp_1(y^2 - bp_\gamma c - 2b^2p_\gamma c_\beta)] + \beta \alpha [(2b - \lambda^2)(y^2 - bp_\gamma c) - \beta bp_1(y^2 - bp_\gamma c - 2b^2p_\gamma c_\beta)]}{\beta \alpha [(2b - \lambda^2)(y^2 - bp_\gamma c) - \beta bp_1(y^2 - bp_\gamma c - 2b^2p_\gamma c_\beta)] + \beta \alpha [(2b - \lambda^2)(y^2 - bp_\gamma c) - \beta bp_1(y^2 - bp_\gamma c - 2b^2p_\gamma c_\beta)]}$$
Thus, the manufacturer’s equilibrium carbon emission reduction effort level is $e^{TS*} = \frac{\beta \{a - \gamma (c + p_o) + (y - b) p_c \}}{[2\beta(b - \lambda^2) - a \lambda^2]}$.

The brand-name retailer’s equilibrium advertising effort level is $m^{TS*} = \frac{4\alpha}{(2b - \lambda^2)}$, and the equilibrium selling price is $p^{TS*} = \frac{\beta \{a - \gamma (c + p_o) + (y - b) p_c \}}{[2\beta(b - \lambda^2) - a \lambda^2]} + w^{TS*}$.

Proof: See proof of proposition 3 in 12.

Information asymmetry

In this subsection, the brand-name retailer lacks full information about the manufacturer’s carbon emission reduction effort cost. Similar to the benchmark model, we also assume that $\alpha$ is uniformly distributed with $g(\alpha) = \frac{1}{\bar{\alpha} - \epsilon}$, where $\alpha \sim U(\bar{\alpha} - \epsilon, \bar{\alpha} + \epsilon)$. The brand-name retailer does not know the exact value of $\alpha$, so that the optimal contract parameters cannot be determined.

The brand-name retailer faces the objective and constraint as follows:

$$
\max_{\Pi_R} E[\Pi_R] = \int \left[ \int_{-\infty}^\infty \left[ \beta \{a - bw\} \left( 2a - \gamma p_c - \alpha \lambda^2 \right) + \beta \gamma^2 \left( w - c - p_o e_o \right)^2 \right] \left( 2\beta b - \lambda^2 \right) \left( 2\beta b \left( a - \gamma p_c \right) - \alpha \lambda^2 \right)^2 \right]^{\frac{1}{2}} d\alpha
$$

$$
\text{s.t. } \Pi_M = \frac{\beta \{a - \gamma (c + p_o) + (y - b) p_c \}}{[2\beta(b - \lambda^2) - a \lambda^2]} \left( 2\beta b - \lambda^2 \right) \left( 2\beta b \left( a - \gamma p_c \right) - \alpha \lambda^2 \right)^2
$$

Thus, the manufacturer’s equilibrium carbon emission reduction effort level is $e^{TA*} = \frac{\beta \{a - \gamma (c + p_o) + (y - b) p_c \}}{[2\beta(b - \lambda^2) - a \lambda^2]}$.

The brand-name retailer’s equilibrium advertising effort level is $m^{TA*} = \frac{4\alpha}{(2b - \lambda^2)}$, and the equilibrium selling price is $p^{TA*} = \frac{\beta \{a - \gamma (c + p_o) + (y - b) p_c \}}{[2\beta(b - \lambda^2) - a \lambda^2]} + w^{TA*}$.

Proof: See proof of proposition 4 in 12.

Next, we use the numerical method to justify the validity of a two-part tariff contract. To compare the manufacturer’s carbon emission reduction effort level and the brand-name retailer’s profit, we assume $a = 800, b = 10, c = 12, \gamma = 20, \lambda = 15, p_o = 10, E = 100, e_o = 5, \alpha = 1500, b = 1000, \bar{\alpha} = 1500,$ and $\epsilon = 50$. Figures 1 and 2 show that the manufacturer’s carbon emission reduction effort level and the brand-name retailer’s profit under a two-part tariff contract are greater than those under the benchmark model. This implies that the two-part tariff contract designed by the brand-name retailer is effective and efficient, in terms of enhancing the brand-name retailer’s economic profit and improving the manufacturer’s carbon emission reduction effort level simultaneously. Thus, a two-part tariff contract achieves Pareto improvement for the brand-name retailer, the manufacturer, and the environment.
Conclusion

This paper constructs a low-carbon supply chain including a brand-name retailer and a manufacturer. This study addresses that the manufacturer’s carbon emission reduction effort cost is the private information, and the brand-name retailer may lack full information about it. Integrating the cap-and-trade mechanism and consumers’ low-carbon preference, this paper respectively formulates information symmetry and asymmetry scenarios under the benchmark model; analytically examines the impacts of the manufacturer’s carbon emission reduction effort cost (variation), the brand-name retailer’s advertising effort cost and consumers’ low-carbon preference on the supply chain members’ decisions; and compares two scenarios to explore the condition in which the manufacturer would be willing to share information with the brand-name retailer. Furthermore, with the aim of maximizing economic performance and motivating the manufacturer to improve the carbon emission reduction effort level, the brand-name retailer designs a two-part tariff contract with the manufacturer.

Fig. 1 Effect of $\alpha$, $\beta$, $\gamma$ on $e$ and $\Pi_R$ with information symmetry

Fig. 2 Effect of $\epsilon$, $\beta$, $\gamma$ on $e$ and $\Pi_R$ with information asymmetry
The main results are summarized as follows: (i) With information symmetry, the manufacturer’s carbon emission reduction effort level and profit, the brand-name retailer’s advertising effort level and profit decrease with $\alpha$ and $\beta$, however, increase with $\gamma$. (ii) With information asymmetry, the manufacturer’s carbon emission reduction effort level and profit, the brand-name retailer’s advertising effort level increase with $\epsilon$ and $\gamma$, however, decrease with $\beta$. The brand-name retailer’s profit may increase or decrease with $\epsilon$, $\beta$ and $\gamma$, depending on the value of $h(e)$. (iii) Comparing with information symmetry and asymmetry scenarios under the benchmark model, the manufacturer’s carbon emission reduction effort level and the brand-name retailer’s advertising effort level depend on the value of $h(e)$. The brand-name retailer always benefits from the manufacturer that shares carbon emission reduction effort cost information. The manufacturer will benefit from sharing information when the carbon emission reduction effort cost is moderate, while the manufacturer will benefit from hiding information when the carbon emission reduction effort cost is high or low enough. (iv) The manufacturer’s carbon emission reduction effort level and the brand-name retailer’s profit under a two-part tariff contract are greater than that under the benchmark effort level and the brand-name retailer’s profit under a two-part tariff contract are greater than that under the benchmark model. Therefore, in case of lacking the manufacturer’s carbon emission reduction effort cost information, implementing a two-part tariff contract is more effective and efficient for the brand-name retailer.

Some managerial insights can be derived as follows: First, with information symmetry, the high carbon emission reduction effort cost and the high advertising effort cost are certainly negative, while high consumers’ low-carbon preference is certainly positive to the brand-name retailer. Different from information symmetry, the brand-name retailer with information asymmetry could strategically adjust decisions to achieve positive economic performance. Second, with the high emission reduction effort cost variation or high consumers’ low-carbon preference, the brand-name retailer lacking information could make more advertising efforts to motivate a higher carbon emission reduction effort level. However, the brand-name retailer should stop this behavior when the value of $h(e)$ is relatively high. With the high advertising effort cost, making less advertising efforts is not necessarily harmful to the brand-name retailer lacking information. Third, the brand-name retailer always benefits from information sharing. However, whether to share the private information with the brand-name retailer follows a cut-off policy. The manufacturer should share information when the carbon emission reduction effort cost is moderate, while should hide information when the carbon emission reduction effort cost is high or low enough. And then, sharing information is always beneficial to the brand-name retailer. Fourth, the brand-name retailer can use a two-part tariff contract to further improve economic preference and environmental preference, which achieves Pareto improvement for the brand-name retailer, the manufacturer, and the environment.

This paper may be further discussed in the following directions. Firstly, it is meaningful to consider different low-carbon policies implemented by the government. Secondly, assuming that the market demand is uncertain, it is interesting to consider that when the manufacturer offers a two-part tariff contract to the brand-name retailer. Thirdly, it is worthwhile to consider flexible measures for coping with an emergency event such as COVID-19. Finally, introducing blockchain technology is a promising direction in guaranteeing information transparency.

Appendix

Proof of Proposition 1 Under information symmetry, the brand-name retailer (the leader) and the manufacturer follow the Stackelberg game. So we apply backward induction to obtain the equilibrium solutions. Firstly, the manufacturer decides the wholesale price and the carbon emission reduction effort level to maximize its profits. The negative definite Hessian matrix $\begin{bmatrix} -2b & \gamma - bp_c \\ \gamma - bp_c & -\alpha + 2bp_c \end{bmatrix}$ indicates that the manufacturer’s profit function is concave. Hence, let $\frac{\partial \Pi_{w,c}}{\partial w} = 0$ and $\frac{\partial \Pi_{w,c}}{\partial c} = 0$ respectively, we obtain the best response function as follows.

$$w(s,m) = \frac{(a - bs + \lambda m)[a - p_s(\gamma + bp_s)] + (c + p_s e_0)[ab - \gamma(\gamma + bp_s)]}{2ab - (\gamma + bp_s)^2} \tag{7}$$

$$e(s,m) = \frac{(\gamma + bp_c)(a - bs + \lambda m) - b(c + p_s e_0)}{2ab - (\gamma + bp_s)^2} \tag{8}$$

Next, according to $e(s,m)$ and $w(s,m)$, the brand-name retailer decides the advertising effort level and sales margin to maximize its profits. The negative definite Hessian matrix $\begin{bmatrix} -2b & \lambda \\ \lambda & -\beta \end{bmatrix}$ indicates that the brand-name retailer’s profit function is concave. Hence, let $\frac{\partial \Pi_{b,s}}{\partial s} = 0$ and $\frac{\partial \Pi_{b,s}}{\partial m} = 0$ respectively, we obtain the brand-name retailer’s equilibrium solutions $s^{\text{WS}}$ and $m^{\text{WS}}$.

Finally, substituting $s^{\text{WS}}$ and $m^{\text{WS}}$ into the best response function $e(s,m)$ and $w(s,m)$, we obtain the manufacturer’s equilibrium solutions $e^{\text{WS}}$ and $w^{\text{WS}}$.

Therefore, the brand-name retailer’s and the manufacturer’s equilibrium profits are obtained.

Proof of Remark 1 Taking the first derivation of the brand-name retailer’s advertising effort level, the sales margin, profit and the manufacturer’s carbon emission reduction effort level, the wholesale price profit respectively with respect to $a$: 
\[
\frac{\partial m_{WS}}{\partial \alpha} = -2\beta \lambda [\gamma + b_{pc}] \left[ a - b (c + p_{ce}) \right] \left[ 2\beta \left[ 2ab - (\gamma + b_{pc}) \right] - \alpha \lambda^2 \right] < 0
\]
\[
\frac{\partial \alpha}{\partial \beta} = -\frac{\beta \lambda^2 [\gamma + b_{pc}] \left[ a - b (c + p_{ce}) \right]}{b \left[ 2\beta \left[ 2ab - (\gamma + b_{pc}) \right] - \alpha \lambda^2 \right]} < 0
\]
\[
\frac{\partial m_{WS}}{\partial \beta} = -\frac{2\alpha \lambda [a - b (c + p_{ce})] \left[ 2ab - (\gamma + b_{pc}) \right]}{\left[ 2\beta \left[ 2ab - (\gamma + b_{pc}) \right] - \alpha \lambda^2 \right]} < 0
\]
\[
\frac{\partial \Pi_{WS}}{\partial \alpha} = -\frac{\beta^2 (\gamma + b_{pc})^2 [a - b (c + p_{ce})]^2 \left[ 2\beta \left[ 2ab - (\gamma + b_{pc}) \right] - \alpha \lambda^2 \right]}{\left[ 2\beta \left[ 2ab - (\gamma + b_{pc}) \right] - \alpha \lambda^2 \right]} < 0
\]
\[
\frac{\partial \Pi_{WS}}{\partial \beta} = -\frac{\beta (4\beta b - \lambda^2) (\gamma + b_{pc}) [a - b (c + p_{ce})]}{\left[ 2\beta \left[ 2ab - (\gamma + b_{pc}) \right] - \alpha \lambda^2 \right]} < 0
\]
\[
\frac{\partial \Pi_{WS}}{\partial \gamma} = \frac{\beta \left[ a - b (c + p_{ce}) \right] \left[ 2\beta (\gamma + b_{pc}) (b_{pc} - \gamma) - \alpha \lambda^2 \right] - \lambda^2 (c + p_{ce}) \left[ 2\beta \left[ 2ab - (\gamma + b_{pc}) \right] - \alpha \lambda^2 \right]}{\left[ 2\beta \left[ 2ab - (\gamma + b_{pc}) \right] - \alpha \lambda^2 \right]^2} > 0
\]
\[
\frac{\partial \Pi_{WS}}{\partial b} = -\frac{\beta^2 [a - b (c + p_{ce})]^2 \left[ 2\beta (\gamma + b_{pc}) (b_{pc} - \gamma) + \lambda^2 (c + p_{ce}) \left[ 4ab - (\gamma + b_{pc}) \right] \right]}{2 \left( 2\beta \left[ 2ab - (\gamma + b_{pc}) \right] - \alpha \lambda^2 \right)^3} < 0
\]

Taking the first derivation of the brand-name retailer’s advertising effort level, the sales margin, profit and the manufacturer’s carbon emission reduction effort level, the wholesale price profit respectively with respect to \( \gamma \):

\[
\frac{\partial \Pi_{WS}}{\partial \gamma} = \frac{4\alpha \beta \lambda (\gamma + b_{pc}) [a - b (c + p_{ce})]}{\left[ 2\beta \left[ 2ab - (\gamma + b_{pc}) \right] - \alpha \lambda^2 \right]^2} > 0
\]
\[
\frac{\partial \Pi_{WS}}{\partial b} = \frac{2\alpha \beta \lambda^2 (\gamma + b_{pc}) [a - b (c + p_{ce})]}{b \left[ 2\beta \left[ 2ab - (\gamma + b_{pc}) \right] - \alpha \lambda^2 \right]^2} > 0
\]
\[
\frac{\partial \Pi_{WS}}{\partial \gamma} = \frac{2\alpha \beta^2 (\gamma + b_{pc}) [a - b (c + p_{ce})]^2}{\left[ 2\beta \left[ 2ab - (\gamma + b_{pc}) \right] - \alpha \lambda^2 \right]^2} > 0
\]
\[
\frac{\partial \Pi_{WS}}{\partial b} = \frac{\beta [a - b (c + p_{ce})] \left[ 2\beta \left[ 2ab + (\gamma + b_{pc}) \right] - \alpha \lambda^2 \right]}{\left[ 2\beta \left[ 2ab - (\gamma + b_{pc}) \right] - \alpha \lambda^2 \right]^2} > 0
\]
\[
\frac{\partial \Pi_{WS}}{\partial \gamma} = \frac{\beta [a - b (c + p_{ce})] \left[ 2\beta (2\gamma - p_{c} (\gamma + b_{pc}) + ap_{c} \lambda) \right]}{\left[ 2\beta \left[ 2ab - (\gamma + b_{pc}) \right] - \alpha \lambda^2 \right]^3} < 0
\]
\[ \frac{\partial \Pi_{s, m}}{\partial \gamma} = \frac{4a^2 \beta (\gamma + b,c)[a - b(c + p,c,e_0)]^2 [2b + (\gamma + b,c) - a\lambda^2]}{4 [2b - (\gamma + b,c)^2] - a\lambda^2} > 0 \] (26)

**Proof of Proposition 2** Under information asymmetry, the brand-name retailer (the leader) and the manufacturer follow Stackelberg game. Based on \(e(s, m)\) and \(w(s, m)\) in the proof of proposition 1, we obtain the brand-name retailer’s profit function.

\[ \Pi_{s, m} = \frac{abx[(a - bs + \lambda m) - b(c + p,c,e_0)]}{2ab - (\gamma + b,c)^2} - \frac{\beta m^2}{2} \] (27)

According to \(\Pi_{s, m}\), we have:

\[ E[\Pi_{s, m}] = \int_{a}^{\infty} \frac{abx[(a - bs + \lambda m) - b(c + p,c,e_0)]}{2ab - (\gamma + b,c)^2} g(a)da \]

\[ = \left[ \frac{1}{m} + \frac{(r + b,c)^2}{2} \ln \left[ \frac{[2b(\pi + r + b,c)]^2}{[2b(\pi - r + b,c)]^2} \right] \right] \frac{[a - b, c + p,c,e_0][b - r(\gamma + b,c)^2]}{2ab - (\gamma + b,c)^2} \] (28)

Let \(\frac{\partial E[\Pi_{s, m}]}{\partial m} = 0\) and \(\frac{\partial E[\Pi_{s, m}]}{\partial \gamma} = 0\) respectively, we obtain the brand-name retailer’s equilibrium solutions \(s^{WA}\) and \(m^{WA}\).

Substituting \(s^{WA}\) and \(m^{WA}\) into the best response function \(e(s, m)\) and \(w(s, m)\), we obtain the manufacturer’s equilibrium solutions \(e^{WA}\) and \(w^{WA}\).

Therefore, the brand-name retailer’s and the manufacturer’s equilibrium profits are obtained.

**Proof of Remark 2** Let \(h'(\epsilon) = (\gamma + b,c)\), where

\[ k(\epsilon) = \frac{4b^2 [2m(\pi - r + b,c)]^2}{[2b(\pi + r + b,c)]^2} \ln \left[ \frac{[2b(\pi + r - b,c)]^2}{[2b(\pi - r - b,c)]^2} \right], \quad k(0) = 0 \]

and \(k'(\epsilon) = \frac{2b(\pi + r - b,c)^2}{[2b(\pi - r - b,c)]^2} \ln \left[ \frac{[2b(\pi + r + b,c)]^2}{[2b(\pi - r + b,c)]^2} \right] > 0\) indicates

\(k(\epsilon) > 0\). Therefore, \(h'(\epsilon) > 0\).

Taking the first derivative of the brand-name retailer’s advertising effort level, the sales margin, profit, and the manufacturer’s carbon emission reduction effort level, the wholesale price respectively with respect to \(\epsilon\):

\[ \frac{\partial m^{WA}}{\partial \epsilon} = \frac{2b b^2 \beta h'(\epsilon)[a - b(c + p,c,e_0)]}{[2b - b^2 h(\epsilon)]^2} > 0 \] (29)

\[ \frac{\partial r^{WA}}{\partial \epsilon} = \frac{\beta \lambda^2 h'(\epsilon)[a - b(c + p,c,e_0)]}{[2b - b^2 h(\epsilon)]^2} > 0 \] (30)

\[ \frac{\partial e^{WA}}{\partial \epsilon} = \frac{\beta b^2 \lambda h'(\epsilon)(\gamma + b,c)[a - b(c + p,c,e_0)]}{[2b - b^2 h(\epsilon)]^2 [2ab - (\gamma + b,c)^2]} > 0 \] (31)

\[ \frac{\partial w^{WA}}{\partial \epsilon} = \frac{\beta b^2 \lambda h'(\epsilon)[a - b(c + p,c,e_0)][a - p,c(\gamma + b,c)]}{[2b - b^2 h(\epsilon)]^2 [2ab - (\gamma + b,c)^2]} > 0 \] (32)

Taking the first derivation of the retailer’s advertising effort level, the sales margin and the manufacturer’s carbon emission reduction effort level, the wholesale price respectively with respect to \(\beta\):

\[ \frac{\partial m^{WA}}{\partial \beta} = -\frac{2b b^2 \beta h'(\epsilon)[a - b(c + p,c,e_0)]}{[2b - b^2 h(\epsilon)]^2} < 0 \] (33)

\[ \frac{\partial r^{WA}}{\partial \beta} = \frac{\beta \lambda^2 h'(\epsilon)[a - b(c + p,c,e_0)]}{[2b - b^2 h(\epsilon)]^2} < 0 \] (34)

\[ \frac{\partial e^{WA}}{\partial \beta} = -\frac{b b^2 \lambda h'(\epsilon)(\gamma + b,c)[a - b(c + p,c,e_0)]}{[2b - b^2 h(\epsilon)]^2 [2ab - (\gamma + b,c)^2]} < 0 \] (35)

\[ \frac{\partial w^{WA}}{\partial \beta} = \frac{\beta b^2 \lambda h'(\epsilon)[a - b(c + p,c,e_0)][a - p,c(\gamma + b,c)]}{[2b - b^2 h(\epsilon)]^2 [2ab - (\gamma + b,c)^2]} < 0 \] (36)

Taking the first derivation of the brand-name retailer’s advertising effort level, the sales margin and the manufacturer’s carbon emission reduction effort level, the wholesale price respectively with respect to \(\gamma\):

\[ \frac{\partial m^{WA}}{\partial \gamma} = \frac{\lambda [a - b(c + p,c,e_0)]}{[2b - b^2 h(\epsilon)]^2} \frac{\partial h(\epsilon)}{\partial \gamma} > 0 \] (37)

\[ \frac{\partial r^{WA}}{\partial \gamma} = \frac{\beta \lambda [a - b(c + p,c,e_0)]}{[2b - b^2 h(\epsilon)]^2} \frac{\partial h(\epsilon)}{\partial \gamma} > 0 \] (38)

\[ \frac{\partial e^{WA}}{\partial \gamma} = \frac{\beta \lambda^2 [a - b(c + p,c,e_0)]}{[2b - b^2 h(\epsilon)]^2} \frac{\partial h(\epsilon)}{\partial \gamma} > 0 \] (39)

\[ \frac{\partial w^{WA}}{\partial \gamma} = \frac{\beta b^2 \lambda [a - b(c + p,c,e_0)]}{[2b - b^2 h(\epsilon)]^2} \frac{\partial h(\epsilon)}{\partial \gamma} > 0 \] (40)
Proof of Remark 3 Taking the first derivation of the brand-name retailer’s and the manufacturer’s profit respectively with respect to \( \epsilon \):

\[
\frac{\partial E[I_{Wa}]^{wa}}{\partial \epsilon} = \frac{2\beta_{h}b_{2}h_{c}(e) \left(ab_{h}(e) \left[2ab_{h}-(y+bp_{c})\right]\right)[a_{b}(e)+(bp_{c})]}{[2ab_{h}-(y+bp_{c})]^{2}} > 0
\]

when

\[
\frac{1}{2} < h(\epsilon) < \min \left\{ \frac{ab_{h}(e)}{2ab_{h}-(y+bp_{c})}, \frac{2\beta_{h}}{\lambda_{c}} \right\},
\]

\[
\frac{\partial E[I_{Ma}]^{wa}}{\partial \epsilon} > 0
\]

Taking the first derivative of the brand-name retailer’s and the manufacturer’s profit respectively with respect to \( \beta \):

\[
\frac{\partial E[I_{Wa}]^{wa}}{\partial \beta} = \frac{\beta_{h}b_{2}h_{c}(e)\left[a_{b}(e)+(bp_{c})\right]}{[2ab_{h}-(y+bp_{c})]^{2}} > 0
\]

when

\[
\frac{1}{2} < h(\epsilon) < \min \left\{ \frac{b}{2}, \frac{\beta_{h}b_{2}}{[2ab_{h}-(y+bp_{c})]^{2}} \right\},
\]

\[
\frac{\partial E[I_{Ma}]^{wa}}{\partial \beta} > 0
\]

Taking the first derivative of the brand-name retailer’s and the manufacturer’s profit respectively with respect to \( \gamma \):

\[
\frac{\partial E[I_{Wa}]^{wa}}{\partial \gamma} = \frac{a_{b}(e)+(bp_{c})}{[2ab_{h}-(y+bp_{c})]^{2}} > 0
\]

when

\[
\frac{1}{2} < h(\epsilon) < \min \left\{ \frac{ab_{h}(e)}{2ab_{h}-(y+bp_{c})}, \frac{2\beta_{h}}{\lambda_{c}} \right\},
\]

\[
\frac{\partial E[I_{Ma}]^{wa}}{\partial \gamma} > 0
\]

Proof of Theorem 1 Calculating the difference between the brand-name retailer’s advertising effort level, the sales margin and the manufacturer’s carbon emission reduction effort level, the wholesale price with information symmetry and information asymmetry respectively, we have:

\[
w_{WS} - m_{WS} = \frac{2\beta_{h}[a_{b}(e)+(bp_{c})][ab_{h}(e) \left[2ab_{h}-(y+bp_{c})\right]]}{[2ab_{h}-(y+bp_{c})]^{2}} < 0
\]

\[
s_{WS} - s_{Wa} = \frac{\beta_{h}h(e) \left[2ab_{h}-(y+bp_{c})\right]}{b_{2}[2ab_{h}-(y+bp_{c})]^{2}} < 0
\]

\[
e_{WS} - e_{Wa} = \frac{\beta_{h}h(e) \left[2ab_{h}-(y+bp_{c})\right]}{b_{2}[2ab_{h}-(y+bp_{c})]^{2}} < 0
\]

According to the above, we can obtain:

\[
m_{WS} > m_{Wa}, s_{WS} > s_{Wa}, e_{WS} > e_{Wa}, w_{WS} > w_{Wa},
\]

when

\[
\frac{1}{2} < h(\epsilon) < \min \left\{ \frac{ab_{h}(e)}{2ab_{h}-(y+bp_{c})}, \frac{2\beta_{h}}{\lambda_{c}} \right\},
\]

\[
m_{WS} < m_{Wa}, s_{WS} < s_{Wa}, e_{WS} < e_{Wa}, w_{WS} < w_{Wa},
\]

when

\[
\frac{ab_{h}(e)}{2ab_{h}-(y+bp_{c})} < h(\epsilon) < \frac{2\beta_{h}}{\lambda_{c}}
\]

Proof of Theorem 2 Calculating the difference about the manufacturer’s profit with information symmetry and information asymmetry, we have:

\[
H_{M}^{WS} - E[H_{M}^{wa}] = \frac{\alpha_{b}[a_{b}(e)+(bp_{c})]^{2}h(e)}{2[2ab_{h}-(y+bp_{c})]^{2}} > 0
\]

\[
H(e) = [\beta_{h}h(e)]^{2} \left[4\beta_{h}h(e) - 16\beta_{h}b_{2}(e) + 8\beta_{h} - \lambda_{c}^{2}\right] - 4\beta_{h}b_{2}(e) + \lambda_{c}^{2}
\]

Let \( H(e) = 0 \) and \( H(\alpha) = 0, \) we can obtain \( \alpha_{1} \) and \( \alpha_{2} \).

According to \( h(\epsilon) > \frac{1}{2} \), we have

\[
4\beta_{h}^{2}h(e)^{2} - 16\beta_{h}b_{2}(e) + 8\beta_{h}b_{2}^{2} - \lambda_{c}^{2} = 0
\]

Moreover, \( 2\beta_{h}h(e)^{2} \left(\gamma + bp_{c}\right)^{2} + 4\beta_{h}(\gamma + bp_{c})^{2} - 8\beta_{h}h(e)(\gamma + bp_{c})^{2} - \lambda_{c}^{2}h(e)(\gamma + bp_{c})^{2} = (\gamma + bp_{c})^{2}[1 - \lambda_{c}^{2}h(e)] [4\beta_{h} - \lambda_{c}^{2}h(e)] < 0 \)

Therefore, \( \alpha_{1} > 0 \) and \( \alpha_{2} > 0 \).

Calculating the difference between the brand-name retailer’s profit with information symmetry and information asymmetry, we have:
Proof of Proposition 3 We use backward induction to obtain the equilibrium contract parameter. Firstly, let $\frac{\partial \Pi_R}{\partial m} = 0$ and $\frac{\partial \Pi_M}{\partial m} = 0$ respectively, we can obtain $p = \frac{\beta (a + \gamma - bw)}{2 \beta b - \lambda^2} + w$ and $m = \frac{\lambda (a + y + bw)}{2 \beta b - \lambda^2}$. Substituting $p$ and $m$ into the manufacturer’s profit function, we can obtain

$$\Pi_M = (w - c) \frac{\beta b (2a - yp_c - \alpha \lambda^2)}{2 \beta b - \lambda^2} - p \left[ (e_0 - \beta p (c + p_e)) + E \right] + F.$$

Secondly, let $\frac{\partial \Pi_M}{\partial w} = 0$, we can obtain

$$e = \frac{\beta \beta (ap - \gamma (c + p_e)) + (r - bp)}{2 \beta (a - yp_e) - \alpha \lambda^2}.$$

Therefore, the brand-name retailer’s and the manufacturer’s profit functions are:

$$\Pi_R = \frac{\beta [a - bw (2a - yp_c - \alpha \lambda^2) + \beta b \gamma^2 (w - c - p_e)]^2}{2 \beta b - \lambda^2} - p c E + F \geq \Pi_M.$$

If the manufacturer’s profit exceeds its reservation profit, the manufacturer would accept the contract. Thus, we have:

$$F^1 = \Pi_M^{WS} - \left[ \frac{\beta (w - c) [a - bw (2a - yp_c - \alpha \lambda^2) + \beta b \gamma^2 (w - c - p_e)]}{2 \beta b - \lambda^2} - p c E + F \right].$$

Substituting $F^1$ into the retailer’s profit function and let $\frac{\partial \Pi_R}{\partial w} = 0$, we can obtain $w^{TS*}$ and $F^{TS*}$.

Proof of Proposition 4 Based on the proof of proposition 1, we can obtain the brand-name retailer’s and the manufacturer’s profit functions $E[\Pi_R]$ and $\Pi_M$.

If the manufacturer’s profit exceeds its reservation profit, the manufacturer would accept the contract. Thus, we have:

$$F^2 = \Pi_M^{WS} - \left[ \frac{\beta (w - c) [a - bw (2a - yp_c - \alpha \lambda^2) + \beta b \gamma^2 (w - c - p_e)]}{2 \beta b - \lambda^2} - p c E + F \right].$$

Substituting $F^2$ into the brand-name retailer’s profit function and let $\frac{\partial \Pi_R}{\partial w} = 0$, we can obtain $w^{TA*}$ and $F^{TA*}$.
References

Apple (2021) Environmental Progress Report. Available at https://www.apple.com/environment/. Accessed Oct 2021
Atasu A, Wassenhove LNV, Sarvary M (2009) Efficient take-back legislation. Prod Oper Manag 18(3):243–258
Bai QG, Chen MY, Xu L (2017) Revenue and promotional cost-sharing contract versus two-part tariff contract in coordinating sustainable supply chain systems with deteriorating items. Int J Prod Econ 187:85–101
Bai QG, Xu JT, Zhang YY (2018) Emission reduction decision and coordination of a make-to-order supply chain with two products under cap-and-trade regulation. Comput Ind Eng 119:131–145
Barrieu P, Fehr M (2014) Market-consistent modeling for cap-and-trade schemes and application to option pricing. Oper Res 62(4):234–249
Bian JS, Zhang GQ, Zhou GH (2020) Contract manufacturer vs consumer subsidy with green technology investment and environmental concern. Eur J Oper Res 287(3):832–843
Cheng F, Chen T, Chen Q (2022) Cost-reducing strategy or emission-reducing strategy? The choice of low-carbon decisions under price threshold subsidy. Transport Res E Logist Transport Rev 157:102560
China Daily (2019) China’s national carbon market: mapping out the road ahead. Available at http://www.chinadaily.com.cn/cndy/2019-01/11/content_37425642.htm. Accessed Jan 2019
Cohen MC, Lobel R, Perakis G (2015) The impact of demand uncertainty on consumer subsidies for green technology adoption. Manag Sci 62(5):1235–1258
Conrad K (2005) Price competition and product differentiation when consumers care for the environment. Environ Resour Econ 31(1):1–19
D’Amato A, Dijkstra BR (2015) Technology choice and environmental regulation under asymmetric information. Resour Energy Econ 41:224–257
D’Aspremont C, Jacquemin A (1988) Cooperative and non-cooperative R&D in duopoly with spillovers. Am Econ Rev 78:1133–1137
Dawid H, Hartl RF, Kort PM (2020) Dynamic models of the firm with green energy and goodwill with a constant size of the output market. Games Manag Sci 280:131–146 Springer, Cham
Du SF, Hu L, Song M (2016) Production optimization considering environmental performance and preference in the cap-and-trade system. J Clean Prod 112:1600–1607
Du SF, Hu L, Wang L (2017) Low-carbon supply policies and supply chain management with carbon concerned demand. Ann Oper Res 255(1-2):569–590
Genasci L (2012) China NGOs tell brands to stop green washing. China Water Risk. Available at https://www.chinawaterrisk.org/resources/analysis-reviews/chin-emos-tell-brands-to-stop-greenwashing/. Accessed Nov 2012
Ghosh SK, Seikh MR, Chakraborty M (2020) Analyzing a stochastic dual-channel supply chain under consumers’ low carbon preferences and cap-and-trade regulation. Comput Ind Eng 149:106765
Grimmer M, Bingham T (2013) Company environmental performance and consumer purchase intentions. J Bus Res 66(10):1945–1953
Hammami R, Nouira I, Frein Y (2018) Effects of customers’ environmental awareness and environmental regulations on the emission intensity and price of a product. Decis Sci 49(6):1116–1155
Hepburn S (2015) Nike and Adidas show cautious support for eco-friendly dye technology. Available at https://www.theguardian.com/sustainablebusiness/sustainable-fashion-blog/2015/apr/24/nike-and-adidas-showcautious-support-for-eco-friendly-dye-technology. Accessed Apr 2015
Hong Z, Guo X (2019) Green product supply chain contracts considering environmental responsibilities. Omega 83:155–166
International Emission Trading Association (2013) The world’s carbon trading markets: a case study guide to emission trading. Available at http://www.ieta.org/worldcarbonmarkets. Accessed Feb 2013
Jin JN, Zhang ZY, Yang L (2017) Carbon emission reduction decisions in the retail/dual-channel supply chain with consumers’ preference. J Clean Prod 141:852–867
Jones R, Mendelson H (2011) Information goods vs. industrial goods: cost structure and competition. Manag Sci 57(1):164–176
José M, Moltó G, Georganzis N, Orts V (2005) Cooperative R&D with endogenous technology differentiation. J Econ Manag Strateg 14(2):461–476
Liu BY, Holmbom M, Segerstedt A, Chen WD (2015) Effects of carbon emission regulations on remanufacturing decisions with limited information of demand distribution. Int J Prod Res 53(2):532–548
Liu H, Kou XF, Xu GY, Qiu X, Liu HB (2021a) Which emission reduction mode is the best under the carbon cap-and-trade mechanism? J Clean Prod 314:128053
Liu ML, Li ZH, Anwar S, Zhang Y (2021b) Supply chain carbon emission reductions and coordination when consumers have a strong preference for low-carbon products. Environ Sci Pollut Res 28:19969–19983
Luo Z, Chen X, Wang XJ (2016) The role of co-opetition in low carbon manufacturing. Eur J Oper Res 253:392–403
Ma P, Shang J, Wang HY (2017) Enhancing corporate social responsibility: contract design under information asymmetry. Omega 67:19–30
Ma X, Ho W, Ji P, Talluri S (2018) Contract design with information asymmetry in a supply chain under an emission trading mechanism. Decis Sci 49(1):121–153
Ma C, Yang HJ, Zhang WP, Huang S (2021) Low-carbon consumption with government subsidy under asymmetric carbon emission information. J Clean Prod 318:128423
Meng XG, Yao Z, Nie JJ, Zhao XY, Li ZL (2018) Low-carbon product selection with carbon tax and competition: effects of the power structure. Int J Prod Econ 200:224–230
Ngai EWT, Law CCH, Carlos WHL, Poon JKL, Peng SS (2018) Business sustainability and corporate social responsibility: case studies of three gas operators in China. Int J Prod Res 56(1-2):660–676

Park S, Cachon GP, Lai G, Seshadri S (2015) Supply chain design and carbon penalty: monopoly vs. Monopolistic competition. Prod Oper Manage 24(9):1494–1508

Parry M, Canziani O, Palutikof J, Linden PVD, Hanson C (2007) Climate change 2007: Impacts, adaptation and vulnerability: contribution of working group II to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge

Peng QY, Wang CX, Xu L (2020) Emission abatement and procurement strategies in a low-carbon supply chain with option contracts under stochastic demand. Comput Ind Eng 144:106502

Toptal A, Çetinkaya B (2017) How supply chain coordination affects the environment: a carbon footprint perspective. Ann Oper Res 250:487–519

Wang K, Wei YM, Huang Z (2016) Potential gains from carbon emission trading in China: a DEA based estimation on abatement cost savings. Omega 63:48–59

Wang ZR, Brownlee AE, Wu QH (2020) Production and joint emission reduction decisions based on two-way cost sharing contract under cap-and-trade regulation. Comput Ind Eng 146:106549

Wang YY, Yu ZQ, Jin MZ, Mao JF (2021) Decisions and coordination of retailer-led low-carbon supply chain under altruistic preference. Eur J Oper Res 293:910–925

Wu P, Jin Y, Shi Y, Shyu H (2017) The impact of carbon emission costs on manufacturers’ production and location decision. Int J Prod Econ 193:193–206

Xia J, Niu WJ (2020) Pushing carbon footprint reduction along environment with carbon-reducing information asymmetry. J Clean Prod 249:119376

Xia LJ, Guo TT, Qin JJ, Yue XH, Zhu N (2018a) Carbon emission reduction and pricing policies of a supply chain considering reciprocal preferences in cap-and-trade system. Ann Oper Res 268:147–175

Xia LJ, Hao WQ, Qin JJ, Ji F, Yue XH (2018b) Carbon emission reduction and promotion policies considering social preferences and consumers’ low-carbon awareness in the cap-and-trade system. J Clean Prod 195:1105–1124

Xu XP, He P, Xu H, Zhang QP (2017) Supply chain coordination with green technology under cap-and-trade regulation. Int J Prod Econ 183(B):433–442

Xu S, Fang L, Govindan K (2022) Energy performance contracting in a supply chain with financially asymmetric manufacturers under carbon tax regulation for climate change mitigation. Omega 106:102535

Yang HX, Chen WB (2018) Retailer-driven carbon emission abatement with consumer environmental awareness and carbon tax: revenue-sharing vs. cost-sharing. Omega 78:179–191

Yang L, Zhang Q, Ji JN (2017) Pricing and carbon emission reduction decisions in supply chains with vertical and horizontal cooperation. Int J Prod Econ 191:286–297

Yang L, Ji J, Wang M, Wang Z (2018) The manufacturer’s joint decisions of channel selections and carbon emission reduction under the cap-and-trade regulation. J Clean Prod 193:506–523

Yang L, Hu YJ, Huang LJ (2020) Collecting mode selection in a remanufacturing supply chain under cap-and-trade regulation. Eur J Oper Res 287(2):480–496

Yao FJ, Parilina E, Zaccour G, Gao HW (2021) Accounting for consumers’ environmental concern in supply chain contracts. Eur J Oper Res 301(3):987–1006

Yu YG, Zhou SJ, Shi Y (2020) Information sharing or not across the supply chain: the role of carbon emission reduction. Transport Res E Logist Transport Rev 137:101915

Zhang ZY, Yu LY (2022) Supply chain joint emission reduction differential decisions and coordination considering altruistic behavior and reference low-carbon effect. Environ Sci Pollut Res 29:22325–22349

Zhang Q, Zhao QH, Zhao X (2019) Manufacturer’s product choice in the presence of environment-conscious consumers: brown product or green product. Int J Prod Res 57(23):7423–7438

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