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Optimal contract design for carbon emission reduction in a green supply chain: Monetary incentive vs. symbolic incentive

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[Correction added on 12 April 2023, after first online publication: The second affiliation was incorrectly linked to Mingchun Jiang instead of Lan Fang. This has been corrected in this version.]

Abstract

A supply chain with a manufacturer and a seller is studied in this paper for the impact of monetary and symbolic incentives on reducing carbon emissions. It is the responsibility of the manufacturer to invest in carbon emission abatement technologies and that of the seller to sell such products to consumers with green preferences. The study findings reveal that (1) both monetary and symbolic incentives can contribute to reducing carbon emissions but the choice between them depends on the trade-off between the cost-sharing ratio and the market interest rate; (2) implementing a hybrid policy could crowd-out carbon emission effects; and (3) the manufacturer may maximize his profits under a hybrid policy, but the seller may struggle to cover his expenses, which could hinder effective collaboration within the supply chain.

1 | INTRODUCTION

“Climate Change 2022: Impacts, Adaptation, and Vulnerabilities” is the report released by the Sixth Assessment Report (AR6) Working Group II of the Intergovernmental Panel on Climate Change on February 28, 2022. It highlights the perilous consequences of anthropogenic climate change, which threaten global biodiversity and billions of people worldwide. As the Earth's temperature continues to rise by 1.5°C within the next two decades, the world will face an array of severe climate risks, with limited response capacity for most people, and the ecological system will be hardest hit. Thus, it has become imperative and pressing for governments to rapidly curb greenhouse gas emissions, predominantly comprised of carbon dioxide.

The reduction of carbon emissions as a policy objective was initially encouraged and driven by government policies, such as subsidies or taxes on emission units. As policies have deepened and the

incentives for firms to reduce carbon emissions have increased, different forms of cooperation between firms have emerged, such as revenue sharing (Bhaskaran & Krishnan, 2009), cost sharing (Ghosh & Shah, 2015), and price subsidy contracts (Nouri et al., 2018). While these incentives may seem diverse, they all fundamentally aim to reduce the financial pressure on emitting firms, allowing them to finance themselves more directly. In this paper, we refer to this type of incentive as a monetary incentive.

Carbon taxes and low-carbon manufacturing subsidies are effective policy tools for controlling greenhouse gas emissions, stimulating low-carbon technological innovation, and optimizing industrial structure (Ari & Sari, 2017; Madani & Rasti-Barzoki, 2017; Nie et al., 2016). Currently, Germany and Denmark use carbon taxes as part of their tax systems to enhance environmental protection, energy conservation, and emission reduction. This contributes to the reduction of local carbon emissions. The sharing of costs and benefits among enterprises

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helps to internalize the externality of pollution control and incentivize emission-reducing investments. However, regardless of the monetary incentives offered by government promotion or enterprise mutual aid, there are concerns about the increased operating costs for businesses or the added financial pressure on the government. In China, for instance, the energy structure is complex, and the imposition of a carbon tax would raise the production costs of high-carbon industries, which could have an impact on the fiscal system. Furthermore, according to this model, social participation is limited and cannot engage the entire population in environmental protection.

Previous research indicates that using monetary incentive alone is often insufficient in achieving desired outcomes (Carpenter & Myers, 2010). It is the social recognition of a company's brand and impact that is integral to a company's longevity. For example, suppliers that achieve superior business transformation, innovation and growth are considered 'outstanding suppliers'. In such cases, suppliers may not be rewarded directly, but they may receive free advertising, preferential status or further opportunities to work with buyers in future transactions. Recently, the Agricultural Bank of China introduced a new policy that recognizes the green credentials of companies and includes their green products as collateral for loans. This type of incentive, which is provided by recognizing the effectiveness of companies in reducing carbon emissions, becomes a symbolic incentive in this paper. To distinguish between the two policies discussed in this paper, we have defined them as follows:

Monetary incentives are intended to offer financial support for emission reduction units and to help enterprises overcome the problem of lacking motivation to reduce emissions, which is partly due to insufficient funds. Symbolic incentives provide rewards to enterprises that excel in reducing emissions, motivating them to continue their efforts and creating a positive social impact. In terms of the order of execution, monetary incentives are given to companies before they reduce emissions, while symbolic incentives always appear after companies have already reduced carbon emissions. The implementation results indicate that monetary incentive can effectively address the issue of insufficient funds for enterprise emission reduction, providing a strong impetus for early-stage emissions reduction. However, it is important to note that these incentives only exist between the government and enterprises, or between enterprises themselves, and have limited social impact. Symbolic incentive recognizes the advanced behavior of enterprises, encourage them to deepen their emission reduction efforts, and promote their green image, thereby enhancing their reputation and advocating for the social benefits of green development.

Although there has been a great deal of researches on monetary incentive for carbon emissions, the policy effects of symbolic incentives on supply chain's carbon emissions reduction have not received much attention. Therefore, A theoretical analysis and comparison of both monetary and symbolic incentives on supply chain operations is presented in this paper. Manufacturer invest in technologies that reduce carbon emissions and offer environmentally friendly products to retailer. The retailer is accountable for the sale of products to consumers who prefer green alternatives. The retailer may offer monetary incentives via cost sharing to encourage carbon-reduction investments

by the manufacturer. The manufacturer with strong performance in reducing carbon emissions may also qualify for interest-free loans secured by their creditworthiness, which we refer to as symbolic incentives. In conclusion, this paper explores four key research questions:

1. What are the conditions for the application of monetary and symbolic incentives?
2. Is there a policy that reduces pollution more effectively and generates greater profits for manufacturer and seller?
3. In what ways do external factors like consumer preferences, market interest rates, and carbon abatement costs impact supply chain performance, pollution emissions, and prices?

A leader-follower game model based on manufacturer and retailer in supply chain is used to provide managerial and policy insight into the above issues. Next, we'll move on to the rest of the article. Research on related topics is reviewed in Section 2. There are four scenarios discussed in Section 3 along with basic assumptions and equilibrium results. A comparison of the results is shown in Section 4, and the paper concludes in Section 5.

2 | LITERATURE REVIEW

A review of the literature pertaining to monetary and symbolic policy will be provided in this subsection, as well as the differences between the findings of this study and those found in other studies.

The first theme of relevance to this paper is monetary incentives, whereby monetary policy incentives are usually the most direct and commonly used method. At the government level, taxes and subsidies are proven programs. For example, Taxing emissions in a competitive supply chain can both increase firms' sustainability and reduce their carbon footprint, according to Yu et al. (2019). Halat et al. (2021) investigated the implementation of a carbon tax policy in a multilevel supply chain, which can reduce the level of carbon emissions. Yi et al. (2021) used a game model to conclude that governmental subsidies can enhance the green innovation capacity of enterprises. In the follow-up study, further subsidies are obtained as a superior solution to tax to enhance carbon emission reduction (Yi, Wei, & Fu, 2021). From the perspective of intra-industry co-operation for emission reduction, cost sharing (Chakraborty et al., 2019), revenue sharing (Ma et al., 2013), quantity flexibility (Sethi et al., 2004), and quantity discount contract (Weng, 2004) are the classic models of collaboration. Vosooghizaji et al. (2020) argued that cost sharing is one of the important means to improve the overall performance of the supply chain by combing different incentive contracts in supply chain management (Chakraborty et al., 2019). Xiao et al. (2020) used a supply chain model to analyze responsibility, cost sharing, product quality selection, and coordination in a secondary supply chain. Yi et al. (2022) showed that cost sharing improves the profitability of manufacturers and retailers in the context of carbon emission reduction when retailers have sufficient capital. Corporate social responsibility plays a key role in corporate partnerships (Li et al., 2023). However,

the existing literature has rarely examined the influence of customers' ecological consciousness on policy. Consumption can impact the supply and demand relationship in the market from the demand side and may lead to the transformation of industrial structure. Consumers' green awareness and willingness to pay are expressed through consumption behavior. Under the influence of past consumption habits, consumption appears to fluctuate less in the short term. However, over time, changes in consumer behavioral preferences will not only directly affect consumption carbon emissions but also influence funding for green production technologies, production processes, and business models. This will guide and constrain corporate production decisions. On the other hand, achieving the goal of low-carbon emissions is a continuous process of transforming the economy and society into a green and low-carbon one. This requires simultaneous efforts on both the supply and demand sides, as well as the creation of a green and low-carbon social atmosphere for sustainable development, while improving institutional constraints.

In addition to monetary incentives for manufacturer, support can be given in the form of recognition of the manufacturer's carbon reduction behavior. A good accolade may be an even better way to motivate companies to move forward (Huberman et al., 2004). As forms of incentives have diversified, managers are increasingly focusing on symbolic incentives for employees (Gerhards & Siemer, 2014). Some scholars argue that symbolic incentives often complement monetary incentives (Kacperski & Kutzner, 2020) and play an important role in business management. In a comparison of two policies involving monetary and symbolic incentives, Kacperski et al. (2020) found that both monetary and symbolic incentives are effective in encouraging consumers to make greener purchasing decisions with no statistically significant difference between the two. Liu et al. (2022) examined the impact of monetary and symbolic incentives on supplier participation in the digital transformation of a two-tier supply chain and found that monetary incentives may lead to free-riding behavior by suppliers, while the combination of the two policies is more likely to increase supplier participation. The literature above systematically describes the use of monetary incentives, while referring to symbolic incentives as a form of verbal commendation or an intangible accolade bestowed upon a company. The paper argues that the categorization of incentives into either monetary or symbolic should not hinge on whether money is involved. Instead, any benefits or incentives that acknowledge a company's success in reducing carbon emissions and are granted after the achievement can be classified as symbolic incentives.

In summarizing the literature, we found that

1. The study considers consumer preferences for eco-friendly products as a crucial market force that propels the development of sustainable and principled supply chains. As per a survey conducted by Accenture, over 80% of those polled prioritize the purchase of such products. The purchase of environmentally friendly products is becoming increasingly important to consumers in the United Kingdom, as evidenced by studies on the greenness of a product (Hong & Guo, 2019). According to the Carbon Trust, about 20% of customers are interested in paying higher prices for these

products (Li et al., 2021). That is why it is crucial to consider offering eco-friendly alternatives in order to meet customer demand and build a sustainable future. The development of eco-friendly technologies, aimed at reducing pollution, is now driven by a combination of government policy and consumer demand, rather than solely relying on governmental regulations. This shift has been primarily due to the increasing consideration of consumer preferences for green products. This trend has impacted the way businesses approach sustainable practices.

2. Limited research exists on symbolic incentives, particularly those intended to reduce carbon emissions. Given their frequent use and proven efficacy, it is imperative that researchers include these incentives when developing programs aimed at reducing carbon emissions. Furthermore, a clear comparison of the effectiveness of these two types of incentives and the situations in which each policy should be used is lacking in the literature. We explore the impact of symbolic incentives on reducing carbon emissions and compare them to monetary incentives, addressing a gap in the literature.
3. This paper departs from the previous criterion of using monetary allocation to determine whether a policy is symbolic or monetary. This paper contends that the divergence between the two policy types must be traced to their initial starting point and the original intention of their implementation. To directly encourage and help enterprises to implement carbon emission reduction policy is called monetary policy, while after the enterprise has achieved the results of emission reduction, to acknowledge the effectiveness of carbon emission reduction, the benefits and preferential policies given to the enterprise are called symbolic incentives.

Based on the above three points, this study presents an extensive analysis to compensate for the limitations of the current literature.

3 | THE MODEL

3.1 | Problem description

In the study of this paper, a secondary supply chain with a manufacturer and a seller is assumed to exist in the market, an assumption that simplifies the model, facilitates highlighting the key information we are interested in, and has been widely used in academia (Wang et al., 2021; Zhang et al., 2020). Manufacturer implements carbon emission reductions and produce products under pressure from government and society, seller is responsible for retail sales, and consumers are environmentally conscious buyers who, all else being equal, prefer to purchase products with low carbon emissions. The profitability of the products offered by manufacturer is determined by the factors such as environmental friendliness and price.

During production, carbon emissions are generated by manufacturer, which can be partially reduced by investing in green innovation to improve technology. To promote carbon emission reduction and decrease their products' carbon footprint upstream, seller is willing to contribute to the expense of carbon emission reduction. This reduces

the production pressure on producers, increasing their sales scale. Consequently, manufacturer and seller engage in a leader–follower game.

In addition to this monetary incentive represented by cost sharing as described above, manufacturers will also voluntarily invest in carbon emission reductions with social approval. We use the example of banks lending interest-free loans to manufacturers for their carbon-reducing investments to represent this socially symbolic incentive. Although in reality, interest-free lending on carbon-reducing production has not yet been realized, there have been cases where some banks have provided lending using green eco-products as collateral, reducing the cost of financing for businesses.

It is assumed that there are four scenarios: no incentives, monetary incentives, symbolic incentives, and hybrid incentives, which are denoted by the symbols “N,” “M,” “S,” and “H” for ease of differentiation.

3.2 | Fundamental assumption

For a clear and convenient description of the model, the symbols and definitions of the variables and parameters are summarized in Table 1.

Consumer demand for supply chain product is defined in the first instance. According to related studies by Hong et al. (2019) and Li and Lv (2021) on green supply chains, consumers are environmentally aware and thus show a preference for and greater willingness to pay for products with a high degree of carbon reduction. This paper defines the degree of product greenness in terms of carbon emission reduction per unit of product produced. Based on Yi et al.'s (2022) findings, it can be deduced that the manufacture of each product unit results in the release of one unit of carbon emissions before the producer adopts carbon abatement practices. To improve their eco-friendly measures, manufacturer can invest in carbon abatement technological innovations, assuming that the carbon dioxide emission reduction for one unit of product is e ($0 < e < 1$). Thus, the product's carbon reduction intensity can be represented by the number of carbon emissions reduced per unit. The purchasing power of consumers has a direct positive correlation with the extent to which carbon emissions are lowered. Moreover, based on classical economic assumptions about demand and price, the following demand function is obtained:

$$d = \alpha - bp + \eta e, \quad (1)$$

where η is the degree of consumer preference for carbon reduction in the product. The potential market size is α , and the sensitivity of demand to price is b .

TABLE 1 Symbols and definitions of variables and parameters

Variables		Parameters	
w	Wholesale price of products	α	Potential market demand
e	Greenness of the product	b	Price elasticity coefficient
d	Market demand	η	Consumer preference for carbon reduction
p	Product sales prices	k	Coefficient of investment cost for greenness
π_m	Profit levels for the manufacturer	r	Market interest rate
π_s	Profit levels for the seller	λ	Proportion of cost sharing

Carbon reduction is an important responsibility for manufacturer. According to Li et al. (2021), green technology innovation is a necessary condition to reduce emissions. In line with Li et al. (2021) and Yi et al. (2021), it is assumed that the cost of an investment in a carbon abatement technology is set at $ke^2/2$ and k is the cost rate of investment in carbon abatement technology. The convexity and marginal increase in investment cost conform to the fundamental principles of microeconomics, as evident in various related studies such as those conducted by Wei et al. (2019) and Yi et al. (2021).

As a downstream link in the supply chain, the seller plays a crucial role in incentivizing carbon reduction. Assuming that seller is willing to share technology investment costs with manufacturer in the proportion of λ ($0 < \lambda < 1$), i.e., the total amount of $\frac{1}{2}\lambda ke^2$. However, the benefit from the resulting reduction in carbon emissions contributes to overall income.

Finally, we assume that if society encourages and provides symbolic incentive for companies to reduce their carbon emissions, banks will be willing to provide interest-free loans for carbon reduction investments with manufacturer's environmental credibility as collateral if the market interest rate is r . Therefore, in the absence of symbolic incentives, manufacturers have to pay financing costs of $\frac{1}{2}ke^2(1+r)^2$.

In what follows, as a baseline, we first discuss the situation without any incentives. Next, we examine the carbon reduction scenarios when monetary and symbolic incentives are present, and finally, we analyze the situation of the manufacturer and seller under mixed policy.

3.3 | Game equilibrium under no incentives (N)

In the absence of any monetary or symbolic incentives, the manufacturer will be driven by policy and by the demand of green consumers to invest in carbon abatement technologies and to pay for the costs of green investments.

The game between manufacturer and seller is analyzed using the inverse induction method. The first step is to solve the optimal decision problem for the follower–retailer.

$$\max_p \pi_s^N = (p - w)d. \quad (2)$$

By calculating the first and second order derivatives of Equation (2), the seller's optimal decision can be determined as follows:

$$p(w, e) = \frac{bw + \alpha + \eta e}{2b}. \tag{3}$$

The optimal decision of the leader-producer is discussed next.

$$\max_{w, e} \pi_m^N = wd - \frac{1}{2}ke^2 \left(1 + (1+r)^2\right) \tag{4}$$

Bringing the optimal solution $p(w, e)$ into Equation (4) and taking first and second order derivatives, we obtain the optimal policy for the manufacturer:

$$w^{N*} = \frac{2\alpha k(2+2r+r^2)}{-\eta^2 + 4bk(2+2r+r^2)}, e^{N*} = \frac{-a\eta}{\eta^2 - 4bk(2+2r+r^2)}.$$

The final optimal decision of the seller is obtained:

$$p^{N*} = \frac{3\alpha k(2+2r+r^2)}{-\eta^2 + 4bk(2+2r+r^2)}.$$

The manufacturer and seller's optimal strategies are inserted into Equations (1), (2), and (4) to calculate consumer demand and both parties' profits in the equilibrium game.

$$d^{N*} = \frac{\alpha bk(2+2r+r^2)}{-\eta^2 + 4bk(2+2r+r^2)},$$

$$\pi_m^{N*} = \frac{\alpha^2 k(2+2r+r^2)}{2(-\eta^2 + 4bk(2+2r+r^2))},$$

$$\pi_s^{N*} = \frac{b\alpha^2 k^2(2+2r+r^2)^2}{(\eta^2 - 4bk(2+2r+r^2))^2}.$$

Up to this point, all optimal decisions and results without incentives are obtained. In Corollary 1, we examine how fluctuations in parameters influence the optimum decisions of the supply chain.

Corollary 1. The optimal decisions in the absence of incentives have the following properties:

- i. $\frac{\partial e^N}{\partial k} < 0, \frac{\partial d^N}{\partial k} < 0, \frac{\partial \pi_m^N}{\partial k} < 0, \frac{\partial \pi_s^N}{\partial k} < 0.$
- ii. $\frac{\partial e^N}{\partial r} < 0, \frac{\partial d^N}{\partial r} < 0, \frac{\partial \pi_m^N}{\partial r} < 0, \frac{\partial \pi_s^N}{\partial r} < 0.$
- iii. $\frac{\partial e^N}{\partial \eta} > 0, \frac{\partial d^N}{\partial \eta} > 0, \frac{\partial \pi_m^N}{\partial \eta} > 0, \frac{\partial \pi_s^N}{\partial \eta} > 0.$

Proof: See Appendix A.

Item (i) in Corollary 1 demonstrates a negative correlation between the cost of reducing carbon emissions and the investment willingness of enterprises in carbon emission reduction, which on the one hand leads to a lower level of carbon emission reduction and on the other hand reduces consumer demand. The subsequent fall in product prices and shrinking margins for manufacturer and seller is then justified.

When Item (ii) is compared to Item (i), it becomes apparent that the rise in the market interest rate has a comparable impact to the rise

in the challenge associated with developing carbon reduction technologies. This phenomenon reflects the complementary relationship between carbon abatement technologies and market interest rates in the profit coalition of supply chains. An increase in investment or interest rates for carbon abatement technologies reduces the incentives for participants to invest. Similar to (ii), the simultaneous fall in demand and price leads to a fall in manufacturer and seller profits.

Item (iii) fully embodies the role of consumer demand in guiding the market. If consumers pay more and more attention to the consumption of carbon-reducing products, it will firstly encourage manufacturer to reduce pollutant emissions in the production process, secondly lead to an increase in the price level, and finally increase the profits of members of the supply chain. Therefore, consumer preference for carbon emission reduction is a signpost for the favorable development of the market.

3.4 | Game equilibrium under monetary incentive (M)

Under the monetary incentives, seller is willing to share the cost of carbon reduction investment for manufacturer in the proportion of λ . The manufacturer sets the wholesale price and the level of carbon investment, and the seller then sets their selling price.

$$\max_p \pi_s^M = (p - w)d - \frac{1}{2}\lambda ke^2 \tag{5}$$

Finding the first order derivative of the seller's profit with respect to p and making it equal to zero yields

$$p(w, e) = \frac{\alpha + bw + e\eta}{2b}. \tag{6}$$

Bring this result into the decision function for the production sector:

$$\max_{w, e} \pi_m^M = wq - \frac{1}{2}k(1-\lambda)e^2 \left(1 + (1+r)^2\right). \tag{7}$$

The Hessian matrix can be obtained as follows:

$$H(w, e) = \begin{bmatrix} \frac{\partial^2 \pi_m^M}{\partial w^2} & \frac{\partial^2 \pi_m^M}{\partial w \partial e} \\ \frac{\partial^2 \pi_m^M}{\partial e \partial w} & \frac{\partial^2 \pi_m^M}{\partial e^2} \end{bmatrix} = \begin{bmatrix} -b & \frac{1}{2}\eta \\ \frac{1}{2}\eta & k(2+2r+r^2)(\lambda-1) \end{bmatrix}.$$

To ensure that the profit has an optimal solution, it is necessary to ensure that the above equation is a negative definite matrix, i.e., $\lambda > 1 - \frac{\eta^2}{4bk(2+2r+r^2)}$. Since $0 < \lambda < 1$, the cost-sharing ratio should satisfy condition $1 - \frac{\eta^2}{4bk(2+2r+r^2)} < \lambda < 1$. Under this constraint, the following equilibrium optimal solution is obtained.

$$w^M = \frac{2\alpha k(2+2r+r^2)(\lambda-1)}{\eta^2+4bk(2+2r+r^2)(\lambda-1)}, \quad (8)$$

$$e^M = \frac{-\alpha\eta}{\eta^2+4bk(2+2r+r^2)(\lambda-1)}, \quad (9)$$

$$p^M = \frac{3\alpha k(2+2r+r^2)(\lambda-1)}{\eta^2+4bk(2+2r+r^2)(\lambda-1)}. \quad (10)$$

Bringing Equations (8)–(10) into Equations (1), (5), and (7) yields the consumer's demand as well as the manufacturer's and seller's profits.

$$d^M = \frac{\alpha bk(2+2r+r^2)(\lambda-1)}{\eta^2+4bk(2+2r+r^2)(\lambda-1)},$$

$$\pi_m^M = \frac{\alpha^2 k(2+2r+r^2)(\lambda-1)}{2(\eta^2+4bk(2+2r+r^2)(\lambda-1))},$$

$$\pi_s^M = \frac{\alpha^2 k(2bk(2+2r+r^2)^2(\lambda-1)^2 - \eta^2 \lambda)}{2(\eta^2+4bk(2+2r+r^2)(\lambda-1))^2}.$$

Corollary 2. The relationship between optimal decision and cost sharing has the following properties under monetary incentive:

$$\frac{\partial e^M}{\partial \lambda} > 0, \frac{\partial w^M}{\partial \lambda} > 0, \frac{\partial p^M}{\partial \lambda} > 0, \frac{\partial d^M}{\partial \lambda} > 0, \frac{\partial \pi_m^M}{\partial \lambda} > 0.$$

Proof: See Appendix B.

Corollary 2 states that when monetary incentives are applied, the greater the proportion of costs that sellers are willing to bear, the more manufacturer will be willing to invest in carbon abatement, thereby contributing to a cleaner environment. This leads to increased consumer purchases of low-carbon products, causing prices to rise and manufacturer and seller to profit.

3.5 | Game equilibrium under symbolic incentive (S)

Under the symbolic incentive policy, the manufacturer financing with carbon reduction credibility receives an interest-free loan, so the manufacturer's profit is expressed as

$$\max_{w,e} \pi_m^S = wq - \frac{1}{2}ke^2.$$

The profit of the seller remains unchanged as indicated in Equation (2).

To obtain the equilibrium optimal solution for each variable, we apply the inverse solution method. Table 2 provides a summary of the findings.

3.6 | Game equilibrium under hybrid incentive (H)

Hybrid incentives refer to a combination of both monetary and symbolic incentives. The profit expression of a manufacturer that receives support from both supply chain members and has unrestricted access to finance is presented as follows:

$$\max_{w,e} \pi_m^H = wd - \frac{1}{2}(1-\lambda)ke^2.$$

The seller's profit can be expressed with Equation (5). The optimal equilibrium solution for the model is obtained and listed in Table 2.

4 | RESULTS DISCUSSION

By analyzing the level of carbon reduction under the four scenarios, we obtain Proposition 1.

Proposition 1. Both monetary and symbolic incentives contribute to the reduction of carbon emissions compared to scenarios where no incentives are provided. The effectiveness of each incentive is dependent on the proportion of the cost that the seller is willing to bear. However, combining both policies may lead to the crowding out of carbon reduction efforts. This contrasts with Liu et al.'s (2022) argument that mixed incentives are more effective in emphasizing the policy's impact as they associate symbolic incentives solely with accolades from other market players for carbon emission reduction implementer. They believe such commendation boosts demand for the product and disregard the interdependent role between symbolic and monetary incentives. That is, $e^M - e^N > 0$, $e^S - e^N > 0$; when $\lambda < \frac{(1+r)^2}{1+(1+r)^2}$, then $e^S > e^M$.

Proof: See Appendix C.

Any of the incentives will encourage manufacturer to reduce carbon emissions more, and which policy is more likely to promote carbon reduction depends on the relationship between the cost-share ratio and the market interest rate, with $\frac{(1+r)^2}{1+(1+r)^2}$ as the threshold; if the cost-share ratio is less than the threshold, carbon emissions will be lower under the symbolic incentive than under the monetary incentive, and vice versa. However, the implementation of a hybrid policy risks crowding out the intended reduction in carbon emissions. Figure 1 illustrates that when the value of λ is taken on both sides of A and B, manufacturer's incentives to reduce carbon emissions are lower than they would be in the absence of the incentive policy. Moreover, an increase in market interest rates decreases sellers' willingness to bear costs from B to C with a lower willingness as interest rates rise; see Figure 1.

Proposition 2. Both monetary and symbolic incentives policies are capable of increasing consumer demand.

TABLE 2 The optimal equilibrium solution under four scenarios

	No incentives (N)	Monetary incentive (M)	Symbolic incentive (S)	Hybrid incentive (H)
w	$\frac{2ak(2+2r+r^2)}{-\eta^2+4bk(2+2r+r^2)}$	$\frac{2ak(2+2r+r^2)(\lambda-1)}{\eta^2+4bk(2+2r+r^2)(\lambda-1)}$	$\frac{2ak}{4bk-\eta^2}$	$\frac{2ak(\lambda-1)}{\eta^2+4bk(\lambda-1)}$
e	$\frac{-c\eta}{\eta^2-4bk(2+2r+r^2)}$	$\frac{-c\eta}{\eta^2+4bk(2+2r+r^2)(\lambda-1)}$	$\frac{c\eta}{4bk-\eta^2}$	$\frac{c\eta}{\eta^2+4bk(\lambda-1)}$
p	$\frac{3ak(2+2r+r^2)}{-\eta^2+4bk(2+2r+r^2)}$	$\frac{3ak(2+2r+r^2)(\lambda-1)}{\eta^2+4bk(2+2r+r^2)(\lambda-1)}$	$\frac{3ak}{4bk-\eta^2}$	$\frac{3ak(\lambda-1)}{\eta^2+4bk(\lambda-1)}$
d	$\frac{abk(2+2r+r^2)}{-\eta^2+4bk(2+2r+r^2)}$	$\frac{abk(2+2r+r^2)(\lambda-1)}{\eta^2+4bk(2+2r+r^2)(\lambda-1)}$	$\frac{bak}{4bk-\eta^2}$	$\frac{abk(\lambda-1)}{\eta^2+4bk(\lambda-1)}$
π^m	$\frac{\alpha^2k(2+2r+r^2)}{2(-\eta^2+4bk(2+2r+r^2))}$	$\frac{\alpha^2k(2+2r+r^2)(\lambda-1)}{2(\eta^2+4bk(2+2r+r^2)(\lambda-1))}$	$\frac{b\alpha^2k^2}{(4bk-\eta^2)^2}$	$\frac{\alpha^2k(\lambda-1)}{2(\eta^2+4bk(\lambda-1))}$
π_s	$\frac{ba^2k^2(2+2r+r^2)^2}{(\eta^2-4bk(2+2r+r^2))^2}$	$\frac{\alpha^2k(2bk(2+2r+r^2)^2(\lambda-1)^2-\eta^2\lambda)}{2(\eta^2+4bk(2+2r+r^2)(\lambda-1))^2}$	$\frac{\alpha^2k}{8bk-2\eta^2}$	$\frac{\alpha^2k(2bk(\lambda-1)^2-\eta^2\lambda)}{2(\eta^2+4bk(\lambda-1))^2}$

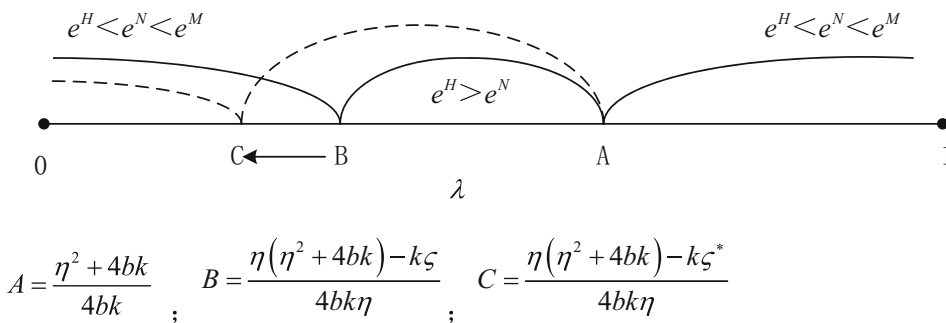


FIGURE 1 Relationship between cost sharing and carbon reduction

However, the impact of these two policies is reliant on the correlation between the parameters. That is, $d^M - d^N > 0, d^S - d^N > 0$.

Proof: See Appendix D.

The implementation of both policies resulted in effective carbon emission reductions by manufacturer, and consumers with green preferences increased their purchasing effort and demand for their products as a result. However, the hybrid policy does not necessarily make the product more attractive to consumers, in contrast to the effective carbon reduction.

Proposition 3. Both monetary and hybrid policies increase profits for manufacturer, with hybrid policies having greater significance. That is, $\pi_m^M - \pi_m^N > 0, \pi_m^H - \pi_m^N > 0, \pi_m^H - \pi_m^M > 0$.

Proof: See Appendix E.

The manufacturer's financial gains derive from a combination of seller cost-sharing and environmental benefits resulting from decreased carbon emissions associated with their products. Community-provided interest-free loans further mitigate the financial burden imposed on manufacturers during policy flux. However, this does not apply to sellers, who may be unable to cover their costs without a rebate from the manufacturer; i.e., the costs they have to bear to reduce carbon emissions are higher than the revenues they

can earn from low-carbon products, which reduces their willingness to cooperate.

Proposition 4. Incentives, whether of a symbolic or monetary character, push up prices at the factory level. However, it appears that hybrid policy has had the greatest impact on retail prices for sellers. That is, $w^M - w^N > 0, w^S - w^N > 0, p^S - p^N > 0, p^H - p^N > 0, p^H - p^S > 0$.

Proof: See Appendix F.

When two policies are implemented individually, the expenses linked with lessening carbon emission gradually shift downstream. Nevertheless, with the introduction of a hybrid policy, the implementation does not necessarily affect the manufacturer's selling price but directly affects the seller's price, as the cost sharing and interest rate reductions crowd out part of the carbon reduction effect.

5 | CONCLUSION

This study explores the profit-maximizing actions of manufacturers and sellers in the secondary supply chain when faced with environmentally conscious consumers, but in the absence of incentives, such as monetary, symbolic, or mixed incentives. Through this approach, we obtain the optimal strategy to incentive manufacturer to enhance carbon

emission reduction, which offers a theoretical foundation for the government to create a mechanism for reducing carbon emissions. Meanwhile, the comparative analyses of manufacturer's and seller's profits under the four scenarios lead to the following basic conclusions.

1. Both monetary and symbolic incentives can encourage carbon abatement. The optimal policy choice is determined by the trade-off between the cost-sharing ratio and the prevailing market interest rate, which is divided by a critical value. When the cost-sharing ratio is below this critical value, symbolic incentives are more effective in promoting carbon emission reduction, and vice versa.
2. Introducing a hybrid policy may decrease the impact of carbon emissions reduction. Furthermore, this policy could potentially decrease the willingness of potential sellers to cover the costs due to a rise in market interest rates. In extreme cases of high interest rates, sellers may decide to withdraw funds from carbon emission reduction and instead invest in projects with higher market returns.
3. Under the hybrid policy, manufacturer can make the most profit, but sellers may not be able to cover their costs; i.e., the cost of carbon emission reduction borne by the sellers is higher than the income generated by the low-carbon products, which leads to the interruption of cooperation. To ensure carbon emission reduction cooperation is sustainable, manufacturers should consider providing performance feedback to sellers when using the hybrid policy.
4. Consumer awareness of reducing carbon emissions is a crucial factor that contributes to price, demand, and profit increase within the supply chain. Therefore, it is incumbent upon every market participant, not just the government, to undertake the task of public education and awareness.

It is important to note that there are limitations to this study. The model does not outline the relationship between carbon emission reduction credits and interest rate reductions for enterprises in detail, and it is important to recognize that units and individuals with different credit ratings receive varying lending preferences. Moreover, it is crucial to consider that consumer preferences not only revolve around product carbon reduction but also focus heavily on product quality. However, due to spatial limitations, these issues will be discussed in subsequent research.

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DATA AVAILABILITY STATEMENT

The authors confirm that the data supporting the findings of this study are available within the article.

CONFLICT OF INTEREST

The authors declare that they do not have any conflict of interest.

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REFERENCES

- Ari, I., & Sari, R. (2017). Differentiation of developed and developing countries for the Paris Agreement. *Energy Strategy Reviews*, 18, 175–182. <https://doi.org/10.1016/j.esr.2017.09.016>
- Bhaskaran, S. R., & Krishnan, V. (2009). Effort, revenue and cost sharing in collaborative new product development. *Management Science*, 55(7), 1152–1169. <https://doi.org/10.1287/mnsc.1090.1010>
- Carpenter, J., & Myers, C. K. (2010). Why volunteer? Evidence on the role of altruism, image, and incentives. *Journal of Public Economics*, 94(11–12), 911–920. <https://doi.org/10.1016/j.pubeco.2010.07.007>
- Chakraborty, T., Chauhan, S. S., & Ouhimmou, M. (2019). Cost-sharing mechanism for product quality improvement in a supply chain under competition. *International Journal of Production Economics*, 208, 566–587. <https://doi.org/10.1016/j.ijpe.2018.12.015>
- Gerhards, L., & Siemer, N. (2014). *Private versus public feedback: The incentive effects of symbolic awards*. Department of Economics and Business Economics, Aarhus BSS.
- Ghosh, D., & Shah, J. (2015). Supply chain analysis under green sensitive consumer demand and cost sharing contract. *International Journal of Production Economics*, 164, 319–329. <https://doi.org/10.1016/j.ijpe.2014.11.005>
- Halat, K., Hafezalkotob, A., & Sayadi, M. K. (2021). Cooperative inventory games in multi-echelon supply chains under carbon tax policy: Vertical or horizontal? *Applied Mathematical Modelling*, 99, 166–203. <https://doi.org/10.1016/j.apm.2021.06.013>
- Hong, Z., & Guo, X. (2019). Green product supply chain contracts considering environmental responsibilities. *Omega*, 83, 155–166. <https://doi.org/10.1016/j.omega.2018.02.010>
- Huberman, B. A., Loch, C. H., & Öncüler, A. (2004). Status as a valued resource. *Social Psychology Quarterly*, 67(1), 103–114. <https://doi.org/10.1177/019027250406700109>
- Kacperski, C., & Kutzner, F. (2020). Financial and symbolic incentives promote 'green' charging choices. *Transportation Research Part F: Traffic Psychology and Behaviour*, 69, 151–158. <https://doi.org/10.1016/j.trf.2020.01.002>
- Li, C., Liu, Q., Zhou, P., & Huang, H. (2021). Optimal innovation investment: The role of subsidy schemes and supply chain channel power structure. *Computers & Industrial Engineering*, 157, 107291. <https://doi.org/10.1016/j.cie.2021.107291>
- Li, D. (2022). Dynamic optimal control of firms' green innovation investment and pricing strategies with environmental awareness and emission tax. *Managerial and Decision Economics*, 43(4), 920–932. <https://doi.org/10.1002/mde.3427>
- Li, D., & Lv, H. (2021). Investment in environmental innovation with environmental regulation and consumers' environmental awareness: A dynamic analysis. *Sustainable Production and Consumption*, 28, 1366–1380. <https://doi.org/10.1016/j.spc.2021.08.012>
- Li, D., Shang, C., & Sun, Z. Y. (2023). Firms' environmental R&D cooperation strategy with strategic corporate social responsibility. *Technology Analysis & Strategic Management*, 1–18. <https://doi.org/10.1080/09537325.2023.2196343>
- Li, Z., Pan, Y., Yang, W., Ma, J., & Zhou, M. (2021). Effects of government subsidies on green technology investment and green marketing coordination of supply chain under the cap-and-trade mechanism. *Energy Economics*, 101, 105426. <https://doi.org/10.1016/j.eneco.2021.105426>
- Liu, W., Wei, S., Li, K. W., & Long, S. (2022). Supplier participation in digital transformation of a two-echelon supply chain: Monetary and symbolic

- incentives. *Transportation Research Part E: Logistics and Transportation Review*, 161, 102688. <https://doi.org/10.1016/j.tre.2022.102688>
- Ma, P., Wang, H., & Shang, J. (2013). Contract design for two-stage supply chain coordination: Integrating manufacturer-quality and retailer-marketing efforts. *International Journal of Production Economics*, 146(2), 745–755. <https://doi.org/10.1016/j.ijpe.2013.09.004>
- Madani, S. R., & Rasti-Barzoki, M. (2017). Sustainable supply chain management with pricing, greening and governmental tariffs determining strategies: A game-theoretic approach. *Computers & Industrial Engineering*, 105, 287–298. <https://doi.org/10.1016/j.cie.2017.01.017>
- Nie, P. Y., Chen, Y. H., Yang, Y. C., & Wang, X. H. (2016). Subsidies in carbon finance for promoting renewable energy development. *Journal of Cleaner Production*, 139, 677–684. <https://doi.org/10.1016/j.jclepro.2016.08.083>
- Nouri, M., Hosseini-Motlagh, S. M., Nematollahi, M., & Sarker, B. R. (2018). Coordinating manufacturer's innovation and retailer's promotion and replenishment using a compensation-based wholesale price contract. *International Journal of Production Economics*, 198, 11–24. <https://doi.org/10.1016/j.ijpe.2018.01.023>
- Sethi, S. P., Yan, H., & Zhang, H. (2004). Quantity flexibility contracts: Optimal decisions with information updates. *Decision Sciences*, 35(4), 691–712. <https://doi.org/10.1111/j.1540-5915.2004.02873.x>
- Vosooghizajaji, M., Taghipour, A., & Canel-Depitre, B. (2020). Supply chain coordination under information asymmetry: A review. *International Journal of Production Research*, 58(6), 1805–1834. <https://doi.org/10.1080/00207543.2019.1685702>
- Wang, Y., Xu, X., & Zhu, Q. (2021). Carbon emission reduction decisions of supply chain members under cap-and-trade regulations: A differential game analysis. *Computers and Industrial Engineering*, 162, 107711.
- Wei, Z., Yi, Y., & Fu, C. (2019). Cournot competition and “green” innovation under efficiency-improving learning by doing. *Physica a: Statistical Mechanics and its Applications*, 531, 121762. <https://doi.org/10.1016/j.physa.2019.121762>
- Weng, Z. K. (2004). Coordinating order quantities between the manufacturer and the buyer: A generalized newsvendor model. *European Journal of Operational Research*, 156(1), 148–161. [https://doi.org/10.1016/S0377-2217\(03\)00003-1](https://doi.org/10.1016/S0377-2217(03)00003-1)
- Xiao, D., Wang, J., & Lu, Q. (2020). Stimulating sustainability investment level of suppliers with strategic commitment to price and cost sharing in supply chain. *Journal of Cleaner Production*, 252, 119732. <https://doi.org/10.1016/j.jclepro.2019.119732>
- Yi, Y., Liu, S., Fu, C., & Li, Y. (2021). Joint tax-subsidy for a manufacturing-recycling system under further extended producer responsibility. *Sustainable Production and Consumption*, 28, 610–623. <https://doi.org/10.1016/j.spc.2021.06.026>
- Yi, Y., Wang, Y., Fu, C., & Li, Y. (2022). Taxes or subsidies to promote investment in green technologies for a supply chain considering consumer preferences for green products. *Computers & Industrial Engineering*, 171, 108371. <https://doi.org/10.1016/j.cie.2022.108371>
- Yi, Y., Wei, Z., & Fu, C. (2021). An optimal combination of emissions tax and green innovation subsidies for polluting oligopolies. *Journal of Cleaner Production*, 284, 124693. <https://doi.org/10.1016/j.jclepro.2020.124693>
- Yu, M., Cruz, J. M., & Li, D. (2019). The sustainable supply chain network competition with environmental tax policies. *International Journal of Production Economics*, 217, 218–231. <https://doi.org/10.1016/j.ijpe.2018.08.005>
- Zhang, Y., Hong, Z., Chen, Z., & Glock, C. H. (2020). Tax or subsidy? Design and selection of regulatory policies for remanufacturing. *European Journal of Operational Research*, 287(3), 885–900. <https://doi.org/10.1016/j.ejor.2020.05.023>

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APPENDIX A

Proof of Corollary 1:

When the variables have an economic meaning, we have $-\eta^2 + 4bk(2 + 2r + r^2) > 0$, $\eta^2 + 4bk(2 + 2r + r^2)(\lambda - 1) < 0$, $4bk - \eta^2 > 0$, so the following sensitivity relationships between variables and parameters are obtained:

$$\frac{\partial e^N}{\partial k} = \frac{-4ba\eta(2+2r+r^2)}{(\eta^2-4bk(2+2r+r^2))^2} < 0; \frac{\partial e^N}{\partial r} = \frac{-4a\eta bk(2+2r)}{(\eta^2-4bk(2+2r+r^2))^2} < 0; \frac{\partial p^N}{\partial k} = \frac{-3\eta^2\alpha(2+2r+r^2)}{(-\eta^2+4bk(2+2r+r^2))^2} < 0; \frac{\partial p^N}{\partial r} = \frac{-3ak\eta^2(2+2r)}{(-\eta^2+4bk(2+2r+r^2))^2} < 0,$$

$$\frac{\partial p^N}{\partial \eta} = \frac{2\eta}{(-\eta^2 + 4bk(2 + 2r + r^2))^2} > 0,$$

$$\frac{\partial d^N}{\partial r} = \frac{-\eta^2 abk(2 + 2r)}{(-\eta^2 + 4bk(2 + 2r + r^2))^2} < 0,$$

$$\frac{\partial d^N}{\partial \eta} = \frac{2\eta}{(-\eta^2 + 4bk(2 + 2r + r^2))^2} > 0,$$

$$\frac{\partial \pi_m^N}{\partial k} = \frac{-2\eta^2\alpha^2(2 + 2r + r^2)}{(2(-\eta^2 + 4bk(2 + 2r + r^2)))^2} < 0,$$

$$\frac{\partial \pi_m^N}{\partial r} = \frac{-2\eta^2 \alpha^2 k(2+2r)}{(2(-\eta^2 + 4bk(2+2r+r^2)))^2} < 0,$$

$$\frac{\partial \pi_m^N}{\partial \eta} = \frac{4\eta}{(2(-\eta^2 + 4bk(2+2r+r^2)))^2} > 0,$$

$$\frac{\partial \pi_s^N}{\partial k} = \frac{2b\alpha^2 k \eta^2 (2+2r+r^2)^2 (\eta^2 - 4bk(2+2r+r^2))}{(\eta^2 - 4bk(2+2r+r^2))^4} < 0,$$

$$\frac{\partial \pi_s^N}{\partial r} = \frac{2b\alpha^2 k^2 \eta^2 (2+2r+r^2)(2+2r)(\eta^2 - 4bk(2+2r+r^2))}{(\eta^2 - 4bk(2+2r+r^2))^4} < 0,$$

$$\frac{\partial \pi_s^N}{\partial \eta} = \frac{-4b\alpha^2 k^2 \eta (2+2r+r^2)^2 (\eta^2 - 4bk(2+2r+r^2))}{(\eta^2 - 4bk(2+2r+r^2))^2} > 0.$$

APPENDIX B

Proof of Corollary 2:

$$\frac{\partial w^M}{\partial \lambda} = \frac{2ak\eta^2(2+2r+r^2)}{(\eta^2 + 4bk(2+2r+r^2)(\lambda-1))^2} > 0, \quad \frac{\partial e^M}{\partial \lambda} = \frac{a\eta(4bk(2+2r+r^2))}{(\eta^2 + 4bk(2+2r+r^2)(\lambda-1))^2} > 0, \quad \frac{\partial p^M}{\partial \lambda} = \frac{3ak\eta^2(2+2r+r^2)}{(\eta^2 + 4bk(2+2r+r^2)(\lambda-1))^2} > 0, \quad \frac{\partial d^M}{\partial \lambda} = \frac{abk\eta^2(2+2r+r^2)}{(\eta^2 + 4bk(2+2r+r^2)(\lambda-1))^2} > 0$$

$$\frac{\partial \pi_m^M}{\partial \lambda} = \frac{2\alpha^2 k \eta^2 (2+2r+r^2)}{(2(\eta^2 + 4bk(2+2r+r^2)(\lambda-1)))^2} > 0.$$

APPENDIX C

Proof of Proposition 1:

$$e^M - e^N = a\eta \left(\frac{1}{-4bk(2+2r+r^2) + \eta^2} - \frac{1}{-4bk(2+2r+r^2)(1-\lambda) + \eta^2} \right) > 0,$$

$$e^S - e^N = a\eta \left(\frac{1}{4bk - \eta^2} - \frac{1}{4bk(2+2r+r^2) - \eta^2} \right) > 0,$$

$$\begin{aligned} e^S - e^M &= \frac{a\eta}{4bk - \eta^2} + \frac{a\eta}{\eta^2 + 4bk(2+2r+r^2)(\lambda-1)} \\ &= a\eta \left(\frac{1}{4bk - \eta^2} + \frac{1}{\eta^2 + 4bk(2+2r+r^2)(\lambda-1)} \right), \end{aligned}$$

When $\lambda < \frac{(1+r)^2}{1+(1+r)}$, $e^S > e^M$.

APPENDIX D

Proof of Proposition 2:

$$d^M - d^N = -\frac{bk\alpha\eta^2\lambda(2+2r+r^2)}{(4bk(2+2r+r^2)-\eta^2)(\eta^2+4bk(2+2r+r^2)(\lambda-1))} > 0,$$

$$d^S - d^N = \frac{bk(1+r)^2\alpha\eta^2}{(4bk-\eta^2)(4bk(2+2r+r^2)-\eta^2)} > 0.$$

APPENDIX E

Proof of Proposition 3:

$$\pi_m^M - \pi_m^N = -\frac{\lambda k\alpha^2\eta^2(2+2r+r^2)}{(2(4bk(2+2r+r^2)-\eta^2))(\eta^2+4bk(2+2r+r^2)(\lambda-1))} > 0,$$

$$\pi_m^H - \pi_m^N = -\frac{k\alpha^2\eta^2(1+2r+r^2+\lambda)}{(2(4bk(2+2r+r^2)-\eta^2))(\eta^2+4bk(\lambda-1))} > 0,$$

$$\pi_m^H - \pi_m^M = -\frac{k\alpha^2\eta^2(\lambda-1)(1+2r+r^2)}{(2(\eta^2+4bk(\lambda-1)))(4bk(2+2r+r^2)(\lambda-1)+\eta^2)} > 0.$$

APPENDIX F

Proof of Proposition 4:

$$w^M - w^N = -\frac{2k\alpha\eta^2\lambda(2+2r+r^2)}{(4bk(2+2r+r^2)-\eta^2)(\eta^2+4bk(2+2r+r^2)(\lambda-1))} > 0,$$

$$w^S - w^N = \frac{2k\alpha\eta^2(1+r)^2}{(4bk-\eta^2)(-\eta^2+4bk(2+2r+r^2))} > 0,$$

$$p^S - p^N = \frac{3k(1+r)^2\alpha\eta^2}{(4bk-\eta^2)(4bk(2+2r+r^2)-\eta^2)} > 0,$$

$$p^H - p^N = -\frac{3k(1+2r+r^2+\lambda)\alpha\eta^2}{(\eta^2+4bk(\lambda-1))(4bk(2+2r+r^2)-\eta^2)} > 0,$$

$$p^H - p^S = \frac{3k\alpha\eta^2\lambda}{(\eta^2-4bk)(\eta^2+4bk(\lambda-1))} > 0.$$