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Original Research

Pricing Ecological Products under Duopoly

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Abstract

The construction of ecological civilization has put forward new requirements for the market-oriented reform of ecological products, and pricing is the most effective mechanism for marketization. This paper actively expands on the definition of ecological products and considers two game models to compare different consumption preferences and tax/subsidy policies. The results show that, under a static game, ecological products pose a disadvantage, which can lead to negative profits. In a dynamic game, an ecological firm can obtain higher profits by virtue of the positive externalities of its products. Changes in subsidies and taxes can achieve the expected effect of policies, which may reduce the price of ecological products and thus improve competitiveness. Meanwhile, we found that tax policy regulation plays a more significant role than a supporting subsidy, but the ecological degree effect may be the opposite under extreme conditions. This research provides theoretical guidance for promoting the use of ecological products for environmental improvement.

Keywords: Ecological products, Game model, Tax and subsidy effect, Policy intervention

Introduction

A healthy ecological environment has become scarce in the face of the current environmental crisis. Ecosystems are the input sources of economies and deeply reflect human impact. Based on the theory of sustainable development, ecosystems have been strictly considered in economic assessments [1]. Ecosystem services and products have long been regarded as invisible, irrelevant to economics, or completely unknown. There is still no definitive conclusion on how to accurately account for ecosystem products and monetize them. "Ecological products" are a dynamic and evolving concept, and most scholars' discussions on ecological products are in light of the "environmental protection" thinking paradigm [2–5], mainly referring to the final products or services provided by ecosystems for the well-being of human ecological life through biological production. It is generally believed that ecological products represent the market value of ecosystems, and most studies on ecological products use the above concepts to discuss this value [6–10].

Certainly, the development and production of ecological products have "dual externalities", which not only have typical spillover effects, but also produce external effects by reducing production and the external environmental costs of products. From the perspective of the environment, ecological products can reduce resource consumption and achieve sustainable development;

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from a commercial perspective, they can reduce social costs and potential liability risks, thereby improving competitiveness. With the further promotion of ecological civilization construction and the continuous improvement of the ecological life quality of social subjects, the demand of social subjects for ecological products has gradually changed from basic and simple to complex and diverse [11]. On the basis of deepening the market-oriented reform of ecological products, we define ecological products as products that have undergone strict ecological design, typically through ecological identification, ecological diagnosis, ecological definition, and ecological evaluation, followed by recurring and optimized adjustment, considering the environmental impact of the entire process of the product lifecycle. The positive externalities of ecological products in the environment are reflected in the improvement of the ecosystem, from the acquisition of raw materials to product production, consumer use, and ultimately recycling. Therefore, we believe that ecological products not only refer to traditional biomass supplies such as water, wood, and air, but also include goods and services provided by humans, such as new energy, physical carbon sequestration, and soil purification. However, when ecological products play an external role, there are still issues such as the absence of laws and regulations or mandatory policies, unclear market establishment and trading rules, and market supervision failure. A closed-loop mechanism for ecological product consumption should be established.

Traditionally, it is believed that the price of a product reflects consumers' willingness to consume from three different perspectives. First, numerous studies suggest that consumer willingness is affected by demographic and economic variables [12–15]; the second is to consider information and knowledge on environmental issues [16, 17]; the third view adopts psychological variables, including values, lifestyles, personality characteristics, and attitudes [18–21]. The purpose of this study is to reflect different environmental protection concepts through consumer choices of general products and ecological products, which is reflected in the utility function as the negative externality of general products and the positive externality of ecological products.

To take "ecological products" into consideration in an economic sense is to seek the path of product marketization from the perspective of balanced production and demand. The most basic and effective regulatory mechanism for the marketization of ecological products is price. Price decision-making refers to the process in which enterprises choose and optimize their product pricing schemes according to their own conditions and market environment. Hermannn [22] proposed a dynamic model of price elasticity related to the brand life cycle. Rao & Shakun [23] put forward a price model for new brands to enter the market, which fully considered the market structure, as well as an enterprise's brand prospect and competition goal in the process of realizing the pricing strategy. Dolan & Jeuland [24] built an optimal price model that takes cost dynamics and diffusion process dynamics into account. However, the connection between supply and demand is the core factor influencing the price formation of any market-oriented product; therefore, we must simultaneously consider the maximization of consumer utility and the maximization of producer profits. The correlation between consumers' ability to pay for ecological products and social demand is positive; that is, consumers' willingness to pay for products is strongly related to production costs. Yang et al. [25], Sun et al. [26], and Wang et al. [27] have conducted different studies in innovation cost reduction, green lending, dual supply-chain pricing, and other fields. Numerous scholars have discussed product pricing using game models [28–30]. Sun and Nie [31] and Huang et al. [32] also presented different forms of the equilibrium solution of a dynamic game. In view of this, we will continue to use the game model to study the pricing behavior of ecological products, mainly setting up a complete-information static game and two complete-information dynamic games between two producers, in which one is a general firm, whose general products have a certain negative externality without considering the impact on the environment, such as fossil energy technology and mining services. Conversely, another is an ecological firm, which produces ecological products with positive externalities, such as new energy technologies and soil purification services.

Furthermore, market competition is inseparable from the government's economic control policies, and the commonly used tools are taxes and subsidies. Producers' profits are largely determined by taxes/subsidies. Levying environmental protection taxes on output can significantly improve consumption structure and ecology [33–35]. Krass et al. [36] established a price-dependent demand model, focusing on the role of environmental taxes in reducing environmental pollution. Yang et al. [37] studied the impact of a renewable energy subsidy game on social welfare based on a dynamic equilibrium model. The level of subsidies greatly affects producers' production and pricing decisions [38, 39]. Gouda et al. [40] and Bian & Zhao [41] considered two sets of policy tools and compared the impact of unified subsidy policy and discriminatory subsidy policy on total welfare and the average environment. Ensure fairness and efficiency in resource allocation and environmental protection by utilizing an adjustable combination of tax and subsidy policies [41–43]. Similarly, Zhang et al. [44] introduced the Stackelberg model to study the choice of tax policy, subsidy policy, and tax subsidy policy. Different from the above study, we considered how the benefits of ecological products in different tax and subsidy scenarios affect price. We also explored whether changes in a tax/subsidy can improve market competition as expected by policymakers and urge manufacturers to change their strategies.

Many studies have analyzed ecosystem products and values, promoting research progress in this field. However, existing research has rarely explored the economic value of ecological products, as it is widely believed that ecological products are an ecological concept and have not been considered in the relationship between production and nature. In addition, in some research on product pricing, apart from focusing on the most important supply-demand relationship, there are few direct considerations of both tax and subsidy effects. This paper emphasizes the tangible economic value of ecological products, which can be reflected in their price formation through supply and demand relationships and tax/subsidy effects. This will provide a new analytical paradigm for the marketization of ecological products.

In summary, the most critical core influencing factor for the formation of ecological product prices is the relationship between supply and demand. By setting the consumption utility function of general products and ecological products, combined with the producer profit function and the equilibrium solution under the duopoly game, we can capture the positive externalities of ecological products and how government taxes/subsidies affect the pricing of ecological products through numerical simulation. The research results will depict the optimization space for price determination in the current market-oriented reform of ecological products, providing a scientific theoretical basis for the marketization of ecological products and also clarifying the direction of government tax/subsidy policy selection, providing scientific guidance for the construction of ecological civilization.

The rest of this paper is organized as follows. The model, based on consumers' heterogeneous preferences and producers' pricing strategies, is presented in methodology section. Subsequently, the game model is analyzed in theoretical analysis and model solution section, and negative and positive externalities are captured. Results and discussion section reports the main results of tax effects and subsidy effects. Concluding remarks are presented in the last section.

Methodology

Consider an industry with two producers producing homogenous products, in which one is a general firm and the other is an ecological firm. The products offered by the general firm have certain negative externalities. On the contrary, ecological products can generate positive externalities. Denote the two producers as *G* and *E*, where firm *G* is a general firm and firm *E* is an ecological one. We then establish two game models and diverse scenarios of tax and subsidy policies.

Demand Function

p_G is the price of general products, p_E is the price of ecological products, and the quantity of products is q_G and q_E. The utility function of representative consumers is given by:

$$U(p_G, q_G, p_E, q_E, \gamma) = A(q_G + q_E) - \frac{1}{2}({q_G}^2 + {q_E}^2) - \tau q_G - p_G q_G - p_E q_E + \gamma q_G q_E \quad (1)$$

where $A > 0$ is the reserve price (expected expenditure) of the commodity purchased by consumers, $\tau > 0$ is the ecological footprint of general product consumption (negative externality), and γ is the alternativeness when choosing between two commodities, which is the performance of consumers' ecological attitude. Regarding preference (γ is a random variable, $\gamma \in [0,1]$, $\int_0^1 f(\gamma)\, d\gamma = 1$), when $\gamma = 0$, consumers have no sense of ecosystem conservation, and $\gamma = 1$ means that consumers strongly support environmental policies and prefer ecological products.

For two products in a market, consumers determine the optimal purchase quantity according to the principle of maximizing their own utility. The inverse demand function is given as follows:

$$\begin{aligned} p_G &= A - q_G - \tau + \gamma q_E \\ p_E &= A - q_E + \gamma q_G \end{aligned} \quad (2)$$

Production Function

The profit functions of firms producing general and ecological products can be expressed as:

$$\begin{aligned} \pi_G &= p_G q_G - c_G q_G - \alpha q_G \\ \pi_E &= p_E q_E - c_E q_E + \beta q_E \end{aligned} \quad (3)$$

For simplification, we introduce the assumption that $c_G < c_E$, implying that the marginal costs of ecological firms are greater than those of general firms. $\alpha > 0$ is the tax on general products, and $\beta > 0$ is the subsidy on ecological products.

Theoretical Analysis and Model Solution

In this section, the above model is analyzed using a static game and two dynamic games of complete information between a general firm and an ecological firm. Here, we capture the positive/negative externalities by comparing product prices with producers' profits.

Static Game of Complete Information

In a similar product market, both firms compete in output, take actions according to their competitors' strategies, and assume that their competitors continue to do so, so as to make their own decisions. The first-order optimal conditions for the profit maximization of two firms can be obtained from Eq. (3).

$$\begin{aligned} \frac{\partial \pi_G}{\partial q_G} &= A - 2q_G - \tau + \gamma q_E - c_G - \alpha = 0 \\ \frac{\partial \pi_E}{\partial q_E} &= A - 2q_E + \gamma q_G - c_E + \beta = 0 \end{aligned} \quad (4)$$

$$\begin{aligned} q_G &= \frac{A + \gamma q_E - \tau - c_G - \alpha}{2} \\ q_E &= \frac{A + \gamma q_G - c_E + \beta}{2} \end{aligned} \quad (5)$$

The equilibrium output of two firms under a static game of complete information is:

$$q_G^{*,1} = \frac{(2+\gamma)A - 2(c_G+\alpha+\tau) - \gamma(c_E-\beta)}{4-\gamma^2}$$
$$q_E^{*,1} = \frac{(2+\gamma)A - \gamma(c_G+\alpha+\tau) - 2(c_E-\beta)}{4-\gamma^2} \tag{6}$$

By substituting Eq. (6) into Eq. (2), we can obtain the equilibrium prices of the two products as follows:

$$p_G^{*,1} = \frac{(2+\gamma)A + (2-\gamma^2)(c_G+\alpha+\tau) - \gamma(c_E-\beta)}{4-\gamma^2} - \tau$$
$$p_E^{*,1} = \frac{(2+\gamma)A - \gamma(c_G+\alpha+\tau) + (2-\gamma^2)(c_E-\beta)}{4-\gamma^2} \tag{7}$$

and

$$\frac{\partial p_G^{*,1}}{\partial \gamma} = \frac{(4+\gamma^2)(A-c_E+\beta) + 4\gamma(A-c_G-\alpha-\tau)}{(4-\gamma^2)^2} > 0$$
$$\frac{\partial p_E^{*,1}}{\partial \gamma} = \frac{(4+\gamma^2+4\gamma)A - (4-\gamma^2+\gamma)(c_G+\alpha+\tau) - 4\gamma(c_E-\beta)}{(4-\gamma^2)^2} > 0 \tag{8}$$

Proposition 1. Under the most ideal premise, $\tau = 0$, $\gamma = 1$, indicating that the initial environmental conditions are favorable, and consumers have strong preference for ecological products. The prices of the two products increase with an increase in γ, and when $c_G + \alpha + \tau - c_E + \beta < \frac{\tau(4-\gamma^2)}{2-\gamma^2+\gamma}$, the price of ecological products is higher than that of general products.

Remarks: From the above, we deduce two products of the same kind and different quality, where, from Eq. (7) ($p_G^{*,1} - p_E^{*,1}$), the price of general products is lower than that of ecological products when $c_G + \alpha + \tau - c_E + \beta < \frac{\tau(4-\gamma^2)}{2-\gamma^2+\gamma}$. This requires that the difference between the production cost of general products with negative externalities to the environment and the marginal cost of ecological products be small, even though the latter has a higher cost than the former. In this situation, the profit of the ecological firm is higher than that of the general firm. This is because the production cost greatly determines the product price and thus affects the profit.

However, from Eq. (8), we can obtain $\frac{\partial p_G^{*,1}}{\partial \gamma} > 0, \frac{\partial p_E^{*,1}}{\partial \gamma} > 0$; it is worth noting that the profit of the ecological firm is negative ($\pi_E^{*,1} < 0$), indicating that the ecological firm has no dominant market position in synchronous output competition, and a cost disadvantage encourages the premium behavior of the general firm.

In addition, for ecological products, consumer recognition is not high, and the price is sticky with less fluctuation. On the contrary, Wang & Ng [45] found that a difficulty in consumer recognition results in a new retail firm occupying a larger market share and possibly obtaining higher profits. Notably, the model in this study emphasizes the impact of commodity externalities on pricing. Due to the existence of taxes, general firms usually incur higher production costs and then set higher prices to pass on the costs to consumers and to ensure profitability.

Interestingly, when market consumption cannot reflect the positive effect of ecological products, consumer utility will reach a maximum. This is different from the common belief that the same kinds of high-quality products can improve the situation of consumers. When faced with the choice of two kinds of goods, consumers are limited by their income levels and fixed cognition, and they will choose familiar traditional products instead.

Dynamic Game of Complete Information

Case of Follower

Under normal conditions, a general firm is the forerunner in the market, and an ecological firm is the follower. The general firm, being in the lead position, makes decisions based on the actions of the ecological firm. The response function of the ecological firm is: $q_E = \frac{A+\gamma q_G - c_E + \beta}{2}$. The general firm's profit maximization problem can be expressed by:

$$\pi_G^{2,1} = \left(A - q_G - \tau + \gamma\frac{A+\gamma q_G - c_E+\beta}{2}\right)q_G - c_G q_G - \alpha q_G \tag{9}$$

$$\frac{\partial \pi_G^{2,1}}{\partial q_G} = A - 2q_G - \tau + \frac{\gamma}{2}A + \gamma^2 q_G - \frac{\gamma}{2}(c_E-\beta) - c_G - \alpha = 0 \tag{10}$$

Then the equilibrium output of the general firm can be obtained by:

$$q_G^{*,2,1} = \frac{(2+\gamma)A - 2(c_G+\alpha+\tau) - \gamma(c_E-\beta)}{4-2\gamma^2} \tag{11}$$

Substituting Eq. (11) into Eq. (5) obtains the equilibrium outputs of the ecological firm:

$$q_E^{*,2,1} = \frac{(4-\gamma^2+2\gamma)A - 2\gamma(c_G+\alpha+\tau) - (4-\gamma^2)(c_E-\beta)}{8-4\gamma^2} \tag{12}$$

By substituting Eq. (11) and Eq. (12) into Eq. (2), we can obtain the equilibrium prices of the two products in this dynamic game with complete information:

$$p_G^{*,2,1} = \frac{(4-\gamma^3-2\gamma^2+2\gamma)A + (4-2\gamma^2)(c_G+\alpha+\tau) + (\gamma^3-2\gamma)(c_E-\beta)}{8-4\gamma^2} - \tau$$
$$p_E^{*,2,1} = \frac{(4-\gamma^2+2\gamma)A - 2\gamma(c_G+\alpha+\tau) + (4-3\gamma^2)(c_E-\beta)}{8-4\gamma^2} \tag{13}$$

and

$$\frac{\partial p_G^{*,2,1}}{\partial \gamma} = \frac{(4+\gamma^4-4\gamma^2)A - (4+3\gamma^4-2\gamma^3+\gamma^2)(c_E-\beta)}{(4-2\gamma^2)^2} > 0$$
$$\frac{\partial p_E^{*,2,1}}{\partial \gamma} = \frac{2(2+\gamma^2+2\gamma)A - 2(2-\gamma^2+2\gamma)(c_G+\alpha+\tau) - 4\gamma(c_E-\beta)}{(4-2\gamma^2)^2} > 0 \tag{14}$$

Case of Forerunner

Moreover, high-quality products of the same kind are often developed depending on the original products on the market. In this case, the general firm makes the first decision; as a new entrant to the market, the ecological firm knows the reaction behavior of the general firm.

According to the reaction function of the general firm $q_G = \frac{A+\gamma q_E-\tau-c_G-\alpha}{2}$, profit maximization of the ecological firm can be expressed by:

$$\pi_E^{2,2} = \left(A - q_E + \gamma\frac{A+\gamma q_E-\tau-c_G-\alpha}{2}\right)q_E - c_E q_E + \beta q_E \quad (15)$$

$$\frac{\partial \pi_E^{2,2}}{\partial q_E} = A - 2q_E + \frac{\gamma}{2}A + \gamma^2 q_E - \frac{\gamma}{2}(c_G + \alpha + \tau) - c_E + \beta = 0 \quad (16)$$

The equilibrium output of the available ecological firm is:

$$q_E^{*,2,2} = \frac{(2+\gamma)A-\gamma(c_G+\alpha+\tau)-2(c_E-\beta)}{4-2\gamma^2} \quad (17)$$

Substituting Eq. (17) into Eq. (5) obtains the general firm's equilibrium outputs:

$$q_G^{*,2,2} = \frac{(4+2\gamma-\gamma^2)A-(4-\gamma^2)(c_G+\alpha+\tau)-2\gamma(c_E-\beta)}{8-4\gamma^2} \quad (18)$$

By substituting Eq. (17) and Eq. (18) into Eq. (2), we can obtain the equilibrium prices of the two products in this dynamic game with complete information:

$$p_G^{*,2,2} = \frac{(4-\gamma^2+2\gamma)A + (4-3\gamma^2)(c_G+\alpha+\tau) - 2\gamma(c_E-\beta)}{8-4\gamma^2} - \tau$$
$$p_E^{*,2,2} = \frac{(4-\gamma^3-2\gamma^2+2\gamma)A+(\gamma^3-2\gamma)(c_G+\alpha+\tau)+(4-2\gamma^2)(c_E-\beta)}{8-4\gamma^2} \quad (19)$$

and

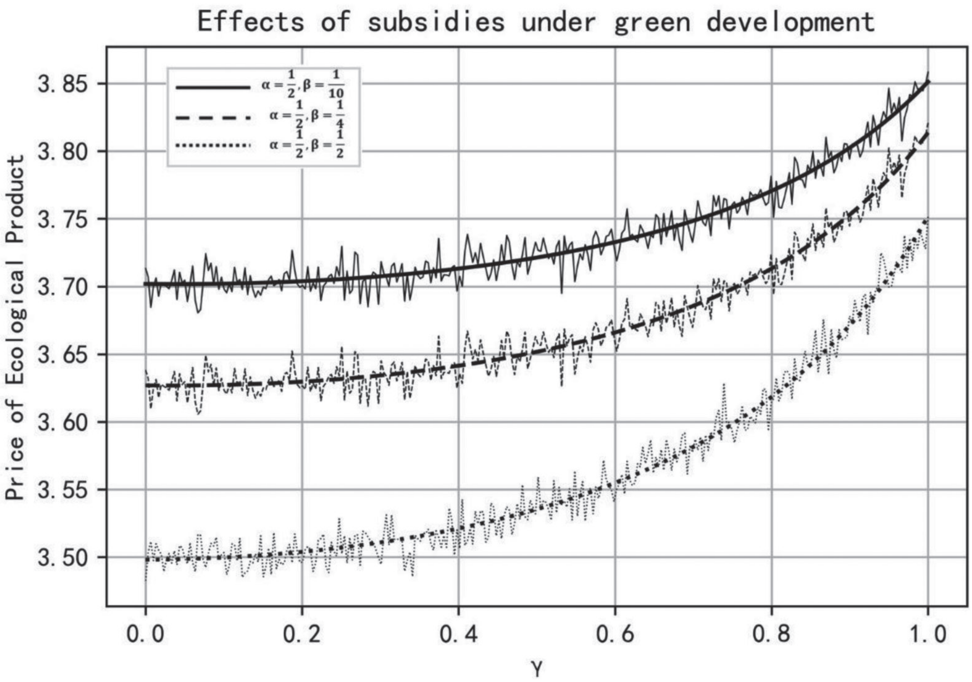
$$\frac{\partial p_G^{*,2,2}}{\partial \gamma} = \frac{(4+\gamma^4-5\gamma^2)A - (4+5\gamma^4+4\gamma^3+8\gamma)(c_G+\alpha+\tau)}{(4-2\gamma^2)^2} > 0$$
$$\frac{\partial p_E^{*,2,2}}{\partial \gamma} = \frac{2(2+\gamma^2+2\gamma)A-2(2-\gamma^2+2\gamma)(c_G+\alpha+\tau)-4\gamma(c_E-\beta)}{(4-2\gamma^2)^2} \quad (20)$$

Proposition 2. In the following and leadership game, the price of general products increases with the improvement of γ, and ecological products are positively correlated, but the price decreases with an increase in τ when the ecological firm is the follower. We also observed that the profit of the ecological firm is higher than that of the general firm, and both firms can attain the highest profit when $\tau = 0$, $\gamma = 1$. However, in the case of the follower, the profit gap between the two firms is the smallest when $\tau = 0, \gamma = 0$.

Remarks: Through calculating, we can obtain $p_G^{*,2,1} < p_E^{*,2,1}$ and $\pi_G^{*,2,1} < \pi_E^{*,2,1}$. In this way, the advantages of ecological products can be reflected. From Eq. (13) and Eq. (19), with an increase in ecological degree γ, the profits of the general firm gradually decrease, while the profits of the ecological firm first increase and then decrease. However, in the case of the follower, although the general firm is the leader of the game model, it will face lower profits. Under these conditions, the profit gap between the two producers fluctuates with an improvement of ecological degree γ, and the ecological firm, as the leader, can expand this profit gap. Otherwise, although the market environment has evolved and the ecological footprint of general products will be of high value, consumer utility will have a more positive effect at the ecological level in favor of the ecological firm.

Results and Discussion

Proposition 3. Generally, in the case of higher taxes on a general firm, increasing subsidies can improve the price curve of an ecological firm, and given the level of subsidies, changes in taxes are also effective. On the contrary, when the market consumption preference



Note: Through fitting, the following parameter values conform to the model assumptions: $A = 4, c_G = 3, c_E = 3.5, \tau = 1/2$

Fig. 1. Numerical simulation of the effects of subsidies on ecological products' price under green development.

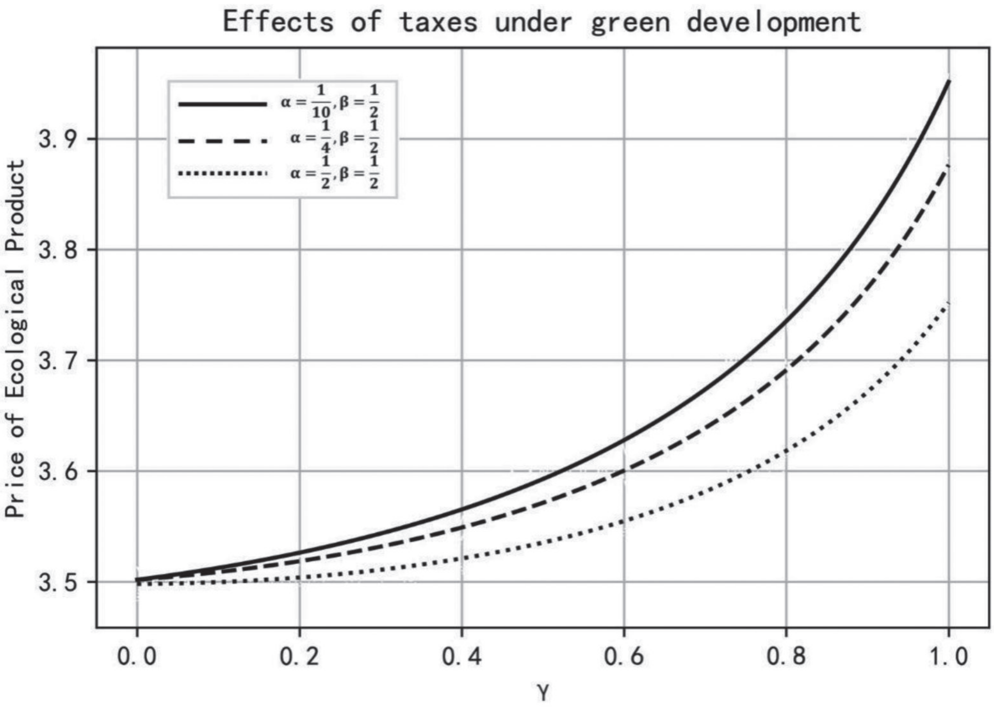


Fig. 2. Numerical simulation of the effects of taxes on ecological products' price under green development.

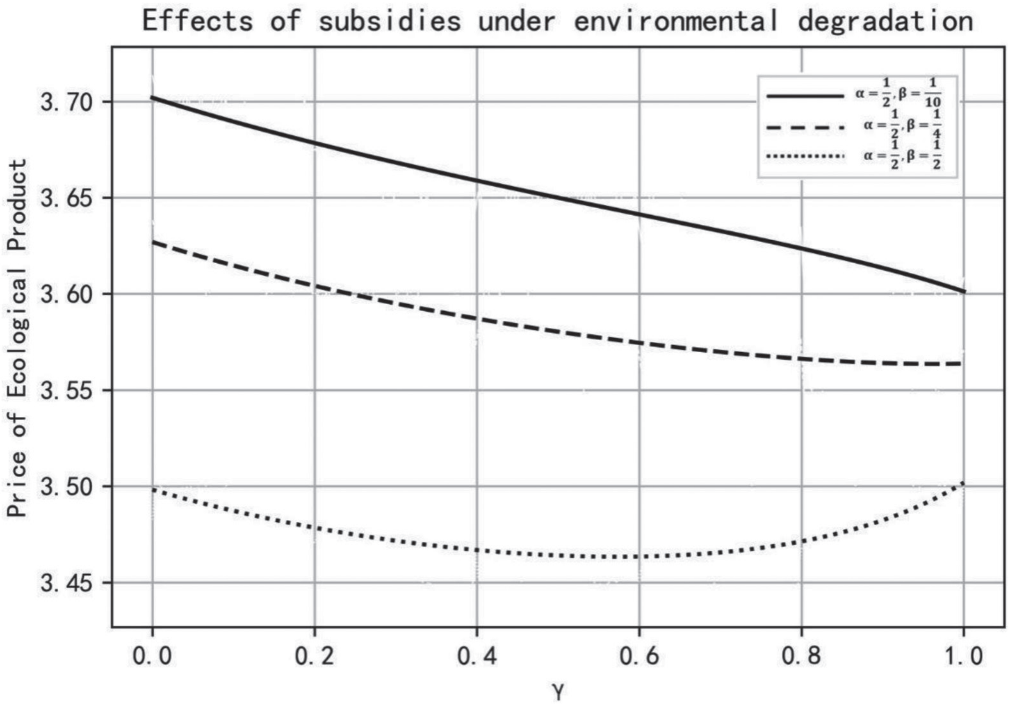


Fig. 3. Numerical simulation of the effects of subsidies on ecological products' price under environmental degradation.

is extreme, the ecological degree will play an opposite role. If no policy is imposed, the ecological firm needs to increase its profits by improving the ecological level, and the tax effect will be more effective.

Remarks: First, we consider the common market background. Through numerical simulation, we observe fluctuations in producer profits through changes in taxes and subsidies and mainly set two policy scenarios under neutral market preference. One is green development, which aims to improve ecosystems, ideally where the government will levy higher taxes on general products. At the same tax level, the subsidy policy for ecological products can improve its price curve, and an ecological firm can set a lower price in response to higher subsidies. Moreover, the higher the subsidy, the greater the slope of the price curve, which means that the ecological degree

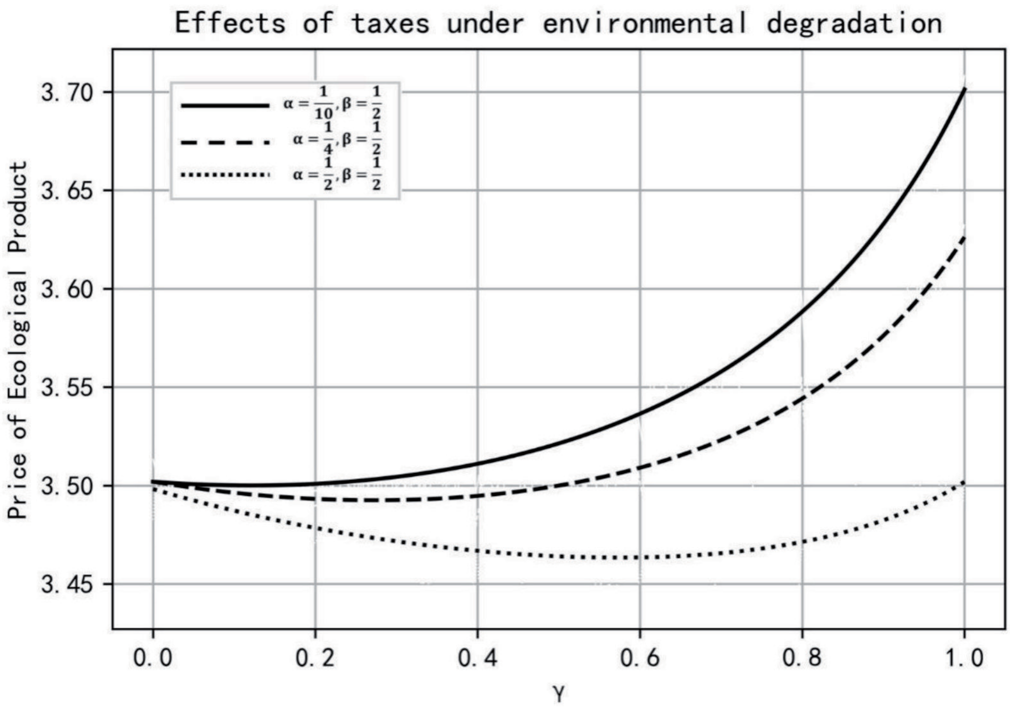


Fig. 4. Numerical simulation of the effects of taxes on ecological products' price under environmental degradation.

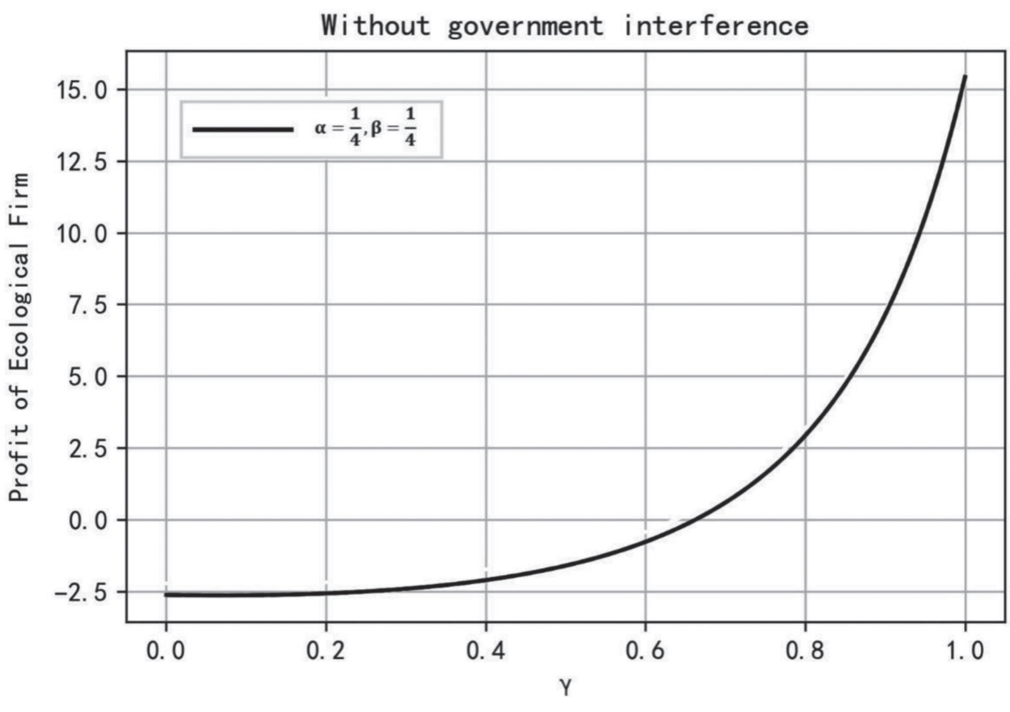


Fig. 5. Numerical simulation of ecological firm's profit without government interference

will also increase. For consumers, this is conducive to the transformation of consumer choice and thus improves consumer utility, as shown in Fig. 1.

On the other hand, in the same market, assuming that the government adopts a high subsidy level for ecological products to support ecological firms, tax changes will also achieve the effect of ecological protection policies. As shown in Fig. 2, higher taxes on general products can improve the business environment of ecological firms, and ecological products will compete at lower prices. However, the impact of the ecological degree on product prices will decrease.

In addition, we considered a situation in which environmental degradation in terms of the ecological footprint of general products originates entirely from an ecosystem, and τ approaches 1. At this point, an

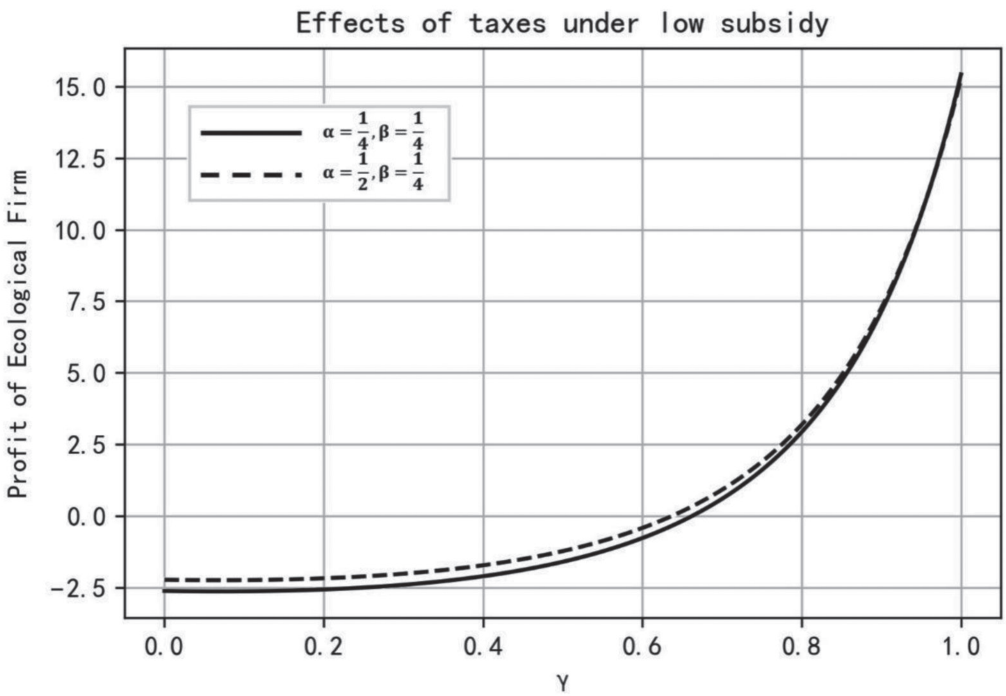


Fig. 6. Numerical simulation of the effects of taxes on ecological firm's profit under low subsidy.

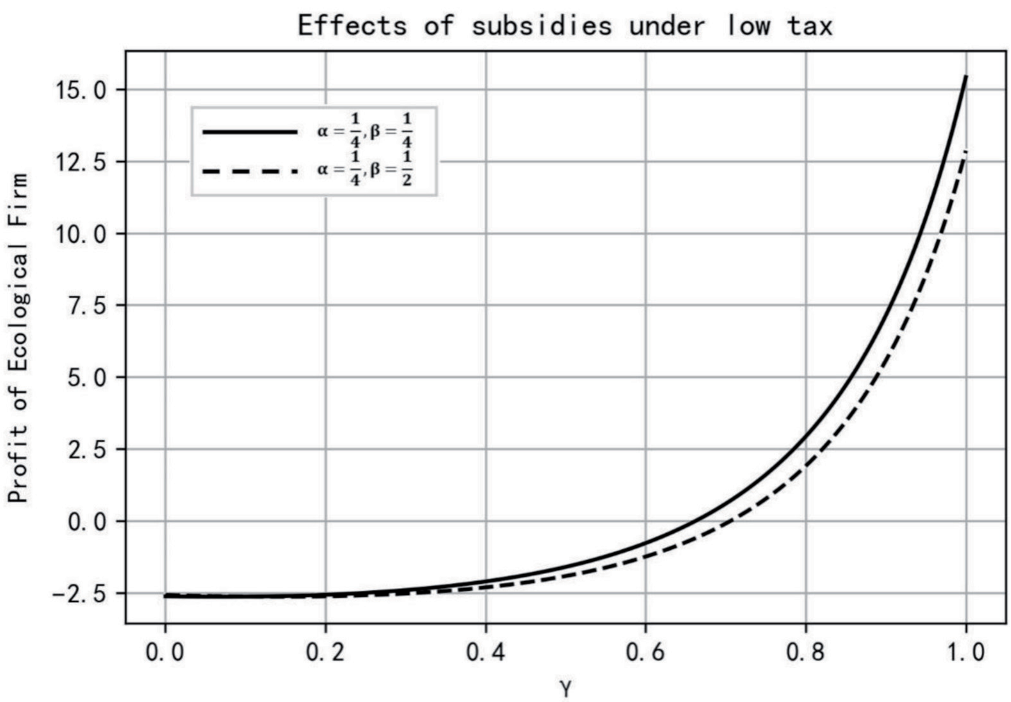


Fig. 7. Numerical simulation of the effects of subsidies on ecological firm's profit under low tax.

environmental policy is highly effective. The adoption of a higher tax level will reverse the price curve of ecological products, which is reflected in Fig. 3 as the price of ecological products and the degree of ecology change in the opposite direction. Only when the subsidy level is equal to the tax level will the price curve first decrease and then increase, with an increase in r. The high subsidies for ecological firms are reflected in Fig. 4, which shows little change compared with the common market environment τ=0.5. Only when the tax level is high will the slope of the price curve first be negative and then positive. The changes in taxes and subsidies also achieved the expected results, and the positive externalities of ecological products also played a considerable role.

Moreover, policymakers reduce intervention in the market, and the taxes and subsidies for the two firms are at a low level. From Fig. 5, we can see that the ecological firm may even face negative profits. The ecological firm can only achieve positive profits by raising the ecological degree (γ) of products to a higher level in the game model, which means that the positive external performance of products needs to be reflected through consumer choice. However, if a regulatory policy lacks proper organization, it may also lead to low environmental and economic efficiency. From Fig. 6 and Fig. 7, we also found that, under the same low subsidy level, an increase in the tax level is conducive to an increase in the profits of ecological producers, but the effect is minor. On the contrary, and interestingly, at the same low tax level, in the face of an increase in subsidies, the profit level of the ecological firm will decline.

According to the above research results, from the perspective of policymakers, the most effective way to develop ecological products is to levy higher taxes on general products, regardless of consumption preferences. An example is in the field of carbon emission control; it was found that a subsidy policy did not achieve the expected purpose of decreasing the carbon emissions of the automobile industry, but it accomplished carbon emission reduction over a large area through taxes and quotas. The tax effect is usually more prominent than the subsidy effect, because a subsidy may be transferred privately. Certainly, the government can improve the price competitiveness of ecological products by increasing subsidies, which can not only improve the price curve but also reflect the positive externality of products, namely the effect of the ecological degree.

Conclusions

This paper redefines ecological products, captures positive externalities, and compares them with the negative externalities of general products, and then further analyzes tax and subsidy effects. The results show that it is difficult for an ecological firm to break through the predetermined advantages of traditional commodities in a static game, and the production of ecological products in dynamic games can lead to higher prices and profits for producers within a certain ecological degree range. Moreover, the entry of an ecological firm could cause a general firm to incur a loss of profits, thereby forcing them to improve their products. In addition, the best way to exert the positive externalities of ecological products is to tax the negative externalities of general products, while subsidies can only improve the price curve of an ecological firm. This research provides theoretical evidence for the market-oriented reform of ecological products, which can obtain policy support by virtue of an improvement of the ecological degree on the ecosystem in practice. According to this research, the government should carefully design and implement policies that support ecological products.

We also provide suggestions for future studies. First, regarding the relationship between the ecological degree and ecological footprint of two products, new products may be improved using an ecological design based on the general products in preceding markets, which would amplify the subsidy effect. More importantly, the types of government taxes and subsidies should also be considered in future research. Finally, the theoretical analysis of this paper is limited to complete information; future research should further discuss the producer game under asymmetry. For example, Yang et al. [46] discussed the output subsidy effect of the renewable energy power industry under asymmetric information, and Nie et al. [47] studied the pricing of intellectual property under asymmetric oligopoly.

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Conflict of Interest

The authors declare no conflict of interest.

References

1. WANG J., YU F., MA G., PENG F., ZHOU X., WU C., YANG W., WANG C., CAO D., JIANG H., JING H., QU S., XU M. Gross economic-ecological product as an integrated measure for ecological service and economic products. Resources, Conservation and Recycling, **171** (3), 105566, **2021.**
2. DAVIDSON N.C., VAN DAM A.A., FINLAYSON C.M., MCINNES R.J. Worth of wetlands: Revised global monetary values of coastal and inland wetland ecosystem services. Marine and Freshwater Research, **70** (8), 1189, **2019.**
3. DARDONVILLE M., LEGRAND B., CLIVOT H., BERNARDIN C., BOCKSTALLER C., THEROND O. Assessment of ecosystem services and natural capital dynamics in agroecosystems. Ecosystem Services, **54** (2), 101415, **2022.**
4. MAKWINJA R., KAUNDA E., MENGISTOU S., ALAMIREW T. Impact of land use/land cover dynamics on ecosystem service value—a case from Lake Malombe, Southern Malawi. Environmental Monitoring and Assessment, **193** (8), 492, **2021.**
5. AROWOLO A.O., DENG X., OLATUNJI O.A., OBAYELU A.E. Assessing changes in the value of ecosystem services in response to land-use/land-cover dynamics in Nigeria. Science of the Total Environment, **636**, 597, **2018.**
6. ESCOBEDO F.J., GIANNICO V., JIM C.Y., SANESI G., LAFORTEZZA R. Urban forests, ecosystem services, green infrastructure and nature-based solutions: Nexus or evolving metaphors? Urban Forestry and Urban Greening, **37** (February 2018), 3, **2019.**
7. PAGDEE A., KAWASAKI J. The importance of community perceptions and capacity building in payment for ecosystems services: A case study at Phu Kao, Thailand. Ecosystem Services, **47** (November 2020), 101224, **2021.**

8. RAUM S., HAND K.L., HALL C., EDWARDS D.M., O'BRIEN L., DOICK K.J. Achieving impact from ecosystem assessment and valuation of urban greenspace: The case of i-Tree Eco in Great Britain. Landscape and Urban Planning, **190** (October 2018), **2019.**
9. SHEN P., WU L., HUO Z., ZHANG J. A Study on the Spatial Pattern of the Ecological Product Value of China's County-Level Regions Based on GEP Evaluation. International journal of environmental research and public health, **20** (4), **2023.**
10. HANSEN K., DUKE E., BOND C., PURCELL M., PAIGE G. Rancher Preferences for a Payment for Ecosystem Services Program in Southwestern Wyoming. Ecological Economics, **146** (November 2017), 240, **2018.**
11. DU W., YAN H., FENG Z., YANG Z., YANG Y. The external dependence of ecological products: Spatial-temporal features and future predictions. Journal of Environmental Management, **304** (12), 114190, **2022.**
12. GILLITZER C., PRASAD N. The effect of consumer sentiment on consumption: Cross-sectional evidence from elections. American Economic Journal: Macroeconomics, **10** (4), 234, **2018.**
13. GOODWIN K.R. Measures of Real Estate Market Sentiment and their Relationship with U.S. Home Prices. Journal of Housing Research, **28** (2), 208, **2019.**
14. SAHIN S. Consumer confidence, consumption, and macroeconomic fluctuations: A systemic stock-flow consistent model. Metroeconomica, **72** (4), 868, **2021.**
15. LI Q., LONG R., CHEN H. Empirical study of the willingness of consumers to purchase low-carbon products by considering carbon labels: A case study. Journal of Cleaner Production, **161** (2017), 1237, **2017.**
16. HAN H. Consumer behavior and environmental sustainability in tourism and hospitality: a review of theories, concepts, and latest research. Journal of Sustainable Tourism, **29** (7), 1021, **2021.**
17. TRANG H.L.T., LEE J.S., HAN H. How do green attributes elicit pro-environmental behaviors in guests? The case of green hotels in Vietnam. Journal of Travel and Tourism Marketing, **36** (1), 14, **2019.**
18. BRYLA P. The impact of consumer schwartz values and regulatory focus on the willingness to pay a price premium for domestic food products: Gender differences. Energies, **14** (19), **2021.**
19. SHIN Y.H., MOON H., JUNG S.E., SEVERT K. The effect of environmental values and attitudes on consumer willingness to pay more for organic menus: A value-attitude-behavior approach. Journal of Hospitality and Tourism Management, **33**, 113, **2017.**
20. SHANKAR A., JAIN S. Factors affecting luxury consumers' webrooming intention: A moderated-mediation approach. Journal of Retailing and Consumer Services, **58** (July 2020), 102306, **2021.**
21. RODRÍGUEZ-ORTEGA T., BERNUÉS A., ALFNES, F. Psychographic profile affects willingness to pay for ecosystem services provided by Mediterranean high nature value farmland. Ecological Economics, **128**, 232, **2016.**
22. HERMANNN S. Dynamics of Price Elasticity and Brand Life Cycles: An Empirical Study. Journal of Marketing Research, **16**, 439, **1979.**
23. RAO A.G., SHAKUN M.F.A. Quasi-Game Theory Approach to Pricing. Management Science, **18** (5, part 2), 110, **1972.**
24. DOLAN R.J., JEULAND A.P. Experience Curves and Dynamic Demand Models: Implications for Optimal Pricing Strategies. Journal of Marketing, **45** (1), 52, **1981.**
25. YANG D., CHEN Z., NIE P. Output subsidy of renewable energy power industry under asymmetric information. Energy, **117**, 291, **2016.**
26. SUN C., ZHANG X., ZHOU Y.W., CAO B. Pricing, financing and channel structure for capital-constrained dual-channel supply chains with product heterogeneity. International Journal of Production Economics, **253** (July), 108591, **2022.**
27. WANG J., YU F., MA G., PENG F., ZHOU X., WU C., YANG W., WANG C., CAO D., JIANG H., JING H., QU S., XU M. Gross economic-ecological product as an integrated measure for ecological service and economic products. Resources, Conservation and Recycling, **171** (March), 105566, **2021.**
28. NIELSEN I.E., MAJUMDER S., SANA S.S., SAHA S. Comparative analysis of government incentives and game structures on single and two-period green supply chain. Journal of Cleaner Production, **235**, 1371, **2019.**
29. SANA S.S. Price competition between green and non green products under corporate social responsible firm. Journal of Retailing and Consumer Services, **55** (April), 102118, **2020.**
30. BARMAN A., DAS R., DE P.K., SANA S.S. Optimal pricing and greening strategy in a competitive green supply chain: Impact of government subsidy and tax policy. Sustainability (Switzerland), **13** (16), 1, **2021.**
31. SUN P., NIE P.A comparative study of feed-in tariff and renewable portfolio standard policy in renewable energy industry. Renewable Energy, **74**, 255, **2015.**
32. HUANG Q., YANG S., SHI V., ZHANG Y. Strategic decentralization under sequential channel structure and quality choices. International Journal of Production Economics, **206**, 70, **2018.**
33. SHAHZAD U. Environmental taxes, energy consumption, and environmental quality: Theoretical survey with policy implications. Environmental Science and Pollution Research, **27** (20), 24848, **2020.**
34. BASHIR M.F., MA B., BILAL KOMAL B., BASHIR M.A. Analysis of environmental taxes publications: a bibliometric and systematic literature review. Environmental Science and Pollution Research, **28** (16), 20700, **2021.**
35. RAFIQUE M.Z., FAREED Z., FERRAZ D., IKRAM M., HUANG S. Exploring the heterogenous impacts of environmental taxes on environmental footprints: An empirical assessment from developed economies. Energy, **238**, **2022.**
36. KRASS D., NEDOREZOV T., OVCHINNIKOV A. Environmental taxes and the choice of green technology. Production and Operations Management, **22** (5), 1035, **2013.**
37. YANG Y., NIE P., LIU H., SHEN M. On the welfare effects of subsidy game for renewable energy investment: Toward a dynamic equilibrium model. Renewable Energy, **121**, 420, **2018.**
38. COHEN M.C., LOBEL R., PERAKIS G. The impact of demand uncertainty on consumer subsidies for green technology adoption. Management Science, **62** (5), 1235; **2016.**
39. ALIZAMIR S., IRAVANI F., MAMANI H. An analysis of price vs. revenue protection: Government subsidies in the agriculture industry. Management Science, **65** (1), 32, **2019.**
40. GOUDA S.K., JONNALAGEDDA S., SARANGA H. Design for the environment: Impact of regulatory policies on product development. European Journal of Operational Research, **248** (2), 558, **2016.**
41. BIAN J., ZHAO X. Tax or subsidy? An analysis of environmental policies in supply chains with retail competition. European Journal of Operational Research, **283** (3), 901, **2020.**

42. LI Y., DENG Q., ZHOU C., FENG L. Environmental governance strategies in a two-echelon supply chain with tax and subsidy interactions. Annals of Operations Research, **290** (1–2), 439, **2020.**
43. ZHOU Z., YU H., SHAO Q., SUN H., ZHANG R., WEI Y.M. Tax and subsidy policy for domestic air pollution with asymmetric local and global spillover effects. Journal of Cleaner Production, **318** (March), 128504, **2021.**
44. ZHANG Y., HONG Z., CHEN Z., GLOCK C.H. Tax or subsidy? Design and selection of regulatory policies for remanufacturing. European Journal of Operational Research, **287** (3), 885, **2020.**
45. WANG X., NG C.T. New retail versus traditional retail in e-commerce: channel establishment, price competition, and consumer recognition. Annals of Operations Research, **291** (1–2), 921, **2020.**
46. YANG D., CHEN Z., NIE P. Output subsidy of renewable energy power industry under asymmetric information. Energy, **117**, 291, **2016.**
47. NIE P., CHEN Z., WANG, C. Intellectual property pricing under asymmetric duopoly. Journal of Retailing and Consumer Services, **58** (6), 102261, **2021.**