The effect of consumer willingness to pay on enterprises' decisions about adopting low-carbon technology

Abstract

There is no 'one size fits all' product strategy for the 'green' market. Although prior studies have explored the influence of consumer environmental awareness on decisions pertaining to green production, further investigation is required regarding the impact of consumer willingness to pay (WTP) on green technology choices and product design, and the ongoing debate about the environmental consequences of both firm and consumer behaviour. This study aims to explore strategies adopted by an enterprise intending to introduce a green product. Utilising optimisation methodology, we investigate the strategies employed for introducing green products, considering pivotal factors such as consumers' WTP, variable costs, the research costs associated with green technology, and the constraints imposed by the level of green technology. Our research investigates the strategies for introducing, and the optimal pricing of, green products, outlining the impact of the aforementioned factors on the market penetration of green products and company profits. Additionally, this research further explores the impact of consumers' WTP and enterprises' use of eco-friendly materials on environmental quality. The results indicate that the strategies for launching green products and the impact of eco-friendly materials on environmental quality depends on the enterprise's technological parameters and consumers' WTP. The findings suggest that the market penetration rate of green products increases in line with consumers' WTP and the level of greenness of products, while higher research costs will decrease the penetration rate of green products. This research contributes to the field of green innovation by showcasing how enterprises make decisions about production and green technology innovation.

Keywords

Low carbon technology, Green technology innovation, Willingness to pay, Consumer environmental awareness

1. Introduction

Elevated levels of economic activity have coincided with heightened anxieties over climate change, energy independence, and the depletion of natural resources. Sustainable production requires producers to be responsible for environmental, social, and economic aspects of their activities (Veleva and Ellenbecker, 2001). However, attempts by industries and/or enterprises to mitigate pollution at the point of discharge are often expensive and ineffective. As Chen (2001) points out, "Green product development, which addresses environmental issues through product design and innovation as opposed to the traditional end-of-pipe-control approach, is receiving significant attention from customers, industries, and governments around the world". Recognising the significance of environmental considerations, many countries have enacted policies, statutes, and ordinances aimed at fostering a green economy. For example, Germany has initiated a pilot project aimed at assessing the carbon footprint of products; China, since the 1990s, China has aggressively implemented environmental policies, exhibiting great dedication to sustainable development and environmental conservation (e.g., Zhang et al., 2020). Environmental awareness and concern among customers is on the rise, leading them to adopt sustainable lifestyles and make eco-friendly choices. According to a survey undertaken by Xu et al. (2024) in China, 77.60% of respondents indicated that they would be willing to pay more for food with carbon labels. For milk, corn, bananas, tomatoes, and eggs with carbon labels, the premium payments were 25.66%, 31.96%, 24.08%, 23.62%, and 20.64%, respectively. A recent questionnaire conducted among Uber riders in Europe found that over half would be willing to pay an additional premium for zero-emission vehicles (Dave, 2020). In Germany, consumers stated that they would be prepared to shell out an additional €31.50 for eco-friendly sports products (Spindler et al., 2023); for instance, they would be happy to pay around 15.32% extra compared to the standard market price of conventional trainers (Baieret al., 2020).

As a result of the increase in environmental concerns, the 'green' market has captured the attention of consumers and businesses. Due to increased consumer awareness of environmental protection, consumers are more likely to spend more money on green products, which will have significant impacts on production, operating strategies, and competition among firms. According to the aforementioned survey conducted in Europe, the proportion of customers willing to pay a premium for green products has increased significantly, rising from 31% in 2005 to 67% in 2008, indicating a growing trend towards environmental consciousness and willingness to support sustainable practices (Yu et al., 2016). Customers with new eco-friendly beliefs are driving the growth in green products. Faced with this shift in market trends, enterprises are investing in green technology and subsequently replacing standard products with green ones, which will benefit them in the long run by building their reputation and enhancing their market competitiveness (Yenipazarli and Vakharia, 2015). However, producing green products requires substantial initial capital investment in innovative green technology, as well as further investment in environmentally friendly materials, to increase the greenness of products. Given the inherent high risks, costs, and external factors associated with green technology innovation, businesses might be more inclined to adopt a cautious 'wait-and-see' policy with regard to greening their products. In addition, green products usually cost more because they are kinder to the environment. (Conrad, 2005). Thus, firms' decisions

about green production are also affected by consumer's willingness to pay (WTP). In reality, consumers' WTP for green products varies across consumer groups and industries, and thus enterprises tend to produce alternative products with different levels of greenness and pricing. To provide a few illustrative examples, Target has introduced an eco-friendly clothing line, and Nike recently launched Nike Organics, a full line of clothing made from 100% organic cotton. However, there is an ongoing debate about which pricing and eco-friendly strategies companies should use to align most closely with WTP and the impact of market participants' behaviour on the environment. Moreover, limited theoretical studies have examined in detail how consumer WTP influences decisions about green technology and product design (producing a single product with a uniform level of greenness or differentiated products that exhibit variations in their level of greenness).

In a production system, manufacturing alternative products constitutes a way to meet consumer demands. The decision about whether to produce differentiated products with differing levels of greenness or a single product with a high level of greenness depends on their respective effects on the enterprise's profits. Alternatively, firms might decide to change the greenness level of a product to satisfy consumer demands. Amending the price and greenness of the product are two key ways for enterprises to obtain the objective of profit maximisation. Because of the close relationship between the price and greenness of the product, a higher level of greenness will mean higher prices because greener products are usually costlier to produce. A higher price may simultaneously affect consumer expectations and shrink the market share of the product. Thus, decisions about pricing and greenness should take into account consumer WTP, which indicates that there are optimal levels of product greenness and pricing, but it is not necessarily a case of the higher, the better. Previous studies have investigated how consumers' environmental awareness influences their decisions about green products, but have overlooked the constraints imposed by green technology, which ultimately limits the extent of greenness and environmental friendliness that are achievable. Motivated by the aforementioned considerations, this study aims to address three key research questions:

1. How does a firm decide whether to produce a single product with a uniform level of greenness or differentiated green products, based on the green technology that it has available, in order to cater to the varying levels of WTP among consumers who are sensitive towards sustainability?

2. What are the optimal decisions regarding pricing and the greenness of products, and what impact does consumers' WTP have on optimal decision making, and the market penetration rate of green products?

3. What impact do consumers' WTP and eco-friendly materials have on enterprises' profits and environmental quality and how can they be improved?

In this study, we propose a model designed to investigate when a firm should introduce green products, and discuss the impact of an enterprise's production behaviour and consumers' consumption behaviour on the environment. In our model, greenness and price are the control variables and the enterprise has two product lines which are used alternatively to manufacture products. It should be noted that the enterprise will either choose to produce a differentiated product with a different level of greenness or a single product with a high level of greenness with the aim of obtaining more profit. The specified technological parameters dictate the upper boundary of greenness that can be achieved, similarly to the production capacity constraint used by

Zhang et al. (2015). Due to the motivation described above, this study is divided into two parts. First, we provide details of the enterprise's optimal decisions regarding greenness and pricing under all possible technological specifications and WTP. We also explore the conditions that determine whether the enterprise should produce a differentiated product that differs only in terms of greenness. Second, we examine the effect of using eco-friendly materials on profit and the environment, taking consumer WTP into account. For the enterprise, WTP is exogenous and increasing profit is a key reason for using eco-friendly materials. The effect of adopting eco-friendly materials on the environment would be apparent in a short space of time compared with investing research and development (R&D) funding in green technology. Consequently, we use the model to determine when the enterprise should use eco-friendly materials to increase the beneficial effect or decrease the adverse effect on profit caused by fluctuations in WTP. We also explore the effect of using eco-friendly materials on the environment and try to determine when the government should intervene.

This study offers both theoretical and practical contributions to the literature. (1) Regarding the former, the study primarily focuses on the entities that are innovators in terms of green technology and the subjects of green consumption, with the aim of revealing the intrinsic interactions between them and exploring the mechanisms behind, and the effects of, such interactions on enterprises' green technology innovation behaviour and decision-making. A systematic investigation of these aspects would enable a clearer comprehension of the underlying behavioural logic behind enterprises' production strategies and provide theoretical references for improving the penetration rate of green products; (2) The second theoretical contribution made by this paper involves examining how enterprises with limited capabilities for innovation in terms of green technology adjust their production strategies in response to consumers' WTP, thereby providing a basis for selecting production lines and producing green products; and (3) This study also contributes to providing a research foundation that the government can use to design incentivisation policies aimed at enhancing the level of green technology innovation and the greenness of products.

In practical terms, our findings provide strategic insights that enterprises can draw on to produce vertically differentiated products in terms of their greenness, in order to meet the diverse needs of consumers. Second, this study offers valuable insights for governments to help them decide on the appropriate timing of interventions and formulate environmental regulation policies designed to enhance the market penetration rate of green products and incentivise enterprises to increase the greenness of their products.

The paper is structured as follows. Section 2 reviews the related literature. Section 3 describes how the model was constructed and run. Section 4 discusses the optimal production strategy. Section 5 describes the effect of eco-friendly materials on profits and the environment and reports on the numerical study. Conclusions and policy implications are provided in Section 6.

2. Literature review

2.1 Consumers' WTP and its impact on firms' production strategies

As key group of market participants, consumers are the primary determinant of business' interests. Consumers' WTP for green products, which is commonly used to

measure their judgement of the value of goods and services, is a topic which is currently receiving considerable attention in the literature (Xu et al., 2024). Chitra (2007) states that the higher the consumers' environmental awareness, the greater consumers' WTP for green products. With the continuing development of the green economy and the ever-increasing awareness of environmental protection, consumers are paying closer attention to the environmental impact of products in their daily lives. As a result, green products, which embody the integration of innovative technology and environmentally friendly design, have become increasingly popular. Consumers are therefore willing to pay a higher premium for green products (Ling et al., 2024). The adoption of green technology by enterprises in response to changes in market demand and the manufacture of green products to satisfy consumer demand create both opportunities and challenges, as previous research has shown that the WTP may vary significantly across industries and consumer groups and change over time (Carlson, 2005, Laroche et al., 2013).

The green consumption behaviour of individual consumers plays a pivotal role in influencing enterprises' decisions about whether to produce green products and to increase research and development into low-carbon technology (Yalabik and Fairchild, 2011). Moreover, when confronted with changes in market consumption behaviour, enterprises have to re-plan their product lines based on their judgement of market trends. As a result, enterprises face competitive operational challenges associated with the acquisition and deployment of green manufacturing technology (Ling et al., 2022). The types of production technology employed by enterprises is one of the decisive factors that affects the production process, its efficiency, and the utilisation of raw materials, and it also play a role in determining the environmental impacts, risks, and costs incurred by companies (Kotha and Orne, 1989). Shrivastava (1995) introduced the concept of environmental technology and argued that improving production processes can have an effect on the firm's and industries' production costs. Hence deciding whether or not to adopt green technology largely hinges on customers' WTP. In addition, environmentally friendly products are more beneficial for the environment than their traditional counterparts but they are also more expensive. Reinhardt (1998) refers to this as environmental product differentiation. For example, hybrid vehicles had reduced carbon dioxide emissions by approximately 3.5 million tons as of April 2007, but are more expensive than traditional vehicles with similar functionalities (Yakita and Yamauchi, 2011).

Numerous studies have investigated the optimal strategies that enterprises could adopt, taking consumers' WTP into account. Conrad (2005) examined the decision to pursue a 'green' policy and outlined how WTP affects prices, product characteristics and the market shares of the competing firms. Xia et al. (2024) explored green product design among green supply chain members, including factors such as pricing and the level of greenness. This study also investigated the impact of consumers' WTP on their optimal decisions. In a green market where consumers are sensitive to sustainability, Ling et al. (2022) assessed the influence of consumers' willingness to pay a premium on the decision-making processes of duopoly enterprises. Due to the close relationship between consumers' WTP and green products, an increasing number of studies have utilised game theory to investigate the impact of WTP on pricing and the level of greenness of green products, such as Yu et al. (2016) and Zhu and He (2017). How to design green products to meet the diverse needs of consumers has become a crucial aspect of corporate production decision-making. This study focuses on the strategy employed by an enterprise seeking to launch a green product, and more specifically,

how an enterprise makes a decision about which production line to use, taking consumers' WTP into account. In the process of making a decision about greenness and price, we take consumers' WTP and the technical parameters of an enterprise into consideration.

2.2 Green product line design

The second stream of literature focuses on enterprises' decisions about product differentiation in response to consumer demand, which comes under the area of product design. The increasing public interest in sustainable development is prompting enterprises to replan their product lines and produce green products to meet consumers' demands for sustainable lifestyles. One marketing approach commonly utilised by companies in response to this is product differentiation, which sets a firm's products apart from other comparable products in the marketplace (He and Deng, 2020). Shen et al. (2020) adopted the game theory approach to create a consumer choice model driven by price and quality in a two-echelon supply chain, and determined the optimal product line designs for green and non-green products. Heese and Swaminathan (2006) focused on firm's development of a product design line, which was used to manufacture two products. The firm determined the quality and price levels to try to maximise their profits. Yenipazarli and Vakharia (2015) focused on a firm's choice of green product strategy by considering two alternative strategies: Greening-Up and Greening-Out, and divided the consumer market into three distinct segments based on consumers' WTP. Leslinmorgan et al. (2001) investigated how a firm's cost structure impacts on its decision-making process regarding product diversification, guided by its manufacturing capabilities and the extent to which it could introduce a diverse product range while minimising disruption to the production processes. Radulescua and Radulescub (2009) devised two distinct production planning models that accounted for uncertainty, integrating both economic and environmental factors into their designs. Meanwhile, He and Deng (2020) constructed a Hotelling model with which to investigate the impact of consumer environmental awareness on product differentiation strategies. Anderson and Dana (2005) attempted to ascertain the profitability of price discrimination and assessed the prerequisite conditions for its success. They investigated the product choice of a single firm, specifically whether to sell one or two products with exogenous qualities and price, taking into consideration consumers' WTP. Further studies relating to the manufacture of green products include: Choudhary et al. (2005), Wu (2010), Basiri and Heydari (2017), Zhu and He (2017), Hong and Zhang (2019).

Some of these works real-life situations, for example, in regard to the green supply chain, how supply chain decisions about the "greenness" of products are affected by the types of green product and competition. Zhu and He (2017) demonstrated that retailer level supply chain pricing has the potential to increase equilibrium greenness, whereas competition based on product greenness may decrease it. Additionally, the combined impact of both price and greenness competition on equilibrium greenness is intimately lined to the relative intensities of these two forms of competition. Concerns about product quality within the supply chain order is a subject that is highly relevant to our study. However, as our study only focuses on one enterprise, we do not consider the relationship between greenness and the strength of competition. Exploring the field of remanufacturing, Radhi and Zhang (2015) developed an optimisation method for remanufacturing systems, aimed at maximising profits through the strategic determination of the quality threshold, return quantity, and demand allocation. Regarding the remanufacturing study, please refer to Souza (2013) and Mahmoum et

al. (2021) for more information about this area. Unlike the aforementioned studies, we explore how an enterprise's technological parameters influence product design, while taking consumers' WTP into account.

2.3 Government intervention and decision-making about green products

Due to the high-risk, high-input nature of technological innovation, as well as the externalities that affect it, enterprises may still be inclined to adopt a 'wait-and-see' policy due to risk aversion considerations, despite the fact that developing green technology can enhance their corporate reputation and market competitiveness in the long run. Therefore, as a means of promoting sustainable consumption, the production of green products may require government intervention to cover the additional costs incurred by enterprises in developing green technology (Ling et al., 2022). Wang et al. (2014) conducted a study that examined the influence of four distinct governmental subsidy policies on Chinese auto engine remanufacturing enterprises, from which they concluded that varying subsidy schemes exert differing impacts on activities within the remanufacturing industry. Sheu and Chen (2012) analysed the effects of governmental financial intervention on green supply chain competition. Bi et al. (2016) focused on government subsidy policies designed to encourage firms to adopt 'green' emissions-reducing technology. Yu et al. (2016) explored the decision-making problem faced by manufacturers, taking into account varying degrees of consumer environmental awareness and the influence of government subsidy policies. Their simplified analysis suggests that the implementation of reasonable subsidy policies by the government can not only incentivise manufacturers to produce products with higher levels of greenness and increase profits, but also save on future investment in government subsidies. Moraga-González and Padrón-Fumero (2002) explored the interplay between subsidies and tax policies, analysing their effects on overall pollution levels and aggregate welfare in a context in which consumers are environmentally conscious. Lee and Park (2021) conducted a study examining the impact of two environmental regulatory measures, namely subsidies and carbon taxes, on green technology innovation. Their findings indicate that the optimal policy choice depends on the efficiency of R&D and spillover effects. Specifically, when green R&D is efficient, green R&D subsidies are preferable to emission taxes, regardless of the level of R&D spillover effects. However, in situations where both green R&D and spillover effects are inefficient, the government should impose emission taxes instead. A growing body of literature has begun to focus on the impact of government subsidies on enterprises' adoption of green technology and innovation associated with it, such as Huang et al. (2019), Li et al., (2020), Meng et al. (2021), Guo et al. (2024). However, firms' technical parameters impose some capacity constraints on production and/or the level of greenness that is achievable. Research investigating this subject is relatively rare. Dana and Yahalom (2008) expanded upon the framework developed by Mussa and Rosen (1978) by incorporating a limitation on the total amount of available resources, thereby offering a more generalised perspective. Tang and Yin (2010) addressed the same issue by examining how a firm's manufacturing capabilities influence the selection of optimal production lines, pricing strategies, and production quantity for each chosen product. These papers all focus on production constraints, whereas our study is concerned with greenness constraints. We focus on one firm's production design taking consumers' WTP into account. In addition, we investigate the effect of WTP and eco-friendly materials on the environment. Our study offers some managerial insights that may be helpful for firms to decide on optimal strategies and makes suggestions about when the

government should intervene. In doing so, this research contributes to the literature on green product design and the green economy.

3. Modelling

Consumers are heterogeneous in their WTP for products. We denote each consumer's WTP by $k\theta$, where k is constant and represents the consumer preference payment coefficient for each higher θ, and θ denotes the satisfaction of each consumers. Drawing on Hotbllino (1929) and Gu's (2015) descriptions of heterogeneity, we capture the heterogeneity of θ by assuming that $f(\theta)$ is uniformly distributed between 0 and $\overline{\theta}$, i.e., $f(\theta) \sim [0, k\overline{\theta}]$. Consumer's utility is sensitive to prices. We assume that an enterprise has the ability to produce two types of homogeneous green products, i.e., a high greenness product and a low greenness product, that differ in terms of their greenness, which also have different prices and production costs. p_H and p_L denote the price of the two types of products, respectively. Consumers whose WTP is lower than p_H and higher than p_L will purchase the low greenness product. With reference to Ülkü and Hsuan (2017) and Ling and Xu (2021), the utility of these consumers can be formulated as:

$$U_L = k\overline{\theta} - p_{H,}\ p_L \le k\bar{\theta} \le p_H . \quad (1)$$

Consumers whose WTP is higher than p_H can choose the high greenness product or the low greenness product. However, this group of consumers value low greenness products less than high greenness products, so we set these consumers' WTP for low greenness products as a fraction $\rho(0 < \rho < 1)$ of their WTP for the greener products. Hence, the utility for this group of consumers is:

$$\begin{cases} U_H = k\theta - p_{H,} \\ U_L = \rho k\theta - p_{L,} \end{cases}, p_H \le k\theta \le k\bar{\theta}. \quad (2)$$

In order to ensure that consumers with high WTP only choose the high greenness product, we set the value of ρ as $\rho \le \frac{p_L}{p_H}$. Θ_L and Θ_H are the sets of customers who buy the low greenness and high greenness products, respectively. Then, $\Theta_L = \{k\theta : U_L \ge 0\}$ and $\Theta_H = \{k\theta : U_H \ge 0\}$. The market share of the differentiated products can be calculated as follows:

$$q_L = \int_{k\theta \in \Theta_L} f(\theta) d\theta = \frac{p_H - p_L}{k\bar{\theta}}, \quad (3)$$

$$q_H = \int_{k\theta \in \Theta_H} f(\theta) d\theta = \frac{k\overline{\theta} - p_H}{k\bar{\theta}}. \quad (4)$$

The enterprise's objective in producing the differentiated products can be expressed as follows:

$$\begin{aligned} \underset{g_i, p_i}{\pi} &= [p_i - c + \varepsilon(g_i - g_0)]q_i - \beta(g_i - g_0)^2, \\ s.t. \quad & g_i - g_0 \le \frac{c}{\varepsilon}. \end{aligned} \quad (5)$$

where $i = L, H$. c denotes the unit production cost, ε denotes the cost-saving rate for every unit of greenness, and g_i represents the greenness of the product. β represents the research cost coefficient for an enterprise. We then assume that the total cost of investment in technology is $\beta(g_i - g_0)^2$.

4. The optimal production strategy

In this section, we explore how consumers' WTP, Φ, and an enterprise's technological parameters, $r(r = \frac{c\beta}{\varepsilon^2})$, affect the decision about whether to produce products with a high level of greenness or differentiated products, and how the optimal price and level of greenness should be determined. We use the mean value of WTP to represent consumers' WTP, that is $\Phi = \frac{k\overline{\theta}}{2}$. q^N and π^N denote that no product is manufactured, and no profit is gained by the enterprise, respectively.

Proposition 1. *When* $\gamma < \frac{1}{8}$

i *if* $\Phi < \frac{c}{2}$, *no product is manufactured for negative profit.*

ii *if* $\frac{c}{2} \le \Phi < \frac{1}{8}\frac{c}{\gamma}$, *the enterprise only produces high greenness products. The optimal strategies are:*

$$g_H = g_0, p_H = \frac{2\Phi + c}{2}, q_H = \frac{2\Phi - c}{4\Phi}, \pi_H = \frac{(2\Phi - c)^2}{8\Phi}.$$

iii *if* $\Phi \ge \frac{1}{8}\frac{c}{\gamma}$, *the enterprise only produces high greenness products. The optimal strategies are:*

$$g_H = g_0 + \frac{c}{\varepsilon}, p_H = \Phi, q_H = \frac{1}{2}, \pi_H = \frac{\Phi}{2} - c\gamma.$$

Proof. Please see Appendix A for proof. □

Proposition 1 implies that when $\gamma < \frac{1}{8}$, if consumers' WTP, Φ, is lower than $0.5c$, the enterprise will not produce a product for a negative profit. If consumers' WTP is higher than $0.5c$, the enterprise will only produce relatively low greenness products based on profit considerations. As WTP increases and exceeds the critical value of $\frac{1}{8}\frac{c}{\gamma}$, the enterprise will produce more greener products to replace the previous standard ones. In this scenario, producing a single type of green product is more profitable than producing differentiated green products. The production strategies for $\gamma < \frac{1}{8}$ are shown in Fig 1.

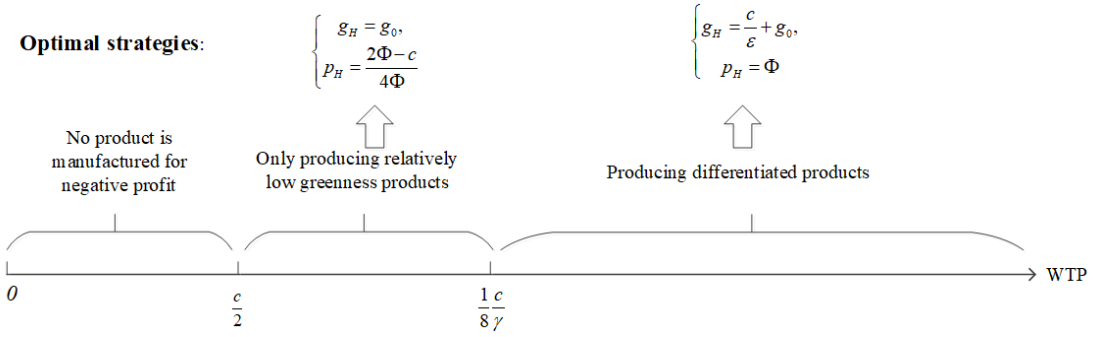


Fig 1. Production strategies for the scenario $\gamma < \frac{1}{8}$.

To avoid a loss of generality and present the results more intuitively, we present the following numerical studies to show the optimal quantity and the corresponding profit when Φ varies, by setting the value of γ as $\gamma = 0.016$. The relevant parameter values are: $c = 2, \beta = 0.002, \varepsilon = 0.5$. Fig 2 and Fig 3 show that, as consumers' WTP increases, the market share and profit will also increase.

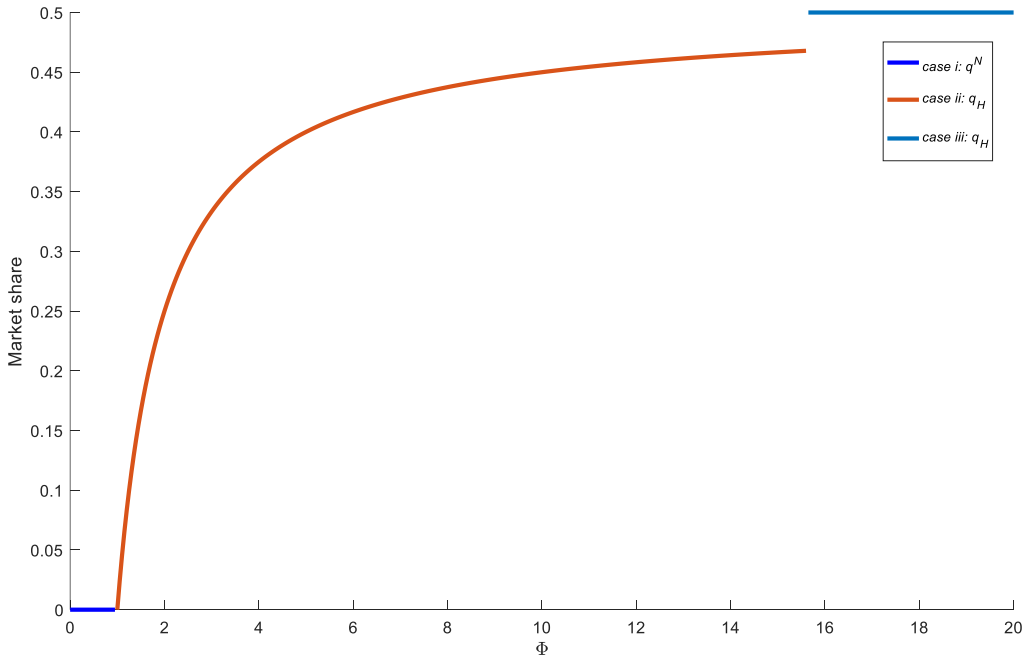


Fig 2. Optimal market share based on different Φ values when $\gamma < \frac{1}{8}$

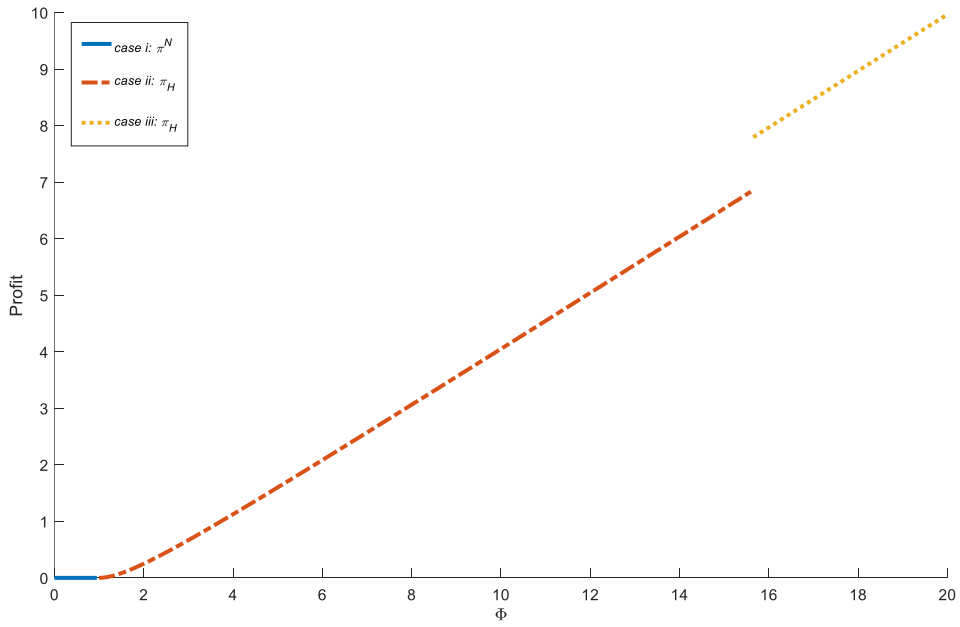


Fig 3. Profit based on different Φ values when $\gamma < \frac{1}{8}$

Proposition 2. *When* $\frac{1}{8} \le \gamma < \frac{1}{4}$

i *if* $\Phi < \frac{c}{2}$*, no product is manufactured for a negative profit.*

ii *if* $\frac{c}{2} \le \Phi < \frac{1}{8}\frac{c}{\gamma}$*, the enterprise only produces high greenness products. The optimal strategies are:*

$$g_H = g_0, p_H = \frac{2\Phi + c}{2}, q_H = \frac{2\Phi - c}{4\Phi}, \pi_H = \frac{(2\Phi - c)^2}{8\Phi}.$$

iii *if* $\frac{1}{8}\frac{c}{\gamma} \le \Phi < c$*, the enterprise only produces high greenness products. The optimal strategies are:*

$$g_H = \frac{c}{\varepsilon} + g_0, p_H = \Phi, q_H = \frac{1}{2}, \pi_H = \frac{\Phi}{2} - c\gamma.$$

iv *if* $\Phi \ge c$*, the enterprise produces differentiated products. The optimal strategies are:*

$$\begin{aligned} g_L &= \frac{\Phi - c}{8\gamma\Phi - c}\frac{c}{\varepsilon} + g_0, & g_H &= \frac{c}{\varepsilon} + g_0, \\ p_L &= \frac{4\gamma\Phi(c + \Phi) - c\Phi}{8\gamma\Phi - c}, & p_H &= \Phi, \\ q_L &= \frac{2\gamma(\Phi - c)}{8\gamma\Phi - c}, & q_H &= \frac{1}{2}, \\ \pi_L &= \frac{(\Phi - c)^2}{8\gamma\Phi - c}\gamma, & \pi_H &= \frac{\Phi}{2} - c\gamma. \end{aligned}$$

Proof. Please see Appendix A for proof. □

Proposition 2 implies that when $\frac{1}{8} \le \gamma < \frac{1}{4}$, if Φ is lower than $0.5c$, the enterprise will not produce products for a negative profit. If the consumers' WTP is higher than $0.5c$ and lower than c, the enterprise will only produce a single type of green product. If consumers' WTP is higher than c, the enterprise will produce differentiated products and the incremental benefit is π_L. The production strategies for $\frac{1}{8} \le \gamma < \frac{1}{4}$ are shown in Fig 4.

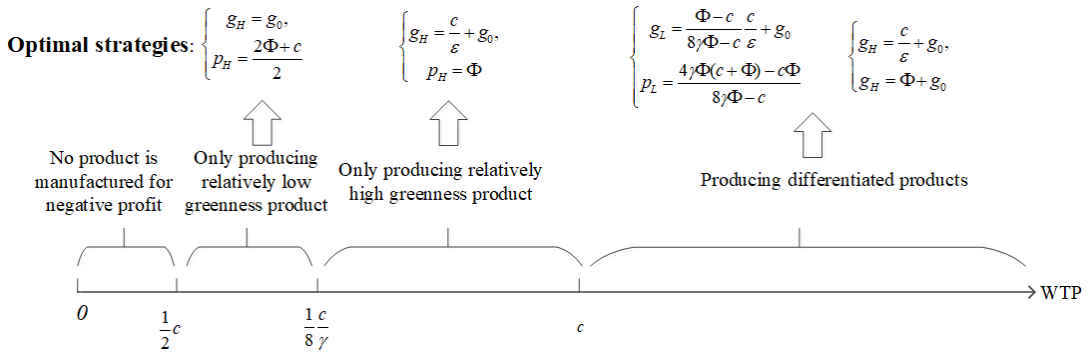


Fig 4. Production strategies for the scenario $\frac{1}{8} \le \gamma < \frac{1}{4}$.

The numerical studies are shown in Fig. 5 and Fig. 6 with the value of γ *set as* $\gamma = 0.16$. The relevant parameter values are the same as in Proposition 1, except $\beta =$

0.02. Fig 5 and Fig 6 show that, as consumers' WTP increases, the market share and profit will also increase, mirroring the same trend as in Proposition 1.

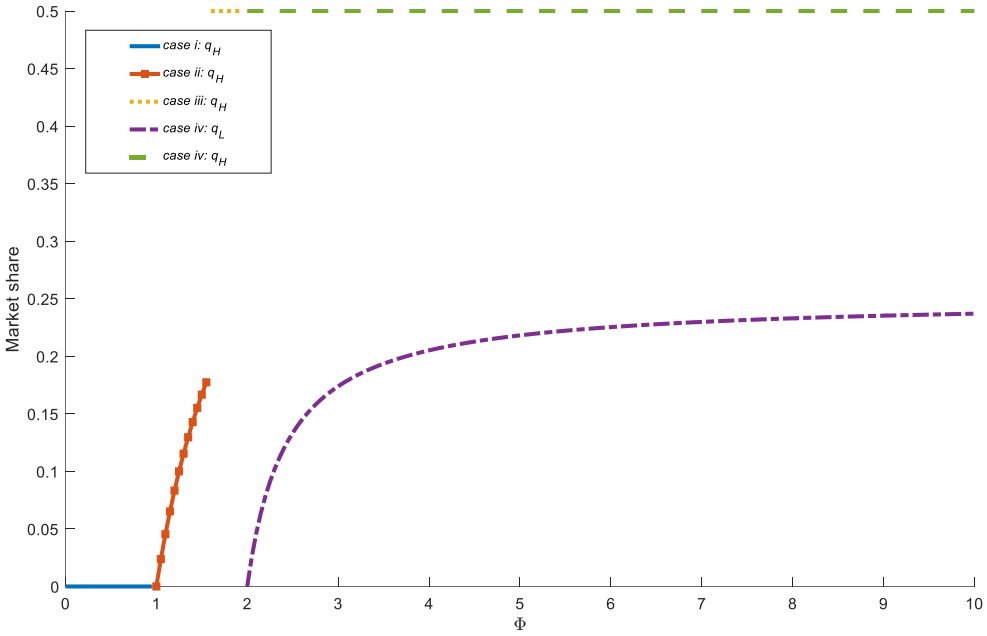


Fig 5. Optimal market share based on different Φ values when $\frac{1}{8} \leq \gamma < \frac{1}{4}$

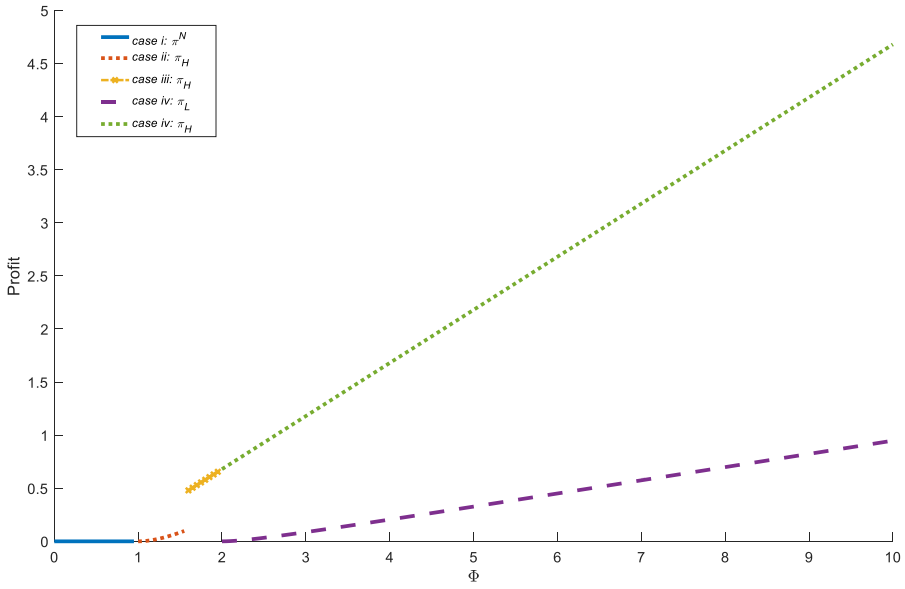


Fig 6. Profit based on different Φ values when $\frac{1}{8} \leq \gamma < \frac{1}{4}$

Proposition 3. *When* $\frac{1}{4} \leq \gamma < \frac{1}{2}$

i *if* $\Phi < \frac{1}{8}\frac{c}{\gamma}$, *no product is manufactured for a negative profit.*

ii *if* $\frac{1}{8}\frac{c}{\gamma} \leq \Phi < \frac{c}{2}$, *no product is manufactured for no market share.*

iii *if* $\frac{c}{2} \leq \Phi < \frac{1}{4}\frac{c}{\gamma}$, *the enterprise only produces high greenness products. The optimal strategies are:*

$$g_H = \frac{2\Phi - c}{8\gamma\Phi - c}\frac{c}{\varepsilon} + g_0, \quad p_H = \frac{2\Phi(4\gamma\Phi + 2\gamma c - c)}{8\gamma\Phi - c},$$
$$q_H = \frac{2\gamma(2\Phi - c)}{8\gamma\Phi - c}, \qquad \pi_H = \frac{(2\Phi - c)^2}{8\gamma}.$$

iv *if* $\Phi \geq \frac{1}{4}\frac{c}{\gamma}$, *the enterprise produces differentiated products. The optimal strategies are:*

$$g_L = \frac{(\Phi - c)(4\gamma\Phi - c)}{(4\gamma\Phi - c)^2}\frac{c}{\varepsilon} + g_0, \qquad g_H = \frac{2\Phi - c}{8\gamma\Phi - c}\frac{c}{\varepsilon} + g_0,$$
$$p_L = \frac{2\Phi + 3c}{4} - \frac{(2\Phi - c)(16\gamma\Phi - 3c)}{4(8\gamma\Phi - c)^2}c, \quad p_H = \frac{2\Phi(4\gamma\Phi + 2\gamma c - c)}{8\gamma\Phi - c},$$
$$q_L = \frac{2\gamma(4\gamma\Phi - c)(2\Phi - c)}{(8\gamma\Phi - c)^2}, \qquad q_H = \frac{2\gamma(2\Phi - c)}{8\gamma\Phi - c},$$
$$\pi_L = \frac{(2\Phi - c)^2(4\gamma\Phi - c)^2}{(8\gamma\Phi - c)^3}\gamma, \qquad \pi_H = \frac{(2\Phi - c)^2}{8\gamma\Phi - c}\gamma.$$

Proof. Please see Appendix A for proof. □

Proposition 3 shows that when $\frac{1}{4} \leq \gamma < \frac{1}{2}$, if consumers' WTP is lower than $0.5c$, the enterprise will not produce a product for a negative profit or no market share. If consumers' WTP is higher than $0.5c$ and lower than $\frac{1}{4}\frac{c}{\gamma}$, the enterprise will only produce a single type of green product. If consumers' WTP increases to above $\frac{1}{4}\frac{c}{\gamma}$, the enterprise will produce differentiated products and obtain higher profits, the incremental benefit is π_L. The production strategies for $\frac{1}{4} \leq \gamma < \frac{1}{2}$ are shown in Fig 7.

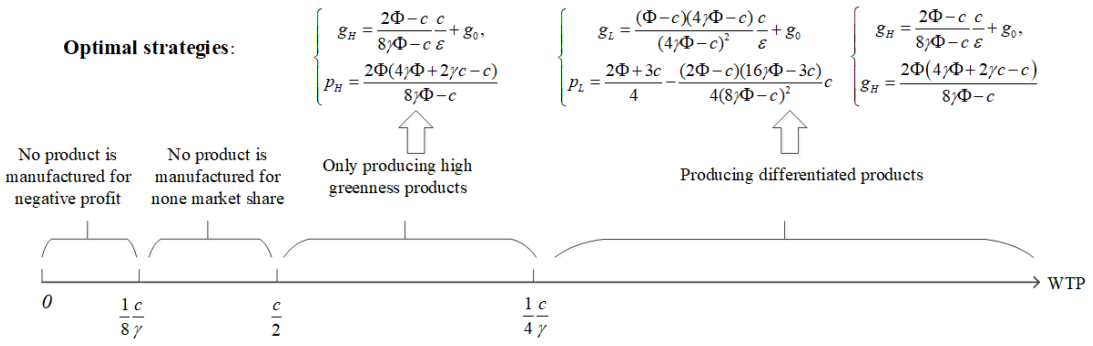


Fig 7. Production strategy for the scenario $\frac{1}{4} \leq \gamma < \frac{1}{2}$

The numerical studies are shown in Fig. 8 and Fig. 9 with the γ value set to $\gamma = 0.4$. The relevant parameter values are the same as in Proposition 1 except $\beta = 0.05$. The two figures show that the increase in consumers' WTP incentivises the enterprise to produce green products, and the market share of and profits generated by green products will rise as the WTP increases. When consumers' WTP reaches a certain threshold, the enterprise becomes willing to offer green products that are differentiated in terms of their greenness. Furthermore, the higher the level of greenness, the higher the market share of the product.

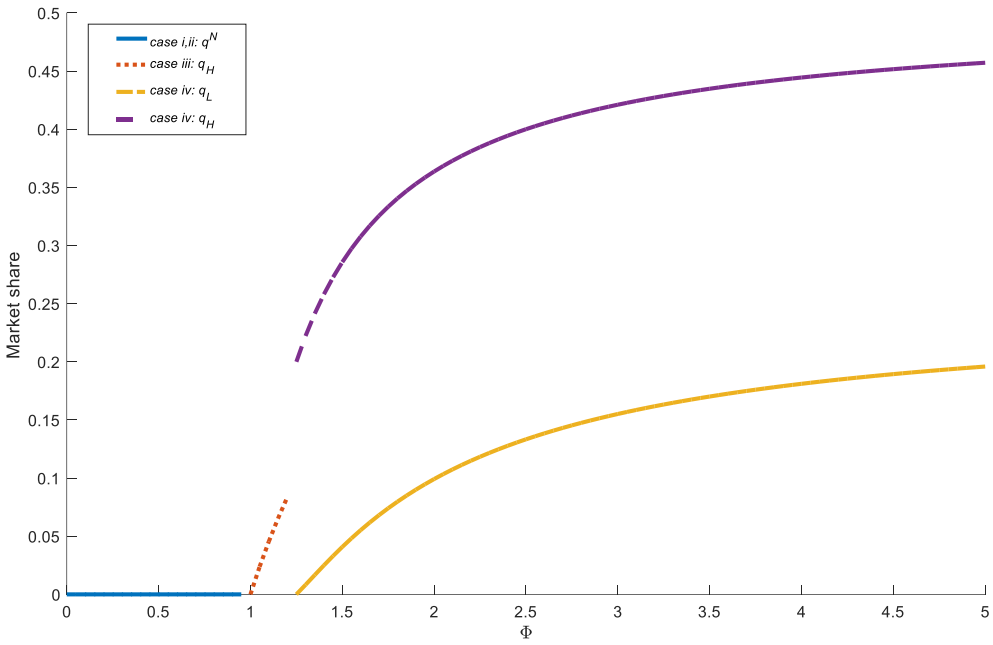


Fig 8. Optimal market share based on different Φ values when $\frac{1}{4} \leq \gamma < \frac{1}{2}$

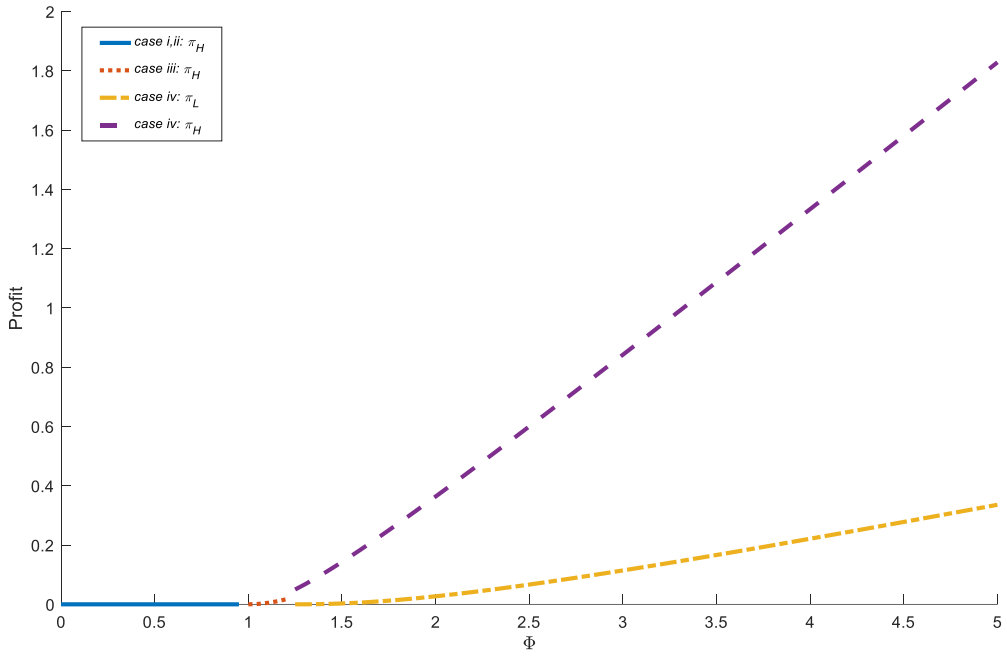


Fig 9. Profit based on different Φ values when $\frac{1}{4} \leq \gamma < \frac{1}{2}$

Proposition 4. *When* $\gamma \geq \frac{1}{2}$

i *if* $\Phi < \frac{1}{8}\frac{c}{\gamma}$, *no product is manufactured for a negative profit.*

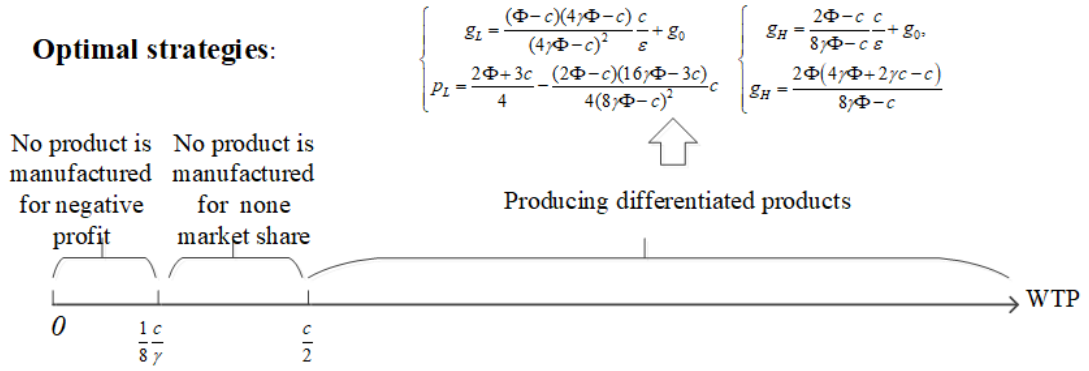
ii *if* $\frac{1}{8}\frac{c}{\gamma} \leq \Phi < \frac{c}{2}$, *no product is manufactured for no market share.*

iii *if* $\Phi \geq \frac{c}{2}$, *the enterprise produces differentiated products. The optimal strategies are:*

458
$$
\begin{aligned}
g_L &= \frac{(\Phi-c)(4\gamma\Phi-c)}{(4\gamma\Phi-c)^2}\frac{c}{\varepsilon}+g_0, & g_H &= \frac{2\Phi-c}{8\gamma\Phi-c}\frac{c}{\varepsilon}+g_0,\\
p_L &= \frac{2\Phi+3c}{4}-\frac{(2\Phi-c)(16\gamma\Phi-3c)}{4(8\gamma\Phi-c)^2}c, & p_H &= \frac{2\Phi(4\gamma\Phi+2\gamma c-c)}{8\gamma\Phi-c},\\
q_L &= \frac{2\gamma(4\gamma\Phi-c)(2\Phi-c)}{(8\gamma\Phi-c)^2}, & q_H &= \frac{2\gamma(2\Phi-c)}{8\gamma\Phi-c},\\
\pi_L &= \frac{(2\Phi-c)^2(4\gamma\Phi-c)^2}{(8\gamma\Phi-c)^3}\gamma, & \pi_H &= \frac{(2\Phi-c)^2}{8\gamma\Phi-c}\gamma.
\end{aligned}
$$

459 *Proof.* Please see Appendix A for proof. □

460 Proposition 4 shows that when $\gamma \geq \frac{1}{2}$, if consumers' WTP is lower than $\frac{1}{8}\frac{c}{\gamma}$, the
461 enterprise will not produce a product for a negative profit or no market share. If
462 consumers' WTP is higher than $\frac{1}{8}\frac{c}{\gamma}$ and lower than $0.5c$, the enterprise will only
463 produce high greenness products. If consumers' WTP is higher than $0.5c$, the enterprise
464 will produce differentiated products and the incremental benefit is π_L. The production
465 strategies for $\gamma \geq \frac{1}{2}$ are shown in Fig 10.



466

467 **Fig 10.** Production strategy for the scenario $\gamma \geq \frac{1}{2}$.

468 The numerical studies are shown in Fig. 11 and Fig. 12 with the γ value set to $\gamma =$
469 0.8. The relevant parameter values are the same as in Proposition 1 except $\beta = 0.1$. In
470 the scenario shown in the following two figures, when consumers' WTP continues to
471 rise and reaches a particular level, the enterprise becomes willing to offer green
472 products that are differentiated in terms of their greenness. The market share of green
473 products and the enterprise's overall profits will also increase accordingly.

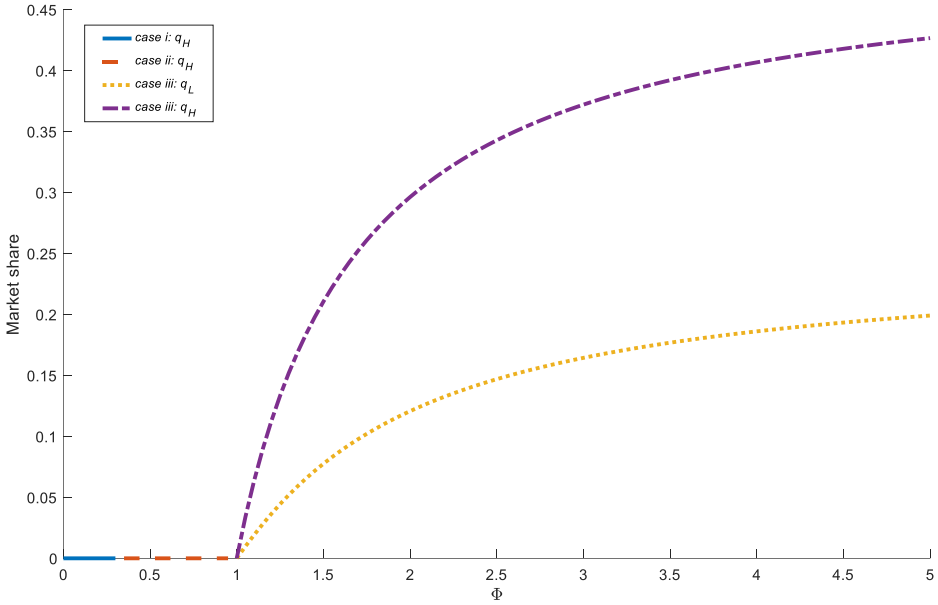


Fig 11. Optimal market share based on different Φ values when $\gamma \geq \frac{1}{2}$

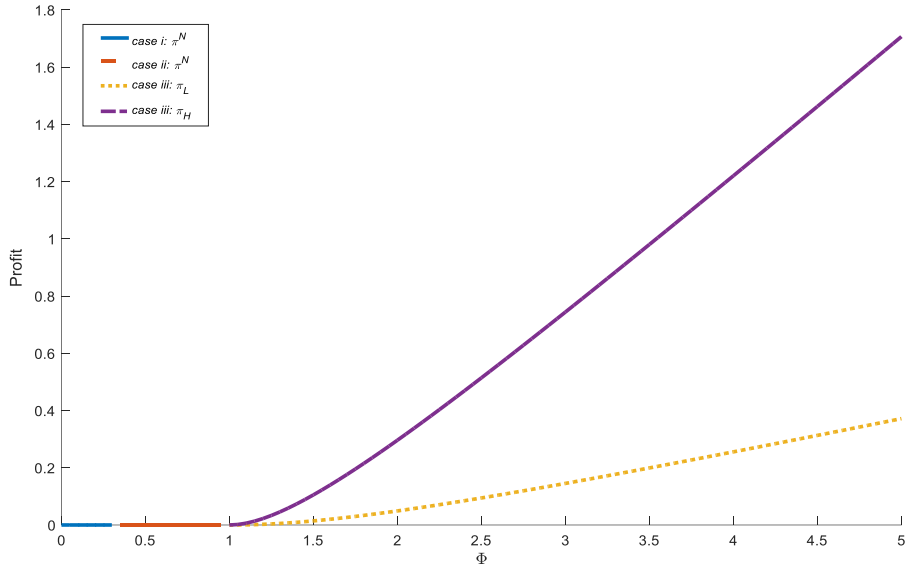


Fig 12. Profit based on different Φ values when $\gamma \geq \frac{1}{2}$

5. The effect of eco-friendly materials on profits and the environment

Both the development of green technology and the adoption of eco-friendly materials by enterprises can enhance the greenness of their products. However, compared to the high risks and costs associated with green technology, adopting eco-friendly materials to make products greener incurs relatively lower costs and can achieve this goal within a shorter timeframe. To this end, we further analysed the impact of enterprises adopting eco-friendly materials on their profits and the quality of the environment.

In this section, we first focus on the effect of eco-friendly materials and WTP on profits. Next, we explore the effect of eco-friendly materials and WTP on the quality of the environment. The environmental impact is defined as the weighted average greenness. From the government's perspective, the environmental impact is their main concern. We also provide information about under which conditions the government should make policy interventions to encourage enterprises to adopt eco-friendly materials, based on the results.

5.1 The effect of eco-friendly materials on profits

In this section, we discuss when the enterprise will use the eco-friendly materials in terms of the cost-benefit ratio. We consider two situations: firstly, what happens when Φ remains constant; secondly, what happens when Φ varies.

Proposition 5. *If Φ remains constant, the enterprise will not use eco-friendly materials as $\frac{\partial \pi}{\partial c} < 0$. If Φ is expected to increase, whether the enterprise decides to use eco-friendly materials depends on the enterprise's technological parameters and the value of Φ, i.e.*[1]

1. *when* $\gamma < \frac{1}{8}$

   i if $\frac{c}{2} \le \Phi < \frac{1}{8}\frac{c}{\gamma}$, $\frac{\partial \pi_H}{\partial \Phi} > 0, \frac{\partial^2 \pi_H}{\partial \Phi \partial c} < 0.$

   ii if $\Phi \ge \frac{1}{8}\frac{c}{\gamma}$, $\frac{\partial \pi_H}{\partial \Phi} > 0, \frac{\partial^2 \pi_H}{\partial \Phi \partial c} = 0.$

2. *when* $\frac{1}{8} \le \gamma < \frac{1}{4}$

   i if $\frac{c}{2} \le \Phi < \frac{1}{8}\frac{c}{\gamma}$, $\frac{\partial \pi_H}{\partial \Phi} > 0, \frac{\partial^2 \pi_H}{\partial \Phi \partial c} < 0.$

   ii if $\frac{1}{8}\frac{c}{\gamma} \le \Phi < c$, $\frac{\partial \pi_H}{\partial \Phi} > 0, \frac{\partial^2 \pi_H}{\partial \Phi \partial c} = 0.$

   iii if $\Phi \ge c$, $\frac{\partial (\pi_L + \pi_H)}{\partial \Phi} > 0, \frac{\partial^2 (\pi_L + \pi_H)}{\partial \Phi \partial c} < 0.$

3. *when* $\frac{1}{4} \le \gamma < \frac{1}{2}$

   i if $\frac{c}{2} \le \Phi < \frac{1}{4}\frac{c}{\gamma}$, $\frac{\partial \pi_H}{\partial \Phi} \ge 0, \frac{\partial^2 \pi_H}{\partial \Phi \partial c} < 0.$

   ii if $\Phi \ge \frac{1}{4}\frac{c}{\gamma}$, $\frac{\partial (\pi_L + \pi_H)}{\partial \Phi} > 0, \frac{\partial^2 (\pi_L + \pi_H)}{\partial \Phi \partial c} < 0.$

4. *when* $\gamma \ge \frac{1}{2}$

   i if $\Phi \ge \frac{c}{2}$, $\frac{\partial (\pi_L + \pi_H)}{\partial \Phi} > 0, \frac{\partial^2 (\pi_L + \pi_H)}{\partial \Phi \partial c} < 0.$

Proposition 5 examines whether the decision about whether to use eco-friendly materials is related to enterprises' technological parameters and the value of Φ. When Φ remains constant, the enterprise will not use eco-friendly materials. When the

[1] Regardless of the technological parameters, no products will be manufactured when $\Phi < \frac{c}{2}$, so we only consider cases where Φ is greater than $\frac{c}{2}$ in this section.

expected WTP of consumers increases, if the enterprise chooses to use eco-friendly materials, it will have no positive effect on profits. These findings indicate that the enterprise has no incentive to use eco-friendly materials. In summary, if adopting eco-friendly materials directly increases the variable costs of production, then regardless of how high the consumers' WTP may be, further enhancing product greenness through the use of these materials may not be an economically rational choice for enterprises. Next, we explore how the use of eco-friendly materials and value of Φ affect the environmental quality.

5.2 The effect of eco-friendly materials on the quality of the environment

In this section, we first study the effect of using eco-friendly materials on the environment when Φ remains constant. We then investigate the influence of eco-friendly materials on environmental impact when Φ is expected to increase. The government's main task is to implement intervention strategies to motivate enterprises to use environmentally friendly materials in order to reduce the environmental impact of products. Based on the following results, we identify the optimal intervention opportunities to encourage enterprises to use eco-friendly materials.

As g_0 is the threshold for the product to enter the market, we use $g_i - g_0$ to represent the environmental impact instead of g_i. The environmental impact function is defined as:

$$G = q_L(g_L - g_0) + q_H(g_H - g_0). \quad (6)$$

Proposition 6. *The effect of eco-friendly materials and Φ on the environmental quality also depends on enterprises' technological parameters and the value of Φ, i.e.*

1. *when* $\gamma < \frac{1}{8}$, *if* $\Phi \geq \frac{1}{8}\frac{c}{\gamma}$, $\frac{\partial G}{\partial c} > 0$; $\frac{\partial G}{\partial \Phi} = 0$, $\frac{\partial^2 G}{\partial \Phi \partial c} = 0$.
2. *when* $\frac{1}{8} \leq \gamma < \frac{1}{4}$,
   - *i* *if* $\frac{1}{8}\frac{c}{\gamma} \leq \Phi < c$, $\frac{\partial G}{\partial c} > 0$; $\frac{\partial G}{\partial \Phi} = 0$, $\frac{\partial^2 G}{\partial \Phi \partial c} = 0$.
   - *ii* *if* $\Phi \geq c$, $\frac{\partial G}{\partial c} > 0$;
     - *a* *if* $c \leq \Phi < 2c - \frac{1}{8}\frac{c}{\gamma}$, $\frac{\partial G}{\partial \Phi} > 0$, $\frac{\partial^2 G}{\partial \Phi \partial c} < 0$.
     - *b* *if* $\Phi \geq 2c - \frac{1}{8}\frac{c}{\gamma}$, $\frac{\partial G}{\partial \Phi} > 0$, $\frac{\partial^2 G}{\partial \Phi \partial c} > 0$.
3. *when* $\frac{1}{4} \leq \gamma < \frac{1}{2}$,
   - *i* *if* $\frac{c}{2} \leq \Phi < \frac{1}{4}\frac{c}{\gamma}$, $\frac{\partial G}{\partial c} < 0$;
     - *a* *if* $\frac{c}{2} \leq \Phi < c - \frac{1}{8}\frac{c}{\gamma}$, $\frac{\partial G}{\partial \Phi} > 0$, $\frac{\partial^2 G}{\partial \Phi \partial c} < 0$.
     - *b* *if* $\Phi \geq c - \frac{1}{8}\frac{c}{\gamma}$, $\frac{\partial G}{\partial \Phi} > 0$, $\frac{\partial^2 G}{\partial \Phi \partial c} > 0$.
   - *ii* *if* $\Phi \geq \frac{1}{4}\frac{c}{\gamma}$, $\frac{\partial G}{\partial c} < 0$;
     - *a* *if* $\frac{1}{4}\frac{c}{\gamma} \leq \Phi < \frac{K^*}{2}$, $\frac{\partial G}{\partial \Phi} > 0$, $\frac{\partial^2 G}{\partial \Phi \partial c} < 0$.

b *if* $\Phi \geq \frac{K^*}{2}, \frac{\partial G}{\partial \Phi} > 0, \frac{\partial^2 G}{\partial \Phi \partial c} > 0.$

4. when $\gamma \geq \frac{1}{2}$, *if* $\Phi \geq \frac{c}{2}, \frac{\partial G}{\partial c} < 0$;

a *if* $\frac{c}{2} \leq \Phi < \frac{K^*}{2}, \frac{\partial G}{\partial \Phi} > 0, \frac{\partial^2 G}{\partial \Phi \partial c} < 0.$

b *if* $\Phi \geq \frac{K^*}{2}, \frac{\partial G}{\partial \Phi} > 0, \frac{\partial^2 G}{\partial \Phi \partial c} > 0.$

where $f(K^*) = 40(K^*)^3 - (80c + 18\frac{c}{\gamma})(K^*)^2 + 10c\frac{c}{\gamma}K^* + (\frac{c}{\gamma})^3 - 10c(\frac{c}{\gamma})^2 = 0.$

Proof. Please see Appendix B for proof. □

Proposition 6 suggests that, when Φ remains constant if $\gamma < \frac{1}{4}, \frac{\partial G}{\partial c} > 0$, the use of enterprise of eco-friendly materials by the enterprise will mitigate the environmental impact but will also reduce profits. Hence, the enterprise has no incentive to use eco-friendly materials and the government should subsidise enterprises at this point; if $\gamma \geq \frac{1}{4}, \frac{\partial G}{\partial c} < 0$, then using eco-friendly materials will decrease the environmental impact and reduce profits. When Φ varies, if using eco-friendly materials can enhance the beneficial effects of Φ on the environment or reduce the adverse effects of Φ on environmental quality, the government should subsidies enterprises to encourage them to use eco-friendly materials; otherwise, the government should not take any action.

Moreover, an increase in Φ has a positive effect on environmental quality and profits (see Proposition 5), which implies that the government and enterprises could take measures designed to influence consumers' WTP and improve the environmental impact of products.

5.3 Numerical study

In this subsection, we conduct numerical experiments to support the theoretical analysis presented in Proposition 6. The effects of using eco-friendly materials and consumers' WTP on the environmental quality are shown in Fig. 13 to Fig. 18.

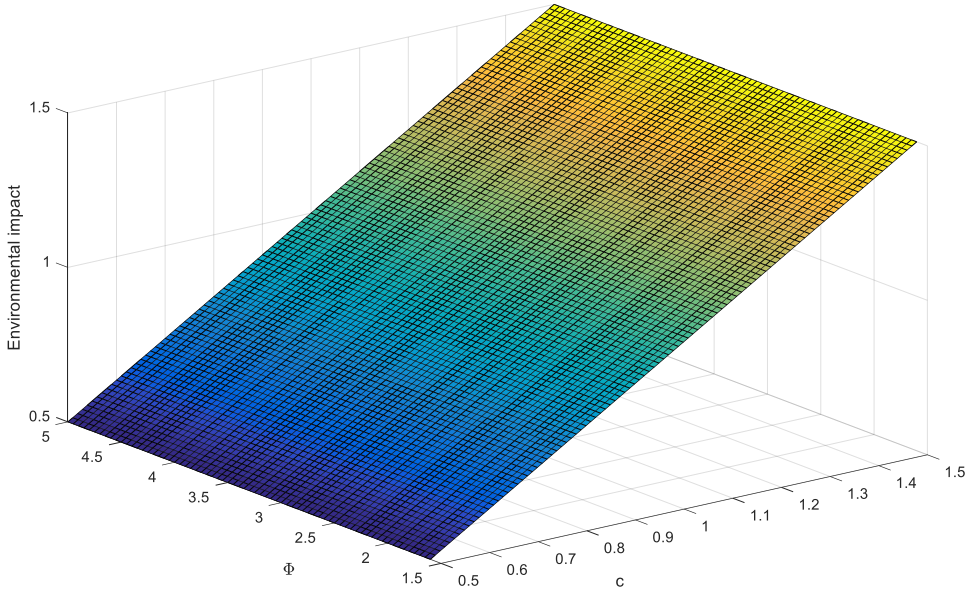


Fig 13. The effect of Φ and c on environmental quality when $\gamma < \frac{1}{8}$

Fig 13. shows the effect of eco-friendly materials and consumers' WTP on environmental quality when $\gamma < \frac{1}{8}$. Fig. 13 illustrates the results produced in Proposition 6 case 1. It shows that using more eco-friendly materials will reduce the environmental impact of products. Consumers' WTP does not affect the quality of the environment. If the government wishes to reduce the environmental impact, then it may be feasible for them to subsidise enterprises to use eco-friendly materials.

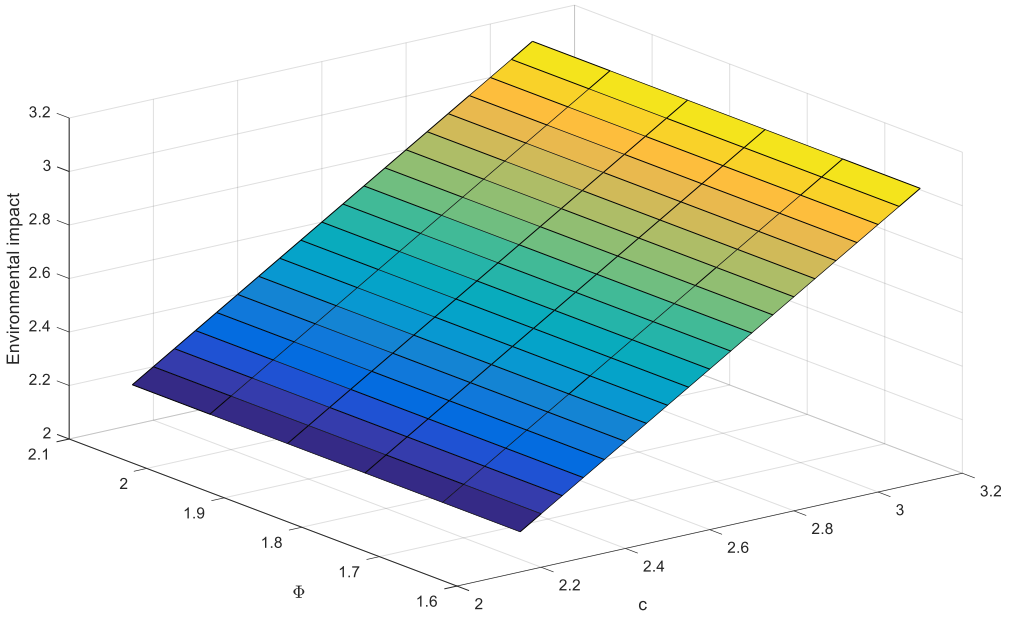


Fig. 14 The effect of Φ and c on environmental quality in case 2(i) when $\frac{1}{8} \leq \gamma < \frac{1}{4}$

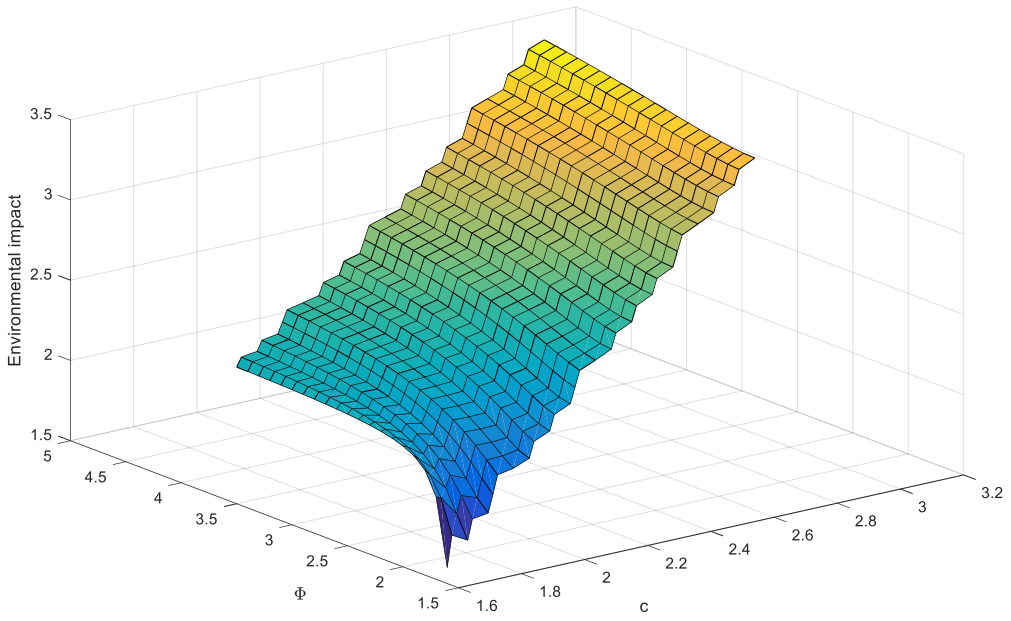


Fig. 15 The effect of Φ and c on environmental quality in case 2(ii) when $\frac{1}{8} \leq \gamma < \frac{1}{4}$

Fig. 14 and Fig. 15 show the effect of using eco-friendly materials and consumers' WTP on the environmental quality when $\frac{1}{8} \leq \gamma < \frac{1}{4}$. Fig. 10 and 11 display the results obtained in case 2(i) and case 2(ii) respectively. The effect of using environmentally

friendly materials and consumers' WTP on the environmental quality shown in Fig. 14 is the same as that shown in Fig. 13. Fig. 15 shows that adopting eco-friendly materials and increasing consumers' WTP can raise the environmental quality. However, the effect of c on $\frac{\partial G}{\partial \Phi}$ can be either positive or negative, depending on consumers' WTP. Accordingly, the government can decide whether to introduce subsidies as a way of encouraging enterprises to use eco-friendly materials.

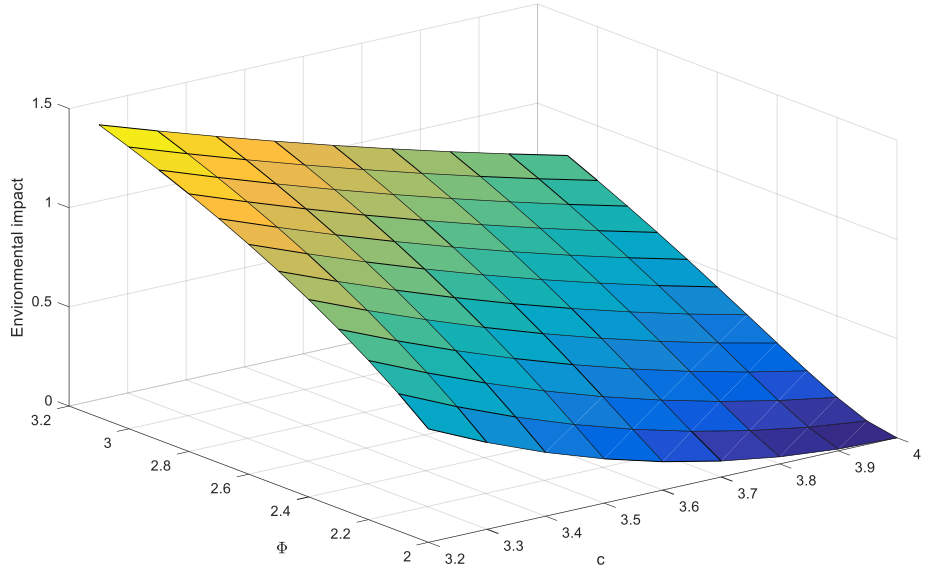


Fig. 16 The effect of Φ and c on environmental quality in case 3(i) when $\frac{1}{4} \leq \gamma < \frac{1}{2}$

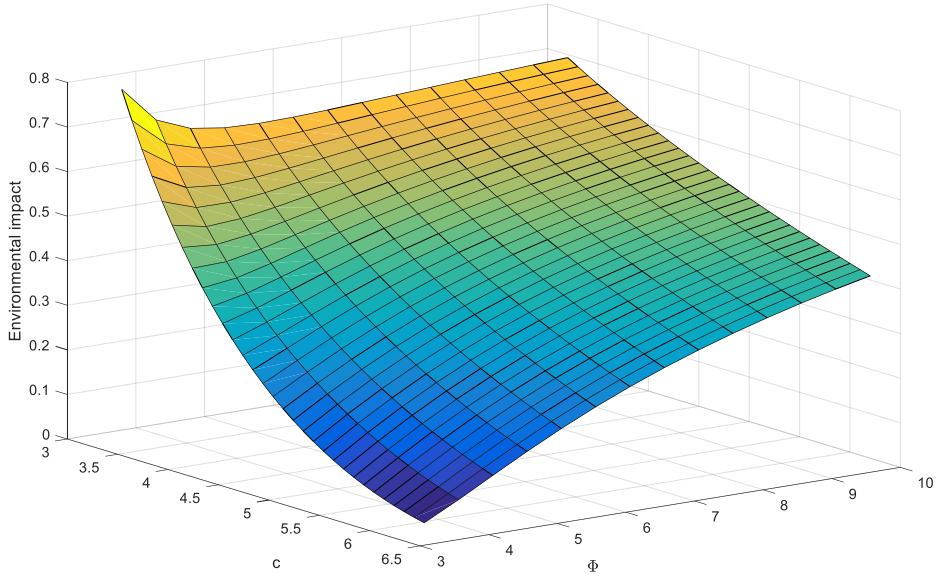


Fig. 17 The effect of Φ and c on environmental quality in case 3(ii) when $\frac{1}{4} \leq \gamma < \frac{1}{2}$

Fig. 16 and Fig. 17, respectively, show the effect of using eco-friendly materials and consumers' WTP on the quality of the environment in case 3(i) and case 3(ii) when $\frac{1}{4} \leq \gamma < \frac{1}{2}$. The effect of using environmentally friendly materials and consumers' WTP on the environmental quality is shown to be the same in Fig. 16 and Fig. 17. Using more eco-friendly materials will decrease the environmental impact, but higher consumers'

WTP will increase environmental impact. Moreover, the decision about whether or not to adopt more eco-friendly materials depends on the critical point of WTP. When WTP exceeds this critical point, the effect is positive, and when it is below the critical point, the effect is negative.

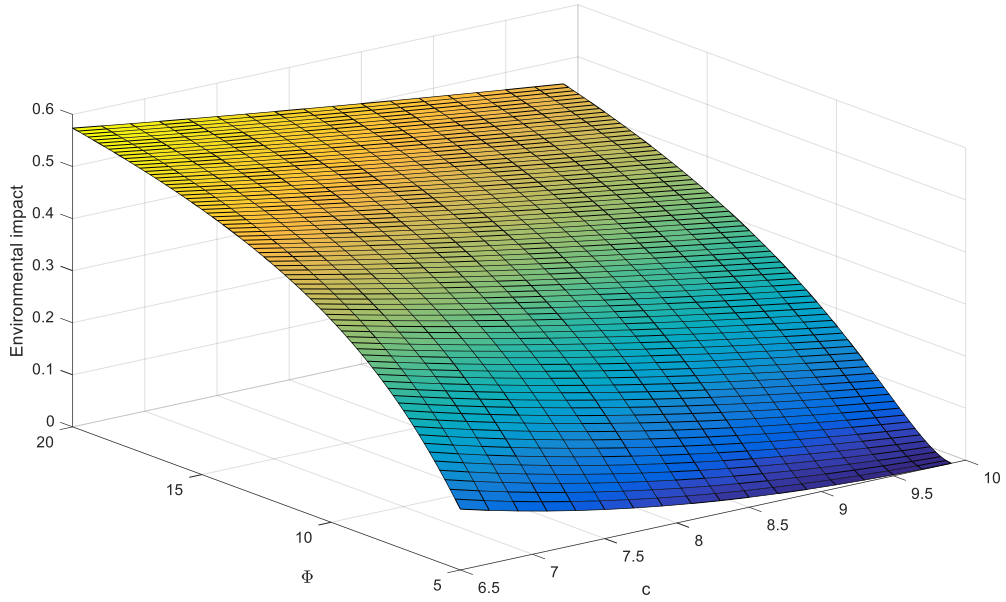


Fig. 18 The effect of Φ and c on environmental quality when $\gamma \geq \frac{1}{2}$

Fig. 18. shows the effect of using eco-friendly materials and consumers' WTP on the quality of the environment when $\gamma \geq \frac{1}{2}$. This effect is shown in Fig. 16 and also is the same as shown in Fig. 15.

6. Conclusion and policy implications

In a green economy, both consumers and businesses are increasingly prioritising environmental sustainability, leading to a growth in the market share of green products. How to improve competitiveness and maximise profits by capitalising on the growing trend for environmental sustainability poses a challenge for many enterprises. This paper focused on the strategies employed by one firm, taking consumers' WTP into account. It explored the strategy adopted by an enterprise when launching a green product and investigated the impact of consumers' WTP on both the enterprise's decision-making process and the environment. These strategies were comprised of two parts: whether to produce alternative products; and how to determine the optimal level of greenness and pricing. The modelling also investigated the effect of using eco-friendly materials. We identified the optimal conditions under which the use of environmentally friendly materials can positively impact environmental quality. This analysis has potential implications for how the government can engage with enterprises to encourage the adoption of environmentally friendly materials in their production processes, particularly when there is no profit-driven incentive for them to do so. The main conclusions and policy implications are as follows.

First, we explored the optimal strategies that enterprises could pursue, including decisions relating to the level of greenness, the price of the product, and whether the enterprise should produce a single product or differentiated products. This study

indicates that the optimal production strategies will change with variations in firms' technological parameters and consumers' WTP. Moreover, consumers' WTP has a significant impact on the decision about whether to introduce green products into the market. When consumers are willing to pay less, an enterprise will not produce green products because doing so would result in negative profits. When the WTP exceeds a certain threshold, the enterprise can produce a single type of green product. As consumers' WTP continues to increase to a higher threshold, the enterprise is able to produce differentiated products to meet consumers' diverse needs. Specifically, we found that when the combined technological parameters of γ are greater than $\frac{1}{8}$, and the WTP exceeds a particular threshold, the enterprise should simultaneously produce alternative product lines with higher and lower levels of greenness. In addition, when the WTP is less than half of the material costs of the product, regardless of the other parameters, the enterprise should not manufacture the product because it will result in negative profits. In other cases, the firm will only offer a single type of green product with a high level of greenness based on its maximum green technological capability. This implies that when enterprises seek to launch green products, they should first conduct market research on consumers' WTP. They can then make decisions about green technology innovation and production strategies based on consumers' WTP and their own production and innovation costs.

Second, an increase in consumers' WTP will also increase the greenness of products, enhance their market penetration, boost enterprises' total profits, and improve the quality of the environment. However, higher research costs will decrease the penetration rate of greener products. The development and application of green technology, as well as the promotion of green products therefore requires support from consumers. As the main group of market participants, consumers' WTP for green products serves as the primary impetus for enterprises to engage in green technology innovation and launch green products. These results indicate that an increase in consumers' WTP for green products not only benefits enterprises but also contributes to improving the quality of the environment. If the current level of consumers' WTP is not sufficient to incentivise enterprises to adopt green technology or produce products with a higher level of greenness, the government and enterprises can introduce measures designed to promote greener lifestyles and green products to enhance consumers' awareness of environmental protection, publicise the environmental benefits of green products, and use role models to demonstrate the benefits of these products to consumers, thus encouraging consumers to translate their environmental awareness into practical actions.

Third, we analysed how the use of eco-friendly materials influences both profitability and the environment in the case of each optimal decision. The results demonstrated that, from an economic perspective, regardless of the anticipated future increase in consumers' WTP, under current decision-making frameworks, companies lack a motivation to use more environmentally friendly materials to improve the quality of the environment, because doing so will increase their variable costs and hence have a detrimental effect on profits. However, if an enterprise's technical parameters are below 1/4, indicating that the production or R&D costs of manufacturing green products are relatively low, and the cost saving rate of the product is relatively high, then using more environmentally friendly materials can help to improve the quality of the environment. In this case, the government could provide appropriate subsidies to further encourage enterprises to enhance the environmental friendliness of their

products, thereby contributing to further improvements in environmental quality. There are two ways in which enterprises can alter the environmental impact of their products. In the short term, they can enhance the greenness of their products by using more eco-friendly materials. In the long term, they can make their products greener by investing in green technology. If the enterprise has already determined its level of greenness, adopting more environmentally friendly materials will not have a positive effect on enhancing market penetration or profits, but it may contribute to improving environmental quality. When such measures are beneficial to the environment, but the level of increase in consumer WTP is insufficient to incentivise enterprises to implement them, the government could provide subsidies to encourage enterprises to strive for improvement in environmental quality and contribute to the development of a green economy.

However, there is still some further work to do, such as extending the investigation to the case of the green supply chain. In addition to firms' greenness capacity, future research could also consider the government's subsidy policy and its effect on green production.

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Appendices

Appendix A.

Proof of Proposition 1 to Proposition 4 The first order conditions of (5) are:

$$g_H=\min\left\{\frac{\varepsilon}{2\beta}\frac{2\Phi-p_H}{2\Phi}+g_0,\frac{c}{\varepsilon}+g_0\right\} \quad (A1)$$

$$p_H=\frac{2\Phi+c-\varepsilon(g_H-g_0)}{2} \quad (A2)$$

The first order conditions of (5) are:

$$g_L=\min\left\{\frac{\varepsilon}{2\beta}\frac{p_H-p_L}{2\Phi}+g_0,\frac{c}{\varepsilon}+g_0\right\},p_L=\frac{p_H+c-\varepsilon(g_L-g_0)}{2}; \quad (A3)$$

$$g_H=\min\left\{\frac{\varepsilon}{2\beta}\frac{2\Phi-p_H}{2\Phi}+g_0,\frac{c}{\varepsilon}+g_0\right\},g_L=\min\left\{\frac{\varepsilon}{2\beta}\frac{2\Phi-p_H}{2\Phi}+g_0,\frac{c}{\varepsilon}+g_0\right\}, \quad (A4)$$

From (A1) to (A4), we can get two main points. Firstly, the optimal strategies for high greenness products are not influenced by the optimal strategies for low greenness products and the optimal strategies for high greenness products have the same form in (A1) and (A2). Secondly, whether the enterprise decides to produce differential products depends on whether the profits from low greenness products are non-negative. Based on the assumption of non-negative profit and the assumption of $g_H>g_L$ and $p_H>p_L$ when an enterprise decides to produce differential products, we can prove Proposition 1 to Proposition 4.

Appendix B.

1. when $\gamma<\frac{1}{8}$, if $\Phi\geq\frac{1}{8}\frac{c}{\gamma}$, $G=\frac{c}{2\varepsilon}$. $\frac{\partial G}{\partial c}=\frac{1}{2\varepsilon}>0$, $\frac{\partial G}{\partial\Phi}=0$, $\frac{\partial^2 G}{\partial\Phi\partial c}=0$.

2. when $\frac{1}{8}\leq\gamma<\frac{1}{4}$,

   i if $\frac{1}{8}\frac{c}{\gamma}\leq\Phi<c$, $G=\frac{c}{2\varepsilon}$.

   $\frac{\partial G}{\partial c}=\frac{1}{2\varepsilon}>0$, $\frac{\partial G}{\partial\Phi}=0$, $\frac{\partial^2 G}{\partial\Phi\partial c}=0$.

   ii if $\Phi\geq c$, $G=\frac{\Phi-c}{8\gamma\Phi-c}\frac{2\gamma(\Phi-c)}{8\gamma\Phi-c}\frac{c}{\varepsilon}+\frac{c}{2\varepsilon}$.

   $\frac{\partial G}{\partial c}=\frac{64\Phi^2-12\frac{c}{\gamma}\Phi+(\frac{c}{\gamma})^2+8c\frac{c}{\gamma}}{2\varepsilon(8\Phi-\frac{c}{\gamma})^2}>0$, $\frac{\partial G}{\partial\Phi}=\frac{4(8c-\frac{c}{\gamma})(\Phi-c)}{(8\Phi-\frac{c}{\gamma})^3}>0$, $\frac{\partial^2 G}{\partial\Phi\partial c}=\frac{4(8\Phi-16c+\frac{c}{\gamma})}{(8\Phi-\frac{c}{\gamma})^3}$

3. when $\frac{1}{4}\leq\gamma<\frac{1}{2}$,

   i if $\frac{c}{2}\leq\Phi<\frac{1}{4}\frac{c}{\gamma}$, $G=\frac{(2\Phi-c)^2}{4\Phi(8\gamma\Phi-c)}\frac{c}{\varepsilon}$.

   $\frac{\partial G}{\partial c}=-\frac{2\Phi-c}{2\Phi(8\gamma\Phi-c)}\frac{c}{\varepsilon}<0$, $\frac{\partial G}{\partial\Phi}=16\frac{(4c-\frac{c}{\gamma})(2\Phi-c)}{(8\Phi-\frac{c}{\gamma})^3}>0$, $\frac{\partial^2 G}{\partial\Phi\partial c}=16\frac{8\Phi-8c+\frac{c}{\gamma}}{(8\Phi-\frac{c}{\gamma})^3}>0$.

   ii if $\Phi>\frac{1}{4}\frac{c}{\gamma}$, $G=\frac{4\varepsilon(2\Phi-c)^2[40\Phi^2-12\Phi\frac{c}{\gamma}+(\frac{c}{\gamma})^2]}{(8\Phi-\frac{c}{\gamma})^3\beta}$.

$$\frac{\partial G}{\partial c} = \frac{-8\varepsilon(2\Phi - c)[40\Phi^2 - 12\Phi\frac{c}{\gamma} + (\frac{c}{\gamma})^2]}{(8\Phi - \frac{c}{\gamma})^3\beta} < 0,$$

$$\frac{\partial G}{\partial \Phi} = \frac{16\varepsilon(2\Phi - c)}{(8\Phi - \frac{c}{\gamma})^5\beta}[4(-8\frac{c}{\gamma} + 40c)\Phi^2 + 2(5\frac{c}{\gamma} - 26c)\frac{c}{\gamma}\Phi + 5c(\frac{c}{\gamma})^2 - (\frac{c}{\gamma})^3] > 0,$$

$$\frac{\partial^2 G}{\partial \Phi \partial c} = \frac{16\varepsilon}{(8\Phi - \frac{c}{\gamma})^5\beta} f(K), \text{ if } \Phi < \frac{K^*}{2}, \frac{\partial^2 G}{\partial \Phi \partial c} < 0 \text{ and vice versa.}$$

4. when $\gamma \geq \frac{1}{2}$, $G = \frac{4\varepsilon(2\Phi - c)^2[40\Phi^2 - 12\Phi\frac{c}{\gamma} + (\frac{c}{\gamma})^2]}{(8\Phi - \frac{c}{\gamma})^3\beta}$, the derivatives are the same as case 3.

where $f(K) = 40(K)^3 - (80c + 18\frac{c}{\gamma})(K)^2 + 10c\frac{c}{\gamma}K + (\frac{c}{\gamma})^3 - 10c(\frac{c}{\gamma})^2$, $K = 2\Phi$, the cubic function has only one zero point K^* and $K^* > \frac{c}{2\gamma}$.