THE EFFECTS OF GOVERNMENT SUBSIDIES ON THE DEVELOPMENT OF GREEN PRODUCTS

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AUTHOR'S DECLARATION

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Abstract

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This thesis tackles the problem of a monopolist firm that is considering designing products with environmental qualities while facing significant research and development costs. A mathematical formulation is adopted to model the impact of government subsidies on the firm's choice between mass marketing, where only one standard product serves the entire market, and market segmentation, in which the firm develops ordinary and green products for two market segments. The firm's behavior in reaction to the subsidies is analyzed through a two-stage Stackelberg game. The obtained results reveal that the subsidy level does not affect the relationships between the environmental qualities of the manufactured products under different marketing strategies when the green market is not strong. Our analyses also demonstrate how an optimal subsidy level should be selected to maximize the social welfare, and how this optimal subsidy is impacted by various parameters such as the magnitude of the development cost.

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Dedication

To my husband, Hossein, and

our children,

Kiana and Kiarash

Table of Contents

List of Tables

List of Figures

1. Introduction

Green product development plays a meaningful role in benefiting the environment while improving the economy. However, it has been observed that firms are usually hesitant to develop green products due to the extensive research and development costs and the high risk of failure. Therefore, governments worldwide are using regulatory policies to encourage firms to produce green products despite the existing challenges. As a result, it is crucial that governments apply the best available regulatory mechanisms to encourage green product development. In the following section, I briefly review some of these mechanisms and then discuss the need for government support in developing green products.

1.1 Government Regulations

Environmental concerns such as air pollution, global warming, ozone layer depletion, and climate change have become an immediate threat in the last decades. Many governments face the dilemma of trying to protect the environment while also endeavoring to stimulate and maintain economic growth. In response to these challenges, several worldwide ecological agreements have been born. A successful example of one is The Montreal Protocol, which was finalized by the United Nations in 1987 (Andersen, Halberstadt, & Borgford-Parnell, 2013). This protocol aimed to protect the earth's ozone layer by reducing the consumption and production of ozone-depleting substances (ODSs). This protocol has already diminished 90% of ODSs, and it is expected to make further improvements by 2060 if the countries continue to phase out the remaining ODSs[i]. In addition to international agreements for environmental protection, many countries (e.g., Canada, China, and European countries) have enforced ecological regulations such as taxes, cap-and-trade systems, carbon labeling, consumer rebates, and subsidies (Andersen et al., 2013; Du, Tang, & Song, 2016; Li & Li, 2017).

Some governments have already found taxation to be an efficient tool in the fight against global warming, given the right implementation and circumstances. A good example of this is the US tax on chlorofluorocarbons (CFCs), which was adopted three years after the Montreal Protocol was signed. As a result of the Montreal Protocol and the US tax on CFCs, along with the reactions of other governments, the global production and consumption of CFCs decreased by more than 70%, beginning in 1990, over the course of three years, (Krass, Nedorezov, & Ovchinnikov, 2013). These outcomes clearly illustrate that government policies can play a crucial role in addressing environmental issues.

In addition to taxation, the cap-and-trade system is another worldwide regulatory instrument that is used for reducing greenhouse gas emissions. A cap sets the maximum amount of greenhouse gas emissions that a company is allowed to emit each year. If a company produces less greenhouse gas emission than its permitted amount, the surplus amount can be stored for the following years or traded with other companies that have exceeded their emission caps. An example of such a system is the European Emissions Trading System, which has been in practice since 2005. After the EU implemented the European Emissions Trading System, emissions related to the cap declined by 29% by 2018[ii].

Apart from the cap-and-trade system, many countries (e.g., Australia, Canada, Japan, and South Korea) have also introduced policies such as carbon labeling. Carbon labeling reports the lifetime carbon dioxide emissions of products in an aim to increase environmental awareness and to stimulate demand for green alternatives (Xunpeng, 2010). Two examples of the use of this mechanism are the China Energy Label (adopted in 2005)[iii], and the European Union Labeling Policy (imposed in 1992). It was reported that the European Union Labeling Policy was able to improve the market share of energy efficient refrigerators, washers, and dryers (Waide, 1998; Vine, du Pont, & Waide, 2001; Waide, 2001).

Another common method of governmental regulation is subsidies on green products (e.g., either rebates or tax credits), which can be given to consumers in order to enhance their purchasing power and incentivize green choices. For instance, Canada's Energy Savings Rebate program provides approximately CAD 200 million to eligible Ontarian retailers so that they can offer up to a 25% sales rebate to consumers who purchase qualified energy-efficient appliances in 2019 and 2020[iv]. A similar way to encourage consumers is to offer a tax credit for purchasing a green product. Since the prices of green products are higher than ordinary ones, the tax credit per product sold helps to fill the gap between the purchase price of the green products and the consumer's willingness to pay. For example, to motivate firms to produce more electric vehicles, the American Authority provides a subsidy so that firms can offer consumers a tax credit of up to $7,500 when they purchase a new electric vehicle. This tax credit is accessible to every firm for the first 200,000 qualifying electric vehicles they sell in the US[v].

A government's financial support can also be used to encourage firms to invest more in the research and development of green products with higher environmental quality. This type of support is common in practice and is being implemented all over the world. The Automotive Innovation Fund (AIF) in Canada (launched in 2008) is one example of such support. This fund supported the research and development cost of ten projects between 2008 and 2017. A large portion of this fund ($569.8 million) was assigned to five automakers (Toyota, Honda, Ford, Linamar, and Magna) in an aim to produce products with higher environmental quality such as energy (fuel) efficient vehicles. The government of Canada confirms that the AIF has had a significant impact on reducing negative environmental consequences[vi], e.g., reducing greenhouse gas emissions (Buekers, et al., 2014).

Another well-known term is new energy vehicles (NEVs). This term has been promoted extensively in China with government support, especially through the "Energy-Saving and New Energy Vehicles Industry Development Program (2012-2020)". In support of NEVs, the Chinese government, at different levels including the national and local authorities, has invested nearly $58.3 billion between 2009 and 2017 in this program. Although the majority of such support ($36.6 billion) was aimed at consumers in the form of discounted prices, a large amount of the funding was also poured into research and development for approved manufacturers[vii]. As stated by the Chinese Ministry of Industry, this support will not change significantly in 2020 (Reuters, 2020).

Due to their importance and practicality, I will focus on government subsidies in this study, specifically on subsidies that support firms in conducting expensive research and innovation activities for developing green products. To further illustrate the importance of government support, I will briefly review the research and development costs of green products below, as they are a critical barrier to green design and development.

1.2 Research and Development (R&D) Costs

During the last decade, firms have shown a greater willingness to spend money on developing green products because of the positive environmental impact and also their potential to improve the firm's reputation (Miles & Covin, 2000; Fraj-Andrés, Martinez-Salinas, & Matute-Vallejo, 2009; Leonidou, Katsikeas, & Morgan, 2013). However, there are some barriers preventing firms from developing green products. This is evidenced by an online survey conducted by McKinsey which reported that over 50 percent of 1,946 executives said they would consider environmental issues in many areas, such as green product development, however, only a small portion (almost

30% of them) were actively seeking opportunities to invest in green product development, due to the steep costs (McKinsey Survey, 2010).

As mentioned earlier, extremely expensive R&D costs and a high chance of failure are two main reasons that can explain a firm's hesitation to develop green products. For instance, since 1974, Japan has invested around $15 billion on hydrogen and fuel cells (Behling, Williams, & Managi, 2015). However, it is unknown when this investment will start generating profit since firms are still unable to offer an effective and durable product at a reasonable price. While many researchers have been employed to improve the design of fuel cells in order to generate a more positive environmental impact, there is a remarkable need for additional investment in such technology[viii].

As exemplified by the case above, I observe that the extraordinary upfront budget that is required for covering research and development costs can be one of the most critical challenges facing firms in their green product development. Moreover, there is always a fear of failure in developing new products because of the high complexity and/or high risk of failure (Hafezi & Zolfagharinia, 2018; Ghosh, Shah, & Swami, 2018). Given these characteristics, financial incentives are often viewed as effective policies for the government to support research and development costs and to encourage green product development. Therefore, the essential question is ***"how can governments set their subsidy levels to encourage profit-maximizing firms to invest in green product development while improving total social welfare?"***.

In this study, I extend the literature by investigating the role of government subsidies on both green product development and social welfare. More precisely, I consider all aspects of social welfare, such as the firm's profit, consumer surplus, government expenses, and environmental improvement. I use a two-stage Stackelberg game theory approach where the government sets its subsidy level for maximizing the social welfare considering a profit-oriented firm that decides on the price and environmental quality of its products. By analyzing the proposed model, I am able to suggest the optimal subsidy level for the government to incentivize the firm to develop green products while also maximizing social welfare.

The remainder of this study is organized as follows: in Section 2, I review the relevant studies to highlight the contributions and novelty of my work. In Section 3, the problem is defined, and its underlying assumptions are discussed. In Section 4, I formulate the mathematical model for both the mass marketing and market segmentation strategies. In addition, the optimal subsidy levels are determined for each marketing strategy, and the effects of parameters on the optimal subsidies are analyzed. In Section 5, the impact of government subsidies on prices and the environmental quality of the products is investigated in detail. Then, in Section 6, I investigate the role of government subsidies on both firms' marketing strategies and the total social welfare. In Section 7, I conclude with a summary of managerial insights and propose some areas for future research.

2. Literature review

Over the last few years, problems related to the impact of government regulations on the production and development of green products have received a remarkable amount of attention. Saberi et al. (2018) believe that to reduce environmental impact, regulators should design policies that encourage firms to invest in environmentally friendly products, or they should penalize companies that do not invest in the production of green products. They pointed out the existence of multiple practical tools in this context, including tax exemptions, tax deductions, regulations such as carbon taxes and minimum standards, information and knowledge sharing programs, and environmental subsidies.

Several studies investigated how government bodies should set their policies so that they benefit the environment without disincentivizing firms from product diversity and innovation (Bi et al., 2016; Chan et al., 2016; Li & Li, 2017; Xu et al., 2017; Hafezi & Zolfagharinia, 2018; Saberi et al., 2018; Xu et al., 2019). Despite all the research that has been conducted in this context, there is still no general agreement on the real impact of government regulations. Some researchers have highlighted that tight standards and government regulations can positively affect firms' decisions to produce green products (e.g., Carraro & Soubeyran, 1996; Kleindorfer, Singhal & Wassenhove, 2005; Chan et al., 2016), while others believe that tight environmental regulations may lead to reverse results (e.g., Bansal & Gangopadhyay, 2003; Brunnermeier & Cohen, 2003; Krass et al., 2013; Ghosh et al., 2018).

For example, Carraro and Soubeyran (1996) discussed that emission taxes induce firms to cleaner production activities, but they increase the price of products and obstruct consumers' surplus. Chan, Yee, Dai, and Lim (2016) conducted research to examine the relationship between strict environmental regulations, green product innovation, cost efficiency, and firm performance. They collected samples from 250 companies in Mainland China and applied structural equation modeling for their analyses. They concluded that strict environmental regulations positively affect green product innovation, and consequently cost efficiency and firm profitability. In contrast, other researchers have discussed the reverse impact of regulations. For instance, Krass et al. (2013) investigated the role of government regulations in the firm's decision to select green technology in a monopoly market. They proposed a model in which a firm chooses the price and quantity produced in response to the level of regulations, including taxes, subsidies, and rebates. They analyzed both the optimal strategies for the firm and the optimal social welfare maximizing strategies for the government. Their results showed that the firm's response to an increase in taxes might be non-monotone: while an initial rise in taxes may encourage switching to greener activity, further tax increases may cause an opposite result. They revealed that strict regulations do not necessarily induce producers to develop greener technology.

To benefit the environment, firms can use green technologies and/or design green products. Green technologies protect the environment by either using a sustainable source of energy or saving energy. Whereas, green products are designed to offer a higher environmental quality than ordinary products in order to benefit the environment. Recycled aluminum foil, LED bulbs, portable smartphone chargers, solar powered grills, solar powered lawnmowers, energy efficient appliances, and electric vehicles are all examples of green products. My current study focuses on three factors: development of green products (especially the ones with high R&D costs), government regulations, and the choice of marketing strategy. Many researchers consider at least one of these factors (e.g., Conrad, 2005; Kammerer, 2009; Dangelico & Pujari, 2010; Sun, 2012; Krass et al., 2013; Peng, 2013; Zhao & Sun, 2015; Chan et al., 2016; Drake, Kleindorfer, & Wassenhove, 2016; Gouda, Jonnalagedda, & Saranga 2016; Zhou & Huang, 2016; Li & Li, 2017; Hong et al., 2018; Ghosh et al., 2018; Hafezi & Zolfagharinia, 2018; Zhou, 2018; Zhao & Chen, 2019; Zhang, Zhao, & Zhao, 2019). Since the main goal of my work is to address the role of government in the development of green products, I have narrowed the relevant studies to those that discuss the development of green products (through quality-based development costs) and/or the impact of government regulations. Throughout my review, I also briefly touch on studies that consider the choice of marketing strategy.

2.1 Considering Quality-based R&D costs

Krishnan and Zhu (2006) presented a quality-based model for a profit-maximizing monopolist, where they considered the development cost of quality-based products. In their study, the monopolist firm segments a heterogeneous market of vertically differentiated customers sorted by their willingness to pay for the quality of products. They analyzed the development-intensive products (DIPs) and explained the firm's barriers with incorporated low-end products (i.e., products with low price range) and then guided the firm in designing multiple products. They found that the existing product-line design methods for variable cost-intensive products, according to quality deterioration and value deduction, could not be directly applied to DIPs. They also suggested that in a low-end emerging market where the segment of consumers who are unwilling to pay for quality is high and/or their ability to pay for quality is low, the firm needs to design extra quality dimensions (e.g., product usability and products with overlapping quality characteristics) such that the ordinary segment of the market is willing to pay for this new quality.

Like Krishnan and Zhu (2006), Lacourbe et al. (2009) explored the optimal product positioning in a monopoly market. They considered a heterogeneous market in which consumers were horizontally heterogeneous in their willingness to pay for product features. In their study, the firm maximized its profit by considering quality, price, and features along with a fixed development cost and the "volume-variable manufacturing'' cost for each product. They concluded that when the variable cost is low compare to the design cost of development intensive products (e.g., movies), the optimal investment is to produce all products with different features but the same quality and price (i.e., horizontally differentiated products). However, when the variable costs are high compared to the fixed costs, vertically differentiated products are suggested due to a higher profit.

Zhang et al. (2017) also considered a firm that was seeking to maximize profit in a monopoly market considering the development cost of products with higher environmental quality. They analyzed the problem of green product development for two cases: (1) firms that produce only one standard product for all customers (i.e., mass-marketing strategy), and (2) firms that provide both green and ordinary products using a market segmentation strategy. Their results showed that market segmentation positively affects both the firm's profit and environmental performance if the green segment is substantial.

Recently, Zhang et al. (2019) analyzed the optimal product decision for a firm by adopting a Stackelberg game between the firm and the retailer, where the firm was the leader and the retailer was the follower. They solved the model for two cases where the firm offered only one product type, or two product types (named brown and green products). They found the optimal wholesale price, retail price, demand, retailer's profit and firm's profit for both cases. Then, they investigated the conditions under which a traditional firm would switch to producing green products considering the research and development costs for green products. They assumed that all consumers are conscious about the environment and willing enough to pay more for green products (i.e., market segmentation was not considered in their study). They derived that a two-part tariff contract between the manufacturer and the retailer can encourage the firm to invest in producing green products. They also pointed out that in unique cases where both the firm's profit and the retailer's profit is smaller than a certain amount, the firm will continue producing brown products. They suggested that there is a need for regulatory policies such as taxes or subsidies in order to encourage the firm to produce green products in this region.

The above-mentioned studies captured the development cost, but they did not examine the impact of government regulations on green product development. To expand my review, I will shift my focus to the relevant studies that address the impact of government regulations on green product design without considering quality-based R&D costs.

2.2 Considering government regulations

Among the early works on the role of government regulations in green product development, Chen (2001) studied green product design by a monopolist firm. The firm manufactured durable product(s) with two competing attributes (traditional and environmental) for two types of consumers. These consumers differed in their willingness to pay (utility) for quality dimensions. He examined the effects of environmental regulations on the development of green products and their ecological benefits. By analyzing the interactions between the consumers' utilities, the firm's design strategies, and the role of government regulations, he derived some strategies to develop green products. He concluded that a high level of environmental standards for green product development might not necessarily improve the environment. However, instead of considering the quality-based development cost, the study only captured a fixed cost.

Conrad (2005) also differentiated the products based on their environmental characteristics. He took into account the green product production costs and consumer awareness of the environmental aspects of the products to determine the impact of product differentiation in the market. Using a non-cooperative game, he analyzed the behavior of two firms to examine the role of environmental concern on the green attributes of products, market shares, and prices. In a two-stage game, the first stage is the environmental quality selection, and the second stage is price competition. Depending on each situation, his study determined the conditions where the government should subsidize the cost of green products, support environmental awareness activities, or apply taxation for the environmental impact. Although this work considered a higher production cost for green products, the research and development cost was not addressed.

Zhang et al. (2012) extended the work of Chen (2001) by analyzing the impact of government subsidies on the product design in a monopoly market. They divided the market into two segments (ordinary and green) in which the firm must decide to offer (1) only ordinary products, (2) both ordinary and green products, or (3) only green products. They found a well-designed subsidy policy to encourage the firm to design both ordinary and green products, and subsequently benefit both the firm and the environment. They concluded that in order to improve the total environmental quality and maximize the profit, the firm needs to produce both ordinary and green products for each segment of consumers.

In another study, Peng (2013) considered two types of products (called green and conventional) competing over the price in a dynamic duopoly market structure where each product can be replaced with the other to some extent. He designed a Stackelberg game to find the optimal subsidy amount for green products to minimize the total social cost consisting of the environmental effects and the government expenditure. The results highlighted that a higher subsidy level is recommended when environmental sustainability or the upfront expenditure of green products increases. Similarly to Chen (2001), a fixed development cost was only considered for the development of green products.

The earlier work of Zhang et al. (2012) was extended by Gouda et al. (2016), as they examined the effect of government regulation on the traditional and environmental quality of the products designed by a multinational automaker. They considered that the car manufacturer operated in both developed and emerging markets with different valuations for environmental product characteristics. They found that the firm also improved its profits by increasing the environmental quality of products, even in an emerging market when the economy is in good condition.

Li and Li (2017) investigated the role of government regulation while considering the market segmentation strategy. They considered a monopoly which created ordinary and green products which varied in their carbon emissions during their lifetime. In their model, the government maximized social welfare by providing rebates to consumers who bought a green product. Similarly to the literature (e.g., Amacher & Malik, 2002; Krass et al., 2013), they adopted a Stackelberg game to analyze how the firm interacts with government regulations. They derived the optimal subsidy level with the assumption that there are two products (regular and green products) and each product has only one quality dimension.

More recently, Zhao and Chen (2019) found the best subsidy policy for green products in terms of maximizing the net profit. Significantly, their study contributed an optimal subsidy plan for the government to increase the development of green products while accomplishing sustainability goals. They concluded that the investors' strategy preference for growing environmental consciousness, and for selecting new green technology, as well as the level of market risk, all have meaningful effects on the government's strategy. They additionally discussed the need for the government to establish a secure market for green producers and investors to guarantee the use of the subsidy strategy for green products.

2.3 Contributions

The papers reviewed in the previous subsections have either studied the role of government regulation on green products or examined quality-based development costs for developing green products. To the best of my knowledge, there are few studies that have addressed the quality-based development cost related to designing and producing green products while examining government regulations for green products. To point out the main contributions of my research, I will discuss the studies that most closely address the role of government regulation on green products reflecting the quality-based development costs.

Hafezi and Zolfagharinia (2018) formulated a mathematical model to analyze the effects of minimal environmental standards in a non-competitive market with consideration to quality-based development costs. The assumption was that the firm must satisfy the minimum environmental quality requirements, set by the government, to access the market. Similarly to Zhang et al. (2017), they considered that the products offered had two quality dimensions while analyzing the firm decisions between mass marketing and market segmentation strategies. They derived some critical intervals, called danger zones, for government regulations in which environmental regulations disincentivize manufacturers from developing green products. The primary result of this study shows that the danger zones are related to strict government regulations, where the reaction of a profit-maximizing firm will be to choose a marketing strategy that cannot necessarily improve the environment.

Another closely related work is one by Ghosh et al. (2018) who analyzed the effects of environmental regulations on firms' decisions about the price and quality of the green product along with social surplus. They defined the social surplus as a collection of consumer surplus, producer surplus, government penalty, and the environmental impact. They first conducted their investigation on a monopolist firm to compare the firm's decisions under environmental regulations in a market with green sensitive consumers. They then extended their method to a duopoly market. In their study, each firm produced only a single product. Their analyses revealed that when government regulations (penalty or subsidy) are too tight, the firm with lower green product development costs will produce a product with higher environmental quality than its competitor. They emphasized that policy makers need to design a set of environmental taxations, subsidies and extra support (e.g., educating consumers in order to foster a green aware consumer market) to encourage green product development. Despite some similarities to the above-mentioned two studies, there are several major differences that can be more clearly observed in Table 1. For example, Hafezi and Zolfagharinia (2018) examined the role of government regulation by considering a minimum environmental quality requirement for manufactured products. However, I formulate and analyze the government behavior using a Stackelberg game where the firm's response to the subsidy level is captured. Moreover, their study was limited to the impact on the environment, while I take a more comprehensive approach by considering the total social welfare, which consists of the firm's profit, consumer surplus, positive environmental impact, and the government expenses related to the subsidy. My work is also different from Ghosh et al. (2018) since I consider multiple products with two quality dimensions (i.e., traditional and environmental qualities) instead of a single product with only one dimension.

Although this research is limited to a monopolist firm, it fills the existing gaps in the literature by investigating the role of government regulation on (1) the development of green products with the consideration of quality-based costs, (2) the firm's choice of marketing strategy, and (3) the total social welfare. To better illustrate the differences between my study and the ones mentioned throughout my literature review, I have summarized them in Table 1.

Table 1. Summary of the studies most relevant to this research.

Author (Year)	Quality-based R&D Costs	Quality Dimension		Consideration				Products		Marketing Strategy		Number of Firms		Government Regulation				Total Social Welfare
		Single	Multiple	Profitability	Environmental Performance	Government Revenue	Consumer Surplus	Single	Multiple	Mass	Segmentation	Monopoly	Duopoly	Min. Environmental Quality Standard	Taxation	Subsidy	Consumer Rebate	
Chen (2001)		✓		✓	✓				✓	✓	✓	✓		✓				
Conrad (2005)		✓		✓	✓		✓		✓				✓		✓	✓		
Krishnan and Zhu (2006)	✓		✓	✓					✓		✓	✓						
Lacourbe et al. (2009)	✓		✓	✓					✓		✓	✓						
Zhang et al. (2012)		✓		✓	✓				✓		✓	✓				✓		
Peng (2013)		✓		✓	✓				✓				✓			✓		
Gouda et al. (2016)			✓	✓	✓			✓				✓			✓			
Li and Li (2017)		✓		✓	✓	✓	✓		✓		✓	✓					✓	✓
Zhang et al. (2017)	✓		✓	✓	✓				✓	✓	✓	✓						
Ghosh et al. (2018)	✓	✓		✓	✓	✓	✓	✓				✓	✓		✓	✓		✓
Hafezi & Zolfagharinia (2018)	✓		✓	✓	✓				✓	✓	✓	✓		✓				
Zhao and Chen (2019)		✓		✓	✓	✓			✓			✓				✓		
Zhang et al. (2019)	✓	✓		✓	✓				✓	✓		✓						
Current study	✓		✓	✓	✓	✓	✓		✓	✓	✓	✓				✓		✓

3. Problem definition

I consider a monopoly firm producing a durable product with traditional quality x and environmental quality y. As a durable product does not need to be purchased frequently, I assume that the purchase cannot be repeated. Therefore, each consumer buys only one unit of the product, regardless of its type, which has been a common assumption in the literature (e.g., Chen, 2001; Jing, 2011; Zhang et al., 2017; Hafezi & Zolfagharinia, 2018). Consumers will select products based on their utilities when the market consists of two groups of consumers (i.e., green and ordinary) with different levels of willingness to pay for environmental product quality. Compared to ordinary consumers, green consumers prefer a higher level of environmental quality and are willing to pay more for this attribute. I assume that the market size is normalized to one, where the green consumers' market share is α, and the rest (i.e., $1-\alpha$) belongs to the ordinary consumers, thus, $0<\alpha<1$.

Similar to some studies in the literature (e.g., Chen, 2001; Zhang et al., 2017; Hafezi & Zolfagharinia, 2018), qualities x and y are normalized such that one unit of quality x or y leads to one unit of utility. Consumers gain utility from both the traditional and environmental qualities of products. A consumer will buy a product only if the price of the product does not exceed his/her utility for that product. The ordinary consumers have the same valuation for both the traditional and environmental quality of a product. Thus, the ordinary consumers' utility function is expressed as $U_o(x,y)=x+y$. However, since the green consumers have a higher valuation for environmental quality, their utility gained from that quality attribute is modeled as βy, where β is the green consumers' preference for environmental quality ($\beta>1$). Therefore, the green consumers' utility can be expressed by $U_g(x,y)=x+\beta y$.

There are two different types of expenses that the firm faces: (1) the variable cost of producing one unit of product, and (2) the fixed development cost. As discussed in the literature (e.g., Chen, 2001; Kim & Chhajed, 2002; Krishnan and Zhu, 2006; Gouda et al., 2016; Hafezi & Zolfagharinia, 2018), the variable production cost for a product with qualities x and y often has a quadratic function such as $\frac{1}{2}C_t x^2 + \frac{1}{2}C_e y^2$, where C_t and C_e are the cost coefficients to produce one unit of traditional quality and one unit of environmental quality, respectively. Assuming the traditional qualities have already been developed, it is then clear that their development cost is negligible compared to the development cost of the environmental qualities. Hence, the development cost for a product with qualities x and y can be expressed as $\frac{1}{2}Cy^2$, where C is the cost coefficient of developing one unit of environmental quality (e.g., Yoo et al., 2015; Zhang et al., 2017; Hafezi & Zolfagharinia, 2018).

The firm can choose between mass marketing and market segmentation strategies to serve the market. In the mass marketing strategy, the firm only designs one standard product with traditional quality x_s and environmental quality y_s for the entire market. However, in the market segmentation strategy, the firm develops two products, (1) a green product with traditional quality x_g and environmental quality y_g for the green segment of the market (Figure 1 (a)), and (2) an ordinary product with traditional quality x_o and environmental quality y_o for the ordinary consumers (Figure 1 (b)).

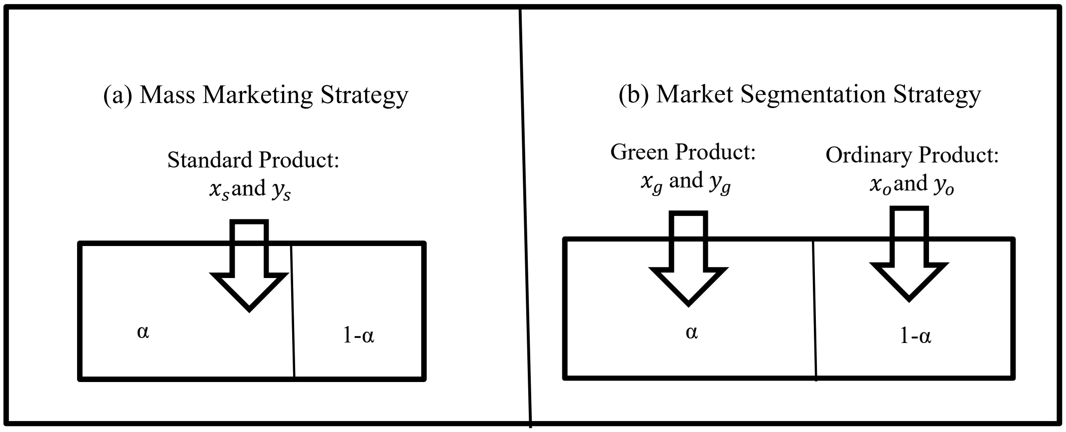

Figure 1. Mass marketing strategy and market segmentation strategy

As discussed earlier, the upfront budget required for covering the development costs of environmental quality is one of the most crucial challenges facing firms in the production and development of green products (Ghosh et al., 2018). To incentivize firms, many countries (such as China, the US, Japan, and the European Union) have paid significant attention to environmental quality and provided ecological support for firms to decrease their pollution (e.g., Coady et al., 2017; Xie & Wang, 2018). According to Coady et al. (2017), around \$4.9 trillion was spent worldwide on fossil fuel subsidies in 2013 and about \$5.3 trillion was spent in 2015. This is because even though subsidies for environmental quality aspects are expensive for the government, they can play a critical role in growing the economy, positively impacting the environment, and consequently, they can improve overall social welfare (Dangelico & Pujari, 2010; Krass et al., 2013; Zhao & Chen, 2019).

The primary purpose of a government is to maximize the total social welfare, and subsidizing the research and development costs of green products is one way that governments can work towards this goal (Stucki et al. 2018). This subsidy is often related to the environmental quality aspect of the product and not necessarily proportionate to the research and development expenses. For example, the subsidy amount for electric vehicles in China is determined based on their driving ranges[ix]. Therefore, one can model the subsidy amount based on the government subsidy amount per unit of environmental quality (θ) and the designed environmental quality of the product (y).

I consider that social welfare consists of the firm's profit, consumer surplus, positive environmental impact, and subsidy expenses. Consistent with the literature, to transfer the environmental improvement into a monetary unit, I use a parameter that measures the degree of environmental impact, either negative (Krass et al., 2013) or positive (Hong & Guo, 2019). In my study, this parameter is denoted by ε, which is measuring the degree of the positive environmental impact of a product. I assume that the degree of positive environmental improvement of a product with qualities x and y as the impact measured by εy. For example, hydrogen fuel cell vehicles indicate environmental improvement because they only generate water and air, which positively affects the environment. In comparison, traditional gasoline and diesel-powered vehicles produce nitrogen oxides and hydrocarbon, which increase air pollution and negatively impact the environment. However, the manufacturer needs a $1 million upfront budget to build one fuel cell vehicle. Additionally, the price for hydrogen fuel cell vehicles will be too high for many people[x].

4. Formulating Marketing Strategies

In this section, I introduce the parameters, notations, and decision variables as shown in Tables 2, 3 and 4. I also briefly review the Stackelberg game which helps analyze the problem under investigation. Then, I formulate the mathematical model for both marketing strategies (i.e., mass marketing and market segmentation strategies) to find the optimal subsidy level. Finally, I will examine the impact of changes in the green consumers' preference for environmental quality, the magnitude of the development cost, and the coefficient of positive environmental impact on the optimal subsidy in both marketing strategies. In what follows, I use the pronouns "he" or "his" to refer to the government and "she" or "her" to refer to the firm, in order to ensure consistency.

Table 2. Parameters

α	Green consumers' market share ($0 \leq \alpha \leq 1$)
β	Green consumers' preference for environmental quality ($\beta > 1$)
C_t	Variable production cost of a unit of traditional quality
C_e	Variable production cost of a unit of environmental quality
C	Cost of developing a unit of environmental quality
γ	Magnitude of development cost computed by $\frac{C}{C_e}$
θ	Subsidy per unit of environmental quality
ε	Coefficient of positive environmental impact

Table 3. Notations

SW_{Mass}	Total social welfare of the mass marketing strategy
π_{Mass}	Firm's profit from the mass marketing strategy
CS_{Mass}	Consumer surplus for the mass marketing strategy
GR_{Mass}	Government revenue for the mass marketing strategy
EI_{Mass}	Positive environmental improvement for the mass marketing strategy
SW_{Seg}	Total social welfare for the market segmentation strategy
π_{Seg}	Firm's profit from the market segmentation strategy
CS_{Seg}	Consumer surplus for the market segmentation strategy
GR_{Seg}	Government revenue for the mass marketing strategy
EI_{Seg}	Positive environmental improvement for the market segmentation strategy
Δ	$-4\alpha((1-\alpha)C_e + C)(\alpha C_e + C)(C_e + C)\left(((3\beta^2 - 2\beta)\alpha - 2\beta + 1)C_e + 2\,\beta C(\alpha\beta - 1)\right)$
α_0	$\frac{\varepsilon}{2\varepsilon-\beta+1}$
γ_0	$\frac{-2\alpha(\beta-1)-2\varepsilon(1-2\alpha)}{\beta-1}$
γ_1	$2\alpha\beta - \alpha - \beta$
γ_2	$\frac{1+\theta-\beta}{\beta}$
γ_3	$\frac{\alpha(\beta-1)+\theta(1-\alpha)}{1-\alpha\beta}$
γ_4	$\frac{3\alpha\beta^2-2\alpha\beta-2\beta+1}{2\beta(1-\alpha\beta)}$

Table 4. Decision variables

x_s	Traditional quality of the standard product in the mass marketing strategy
y_s	Environmental quality of the standard product in the mass marketing strategy
x_g	Traditional quality of the green product in the market segmentation strategy
y_g	Environmental quality of the green product in the market segmentation strategy
x_o	Traditional quality of the ordinary product in the market segmentation strategy
y_o	Environmental quality of the ordinary product in the market segmentation strategy
p_o	Price of the ordinary product in the market segmentation strategy
p_s	Price of the standard product when using the mass-marketing strategy
p_g	Price of the green product when using the market-segmentation strategy

This research study will address a problem where the government as the regulator and the profit-maximizing firm are interacting to optimize their objectives. Considering the firm's reaction, the government sets the subsidy level to improve social welfare. Then, the firm selects her marketing strategy and the quality of the product(s) along with the selling price as a response to the government decision. Therefore, the firm and the government are two players and their decisions are related to each other. Due to this behavior, game theory will be a useful tool for assessing possible government policies. This is also a common approach in the literature (e.g., Krass et al., 2013; Feichtinger et al., 2016; Zhou, 2018; Zhu and He, 2017).

I first develop a mathematical model in which a monopolist firm receives subsidies provided by the government for each unit of environmental quality that is incorporated into the developed products. Then, based on the given subsidy level, the firm will select her marketing strategy along with the environmental qualities of the offered product(s). Hence, the government needs to set the best subsidy level as an appropriate incentive mechanism to encourage the firm to maximize the social welfare. Therefore, the natural choice is to incorporate a Stackelberg game to find a set of all the equilibrium strategies for the proposed problem. In this game, there are two players: a leader (government) and a follower (firm). The leader first makes his decision by taking the follower's reactions into account, and then the follower selects her strategy after observing the leader's decision.

In the proposed two-stage Stackelberg game shown in Figure 2 there are two players: (1) the government (the "leader") who first decides the subsidy level to maximize the social welfare, and (2) the firm (the "follower") who then selects the best marketing strategy, based on the observed subsidy level, to maximize her own profit. I analyze this problem using a backward induction approach, i.e., starting from Stage 2 where the firm chooses the most profitable marketing strategy and determines the traditional and environmental qualities of the product(s) along with the selling price(s). Since the firm's decision in Stage 2 depends on the government's decision, I consider the following two cases based on the subsidy level:

- Case 1: The subsidy level incentivizes the firm to adopt the mass-marketing strategy.
- Case 2: The subsidy level leads the firm to select the market segmentation strategy.

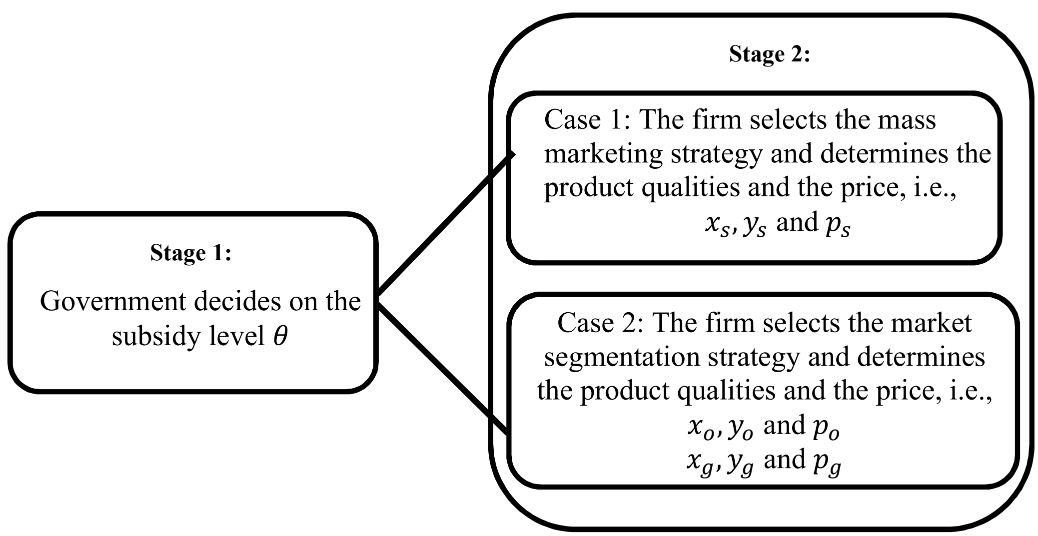

Figure 2. Two-stage Stackelberg game between the firm and government

4.1. Optimal subsidy level under mass marketing

In the second stage if Case 1 occurs, the firm maximizes her profit (π_{Mass}) by deciding on the traditional and environmental qualities of a standard product (x_s and y_s) and the selling price (p_s) for a given subsidy level (θ). Therefore, I model the firm's optimization problem under the mass marketing strategy.

In Equation (1), the firm's objective function (π_{Mass}) is the financial gain under the mass marketing strategy choice, i.e., the difference between the firm's revenue and the amount spent on both variable production and development costs. For the environmental quality y_s of the standard product, the firm receives θy_s from the government in the form of a subsidy for environmental quality, where θ is the government subsidy amount per unit of environmental quality. Hence, the firm's revenue is the sum of the selling price (p_s) and the subsidy earned from the environmental quality of the product. Since the market size is normalized to one and the firm serves both green and ordinary consumers, the quantity does not appear in equation (1). Constraint (2) guarantees that the green consumers earn a nonnegative surplus, and hence the green consumers are willing to pay for standard products. Similarly, constraint (3) ensures that the ordinary consumer's utility is greater than or equal to the selling price and hence the ordinary consumers are also willing to pay for standard products. Constraint (4) is used to guarantee that the traditional quality, environmental quality, and the selling price are all nonnegative. Therefore, the firm's optimization problem is formulated as follows:

$$\text{Max}\ \pi_{Mass} = \left(p_s - \frac{1}{2}C_t x_s^2 - \frac{1}{2}C_e y_s^2\right) - \frac{1}{2}C {y_s}^2 + \theta y_s \tag{1}$$

Subject to,

$$x_s + \beta y_s \geq p_s \tag{2}$$

$$x_s + y_s \geq p_s \tag{3}$$

$$x_s, y_s, p_s \geq 0 \tag{4}$$

Since I maximize a convex quadratic function over a convex set, the optimal solution lies on the boundary of the feasible region (Bazaraa, Sherali, & Shetty, 2013). When the firm sets its selling price of standard products p_s equal to $x_s + \beta y_s$ for any positive value of y_s, the selling price of standard products strictly exceeds the ordinary consumer's utility (i.e., $x_s + y_s < p_s$). This means that ordinary consumers cannot earn a nonnegative surplus from using standard products, and hence they are not willing to pay for standard products. Therefore, the optimal solution does not lie in $x_s + \beta y_s = p_s$ which means that the firm cannot extract the full surplus of green consumers. Thus, she must focus on ordinary consumers and extract the entire surplus of ordinary consumers (i.e., the firm must set the selling price of the standard product (p_s) to $x_s + y_s$.) Below, I solve the firm's optimization problem under the mass marketing strategy.

Proposition 1. Under the mass marketing strategy:

(i) the optimal traditional and environmental qualities of a standard product are:

$x_s = \frac{1}{C_t}$ and $y_s = \frac{1+\theta}{C_e+C}$,

(ii) the optimal price of a standard product and the optimal value of the firm's profit are:

$p_s = \frac{1}{C_t} + \frac{1+\theta}{C_e+C}$ and $\pi_{Mass} = \frac{1}{2C_t} + \frac{(1+\theta)^2}{2(C_e+C)}$

Proof (i). Since the firm sets the price of the standard product to $x_s + y_s$, I substitute (p_s) with $x_s + y_s$in the firm's objective function as follows.

$$\pi_{Mass} = \left(x_s + y_s - \frac{1}{2}C_t x_s^2 - \frac{1}{2}C_e y_s^2\right) - \frac{1}{2}C{y_s}^2 + \theta y_s \qquad (5)$$

Solving the first-order condition of π_{Mass} with respect to the decision variables x_s and y_s, the following optimal qualities are derived:

$$x_s = \frac{1}{C_t} \qquad (6)$$

$$y_s = \frac{1+\theta}{C_e+C} \tag{7}$$

Proof (ii). I use the obtained optimal qualities to find the optimal p_s as follows.

$$p_s \ = x_s + y_s = \frac{1}{C_t} + \frac{1+\theta}{C_e+C} \tag{8}$$

Plugging the optimal qualities and price of the standard product into π_{Mass}, I have

$$\pi_{Mass} = \left(x_s + y_s - \frac{1}{2}C_t x_s^2 - \frac{1}{2}C_e y_s^2\right) - \frac{1}{2}C{y_s}^2 + \theta y_s$$

$$= \left(\frac{1}{C_t} - \frac{1}{2}C_t\left(\frac{1}{C_t}\right)^2 - \frac{1}{2}C_e{y_s}^2\right) - \frac{1}{2}C{y_s}^2 + (1+\theta)y_s$$

$$= \frac{1}{2C_t} - \frac{1}{2}(C_e + C)\left(\frac{1+\theta}{C_e+C}\right)^2 + (1+\theta)\left(\frac{1+\theta}{C_e+C}\right)$$

$$= \frac{1}{2C_t} - \frac{(1+\theta)^2}{2(C_e+C)} + \frac{(1+\theta)^2}{(C_e+C)}$$

$$= \frac{1}{2C_t} + \frac{(1+\theta)^2}{2(C_e+C)}$$

Therefore, the maximum value of the firm's profit is:

$$\pi_{Mass} = \frac{1}{2C_t} + \frac{(1+\theta)^2}{2(C_e+C)} \tag{9}$$ □

From **Proposition 1**, it is inferred that the optimal traditional quality of standard products (under the mass marketing strategy) only depends on the variable production cost of the traditional quality. However, the optimal environmental quality of the standard product depends on both the production and development costs of the environmental quality as well as the government's subsidy per unit of the environmental quality. It is intuitive that the environmental quality of standard products increases with the government subsidy. Moreover, the price of a standard product increases with the government subsidy. The fact that the government's subsidy results in a higher price may seem counter-intuitive at first glance. However, the government's subsidy results in greater environmental quality for the standard products. And it is evident that developing and producing alternative products with higher environmental quality increases the overall expenses. Since government subsidies cover some part of the development expenses, they motivate the firm to improve the environmental quality of the product. To maximize the profit, the firm is now in a position to increase the price because green consumers are willing to pay more for products that have a higher environmental quality. This provides a possible explanation for why introducing government subsidies leads to a higher price.

I also observed that both traditional and environmental optimal quality levels are independent of the green consumers' market share (α) and the green consumers' preference for environmental quality (β). This is because under the mass marketing strategy, the firm is offering only one single standard product to all consumers. I recall that the ordinary consumers do not earn any positive surplus from purchasing standard products (due to the firm's optimal pricing), while the green consumers will gain positive surplus because of their higher valuation for environmental quality.

In the first stage, the government strategically sets the subsidy level to maximize his objective function, i.e., the total social welfare. The total social welfare consists of four components: the firm's profit, total consumer surplus, government expenses (in the form of the allocated subsidy amount), and environmental improvement. These components can be interpreted as follows.

- The firm's profit is the difference between the firm's revenue and its development and production cost components, which are also shown in equation (1). I recall that the firm's revenue consists of the financial earnings from the selling price of a standard product, as well as the subsidies received from the government.
- Consumer surplus is the green consumer's utility minus the price offered under the mass marketing strategy multiplied by the green consumers' market share, i.e., $CS_{Mass} =$

$\alpha(x_s + \beta y_s - p_s)$. I recall that at the optimal pricing, the ordinary consumer's utility is equal to the price. Hence, the ordinary consumer's surplus component is zero and does not appear in the consumer surplus.

- Government expense is the subsidy amount. As discussed earlier, this can be computed as the multiplication of the government subsidy per unit of environmental quality by the environmental quality of the product ($GE_{Mass} = \theta y_s$). The government applies the subsidy to incentivize the firm to develop green products (Hong & Guo, 2019) or adopt green technologies (Krass et al., 2013).
- Consistent with the literature, I use a coefficient that converts emissions into monetary units. This coefficient measures the degree of the environmental impact, and it is denoted by ε. Following the work of Hong and Guo (2019), I assume that this impact is positive and measure by $EI_{Mass} = \varepsilon y_s$.

Given the above-mentioned components, the social welfare is formulated as follows.

$$SW_{Mass} = \pi_{Mass} + CS_{Mass} - GE_{Mass} + EI_{Mass}$$

$$= \left(p_s - \frac{1}{2}C_t x_s^2 - \frac{1}{2}C_e y_s^2\right) - \frac{1}{2}C{y_s}^2 + \theta y_s + \alpha(x_s + \beta y_s - p_s) - \theta y_s + \varepsilon y_s$$

$$= \left(p_s - \frac{1}{2}C_t x_s^2 - \frac{1}{2}C_e y_s^2\right) - \frac{1}{2}C{y_s}^2 + \alpha(x_s + \beta y_s - p_s) + \varepsilon y_s \qquad (10)$$

I proceed to find the government's decision on the subsidy level by maximizing the social welfare under the mass marketing strategy, given the firm's response at the second stage.

Proposition 2. The optimal level of subsidy under the mass marketing strategy is computed as follows:

$$\theta^*_{Mass} = \alpha(\beta - 1) + \varepsilon$$

Proof. To obtain the optimal subsidy level, I first need to substitute the optimal traditional and environmental qualities and the selling price of the standard product in SW_{Mass} as follows.

$$SW_{Mass} = \left(x_s + y_s - \frac{1}{2}C_t x_s^2 - \frac{1}{2}C_e y_s^2\right) - \frac{1}{2}C{y_s}^2 + \alpha(x_s + \beta y_s - x_s - y_s) + \varepsilon y_s$$

$$= \left(\frac{1}{C_t} - \frac{1}{2}C_t\left(\frac{1}{C_t}\right)^2 - \frac{1}{2}C_e{y_s}^2\right) - \frac{1}{2}C{y_s}^2 + (1 + \alpha\beta - \alpha + \varepsilon)y_s$$

$$= \frac{1}{2C_t} - \frac{1}{2}(C_e + C){y_s}^2 + (1 + \alpha\beta - \alpha + \varepsilon)y_s$$

$$= \frac{1}{2C_t} - \frac{1}{2}(C_e + C)\left(\frac{1+\theta}{C_e+C}\right)^2 + (1 + \alpha\beta - \alpha + \varepsilon)\left(\frac{1+\theta}{C_e+C}\right) \quad (11)$$

By solving the first-order condition of social welfare under the mass marketing strategy with respect to the decision variable θ, the optimal subsidy level is obtained as $\theta^*_{Mass} = \alpha(\beta - 1) + \varepsilon$. □

Considering **Proposition 2**, I can observe that the optimal subsidy under the mass marketing strategy depends on green consumers' market share (α), green consumers' valuation for environmental quality (β), and the coefficient of positive environmental impact (ε). Not surprisingly, this optimal subsidy level increases when the values of the following parameters grow: The green market share, the green consumers' preference for environmental qualities, and the coefficient of positive environmental impact.

4.2. Optimal subsidy level under market segmentation

The firm may choose the market segmentation strategy and supply each segment of the market based on the needs of that segment, i.e., manufacturing green and ordinary products to serve both segments of the market. In the case of the market segmentation strategy, for a given subsidy level (θ), the firm maximizes its profit (π_{Seg}) by deciding on: (1) the traditional and environmental qualities of both ordinary (x_o and y_o) and green products (x_g and y_g), and (2) the selling prices (p_o for ordinary products and p_g for green products). It is natural that the environmental quality of green products is higher, i.e., $y_g > y_o$.

In Equation (12), π_{Seg} is the firm's profit from both segments of the market under the market segmentation strategy. Therefore, the firm's profit is represented by the sum of two major components: 1) the profit earned from the green and ordinary segments, and 2) the revenue earned through the government subsidy on its products. Constraint (13) guarantees that the ordinary consumer's utility is never smaller than the selling price of the ordinary product (i.e., what the ordinary consumers are willing to pay for ordinary products). Similarly, constraint (14) ensures that green consumers are willing to pay for green products, which are designed specifically for them. Constraints (15) and (16) guarantee that ordinary and green consumers will earn a higher utility when they buy their exclusive products. These constraints are known as self-selection constraints in the literature (Moorthy, 1984; Chen, 2001; Zhang et al., 2017; Hafezi & Zolfagharinia, 2018). Since the quality levels and selling price of products are nonnegative variables, constraint (17) is included. Therefore, the firm's optimization problem is presented below.

$$\text{Max}\,\pi_{Seg} = (1-\alpha)\left(p_o - \tfrac{1}{2}C_t x_0^2 - \tfrac{1}{2}C_e y_0^2\right) - \tfrac{1}{2}C{y_o}^2 + \theta y_o + \alpha\left(p_g - \tfrac{1}{2}C_t x_g^2 - \tfrac{1}{2}C_e y_g^2\right) - \tfrac{1}{2}C y_g^2 + \theta y_g \tag{12}$$

Subject to:

$$x_o + y_o - p_o \geq 0, \tag{13}$$

$$x_g + \beta y_g - p_g \geq 0 \tag{14}$$

$$x_o + y_o - p_o \geq x_g + y_g - p_g \tag{15}$$

$$x_g + \beta y_g - p_g \geq x_o + \beta y_o - p_o \tag{16}$$

$$x_g, y_g, p_g, x_o, y_o, p_o \geq 0 \tag{17}$$

I recall that when maximizing a convex quadratic function over a convex set, the optimal solution lies on the boundary of the feasible region. Thus, I proceed to find the binding constraints to derive the optimal solution. If the firm sets the price of green product p_g equal to the utility of green consumers (i.e., $p_g = x_g + \beta y_g$), then Equation (13) and $\beta > 1$ imply that for any positive value of y_o, $x_o + \beta y_o - p_o > x_o + y_o - p_o \geq 0$. This means that the green consumers will immediately switch to the ordinary product due to a higher gained surplus ($x_o + \beta y_o > p_o$). Since this violates the feasible region, for any positive value of y_o, the green consumers' utility must exceed the price of green products, i.e., $x_g + \beta y_g > p_g$, for any $y_o > 0$ or Equation (14) is not binding. This ensures that the consumers are purchasing only the products exclusively designed for them.

One can also observe that both constraints (15) and (16) cannot be binding at optimality. Otherwise, the ordinary and green consumers become indifferent in their purchase selections (i.e., $y_o - p_o = x_g + y_g - p_g$ and $x_g + \beta y_g - p_g = x_o + \beta y_o - p_o$) and this leads to the same environmental quality for both products (i.e., $y_g = y_o$). This is against the initial assumption that green products have a higher environmental quality ($y_g > y_o$).

Another observation is that the optimal pricing cannot be obtained by making constraints (13) and (14) binding. This is because they can only be binding simultaneously under one condition. This condition is when $\beta = 1$, which contradicts the assumption of $\beta > 1$. Therefore, constraints (13) and (16) have to be binding at the maximum value of the firm's profit. In other words, the firm first sets the selling price of ordinary products to extract the entire surplus of ordinary consumers (i.e., $x_o + y_o = p_o$). The firm then increases the price of green products as much as possible without causing the consumers to switch to ordinary products, i.e., $x_g + \beta y_g - p_g = x_o + \beta y_o - p_o$. Therefore, the firm extracts the maximum surplus of green consumers by using this pricing strategy as well.

Proposition 3. In the market segmentation strategy,

(i) the optimal values of traditional quality for the ordinary and green products are:

$x_o = x_g = \frac{1}{C_t}$

(ii) the optimal environmental qualities of the ordinary and green products are:

$y_o = \frac{1+\theta-\alpha\beta}{(1-\alpha)C_e+C}$ and $y_g = \frac{\theta+\alpha\beta}{\alpha C_e+C}$

(iii) the optimal prices for the ordinary and green products are:

$p_o = \frac{1}{C_t} + \frac{1+\theta-\alpha\beta}{(1-\alpha)C_e+C}$ and $p_g = \frac{1}{C_t} + \beta\left(\frac{\theta+\alpha\beta}{\alpha C_e+C}\right) + (1-\beta)\left(\frac{(1+\theta-\alpha\beta)}{(1-\alpha)C_e+C}\right)$

(iv) the firm's profit is obtained as follows:

$\pi_{seg} = \frac{1}{2C_t} + \frac{(1+\theta-\alpha\ \ )^2}{2((1-\alpha)C_e+C)} + \frac{(\theta+\alpha\beta)^2}{2(\alpha C_e+C)}$

Proofs (i, ii). I recall that the firm first sets the selling price of ordinary products by extracting the entire surplus of ordinary consumers, and then, she sets the price of green products by $x_g + \beta y_g - p_g = x_o + \beta y_o - p_o$. Therefore, one can obtain the optimal solution by solving these two equations (i.e., $x_o + y_o = p_o$, and $x_g + \beta y_g - p_g = x_o + \beta y_o - p_o$). These equations imply that $p_g = x_g + \beta y_g + y_o(1-\beta)$. Substituting $x_o + y_o = p_o$ and $p_g = x_g + \beta y_g + y_o(1-\beta)$ in the firm's objective function, I have:

$$\pi_{Seg} = (1-\alpha)\left(p_o - \frac{1}{2}C_t x_0^2 - \frac{1}{2}C_e y_0^2\right) - \frac{1}{2}C {y_o}^2 + \theta y_o + \alpha\left(p_g - \frac{1}{2}C_t x_g^2 - \frac{1}{2}C_e y_g^2\right) - \frac{1}{2}C y_g^2 + \theta y_g$$

$$= (1-\alpha)\left(x_o + y_o - \tfrac{1}{2}C_t x_0^2 - \tfrac{1}{2}C_e y_0^2\right) - \tfrac{1}{2}C {y_o}^2 + \theta y_o$$

$$+\alpha\left(x_g + \beta y_g + y_o - \beta y_o - \tfrac{1}{2}C_t x_g^2 - \tfrac{1}{2}C_e y_g^2\right) - \tfrac{1}{2}C y_g^2 + \theta y_g \qquad (18)$$

The firm's optimal variables can be found by solving the first-order condition of π_{Seg} with respect to traditional and environmental qualities of both green and ordinary products as follows:

$$\frac{\partial \pi_{seg}}{\partial x_o} = (1-\alpha)(1-C_t x_o) = 0 \Rightarrow x_o = \frac{1}{C_t} > 0 \qquad (19)$$

$$\frac{\partial \pi_{seg}}{\partial x_g} = \alpha\left(1 - C_t x_g\right) = 0 \Rightarrow x_g = \frac{1}{C_t} \tag{20}$$

$$\frac{\partial \pi_{seg}}{\partial y_o} = (1-\alpha)(1 - C_e y_o) - C y_o + \theta + \alpha - \alpha\beta = 0 \Rightarrow y_o = \begin{cases} \frac{1+\theta-\alpha\beta}{(1-\alpha)C_e + C}, if\ \alpha\beta < \theta + 1 \\ 0, \quad otherwise \end{cases} \tag{21}$$

$$\frac{\partial \pi_{seg}}{\partial y_g} = \alpha\beta - \alpha C_e y_g - C y_g + \theta = 0 \Rightarrow y_g = \frac{\theta + \alpha\beta}{\alpha C_e + C} > 0 \tag{22}$$

Proofs (iii, iv). Now, by substituting the obtained solutions in $p_o = x_0 + y_0$ and $p_g = x_g + \beta y_g + y_o - \beta y_o$, I get the optimal prices of ordinary and green products as follows.

$$p_o = \frac{1}{C_t} + \frac{1+\theta-\alpha}{(1-\alpha)C_e + C} \tag{23}$$

$$p_g = \frac{1}{C_t} + \beta\left(\frac{\theta+\alpha\beta}{\alpha C_e + C}\right) + (1-\beta)\left(\frac{(1+\theta-\alpha\ )}{(1-\alpha)C_e + C}\right) \tag{24}$$

Substituting the obtained optimal solutions in π_{seg}, the optimal profit is presented as follows:

$$\pi_{seg} = (1-\alpha)\left(x_o + y_o - \frac{1}{2}C_t x_0^2 - \frac{1}{2}C_e y_0^2\right) - \frac{1}{2}C y_o{}^2 + \theta y_o$$
$$+\alpha\left(x_g + \beta y_g + y_o - \beta y_o - \frac{1}{2}C_t x_g^2 - \frac{1}{2}C_e y_g^2\right) - \frac{1}{2}C y_g^2 + \theta y_g$$
$$= \frac{1}{2C_t} + \frac{(1+\theta-\alpha\beta)^2}{2((1-\alpha)C_e + C)} + \frac{(\theta+\alpha\beta)^2}{2(\alpha C_e + C)} \tag{25}$$ □

Proposition 3 reveals that under the market segmentation strategy, the optimal traditional quality of both ordinary and green products decreases in the variable production cost of the traditional quality, and it is independent of all other parameters and variables. In contrast, the optimal environmental quality of the ordinary and green products depends on the production and development costs of the environmental quality, the green consumers' market share (α), and the green consumers' preference (β) for environmental quality, as well as the government's subsidy (θ). It is interesting to note that increasing the green market share does not necessarily translate to a higher environmental attribute, since its impact depends on the green consumer valuation for environmental quality against the unit production cost of environmental quality.

As I use the backward induction approach, it is now time to consider the first stage where the government decides on the subsidy level to maximize the social welfare. The components of social welfare are presented below.

- The firm's profit is the difference between its total revenue (through selling and the receiving subsidies) and its development and production cost components, which is given by Equation (12).
- Consumer surplus is represented by multiplying the green consumers' surplus by their market share, i.e., $CS_{Seg} = \alpha(x_g + \beta y_g - p_g) + (1-\alpha)(x_o + y_o - p_o)$. As discussed previously, I know that the second term is zero at the optimal values since the price was set to extract the full surplus of ordinary consumers. Therefore, the total consumer surplus in the market segmentation is simplified to $CS_{Seg} = \alpha(x_g + \beta y_g - p_g)$.
- Government expenses are the subsidies that are paid to the firm based on the environmental quality of her manufactured products, which is presented by $\theta(y_o + y_g)$.
- The environmental improvement under the market segmentation strategy can be presented as a combination of environmental qualities for both green and ordinary products considering their market shares. Thus, the monetary value of such improvement is equal to $\varepsilon((1-\alpha)y_o + \alpha y_g)$.

Given the above-mentioned components, the total social welfare under the market segmentation strategy is formulated as follows:

$$\begin{aligned} SW_{Seg} &= \pi_{Seg} + CS_{Seg} - GE_{Seg} + EI_{Seg} \\ &= (1-\alpha)\left(p_o - \tfrac{1}{2}C_t x_0^2 - \tfrac{1}{2}C_e y_0^2\right) - \tfrac{1}{2}C{y_o}^2 + \theta y_o + \alpha\left(p_g - \tfrac{1}{2}C_t x_g^2 - \tfrac{1}{2}C_e y_g^2\right) - \tfrac{1}{2}C y_g^2 + \theta y_g \\ &\quad + \alpha(x_g + \beta y_g - p_g) - \theta(y_o + y_g) + \varepsilon(1-\alpha)y_o + \varepsilon\alpha y_g \end{aligned} \tag{26}$$

In what follows, I first determine the government's decision on the subsidy level for maximizing the social welfare while considering the firm's response in the second stage. Then, I analyze how the optimal subsidy level can be affected by other parameters such as green consumers' market share, green consumers' preference for environmental quality, and the coefficient of positive environmental impact.

Proposition 4. The optimal subsidy level is computed as:

$$\theta_{Seg}^{*} = \frac{\alpha^2\beta - 2\varepsilon\alpha^2 - \alpha^2 + \alpha\beta\gamma + 2\alpha\varepsilon - \alpha\gamma + \varepsilon\gamma}{1 + 2\gamma}$$

Proof. I first substitute the firm's optimal decisions for the market segmentation strategy (Equations (18), (19), (20), (21) and (22)) in Equation (26) as follows.

$$SW_{Seg} = \frac{1}{2C_t} + \frac{(1+\theta-\alpha\beta)^2}{2((1-\alpha)C_e+C)} + \frac{(\theta+\alpha\beta)^2}{2(\alpha C_e+C)} + \alpha\left(x_g + \beta y_g - x_g - \beta y_g - y_o + \beta y_o\right) - \theta y_o -$$

$$\theta y_g + \varepsilon(1-\alpha)y_o + \varepsilon\alpha y_g$$

$$= \frac{1}{2C_t} + \frac{(1+\theta-\alpha\ \ )^2}{2((1-\alpha)C_e+C)} + \frac{(\theta+\alpha\beta)^2}{2(\alpha C_e+C)} + \alpha\frac{1}{C_t} + (-\alpha + \alpha\beta - \theta + \varepsilon - \varepsilon\alpha)\left(\frac{1+\theta-\alpha}{(1-\alpha)C_e+C}\right) +$$

$$(\varepsilon\alpha - \theta)\left(\frac{\theta+\alpha\beta}{\alpha C_e+C}\right) \qquad (27)$$

Now, I solve the first-order condition of SW_{Seg} with respect to θ.

$$\frac{\partial SW_{Seg}}{\partial\theta} = \frac{1+\theta-\alpha\beta}{(1-\alpha)C_e+C} + \frac{\theta+\alpha\beta}{\alpha C_e+C} + \frac{-\alpha+\alpha\beta-\theta+\varepsilon-\varepsilon\alpha-1-\theta+\alpha\beta}{(1-\alpha)C_e+C} + \frac{\varepsilon\alpha-\theta-\theta-\alpha\beta}{\alpha C_e+C}$$

$$= \frac{\alpha\beta-\alpha+\varepsilon-\varepsilon\alpha}{(1-\alpha)C_e+C} + \frac{\varepsilon\alpha-\theta}{\alpha C_e+C} = 0 \Leftrightarrow$$

$$(C_e - \alpha C_e + C + \alpha C_e + C)\theta = \alpha^2\beta C_e - 2\varepsilon\alpha^2 C_e - \alpha^2 C_e + \alpha\beta C + 2\alpha\varepsilon C_e - \alpha C + \varepsilon C \Leftrightarrow$$

$$(1 + 2\gamma)\theta = \alpha^2\beta - 2\varepsilon\alpha^2 - \alpha^2 + \alpha\beta\gamma + 2\alpha\varepsilon - \alpha\gamma + \varepsilon\gamma$$

Therefore, the optimal subsidy level is:

$$\theta_{Seg}^{*} = \frac{\alpha^2\beta-2\varepsilon\alpha^2-\alpha^2+\alpha\beta\gamma+2\alpha\varepsilon-\alpha\gamma+\varepsilon\gamma}{1+2\gamma} \qquad (28)\square$$

Proposition 5. The optimal subsidy level under the market segmentation strategy (θ^*_{Seg}) has the following properties:

(i) The optimal subsidy level is increasing when $\alpha \leq 1/2$; the green market is dominant ($\alpha > 1/2$), the optimal subsidy level increases only if the development cost is greater than a certain threshold $\gamma > \gamma_0$.

(ii) The optimal subsidy level is increasing in green consumers' preference for environmental quality.

(iii) The optimal subsidy level is increasing in the coefficient of positive environmental impact.

Proof (i). By taking the derivative of the optimal subsidy with respect to the green market share, I obtain:

$$\frac{\partial \theta^*_{Seg}}{\partial \alpha} = \frac{2\alpha\beta - 4\varepsilon\alpha - 2\alpha + \beta\gamma + 2\varepsilon - \gamma}{1+2\gamma}$$

$$= \frac{2\alpha(\beta-1) + 2\varepsilon(1-2\alpha) + \gamma(\beta-1)}{1+2\gamma} \tag{29}$$

When I demonstrated ($\gamma > \gamma_0 = \frac{-2\alpha(\beta-1)-2\varepsilon(1-2\alpha)}{\beta-1}$), it is evident that ($\frac{\partial \theta^*_{Seg}}{\partial \alpha}$) is always positive. This is because γ_0 is negative when $\alpha \leq 1/2$. As a result, the optimal subsidy level is always increasing in green consumers' market share when the green market is not dominant. Otherwise, the optimal subsidy level is growing in green consumers' market share only if $\gamma > \gamma_0$.

Proof (ii, iii) From $\frac{\partial \theta^*_{Seg}}{\partial \beta} = \frac{\alpha^2 + \alpha\gamma}{1+2\gamma} > 0$, it readily follows that the optimal subsidy level is increasing in green consumers' preference for environmental quality. Lastly, $\frac{\partial \theta^*_{Seg}}{\partial \varepsilon} = \frac{-2\alpha^2+2\alpha+\gamma}{1+2\gamma} = \frac{2\alpha(1-\alpha)+\gamma}{1+2\gamma}$ is obviously positive and thus the optimal subsidy level is increasing in the coefficient of positive environmental impact. □

Considering **Proposition 5**, I can observe that when the green market is not dominant (i.e., $\alpha \leq 1/2$), increasing the green market share encourages the government to provide a larger subsidy since this additional subsidy can motivate firms to invest more in environmental quality and eventually improve social welfare. However, when the green market share is dominant, the firm already has enough incentive. Therefore, the only condition is when the development cost is greater than a certain threshold (γ_0), which can be a barrier for the firm when investing in green attributes. This is where the government provides more incentive to encourage the firm to increase her investment. In addition, it is natural to observe that the optimal decision for the government is to increase the subsidy level when the green consumers' valuation for environmental quality (β) or the coefficient of the positive environmental impact (ε) increases regardless of the development cost.

Proposition 6. Let $\alpha_0 = \frac{\varepsilon}{2\varepsilon-\beta+1}$. The optimal subsidy level is increasing in the magnitude of the development cost (i.e., γ), when

a. $\alpha < \frac{1}{2}$; or

b. $\alpha > \frac{1}{2}, \alpha_0 < \alpha < 1$ and $\varepsilon > \beta - 1$,

The optimal subsidy level is decreasing in the magnitude of development cost when one of the following conditions holds.

c. $\alpha > \frac{1}{2}$ and $\varepsilon < \beta - 1$,

d. $\frac{1}{2} < \alpha < \alpha_0$ and $\varepsilon > \beta - 1$.

Proof. To prove this proposition, I consider the following two conditions:

- Condition 1. $\alpha < \frac{1}{2}$

By taking the first derivative of θ^*_{Seg} with respect to γ, I have

$$\frac{\partial\theta^*_{Seg}}{\partial\gamma} = \frac{(1-2\alpha)\big(\varepsilon(1-2\alpha)+\alpha(\beta-1)\big)}{(1+2\gamma)^2} \tag{30}$$

Since $\alpha < \frac{1}{2}$, it is clear that $\frac{\partial\theta^*_{Seg}}{\partial\gamma} > 0$. Therefore,

$$\frac{\partial\theta^*_{Seg}}{\partial\gamma} > 0, \text{ if } \alpha < \frac{1}{2} \tag{31}$$

- Condition 2. $\alpha > \frac{1}{2}$

Since $\varepsilon(1-2\alpha)+\alpha(\beta-1) = \varepsilon - \alpha(2\varepsilon-\beta+1)$, it is obvious that $\varepsilon(1-2\alpha)+\alpha(\beta-1) > 0$ if $2\varepsilon-\beta+1 < 0$ (or $\varepsilon < \frac{\beta-1}{2}$). When $\varepsilon < \frac{\beta-1}{2}$, then $\varepsilon(1-2\alpha)+\alpha(\beta-1) = \varepsilon - \alpha(2\varepsilon-\beta+1) > 0$, and thus, $\frac{\partial\theta^*_{Seg}}{\partial\gamma} < 0$. Concluding that:

$$\frac{\partial\theta^*_{Seg}}{\partial\gamma} = \frac{(1-2\alpha)\big(\varepsilon-\alpha(2\varepsilon-\beta+1)\big)}{(1+2\gamma)^2} < 0, \text{ if } \alpha > \frac{1}{2} \text{ and } \varepsilon < \frac{\beta-1}{2} \tag{32}$$

I proceed to analyze the case of $\alpha > \frac{1}{2}$ and $\varepsilon > \frac{\beta-1}{2}$. Since $\varepsilon > \frac{\beta-1}{2}$ follows that $2\varepsilon-\beta+1 > 0$, I have

$$\varepsilon - \alpha(2\varepsilon-\beta+1) < 0 \ \text{ if } \alpha > \frac{\varepsilon}{2\varepsilon-\beta+1} \tag{33}$$

$$\varepsilon - \alpha(2\varepsilon-\beta+1) > 0 \ \text{ if } \alpha < \frac{\varepsilon}{2\varepsilon-\beta+1}. \tag{34}$$

For the sake of simplicity, I denote $\frac{\varepsilon}{2\varepsilon-\beta+1}$ as α_0. Given that $\alpha < 1$, I can conclude that $\alpha > \alpha_0 = \frac{\varepsilon}{2\varepsilon-\beta+1}$ holds only if $\frac{\varepsilon}{2\varepsilon-\beta+1} < 1$. Moreover, $\frac{\varepsilon}{2\varepsilon-\beta+1} < 1$ if and only if $\varepsilon > \beta - 1$. This implies that $\varepsilon - \alpha(2\varepsilon-\beta+1) < 0$ when $\alpha > \alpha_0$, $\varepsilon > \beta-1$, and $\varepsilon > \frac{\beta-1}{2}$.

Since $\beta \geq 1$, $\beta - 1$ is always nonnegative. Adding 2ε to both sides, I obtain $2\varepsilon-\beta+1 \leq 2\varepsilon$ which implies that $\alpha_0 = \frac{\varepsilon}{2\varepsilon-\beta+1} \geq \frac{1}{2}$. Therefore, $\alpha_0 \geq \frac{1}{2}$ always holds true.

Now, I can conclude that $\frac{\partial\theta^*_{Seg}}{\partial\gamma} > 0$, if $\alpha > \frac{1}{2}$, $\frac{1}{2} < \alpha_0 < \alpha$, $\varepsilon > \frac{\beta-1}{2}$ and $\varepsilon > \beta - 1$. Therefore,

$$\frac{\partial \theta^*_{Seg}}{\partial \gamma} > 0, \text{ if } \frac{1}{2} < \alpha_0 < \alpha \text{ and } \varepsilon > \beta - 1 \tag{35}$$

Finally, (34) follows that

$$\frac{\partial \theta^*_{Seg}}{\partial \gamma} < 0, \text{ if } \frac{1}{2} < \alpha < \alpha_0 \text{ and } \varepsilon > \frac{\beta-1}{2} \tag{36}$$

Note that if $\alpha_0 > 1$, then since $\alpha < 1$, it is obvious that $\alpha < \alpha_0$ always holds. It is also easy to verify that $\alpha_0 > 1$ if and only if $\varepsilon < \beta - 1$. Therefore, when $\varepsilon < \beta - 1$, then $\alpha < \alpha_0$ holds. This result along with (36) follow that $\frac{\partial \theta^*_{Seg}}{\partial \gamma} < 0$ when

$$\alpha > \frac{1}{2} \text{ and } \frac{\beta-1}{2} < \varepsilon < \beta - 1\text{,or} \tag{37}$$

$$\frac{1}{2} < \alpha < \alpha_0 \text{ and } \varepsilon > \beta - 1 \tag{38}$$

From (32) and (37), I conclude that

$$\frac{\partial \theta^*_{Seg}}{\partial \gamma} < 0, \text{ if } \alpha > \frac{1}{2} \text{ and } \varepsilon < \beta - 1 \tag{39}$$

This completes the proof. The obtained conditions are also summarized in Table 5. □

Table 5. Summary of conditions of Proposition 6

$\alpha > \frac{1}{2}$			$\alpha < \frac{1}{2}$
$\varepsilon > \beta - 1$		$\varepsilon < \beta - 1$	
$\alpha_0 < \alpha < 1$	$\frac{1}{2} < \alpha < \alpha_0$		
$\frac{\partial \theta^*_{Seg}}{\partial \gamma} > 0$	$\frac{\partial \theta^*_{Seg}}{\partial \gamma}$ <0	$\frac{\partial \theta^*_{Seg}}{\partial \gamma}$ <0	$\frac{\partial \theta^*_{Seg}}{\partial \gamma} > 0$

According to **Proposition 6**, I observe that when the magnitude of the development cost is increasing, the impact on the optimal subsidy level is complex since it depends on several parameters such as the green market share, the green consumer's valuation for green products, and the coefficient of environmental impact. The government increases the subsidy level if the green market share is strong ($\alpha > \frac{1}{2}$), meaning higher than a certain threshold ($\alpha > \alpha_0$), and the coefficient of the environmental impact is high enough (i.e., $\varepsilon > \beta - 1$). This is an intuitive behavior since all the parameters suggest that it is beneficial for improving social welfare to keep the firm encouraged by increasing the subsidy level when it becomes expensive to develop environmental aspects. However, when only one of these conditions does not hold (i.e., either the green market share is not higher than a certain threshold (α_0) or the quality of the product has not had enough of a positive impact on the environment), the government loses its incentive to support the environmental quality attributes, and thus, by increasing the magnitude of the development cost, the government reduces its support. Finally, when the green market share is not dominant ($\alpha < \frac{1}{2}$), the firm may not have enough interest in manufacturing products with a higher environmental quality while the magnitude of development goes up. However, to keep the social welfare high, the government should motivate the firm to spend more on environmental quality by increasing the subsidy level.

5. The Impact of Government Subsidies

I will now analyze how the optimal subsidy level affects prices and the environmental quality of the products, along with the firm's profits, in both marketing strategies.

Proposition 7.

(i) The traditional quality level of standard, ordinary, and green products, i.e., x_s, x_o and x_g do not change by increasing the subsidy level θ.

(ii) The environmental quality level of standard, ordinary, and green products, i.e., y_s, y_o and y_g increase by increasing the θ value.

Proof (i). I recall that

$$x_s = x_o = x_g = \frac{1}{C_t}, y_s = \frac{1+\theta}{C_e + C}, y_o = \frac{1+\theta-\alpha\beta}{(1-\alpha)C_e + C}, y_g = \frac{\theta+\alpha\beta}{\alpha C_e + C}$$

I obtain $\frac{\partial x_s}{\partial \theta}\left(=\frac{\partial x_o}{\partial \theta}=\frac{\partial x_g}{\partial \theta}\right)=0$, which implies that the traditional quality level of standard, ordinary, and green products are independent of the subsidy.

Proof (ii). To prove the second part, I take the derivatives of environmental qualities with respect to θ.

$$\frac{\partial y_s}{\partial \theta}=\frac{1}{C_e+C}>0 \tag{40}$$

$$\frac{\partial y_o}{\partial \theta}=\frac{1}{(1-\alpha)C_e+C}>0 \tag{41}$$

$$\frac{\partial y_g}{\partial \theta}=\frac{1}{\alpha C_e+C}>0 \tag{42}$$ □

The results of **Proposition 7** are expected since increasing the subsidy level motivates the firm to increase the environmental quality of products regardless her marketing strategy. Now, I proceed to analyze the effects of subsidy level on the price of products and the firm's profit in both marketing strategies.

Proposition 8. Let $\gamma_1=2\alpha\beta-\alpha-\beta$, then

(i) The firm's profit in mass marketing strategy is increasing in subsidy.

(ii) The price in mass marketing strategy is increasing in subsidy.

(iii) The firm's profit in the market segmentation strategy is increasing in subsidy.

(iv) The price of ordinary products in the market segmentation strategy is increasing in subsidy.

(v) The price of green products is decreasing in subsidy when $\alpha\beta>1$, $\alpha>1/2$ and $\gamma<\gamma_1$; Otherwise, the price elevates with the increase of subsidy.

Proof (i). Since $\frac{\partial \pi_{Mass}}{\partial \theta}=\frac{1+\theta}{(C_e+C)}\geq 0$, π_{Mass} is increasing in subsidy.

Proof (ii). From $\frac{\partial p_s}{\partial \theta}=\frac{1}{C_e+C}>0$, it follows that p_s is increasing in subsidy.

Proof (iii). Since $y_o = \frac{1+\theta-\alpha}{(1-\alpha)C_e+C} \geq 0$, I conclude that $\frac{\partial \pi_{seg}}{\partial \theta} = \frac{1+\theta-\alpha\beta}{(1-\alpha)C_e+C} + \frac{\theta+\alpha\beta}{\alpha C_e+C} > 0$. Thus, π_{seg} is increasing in θ.

Proof (iv). From $\frac{\partial p_o}{\partial \theta} = \frac{1}{(1-\alpha)C_e+C} > 0$, it follows that p_o is increasing in subsidy.

Proof (v). Similarly, I need to take the derivative of green product price with respect to the subsidy level:

$$\frac{\partial p_g}{\partial \theta} = \frac{\beta}{\alpha C_e+C} + \frac{1-\beta}{(1-\alpha)C_e+C}$$

$$= \frac{\beta C_e-\alpha\beta C_e+\beta C+\alpha C_e+C-\alpha\beta C_e-\beta}{(\alpha C_e+C)((1-\alpha)C_e+C)}$$

$$= \frac{(\alpha+\beta-2\alpha\beta)C_e+C}{(\alpha C_e+C)((1-\alpha)C_e+C)}$$

$$= \frac{\alpha+\beta(1-2\alpha)+\gamma}{(\alpha+\gamma)\big((1-\alpha)+\gamma\big)} \tag{43}$$

This implies that:

1) If $\alpha\beta < 1$, then from $\frac{\alpha+\beta}{2} \geq \sqrt{\alpha\beta}$ and $\sqrt{\alpha\beta} > \alpha\beta$, it follows that $\frac{\alpha+\beta}{2} \geq \alpha\beta$. Thus, $\alpha + \beta - 2\alpha\beta \geq 0$, and therefore p_g is increasing in θ.
2) When $\alpha\beta > 1$ and $\alpha < 1/2$, it is clear that $\frac{\partial p_g}{\partial \theta}$ is positive, and hence p_g is increasing in θ.
3) When $\alpha\beta > 1$, $\alpha > 1/2$, and $\gamma > \gamma_1$, then p_g is increasing in θ.
4) When $\alpha\beta > 1$, $\alpha > 1/2$, and $\gamma < \gamma_1$, then p_g is decreasing in θ.

The obtained results (1-4) complete proof (v). □

Proposition 8 states that the price of all products is increasing in the government subsidy level except in a special case for the green products. The higher government subsidy encourages the firm to design products with higher environmental quality. In addition, green consumers are willing to pay more for the product with higher environmental quality. Thus, to improve its profit, it is logical for the firm to invest more in the environmental quality attributes and to increase the price of products. Therefore, the price of products and the firm's profit in both marketing strategies increase in government subsidy. However, there is one exception that should be assessed carefully.

When the green market is strong ($\alpha\beta > 1$), the magnitude of development cost is smaller than a certain threshold ($\gamma < \gamma_1$), and green market share is dominant ($\alpha > 1/2$), the price of green products drops with a higher subsidy. In this case, a smaller development cost results in a greater change in environmental quality for both green and ordinary products. However, it is easy to observe that the environmental quality of ordinary products is growing at the faster rate than the environmental quality of the green product by increasing the subsidy level (i.e., $\frac{\partial y_o}{\partial \theta} = \frac{1}{(1-\alpha)C_e+C} > \frac{\partial y_g}{\partial \theta} = \frac{1}{\alpha C_e+C}$ and when $\alpha > 1/2$). Thus, if the firm increases or even freezes the price of green products, then the green consumers will gain a higher utility from purchasing ordinary products and will eventually switch to the other product. Therefore, under this set of conditions, the firm will have to decrease the price of green products even with a higher subsidy level.

Since there are three possible relationships between environmental quality of standard, ordinary, and green products (i.e., (1) $y_s < y_o < y_g$, (2) $y_o < y_s < y_g$ and (3) $y_o < y_g < y_s$), I analyze the impact of the subsidy level along with the magnitude of development cost and investigate how they can impact the relationship between the environmental qualities through **Propositions 9 to 11**.

Proposition 9. The quality level of ordinary products is less than the environmental quality of standard products ($y_o \leq y_s$), if ($\alpha\beta \geq \theta + 1$) or ($\alpha\beta < \theta + 1$ and $\gamma > \gamma_2$), where $\gamma_2 = \frac{1+\theta-\beta}{\beta}$. Also, the environmental quality of ordinary products is greater than the quality level of standard products ($\text{i.e.}, y_o > y_s$), if $\alpha\beta < \theta + 1$ and $\gamma < \gamma_2$.

Proof. When $\alpha\beta \geq \theta + 1$, it is clear that $y_s \geq y_o$ since I know from **Proposition 3** that y_o is zero under such a condition. If $\alpha\beta < \theta + 1$, I consider the environmental quality difference:

$$y_s - y_o = \frac{1+\theta}{C_e+C} - \frac{1+\theta-\alpha\beta}{(1-\alpha)C_e+C}$$

$$= \frac{(1+\theta)(C_e-\alpha C_e+C)-(1+\theta-\alpha\beta)(C_e+C)}{(C_e+C)((1-\alpha)C_e+C)}$$

$$= \frac{C_e-\alpha C_e+C+\theta C_e-\alpha\theta C_e+\theta C-C_e-\theta C_e+\alpha\beta C_e-C-\theta C+\alpha\beta C}{(C_e+C)((1-\alpha)C_e+C)}$$

$$= \frac{-\alpha C_e-\alpha\theta C_e+\alpha\beta C_e+\alpha\beta C}{(C_e+C)((1-\alpha)C_e+C)}$$

$$= \frac{-\alpha-\alpha\theta+\alpha\beta+\alpha\beta\gamma}{(1+\gamma)\big((1-\alpha)+\gamma\big)} \tag{44}$$

This difference is positive (i.e., $y_s > y_o$) only if $\gamma > \frac{1+\theta-\beta}{\beta}$; Otherwise, when $\gamma < \frac{1+\theta-\beta}{\beta}$, then $y_o > y_s$. □

Proposition 10. Let $\gamma_3 = \frac{\alpha(\beta-1)+\theta(1-\alpha)}{1-\alpha\beta}$, the environmental quality of the standard product is between the environmental qualities of ordinary and green products ($y_o < y_s < y_g$) when one of the following sets of conditions holds

i. $\alpha\beta < 1$ and $\gamma_2 < \gamma < \gamma_3$,

ii. $1 \leq \alpha\beta < 1 + \theta$ and $\gamma \geq \gamma_2$,

iii. $\alpha\beta > \theta + 1$.

Proof. To prove this proposition, I compare the environmental qualities of standard products and green products and I also use the condition(s) derived in **Proposition 9**.

$$y_g - y_s = \frac{\theta+\alpha\beta}{\alpha C_e+C} - \frac{1+\theta}{C_e+C}$$

$$= \frac{(\theta+\alpha\beta)(C_e+C)-(1+\theta)(\alpha C_e+C)}{(\alpha C_e+C)(C_e+C)}$$

$$= \frac{\theta C_e+\alpha\beta C_e+\theta C+\alpha\beta C-\alpha C_e-C-\alpha\theta C_e-\theta C}{(\alpha C_e+C)(C_e+C)}$$

$$= \frac{(\theta+\alpha\beta-\alpha-\alpha\theta)C_e-(1-\alpha\beta)C}{(\alpha C_e+C)(C_e+C)}$$

$$= \frac{\alpha(\beta-1)+\theta(1-\alpha)+(\alpha\beta-1)\gamma}{(\alpha_e+\gamma)(1+\gamma)} \quad (45)$$

This difference is positive (i.e., $y_g - y_s > 0$) if and only if $\alpha(\beta - 1) + \theta(1 - \alpha) + (\alpha\beta - 1)\gamma > 0$. It is obvious that when $\alpha\beta > 1$, then $\alpha(\beta - 1) + \theta(1 - \alpha) + (\alpha\beta - 1)\gamma > 0$. Therefore,

$$y_g > y_s \text{ if } (\alpha\beta > 1) \text{ or } (\alpha\beta < 1 \text{ and } \gamma < \gamma_3) \quad (46)$$

Also, it is easy to observe $\gamma_2 - \gamma_3 = \frac{(1+\theta)(1-\beta)}{\beta(1-\alpha\ \ )} < 0$ (i.e., $\gamma_2 < \gamma_3$) when $\alpha\beta < 1$. Now, **Proposition 9** and conditions (46) imply that $y_o < y_s < y_g$ only if (i) $\alpha\beta < 1$ and $\gamma_2 < \gamma < \gamma_3$, or (ii) $1 \leq \alpha\beta < 1 + \theta$ and $\gamma \geq \gamma_2$, (iii) $\alpha\beta > \theta + 1$. □

Proposition 11. The environmental quality of the green product is lower than the environmental quality of the ordinary product ($y_o < y_g < y_s$), when $\alpha\beta < 1$ and $\gamma > \gamma_3$.

Proof. To prove this proposition, I only need to compare the two environmental qualities y_g and y_s since I already know that $y_g \geq y_o$ (it is easy to check by adding constraints (15) and (16)).

$$y_g - y_s = \frac{\theta+\alpha\beta}{\alpha C_e+C} - \frac{1+\theta}{C_e+C}$$

$$= \frac{(\theta+\alpha\beta)(C_e+C)-(1+\theta)(\alpha C_e+C)}{(\alpha C_e+C)(C_e+C)}$$

$$= \frac{\theta C_e+\alpha\beta C_e+\theta C+\alpha\beta C-\alpha C_e-C-\alpha\theta C_e-\theta C}{(\alpha C_e+C)(C_e+C)}$$

$$= \frac{(\theta+\alpha\beta-\alpha-\alpha\theta)C_e-(1-\alpha\beta)C}{(\alpha C_e+C)(C_e+C)}$$

$$= \frac{\alpha(\beta-1)+\theta(1-\alpha)C_e-(1-\alpha\beta)C}{(\alpha C_e+C)(C_e+C)}$$

$$= \frac{\alpha(\beta-1)+\theta(1-\alpha)+(\alpha\beta-1)\gamma}{(\alpha_e+\gamma)(1+\gamma)} \quad (47)$$

It is clear that $y_s - y_g > 0$ if and only if $\alpha(\beta - 1) + \theta(1 - \alpha) + (\alpha\beta - 1)\gamma < 0$. With $\alpha\beta > 1$, this condition does not hold since it results in a greater y_g than y_s. With $\alpha\beta < 1$, I still need an additional condition on the development cost ($\gamma > \gamma_3$) to ensure that this difference ($y_s - y_g$) is always positive. The obtained results show that when $\alpha\beta < 1$ and $\gamma > \gamma_2$, then $0 < y_g < y_s$. This completes the proof. □

I summarize the results of **Propositions 9-11** in Table 6 to make my discussions easier to follow. I first consider two categories whether $\alpha\beta < 1$ or not. In the first category, when the green market is weak (i.e., $\alpha\beta < 1$), the relationship between the environmental quality of the products depends on the magnitude of the development cost. More accurately, if the development cost is low enough ($\gamma < \gamma_2$), then the firm has enough motivation to provide a very high environmental quality for both ordinary and green products when she selects the market segmentation strategy (i.e., $y_s < y_o < y_g$). When the development cost gets larger, but it is still reasonable (i.e., $\gamma_2 < \gamma < \gamma_3$), the firm does not have enough incentive to design two products where both have significantly high environmental quality. In this circumstance, the environmental quality of the standard product lies between the environmental qualities of the ordinary and green products ($y_o < y_s < y_g$). Finally, when the development cost is high (i.e., $\gamma > \gamma_3$), it is not difficult to observe that the firm incorporates more environmental quality into a standard product compared to the products in the market segmentation strategy (i.e., $y_o < y_g < y_s$).

In the second category, when the green market is very strong ($\alpha\beta \geq \theta + 1$), the firm's decision is to set the environmental quality of the ordinary product to zero (see Equation (21)) and to allocate all the development efforts to the green product under the market segmentation strategy. In this situation, it makes sense to observe that the environmental quality of the green product will be higher than the standard product regardless of the magnitude of the development cost. However, when the green market is strong, but not as strong as before ($1 < \alpha\beta < \theta + 1$), the relationship between the environmental quality of the products depends on the magnitude of the development cost. More precisely, if the development cost is lower than a certain amount ($\gamma < \gamma_2$), the firm still has enough incentive to select a higher environmental quality for both products under the market segmentation strategy compared to a standard product under the mass marketing strategy. Otherwise, if the development cost is more than a certain level ($\gamma > \gamma_2$), then it does not make sense for the firm to introduce two products where both have significantly higher environmental quality ($y_o < y_s < y_g$).

Table 6. Comparison of environmental quality of the products

Category 1	$\alpha\beta < 1$		
	$\gamma < \gamma_2$	$\gamma_2 < \gamma < \gamma_3$	$\gamma > \gamma_3$
	$y_s < y_o < y_g$	$y_o < y_s < y_g$	$y_o < y_g < y_s$
Category 2	$\alpha\beta \geq 1$		
	$\alpha\beta \geq \theta + 1$	$\alpha\beta < \theta + 1$	
		$\gamma < \gamma_2$	$\gamma > \gamma_2$
	$y_o < y_s < y_g$	$y_s < y_o < y_g$	$y_o < y_s < y_g$

Proposition 12. When $\alpha\beta > 1$, the market segmentation strategy results in a higher profit than the mass marketing strategy.

Proof. I only need to compare the difference between the firm's profits under the mass marketing and market segmentation strategies.

$$\delta_\pi = \pi_{Seg} - \pi_{Mass}$$

$$= \frac{1}{2C_t} + \frac{(1+\theta-\alpha\ )^2}{2((1-\alpha)C_e+C)} + \frac{(\theta+\alpha\beta)^2}{2(\alpha C_e+C)} - \frac{1}{2C_t} - \frac{(1+\theta)^2}{2(C_e+C)}$$

$$= \frac{(1+\theta-\alpha\ )^2}{2((1-\alpha)C_e+C)} + \frac{(\theta+\alpha\beta)^2}{2(\alpha C_e+C)} - \frac{(1+\theta)^2}{2(C_e+C)}$$

$$= \frac{1}{2((1-\alpha)C_e+C)(\alpha C_e+C)(C_e+C)}(2\alpha^2\beta^2C^2 + 3\alpha^2\beta^2CC_e + \alpha^2\beta^2{C_e}^2 - 4\alpha^2\beta CC_e\theta - 4\alpha^2\beta{C_e}^2\theta$$

$$+\alpha^2{C_e}^2\theta^2 - 2\alpha^2\beta CC_e - 2\alpha^2\beta{C_e}^2 + 2\alpha^2{C_e}^2\theta + 2\alpha\beta CC_e\theta + 2\alpha\beta{C_e}^2\theta - \alpha{C_e}^2\theta^2 + \alpha^2{C_e}^2$$

$$-2\alpha\beta C^2 - 2\alpha\beta CC_e + 2\alpha CC_e\theta + C^2\theta^2 + 2CC_e\theta^2 + {C_e}^2\theta^2 + \alpha CC_e)$$

$$= \frac{1}{2((1-\alpha)C_e+C)(\alpha C_e+C)(C_e+C)} \Big(\big(\alpha^2 {C_e}^2 - \alpha {C_e}^2 + C^2 + 2CC_e + {C_e}^2\big)\theta^2 + \big(-4\alpha^2\beta CC_e - 4\alpha^2\beta {C_e}^2 + 2\alpha^2 {C_e}^2 + 2\alpha\beta CC_e + 2\alpha\beta {C_e}^2 + 2\alpha CC_e\big)\theta + 2\alpha^2\beta^2C^2 + 3\alpha^2\beta^2CC_e + \alpha^2\beta^2{C_e}^2 - 2\alpha^2\beta CC_e - 2\alpha^2\beta {C_e}^2 + \alpha^2{C_e}^2 - 2\alpha\beta C^2 - 2\alpha\beta CC_e + \alpha CC_e\Big) \quad (48)$$

Let $\delta_\pi(\theta) = \pi_{Seg} - \pi_{Mass} = \frac{1}{2((1-\alpha)C_e+C)(\alpha C_e+C)(C_e+C)}(a\theta^2 + b\theta + c)$, where,

$$a = \alpha^2{C_e}^2 - \alpha{C_e}^2 + C^2 + 2CC_e + {C_e}^2 \quad (49)$$

$$b = -4\alpha^2\beta CC_e - 4\alpha^2\beta{C_e}^2 + 2\alpha^2{C_e}^2 + 2\alpha\beta CC_e + 2\alpha\beta{C_e}^2 + 2\alpha CC_e \quad (50)$$

$$c = 2\alpha^2\beta^2C^2 + 3\alpha^2\beta^2CC_e + \alpha^2\beta^2{C_e}^2 - 2\alpha^2\beta CC_e - 2\alpha^2\beta{C_e}^2 + \alpha^2{C_e}^2 - 2\alpha\beta C^2 - 2\alpha\beta CC_e + \alpha CC_e \quad (51)$$

and

$$\Delta = b^2 - 4ac$$
$$= -4\alpha((1-\alpha)C_e + C)(\alpha C_e + C)(C_e + C)\big((\alpha(3\beta^2 - 2\beta) - 2\beta + 1)C_e + 2\,\beta C(\alpha\beta - 1)\big) \quad (52)$$

If $\alpha\beta > 1$,

$$(\alpha(3\beta^2 - 2\beta) - 2\beta + 1)C_e + 2\,\beta C(\alpha\beta - 1) = 3\alpha\beta^2 - 2\alpha\beta - 2\beta + 1$$
$$= \alpha\beta^2 - \alpha\beta + 2\alpha\beta^2 - \alpha\beta - 2\beta + 1$$
$$= \alpha\beta^2 - \alpha\beta + \alpha\beta(2\beta - 1) - (2\beta - 1)$$
$$= \alpha\beta(\beta - 1) + (2\beta - 1)(\alpha\beta - 1) > 0 \quad (53)$$

Under the condition of $\alpha\beta > 1$, I observe that $\Delta < 0$. Therefore, $\delta_\pi(\theta) = \pi_{Seg} - \pi_{Mass}$ does not have a real root. Since a is positive, I can conclude that for all $\theta \geq 0$, $\delta(\theta) > 0$, and therefore, the market segmentation strategy leads to a higher profit. □

From **Proposition 12**, it can be observed that the firm's profit is higher under the market segmentation strategy when the green market is strong because of the high green market share and/or high willingness to pay for green attributes. This proposition also shows that the firm's choice in this situation is always the market segmentation strategy and this is independent of the government subsidy.

Proposition 13. When $\alpha\beta < 1$,

(i) the market segmentation strategy results in higher profits for the firm if $\gamma < \gamma_4$,

(ii) the market segmentation strategy results in higher profits for the firm if $\gamma > \gamma_4$ and $\sqrt{\Delta} < \mathrm{b}$,

(iii) the mass marketing strategy results in higher profits for the firm if $\gamma > \gamma_4, \sqrt{\Delta} \geq \mathrm{b}$ and $\theta < \theta_1$,

(iv) the market segmentation strategy results in higher profits for the firm if $\gamma > \gamma_4, \sqrt{\Delta} \geq \mathrm{b}$ and $\theta > \theta_1$,

Where, $\gamma_4 = \frac{3\alpha\beta^2 - 2\alpha\beta - 2\beta + 1}{2\beta(1-\alpha\beta)}$, $\theta_1 = \frac{-b+\sqrt{\Delta}}{2a}$ and

$$\Delta = -4\alpha((1-\alpha)C_e + C)(\alpha C_e + C)(C_e + C)\big((\alpha\beta(3\beta - 2) - 2\beta + 1)C_e + 2\,\beta C(\alpha\beta - 1)\big)$$

Proof (i). When $\gamma < \gamma_4$, I have $\frac{3\alpha\beta^2 - 2\alpha\beta - 2\beta + 1}{2\beta(1-\alpha\beta)} C_e > C$. Since $\alpha\beta < 1$, the term $(3\alpha\beta^2 - 2\alpha\beta - 2\beta + 1)\ C_e + 2\,\beta C(\alpha\beta - 1))$ is positive. Thus, Δ becomes negative, which means that $\delta(\theta) = 0$ does not have any real root. Moreover, since a is positive for all $\theta \geq 0$, and $\delta(\theta) > 0$, I can conclude that the market segmentation strategy leads to a higher profit. □

Proofs (ii)-(iv). When $\gamma > \gamma_4$, I have $\frac{3\alpha\beta^2 - 2\alpha\beta - 2\beta + 1}{2\beta(1-\alpha\beta)} C_e < C$. Since $\alpha\beta < 1$, the term $(3\alpha\beta^2 - 2\alpha\beta - 2\beta + 1)\ C_e + 2\,\beta C(\alpha\beta - 1))$ is negative, and thus Δ becomes positive, indicating that $\delta(\theta) = 0$ has two real roots, $\theta_1 = \frac{-b+\sqrt{\Delta}}{2a}$ and $\theta_2 = \frac{-b-\sqrt{\Delta}}{2a}$. Recalling the value of b,

$$\begin{aligned} b &= -4\alpha^2\beta C C_e - 4\alpha^2\beta {C_e}^2 + 2\alpha^2 {C_e}^2 + 2\alpha\beta C C_e + 2\alpha\beta {C_e}^2 + 2\alpha C C_e \\ &= (-2\alpha^2\beta C C_e + 2\alpha\beta C C_e) + (-2\alpha^2\beta C C_e + 2\alpha C C_e) + (-4\alpha^2\beta {C_e}^2 + 2\alpha^2 {C_e}^2 + 2\alpha\beta {C_e}^2) \\ &= 2\alpha\beta C C_e(1-\alpha) + 2\alpha C C_e(1-\alpha\beta) + 2\alpha {C_e}^2(\alpha + \beta - 2\alpha\beta) \qquad (54) \end{aligned}$$

It can be shown that b is not negative since none of its three terms are negative. The non-negativity of the first two terms is clear. The last term $\alpha + \beta - 2\alpha\beta$ is also greater than or equal to zero because of $\frac{\alpha+\beta}{2} \geq \sqrt{\alpha\beta}$ and $\alpha\beta < 1$. Therefore, $\theta_1 = \frac{-b+\sqrt{\Delta}}{2a}$ is the only non-negative root of $\delta(\theta) = a\theta^2 + b\theta + c = 0$ if $\sqrt{\Delta} \geq$ b. Given that $a > 0$ and $\delta(\theta) = \pi_{Seg} - \pi_{Mass}$, the following relations hold true.

(i) $\pi_{Seg} > \pi_{Mass}$ if $\gamma < \gamma_4$

(ii) $\pi_{Seg} > \pi_{Mass}$ if $\gamma > \gamma_4$ and $\sqrt{\Delta} <$ b

(iii) $\pi_{Seg} < \pi_{Mass}$ if $\gamma > \gamma_4$, $\sqrt{\Delta} \geq$ b and $\theta < \theta_1$

(iv) $\pi_{Seg} > \pi_{Mass}$ if $\gamma > \gamma_4$, $\sqrt{\Delta} \geq$ b and $\theta \geq \theta_1$ □

Proposition 13 illustrates that when the green market is not strong ($\alpha\beta < 1$), the most profitable marketing strategy depends on the magnitude of the development cost (γ), the government subsidy level θ, and the magnitude of Δ. As one can observe, Δ is a complex term consisting of four parameters. The value of Δ grows by increasing the variable production cost of a unit of environmental quality (C_e) and/or the development cost of a unit of environmental quality (C), while its value decreases with a larger market share for green products (α) and/or higher preferences for environmental quality (β). Therefore, a higher value of Δ suggests that there will be less motivation to develop environmental attributes. Therefore, according to this proposition, I can observe that the market segmentation strategy is the firm's choice if there is enough interest for the firm to develop environmental attributes (due to $\sqrt{\Delta} <$ b). If this attraction does not exist ($\sqrt{\Delta} \geq$ b), the government can play a role and make this strategy more profitable for the firm by providing a minimum subsidy level ($\theta > \theta_1$). I call this minimum subsidy level the ***turning point subsidy***.

6. The Optimal Government Subsidy

Before finding the optimal subsidy level, I need to check whether there is any relationship between optimal subsidy levels under different marketing strategies. **Proposition 14** shows that the optimal subsidy level under the mass marketing strategy is always larger than or equal to the optimal subsidy level under market segmentation. Therefore, in my analysis, I consider all the possibilities except the cases with $\theta^*_{Mass}<\theta^*_{Seg}$. I now have all the required information for deriving the optimal subsidy level that maximizes the government's social welfare considering the firm's behavior.

Proposition 14. The optimal subsidy level for the mass marketing strategy is always larger than or equal to the optimal subsidy level for the market segmentation strategy, i.e., $\theta^*_{Mass} > \theta^*_{Seg}$.

Proof. To prove this proposition, I need to calculate the difference between the optimal subsidy levels:

$$\theta^*_{Mass} - \theta^*_{Seg} = \alpha(\beta - 1) + \varepsilon - \frac{\alpha^2\beta - 2\varepsilon\alpha^2 - \alpha^2 + \alpha\beta\gamma + 2\alpha\varepsilon - \alpha\gamma + \varepsilon\gamma}{1+2\gamma}$$

$$= \frac{(\alpha\beta - \alpha + \varepsilon)(1+2\gamma) - \alpha^2\beta + 2\varepsilon\alpha^2 + \alpha^2 - \alpha\beta\gamma - 2\alpha\varepsilon + \alpha\gamma - \varepsilon\gamma}{1+2\gamma}$$

$$= \frac{(\alpha\beta - \alpha + \varepsilon + 2\alpha\beta\gamma - 2\alpha\gamma + 2\varepsilon\ \ ) - \alpha^2\beta + 2\varepsilon\alpha^2 + \alpha^2 - \alpha\beta\gamma - 2\alpha\varepsilon + \alpha\gamma -}{1+2\gamma}$$

$$= \frac{(\alpha\beta - \alpha + \varepsilon) - \alpha^2\beta + 2\varepsilon\alpha^2 + \alpha^2 + \alpha\beta\gamma - 2\alpha\varepsilon - \alpha\gamma + \varepsilon}{1+2\gamma}$$

$$= \frac{\alpha\big(\beta(1-\alpha) - \alpha(1-\alpha)\big) + \alpha\gamma(\beta - 1) + \varepsilon\big(1 + \gamma + 2\alpha^2 - 2\alpha\big)}{1+2\gamma}$$

$$= \frac{\alpha(1-\alpha)(\beta - \alpha) + \alpha\gamma(\beta - 1) + \varepsilon\big(1 + \gamma + 2\alpha^2 - 2\alpha\big)}{1+2\gamma}$$

$1 + \gamma \geq 2$ and $-2 \leq 2\alpha^2 - 2\alpha \leq 0$ imply that $1 + \gamma + 2\alpha^2 - 2\alpha \geq 0$. Hence, $\theta^*_{Mass} - \theta^*_{Seg} \geq 0$. This completes the proof. □

Corollary 1. When $\alpha\beta > 1$, the best subsidy level is equal to the optimal subsidy for the market segmentation strategy, i.e., $\theta^* = \theta^*_{Seg}$.

Proof. According to **Proposition 12**, when $\alpha\beta > 1$, the firm always selects the market segmentation strategy because of the larger profit, i.e., $\pi_{Seg} > \pi_{Mass}$. Therefore, the best subsidy level is the optimal subsidy for the market segmentation strategy, which also maximizes the social welfare (i.e., $\theta^* = \theta^*_{Seg}$) given the firm's choice of marketing strategy. □

It is also demonstrated through an example in Figure 3 that the maximum social welfare is achieved when the optimal subsidy level is set based on the firm's choice of market segmentation strategy. As seen from this figure, although the social welfare of the mass marketing strategy is greater, it will never be selected by the firm due to its lower profit. Considering the marketing segmentation strategy, it is natural that the firm's profit increases by receiving a greater subsidy. However, the social welfare drops after reaching θ^*_{Seg}, which is the highest possible social welfare.

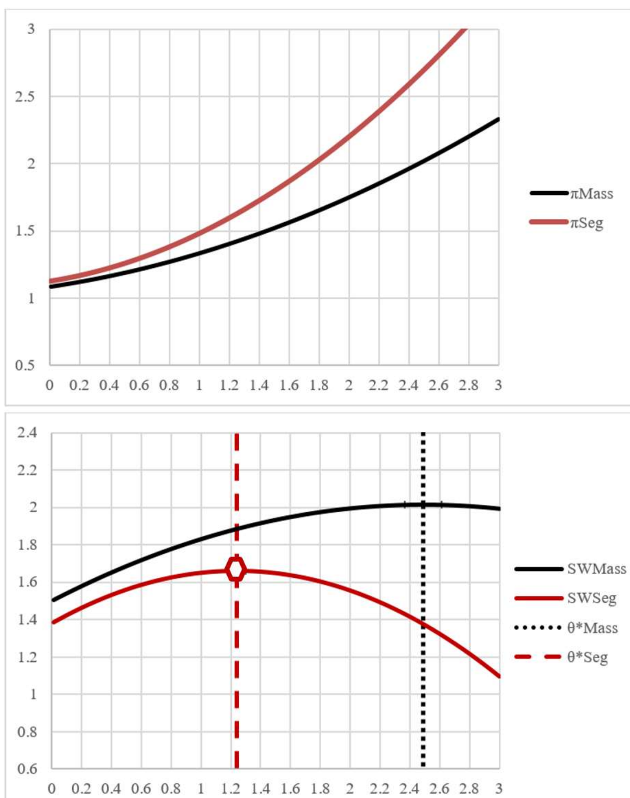

Figure 3. An illustrative example for the first corollary (with parameters $\alpha = 0.7, \beta = 1.7,\ \alpha\beta = 1.19, \varepsilon = 2, b = 2.27,\ \Delta = -2293.52, \theta_1 = 0.599, \gamma = 5, \theta^*_{Mass} = 2.49, \theta^*_{Seg} = 1.24$)

On the other hand, when $\alpha\beta < 1$, the green market is not strong (i.e., because of the low percentage of green consumers and/or low willingness to pay for green attributes), even with no support from the government, there are still two conditions under which the firm chooses to produce two products (ordinary and green) based on the market segmentation strategy. As seen from the second corollary, the optimal subsidy level is the same as the outcome of the first corollary since the profit of the market segmentation strategy is always greater than the mass marketing strategy, regardless of government support (see Figure 4).

Corollary 2. When $(\alpha\beta < 1, \gamma < \gamma_4)$ or $(\alpha\beta < 1, \gamma > \gamma_4$ and $\sqrt{\Delta} <$ b), the best subsidy level is equal to the optimal subsidy for the market segmentation strategy, i.e., $\theta^* = \theta^*_{Seg}$.

Proof. According to **Propositions 13 (i, ii)**, one can observe that the firm always selects the market segmentation strategy under the above conditions due to a larger profit. Therefore, it is clear that the best choice is a subsidy level that maximizes social welfare given the firm's choice of marketing strategy (i.e., $\theta^* = \theta^*_{Seg}$). □

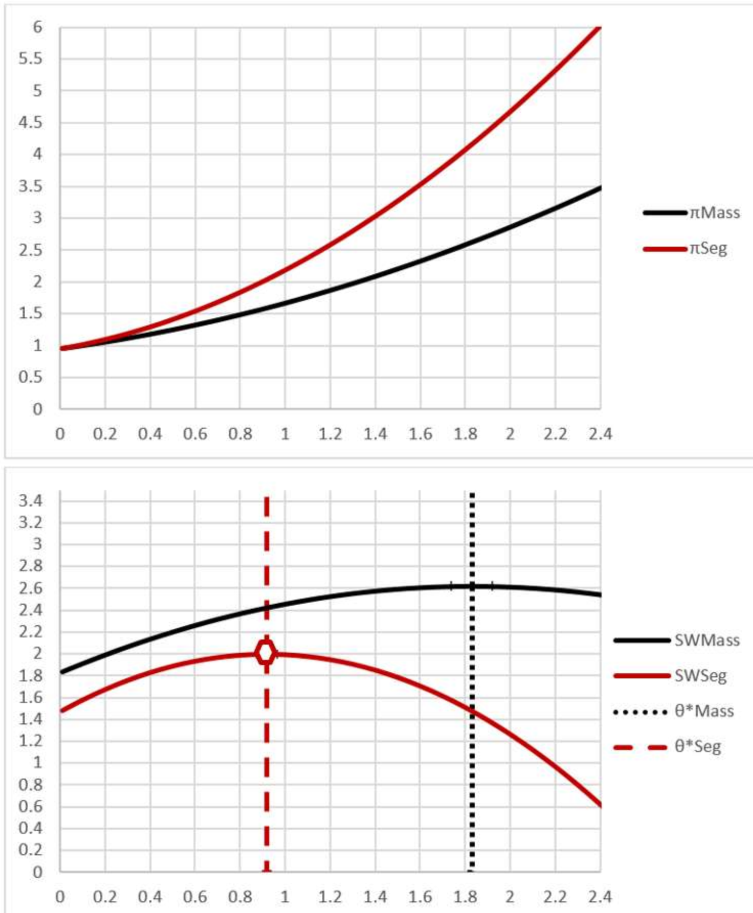

Figure 4. An illustrative example of the second corollary (with parameters $\alpha = 0.55, \beta = 1.6, \alpha\beta = 0.88 < 1, \varepsilon = 1.5, b = 1.45, \sqrt{\Delta} = 1.37, \gamma = 1.1,\ \gamma_4 = 0.69, \theta^*_{Mass} = 0.92, \theta^*_{Seg} = 1.83$)

In addition to the conditions discussed above, there are situations where the subsidy level can change the firm's choice of marketing strategy. It occurs when the incentive to produce both ordinary and green products is very low, i.e., the green market is not strong ($\alpha\beta < 1$), the development cost is higher than a certain amount ($\gamma > \gamma_4$), and there is less attraction for the development of environmental attributes based on both the market and cost parameters ($\sqrt{\Delta} > b$). In this situation, the firm initially selects the mass marketing strategy, but will switch to the market segmentation strategy by receiving a minimum subsidy level (θ_1). Depending on the optimal subsidy levels for different marketing strategies, and the turning point subsidy value, the best subsidy level will be derived through corollaries 3, 4, and 5.

Corollary 3. When $\alpha\beta < 1, \gamma > \gamma_4, \sqrt{\Delta} \geq$ b, $\theta^*_{Mass} < \theta_1$ and $\theta^*_{Seg} < \theta_1$, the best subsidy level is achieved by selecting the subsidy value that maximizes the social welfare under the mass marketing strategy, ($i.e.,\ \theta^* = \theta^*_{Mass}$) if $SW_{Mass}(\theta^*_{Mass}) \geq SW_{Seg}(\theta_1)$; otherwise, the best subsidy level is θ_1.

Proof. To complete the proof of this corollary, I need to check the following two cases:

- When $\theta < \theta_1$

  In this case, according to **Propositions 13 (iii)**, the mass marketing strategy is the firm's choice since it generates a higher profit. Therefore, the subsidy level that maximizes social welfare is the optimal subsidy for the mass marketing strategy (i.e., θ^*=θ^*_{Mass}).

- When $\theta \geq \theta_1$

  In this case, the firm selects the market segmentation strategy due to a higher profit, i.e., $\pi_{Mass} > \pi_{Seg}$. It is easy to verify that the second derivative of the social welfare of the market segmentation strategy, with respect to θ, is negative. Therefore, the social welfare of the market segmentation strategy is a concave function, and hence, it is decreasing in θ after passing its optimal solution (θ^*_{Seg}). Since $\theta^*_{Seg} < \theta_1$ and $\theta \geq \theta_1$, the social welfare does not improve by increasing the subsidy level beyond θ_1. Therefore, it is evident that the maximum social welfare is achieved under the market segmentation strategy at θ_1, for every θ larger than or equal to θ_1.

Therefore, in conclusion, I have to compare and choose the best subsidy level between (1) the optimal social welfare value under the mass marketing strategy, and (2) the social welfare value under the market segmentation strategy at θ_1.

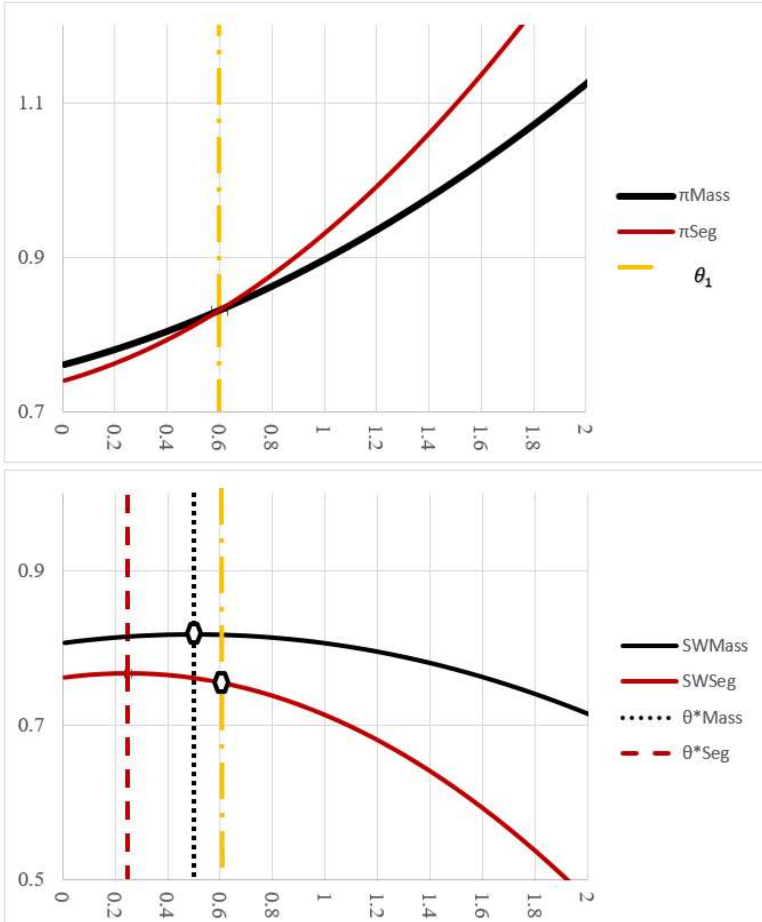

Figure 5. An illustration example for Corollary 3 (with parameters $\alpha = 0.4, \beta = 1.5,\ \alpha\beta = 0.6 < 1, \varepsilon = 1, b = 10.96,\ \sqrt{\Delta} = 155.73,, \theta_1 = 0.599, \gamma = 10, \gamma_4 = -0.42, \theta^*_{Mass} = 0.5, \theta^*_{Seg} = 0.24$)

Under the conditions of Corollary 3, the firm's strategy is the mass marketing strategy, since it does not have enough financial incentive to develop two different products (see the illustrative example in Fig 5.). Introducing the government subsidy for producing green aspects increases the firm's profit. If the subsidy level reaches its turning point value (θ_1), the market segmentation strategy becomes a better choice for the firm, since the profit grows faster under this strategy with government support. When this threshold is greater than the optimal subsidy levels of both marketing strategies (θ^*_{Mass} and θ^*_{Seg}), the government would not increase the subsidy beyond the θ_1 threshold, since the total social welfare would decrease due to its concavity. Therefore, the government should check two critical points. The first critical point is when the optimal subsidy level results in the highest social welfare under the mass marketing strategy (θ^*_{Mass}). Given the firm's choice of mass marketing when $< \theta_1$, this is the largest achievable social welfare. The second critical point is when the firm starts to switch its marketing strategy, i.e., when the subsidy level reaches θ_1. The largest possible social welfare under the market segmentation strategy is θ_1 (i.e., as mentioned earlier, increasing the subsidy level beyond this point deteriorates the social welfare). By evaluating and comparing these two critical points, the government can decide on the subsidy level. In the example of Figure 5, the best maximum social welfare is obtained by selecting the optimal subsidy under the mass marketing strategy.

Corollary 4. When $\alpha\beta < 1, \gamma > \gamma_4, \sqrt{\Delta} \geq$ b and $\theta^*_{Seg} < \theta_1 < \theta^*_{Mass}$, the optimal subsidy level is θ_1.

Proof. To prove this corollary, I consider the following two cases:

- When $\theta < \theta_1$

  According to **Propositions 13 (iii)**, the firm selects the mass marketing strategy because of the higher profit, i.e., $\pi_{Mass} > \pi_{Seg}$. Since the second derivative of the social welfare of the mass marketing strategy with respect to θ is negative, the social welfare of the mass marketing strategy is a concave function of θ. Therefore, the social welfare of the mass marketing strategy is increasing by $\theta, \forall \theta \leq \theta^*_{Mass}$. Since $\theta^*_{Mass} > \theta_1$, the social welfare from the mass marketing strategy gains its maximum value at θ_1.

- When $\theta \geq \theta_1$

In this case, according to **Propositions 13 (iv)**, the market segmentation strategy is the firm's choice due to a higher profit, i.e., $\pi_{Seg} > \pi_{Mass}$. As discussed earlier, the social welfare of the market segmentation strategy is a concave function, and hence, it is declining by increasing $\theta, \forall\ \theta \geq \theta^*_{Seg}$. Since $\theta^*_{Seg} < \theta_1$, it is obvious that the social welfare under the market segmentation strategy obtains its maximum value at θ_1.

Thus, I can conclude that the best subsidy level is θ_1, i.e., $\theta^* = \theta_1$. □

An example of such a case is illustrated in Figure 6. When the government does not provide a high enough subsidy as an incentive for environmental quality ($< \theta_1$), the firm selects the mass marketing strategy to gain a higher profit. After reaching a certain subsidy level ($\theta_1 = 0.61$), the firm has an adequate motive to choose the market segmentation strategy. Given such behavior, the higher subsidy level increases the total social welfare up to 0.61, when mass marketing is the first choice. After passing this threshold, the social welfare drops as the firm switches to the market segmentation strategy. Therefore, the government should increase the subsidy up to θ_1, but not push it any further than that because this is the last point before the firm switches to market segmentation.

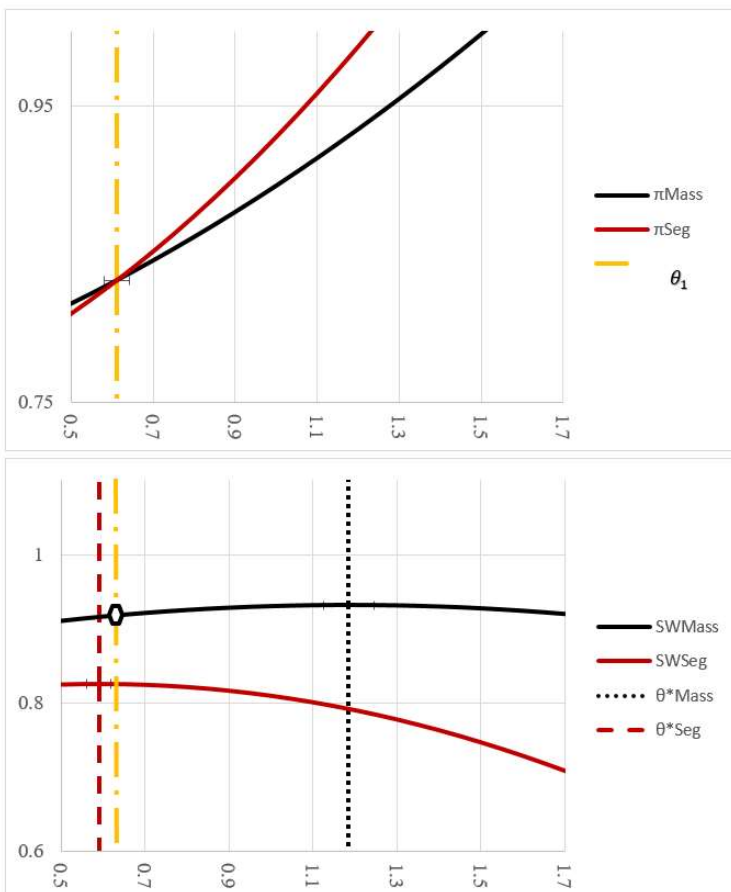

Figure 6. An illustration example for Corollary 4 (with parameters $\alpha = 0.37, \beta = 1.5,\ \alpha\beta = 0.56 < 1,\ \varepsilon = 1,\ b = 10.84,\ \sqrt{\Delta} = 158.29, \theta_1 = 0.61,\ \gamma = 10, \gamma_4 = -0.45,\ \theta^*_{Mass} = 1.18, \theta^*_{Seg} = 0.59$)

Corollary 5. When $\alpha\beta < 1, \gamma > \gamma_4, \sqrt{\Delta} \geq$ b, $\theta^*_{Mass} > \theta_1$ and $\theta^*_{Seg} > \theta_1$, the optimal subsidy level is equal to θ^*_{Seg}, if the optimal social welfare of the market segmentation strategy is greater than the social welfare of the mass marketing strategy at θ_1; otherwise, the optimal subsidy level is equal to θ_1.

Proof. Two following cases are considered:

- When $\theta < \theta_1$

  In this case, **Propositions 13 (iii)** implies that the firm selects the mass marketing strategy. Since the social welfare of the mass marketing strategy is a concave function of θ, it follows that the social welfare of the mass marketing strategy is increasing by $\theta, \forall\theta \leq \theta^*_{Mass}$. Since $\theta^*_{Mass} > \theta_1$, the social welfare of the mass marketing strategy gains its maximum value at θ_1.

- When $\theta \geq \theta_1$

  According to **Propositions 13 (iv)**, the market segmentation strategy is the firm's choice due to a higher profit. In this case, the best level is the optimal subsidy for the market segmentation strategy because $\theta^*_{Seg} > \theta_1$.

Clearly, the optimal subsidy level is equal to θ^*_{Seg}, if the optimal social welfare value of the market segmentation strategy is greater than the social welfare value of the mass marketing strategy at θ_1; otherwise, the optimal subsidy level is equal to θ_1. □

An illustration for this case is shown in Figure 7 where the firm selects the mass marketing strategy without any subsidy (θ=0). The social welfare of the mass marketing strategy grows by increasing the subsidy level before reaching its optimal value (θ^*_{Mass}=1.02). Since the firm changes her marketing strategy at $\theta_1 = 0.29$ (and I know that θ^*_{Mass}>θ_1), the best social welfare under the mass marketing strategy is obtained at θ_1. Increasing the subsidy level beyond θ_1, the firm switches to market segmentation and the corresponding social welfare increases up to θ^*_{Seg}=0.46. Now, the government would compare the social welfare values from the mass marketing strategy at $\theta_1 = 0.29$ and the market segmentation strategy at $\theta^*_{Seg} = 0.46$ and then select $\theta^* = 0.29$ because of its higher social welfare value.

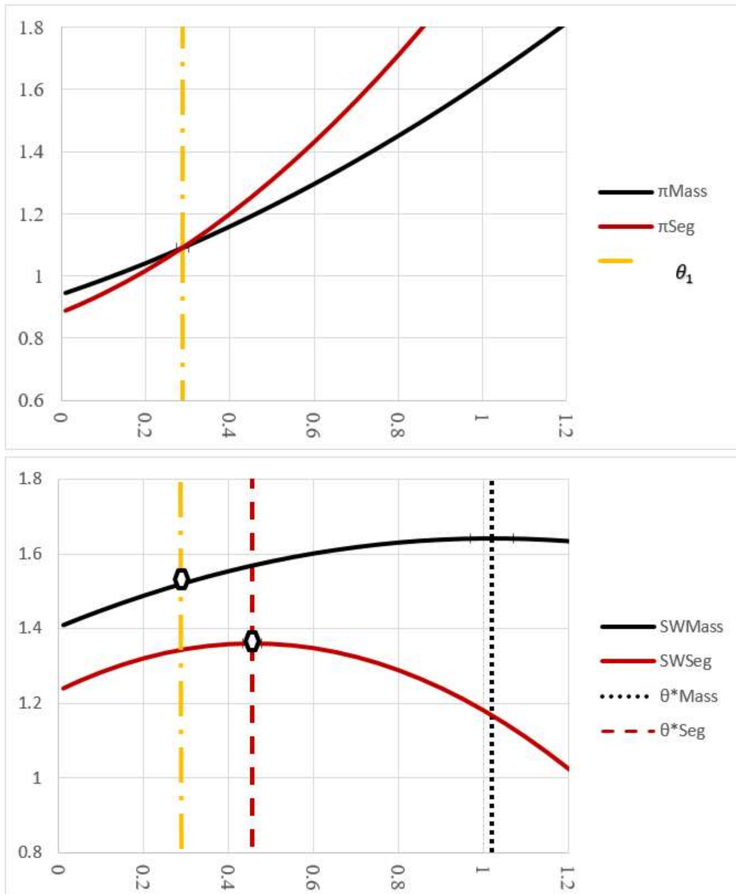

Figure 7. An illustration example for Corollary 5 (with parameters $\alpha = 0.2, \beta = 1.1,\ \alpha\beta = 0.22 < 1,\ \varepsilon = 1,\ \mathrm{b} = 1.14, \sqrt{\Delta} = 3.83,\ \theta_1 = 0.29, \gamma = 1.2, \gamma_4 = -0.53, \theta^*_{Mass} = 1.02, \theta^*_{Seg} = 0.46$)

7. Conclusions, Implications, and Future Research Directions

Environmental regulations and their effects on green product development have become a critical challenge for governments. While the government's target is to use regulations as an incentivizing tool to encourage firms to develop and produce green products and to support the research and development costs of green aspects, subsidies for environmental quality receive a lot of attention.

However, governments need to set subsidy levels strategically to improve the social welfare. In this study, I adopted a two-stage Stackelberg game to analyze the effects of government subsidies on firm's marketing strategies, as well as the overall social welfare. In this game, the government sets the subsidy level to benefit social welfare including the firm's profit, the consumers' surplus, the environmental impact, and the government's expenses.

Responding to the subsidy level, the firm selects her marketing strategy, i.e., to offer only a single product for the whole market (mass marketing) or two products exclusively for each segment (market segmentation). Based on the selected marketing strategy, the firm also decides on the environmental attributes of the product(s) and the selling price(s).

Considering both marketing strategies, I investigated the impact of subsidies on the relationship between the environmental attributes of the manufactured products, and I was able to derive several interesting results. For example, it has been found that the relationship between the environmental qualities of the products is independent of government subsidy when the green market is not strong (i.e., $\alpha\beta < 1$). Under this condition, if the development cost is low enough ($\gamma < \gamma_2$), selecting the market segmentation strategy will result in higher environmental qualities for both ordinary and green products compared to the standard products under mass marketing. However, when the development costs become larger, but remain reasonable ($\gamma_2 < \gamma < \gamma_3$), the choice of environmental quality attributes will be different. In this case, the environmental quality of the standard product will lie in between the ordinary and green products. By increasing the development cost while exceeding a certain level ($\gamma > \gamma_3$), a decision to offer two products (ordinary and green) leads to lower environmental qualities for both products in comparison with the standard product under mass marketing. Lastly, as discussed in Section 4, it is important to point out that when the green market is strong (i.e., $\alpha\beta > 1$), the relationship between the environmental qualities of the products will depend on the subsidy level.

The obtained results reveal that when the green market is strong (i.e., $\alpha\beta > 1$), the firm selects the market segmentation strategy and offers two products to earn higher profits. In this case, the firm's choice of marketing strategy is independent of the subsidy level, and it depends only on the green consumers' market share and the green consumers' preference for environmental quality. Although the firm's decision to choose the market segmentation strategy is not dependent on the level of the subsidy, providing the best subsidy level is essential for the government since the government's objective is to improve the total social welfare. Therefore, the government should provide a subsidy level equal to the optimal subsidy level under market segmentation to promote social welfare. Based on the obtained results, when the green market is not strong (i.e., $\alpha\beta < 1$), the firm still chooses a market segmentation strategy if the development cost is low enough ($\gamma < \gamma_4$). Even if the development cost is higher than γ_4, the market segmentation will be selected if there is still enough attractiveness to develop environmental quality (i.e., $\sqrt{\Delta} < \mathrm{b}$) considering all the market and cost parameters. Therefore, in these conditions, the government should still choose the subsidy equal to the optimal subsidy of market segmentation.

If none of the above conditions hold, the firm's decision is to select the mass marketing strategy without government support. By introducing the government subsidy, it is evident that the firm's profit increases. However, the incremental growth of the market segmentation strategy grows faster and exceeds the profit of the mass marketing strategy when the subsidy level passes a certain threshold (θ_1), also known as the turning point subsidy. Based on the relationships between the optimal subsidy levels under different marketing strategies and the turning point subsidy, I found several conditions to derive the best subsidy level. For example, if $\theta^*_{Mass} > \theta_1$

and $\theta_{Seg}^{*} < \theta_1$, then the best subsidy level is the turning point subsidy. This is because the social welfare is improved by increasing the subsidy level. Once the subsidy level passes θ_1, the firm immediately switches to the market segmentation strategy. Moreover, any additional subsidy deteriorates the social welfare since the social welfare function is concave and $\theta_{Seg}^{*} < \theta_1$.

This work opens up interesting avenues for future research. In this study, I considered a monopolist firm, which can be extended to a duopoly market where two firms compete. Understanding how the government's choice of subsidy can influence the firms' competition is a promising area of research. Furthermore, this study only assumes that the government provides the subsidy to encourage the research and development of green products. Future studies could analyze other types of subsidies, such as tax credits and/or consumer rebates for green products. Lastly, I investigated the impact of government subsidies on social welfare and firms' marketing strategies. It would be interesting to examine the effects of the other available policies, such as taxes, cap-and-trade systems, and carbon labeling, on green product development and social welfare.

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