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Research Article

How Does Leasing Affect Green Product Design?

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Leasing has been increasingly seen as a viable alternative to traditional business models. In this paper, we consider a manufacturer making decisions on green product design by accounting for the trade-off between traditional and environmental qualities under three business models, including a pure selling, a pure leasing, and a hybrid model with both selling and leasing. Under leasing, there exists the pooling effect that allows a manufacturer to meet consumer needs with fewer products. Since the pooling effect decreases the marginal cost of production, leasing produces positive incentives to increase product quality. However, the cannibalization effect within the product line distorts the incentives so that the pooling effect only increases the traditional quality rather than the environmental quality. As a result, leasing may have a negative impact on the average environmental quality of products. The manufacturer should make business model choices depending on some factors, including the types of markets, the usage cost, and the pooling effect. In general, when the pooling effect is strong, the manufacturer prefers a leasing or hybrid model to selling but designs products with lower environmental quality than selling. When the pooling effect is weak, the optimal decision should be made depending on the types of markets and the usage cost: in the high-end (low-end) market, the manufacturer should adopt a leasing or hybrid model only when the usage cost is high (low); the adoption of leasing or hybrid model can improve the average environmental quality.

1. Introduction

More manufacturers are shifting their business models from selling to leasing as an approach to enhance their profitability. For example, Rolls Royce offers the “Power by the Hour” program under which the airlines lease the engines and pay for the duration of the time they use the engines. In 2014, more than 50% of Rolls Royce’s revenues come from its leasing services (https://productserviceinnovation.com/home/2014/08/20/powering-the-future-rolls-royce-total-care-business-success/, retrieved 22 June 2019). Daimler introduced the car-sharing program in 2010, which allows users to lease vehicles in increments of one hour [1]. In 2017, car2go has grown to 3 million customers on a global scale (https://www.thedrive.com/sheetmetal/17593/car-sharing-platform-car2go-has-huge-2017, retrieved 22 June 2019). Other firms such as Interface Inc., IBM, and Xerox also have launched their own leasing programs successfully [2]. Therefore, leasing has become a significant trend in the manufacturing industry.

Leasing has been increasingly seen as a green business model. For example, Daimler is convinced that car sharing is currently the best solution for less traffic and more sustainability (https://www.daimler-financialservices.com/en/company/we-move-you/sustainability, retrieved 22 June 2019). Interface Inc., Xerox, IBM, and HP also promote their leasing programs as being environmentally beneficial [2]. One important reason why leasing is considered a green business model is that, under a leasing model, the same product can be used by multiple customers at different periods of time. As a result, the manufacturer is able to meet the consumers’ needs with fewer products than those under selling, thus decreasing the impact on the environment. For example, Xerox reduced the number of products from a ratio of more than one device per employee to one device per 10 employees through leasing services [3]. However, the total impact of leasing on the environment depends not only on the number of products but also on the extent to which each product affects the environment. While reducing the number of products, leasing influences green product design profoundly. For examining the environmental impact of leasing, it is necessary to understand how leasing affects green product design. Specifically, by investigating the mechanism of leasing affecting green product design, we aim to answer the following questions:

(i) Can leasing improve both the environmental quality of products and the manufacturer's profit?

(ii) What are the conditions under which leasing improves both the manufacturer's profit and the environmental quality?

(iii) How should the manufacturer make decisions on business models and green product design strategy?

We employ a mathematical framework for green product design and consumer choice to analyze the problems above. In particular, we consider three business models that the manufacturer is able to adopt in practice: First, a pure selling model under which the manufacturer sells the products to consumers. Second, a pure leasing model under which the manufacturer only leases the products to consumers. Third, a hybrid model with both selling and leasing. Moreover, the pooling effect, consumers' self-selection, and the trade-off between traditional and environmental qualities are taken into account in our mathematical model, which captures the critical characteristics of green product design under leasing.

The rest of the paper is organized as follows. Section 2 provides a brief review of relevant literature regarding leasing and green product design. The assumptions are given in Section 3. Section 4 establishes the mathematical models for green product design under different business models and the optimal solutions are obtained. In Section 5, the economic and environmental consequences associated with different business models are compared, the optimal decisions on business models and green product design are concluded, and the interaction between business models and green product design is analyzed. Section 6 provides the numerical analysis to illustrate the sensitivity of the optimal decisions to some important parameters. Section 7 gives the conclusions and future research directions.

2. Literature Review

There are two streams of literature related to this paper: research on leasing and research on green product design. In this section, we review the literature relevant to each stream, respectively.

2.1. Leasing. Our work builds on the previous literature that focuses on the comparison between selling and leasing. Coase [4] conjectures that there exists time inconsistency under selling, which leads to a decline in prices for durable goods with the passage of time. Bulow [5] proposes that the time inconsistency problem can be avoided under leasing; thus, leasing is more profitable than selling. Desai and Purohit [6, 7] analyze the marketing and competition problems associated with leasing and selling; they find that leasing may be less profitable than selling, which depends on the depreciation rates of products. Bhaskaran and Gilbert [8] investigate selling and leasing strategies for durable goods in the presence of complementary products. Bhaskaran and Gilbert [9, 10] further investigate the impact of channel structure on selling and leasing strategies. Agrawal et al. [2] examine whether leasing is environmentally superior to selling and find leasing may be environmentally inferior to selling. Bellos et al. [1] analyze the interaction between business models and product design in the car-sharing program; it is concluded that car sharing is not always environmentally beneficial. Avci et al. [11] take range anxiety for electric vehicles (EVs) and high battery cost into account and analyze the environmental impact of a business model under which consumers can lease EVs batteries at the pay-per-use price. They find that this business model is more effective at reducing emissions. Lim et al. [12] show that the business model of leasing EVs batteries may increase the adoption of EVs, thus increasing environmental performance. Although Bellos et al. [1] and Agrawal et al. [2] consider the environmental impact of leasing. Bellos et al. [1] ignore the impact of green consumers, and Agrawal et al. [2] ignore the consumer segmentation.

Leasing also falls under a type of business model, which is often referred to as servicizing. Rothenberg [3] studies the servicizing cases of Xerox, Gage Products Co., and PPG Industries Inc. and analyzes the sustainability of servicizing. Agrawal et al. [13] examine the economic and environmental impact of servicizing. They find that the pooling effect has an important role in the sustainability of servicizing. Örsdemir et al. [14] investigate whether servicizing can be a win-win strategy on profitability and sustainability; they find that only when the operating efficiency is sufficiently low and consumers are adequately similar, servicizing is a win-win strategy. These papers consider the environmental impact of servicizing. However, the consumer segmentation is not taken into account in [13], and the pooling effect is not considered in [14], which are both proved important in this paper.

In this stream of research, our paper is most related to Agrawal et al. [2, 13], Örsdemir et al. [14], and Bellos et al. [1]. However, Agrawal et al. [2, 13] do not consider market segmentation which produces the cannibalization effect. Örsdemir et al. [14] do not consider the pooling effect. This paper considers the market segmentation and the pooling effect at the same time; as a result, we find that the interaction between cannibalization and pooling leads to low environmental quality under leasing. Although Bellos et al. [1] take the two effects above into account, they only study leasing in the context of car sharing and ignore the impact of green consumers on product design. Green consumers have an important impact on green product design [15–17]. In this paper, we consider the difference between the ordinary and green consumers.

2.2. Green Product Design. There are a number of articles addressing the green product design problem. Chen [18] develops a framework to analyze green product design, which considers the trade-off between traditional and environmental qualities. Su et al. [19] and Zhang et al. [20] employ the framework to analyze the impact of technology evolution and development cost on green product design, respectively. Dangelico and Pujari [21] propose a framework that presents three key environmental dimensions of green product innovation by means of a multiple case study analysis. Kim and Chhajed [22] consider multiple dimensions of product quality and investigate the product design problem. Chung and Wee [23] investigate green product design problem in the presence of technology evolution and remanufacture. Chen and Liu [24] discuss the impact of the price leadership on design for recyclability. Huang et al. [25] study the design decision on product recyclability and durability in the presence of Extended Producer Responsibility. Eichner and Pethig [26] study green product design under pollution taxation. Albino et al. [27] study the influence of different environmental strategies on green product development. Wong [28] investigates the relationship among green product competitive advantage, green product innovations, and green process innovations. Zhu and He [29] and Xu et al. [30] analyze green product design under competition.

In this stream of research, our paper is most related to Chen [18], Su et al. [19], and Zhang et al. [20], but they do not consider leasing. We employ the framework developed by Chen [18] to analyze green product design under leasing.

To sum up, the related works are shown in Table 1. It is clear that our paper differs from related works. This paper makes contributions to the related literature in two ways. The first is modeling. We extend the classic green product design framework, which is developed by Chen [18], to the field of leasing. The second contribution is managerial. (i) Leasing may not improve the average environmental quality of products. The intuition is that the pooling effect decreases the marginal cost by reducing the number of products, thus encouraging the manufacturer to improve the quality. But the cannibalization effect distorts the incentives, resulting in a decrease in the environmental quality. (ii) Leasing may improve both profitability and environmental quality, which depends on the usage cost, the pooling effect, and the types of markets.

3. Assumptions

We consider a model where a manufacturer may sell and lease products in the same market. The sequence of events is the following: First, the manufacturer makes a decision on business models. Second, the manufacturer designs the product, including the traditional and environmental qualities design, and determines the selling price and/or leasing price. Third, consumers make decisions on whether to buy or lease the products.

The manufacturer is able to make a choice from three business models: a pure selling, a pure leasing, and a hybrid model with both selling and leasing, as illustrated in Figure 1. In Figure 1(a), the manufacturer adopts a pure selling model (denoted by S), under which the manufacturer sells products at the selling price F. In Figure 1(b), the manufacturer adopts a pure leasing model (denoted by L), under which consumers lease the products and pay the leasing price P which is paid based on the consumers' usage. In Figure 1(c), the manufacturer adopts a hybrid model (denoted by H), under which consumers can either buy or lease the products. We assume that there exists the pooling effect under leasing [1, 13]. That is, as leasing allows consumers to share a pool of products so that the same product can be used by multiple consumers at different periods of time, thus fewer products are required to meet consumer needs under leasing. For example, in the SmartCloud program of IBM, which offers computing and storage services to consumers, a server can meet multiple consumers' needs. We describe the pooling effect with the parameter r, ($r \in [0,1]$), the manufacturer should provide rD units of products to meet the needs of D consumers [31]. It is worthwhile to note that a small parameter r represents a strong pooling effect. The strength of the pooling effect depends on some exogenous factors related to the characteristics of the product or industry. For example, the "Power by the Hour" program of Rolls Royce has a weaker pooling effect because an aircraft still requires the same number of engines as those under the selling model.

We assume that the manufacturer produces green products with two competing qualities, the traditional quality q_t and the environmental quality q_e [18–20]. The traditional quality includes typical performance attributes, and the environmental quality reflects the environmental performance of the product. For example, the traditional quality of an automobile includes power and safety, and the environmental quality includes fuel efficiency. According to [18, 19], the sum of q_t and q_e equals to 1; this assumption implies that once the environmental quality increases, the traditional quality decreases. For example, q_t and q_e represent the levels of engine horsepower and fuel efficiency, respectively; the higher the fuel efficiency, the lower the engine horsepower [1]. Assume that the unit production cost is $c_t q_t^2 + c_e q_e^2$, where c_t and c_e are positive cost coefficients [18, 20].

We consider a market in which exist two types of consumers: ordinary consumers denoted by o and green consumers denoted by g. The size of ordinary consumers and green consumers is D_o and D_g, respectively. Assume that only green consumers are concerned about the environment [18, 20]. According to [18], the ordinary consumers' utility of each use of the product is $V_o = v_t q_t$; the green consumers' utility of each use of the product is $V_g = v_t q_t + v_e q_e$, where v_t and v_e are the consumers' traditional quality and environmental quality sensitivities, respectively ($v_t > 0$, $v_e > 0$). The environmental quality sensitivity (v_e) reflects the consumers' environmental preference. We assume that every consumer needs to use the product d times within the product's useful life [1]. Because consumers share a pool of products under leasing, products may not be available all the time. We assume the level of product availability is a under leasing ($a \in (0,1]$) [1], which means every consumer only can use the product ad times within the product's useful life under leasing. Each use of the product incurs the usage cost c [1], for example, the cost of product maintenance. The product owners bear the usage cost; specifically, the manufacturer under leasing and consumers under selling bear the usage cost. The consumers' price

Table 1: Position of our work in the literature.

Literature	Green consumers	Market segmentation	Pooling effect	Leasing
Chen [18]	✓	✓		
Agrawal et al. [2]				✓
Agrawal et al. [13]			✓	✓
Örsdemir et al. [14]		✓		✓
Bellos et al. [1]		✓	✓	✓
Our paper	✓	✓	✓	✓

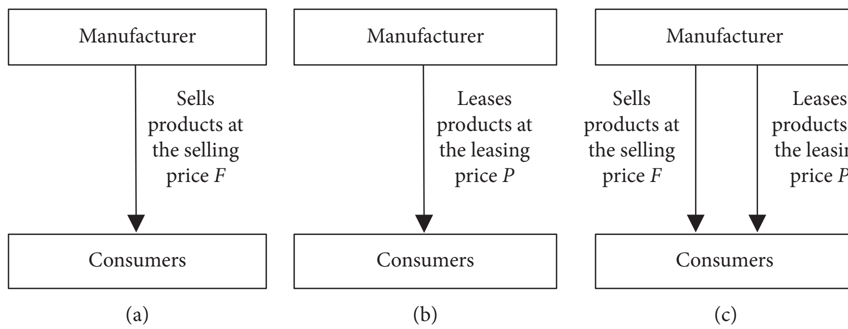

Figure 1: Manufacturer's business model choices. (a) Pure selling model (S). (b) Pure leasing model (L). (c) Hybrid model (H).

sensitivity is w ($w > 0$). Therefore, the net utility of customer $i \in \{o, g\}$ is given by $U_i^S = d(V_i - c) - wF$ under selling and $U_i^L = ad(V_i - wP)$ under leasing, where $V_i - wP$ is the net utility of each use (the leasing price is paid based on usage).

In addition, facing two types of consumers, the manufacturer is able to adopt the mass-marketing strategy (denoted by mas) and the market-segmentation strategy (denoted by seg) [18, 20]. Under the mass-marketing strategy, the manufacturer introduces a single product to both types of consumers. Under the market-segmentation strategy, the manufacturer offers two types of products to two consumer segments, respectively. We consider both strategies under each business model; we use the subscript (k, j) to denote the combinations of the business model k and the strategy j, where $k \in \{S, L, H\}$ and $j \in \{\text{mas}, \text{seg}\}$.

4. Model Formulation and Solution

In this section, we build the green product design models under the three business models, respectively, and then obtain the optimal price and quality decisions.

4.1. Green Product Design under the Pure Selling Model. Under a pure selling model, when adopting the market-segmentation strategy, the manufacturer sells products with quality q_t^o and q_e^o to ordinary consumers at the selling price F_o and products with quality q_t^g and q_e^g to green consumers at the selling price F_g. Therefore, the optimization problem of the manufacturer is as follows:

$$\max_{F_o, F_g, q_t^o, q_t^g} \pi_{(S,\text{seg})}\left(F_o, F_g, q_t^o, q_t^g\right) = \sum_{i \in \{o,g\}} \left(F_i - c_t q_t^{i2} - c_e q_e^{i2}\right) D_i, \tag{1}$$

subject to

$$d\left(v_t q_t^o - c\right) - wF_o \geq 0, \tag{2}$$

$$d\left(v_t q_t^g + v_e q_e^g - c\right) - wF_g \geq 0, \tag{3}$$

$$d\left(v_t q_t^o - c\right) - wF_o \geq d\left(v_t q_t^g - c\right) - wF_g, \tag{4}$$

$$d\left(v_t q_t^g + v_e q_e^g - c\right) - wF_g \geq d\left(v_t q_t^o + v_e q_e^o - c\right) - wF_o. \tag{5}$$

The objective function (1) is the manufacturer's profit, which is the revenue minus the production cost. The manufacturer maximizes the profit by choosing the qualities q_t^i and prices F_i (according to the assumption, $q_e^i = 1 - q_t^i$). The constraints (2) and (3) are the individual rationality constraints, which ensure that both types of consumers gain nonnegative utilities from their respective products. The constraints (4) and (5) are the incentive compatibility constraints, which ensure that each type of consumer gains a higher utility from buying their respective products. The four constraints describe the consumers' self-selection, and only when four constraints are satisfied, the market-segmentation strategy can be successfully implemented [18].

According to the constraints, we find that prices for two products are restricted by each other, i.e., if F_g is too high, green consumers will buy the other product at the selling price F_o, and vice versa. Therefore, there exists the cannibalization effect, which may lead to a price reduction as a consequence of introducing two types of products.

When adopting the mass-marketing strategy under a pure selling model, the manufacturer sells a single product with quality q_t and q_e to both types of consumers at the selling price F. The optimization problem of the manufacturer is as follows:

$$\max_{F, q_t} \pi_{(S,\text{mas})}\left(F, q_t\right) = \sum_{i \in \{o,g\}} \left(F - c_t q_t^2 - c_e q_e^2\right) D_i, \tag{6}$$

subject to

$$d\left(v_t q_t - c\right) - wF \geq 0, \tag{7}$$

$$d\left(v_t q_t + v_e q_e - c\right) - wF \geq 0. \tag{8}$$

The constraints (7) and (8) are the individual rationality constraints. Since consumers have only a single product to choose, there is no need to consider the incentive compatibility constraints.

4.2. Green Product Design under the Pure Leasing Model. Under a pure leasing model, when adopting the market-segmentation strategy, the manufacturer leases the products with quality q_t^o and q_e^o to ordinary consumers at the leasing price P_o and the products with quality q_t^g and q_e^g to green consumers at the leasing price P_g. The optimization problem of the manufacturer is as follows:

$$\begin{aligned}&\max_{P_o,P_g,q_t^o,q_t^g} \quad \pi_{(L,\mathrm{seg})}\left(P_o, P_g, q_t^o, q_t^g\right)\\ &= \sum_{i\in\{o,g\}} \left(\left(P_i - c\right)adD_i - \left(c_t q_t^{i2} + c_e q_e^{i2}\right)rD_i\right),\end{aligned} \tag{9}$$

subject to

$$ad\left(v_t q_t^o - wP_o\right) \geq 0, \tag{10}$$

$$ad\left(v_t q_t^g + v_e q_e^g - wP_g\right) \geq 0, \tag{11}$$

$$ad\left(v_t q_t^o - wP_o\right) \geq ad\left(v_t q_t^g - wP_g\right), \tag{12}$$

$$ad\left(v_t q_t^g + v_e q_e^g - wP_g\right) \geq ad\left(v_t q_t^o + v_e q_e^o - wP_o\right). \tag{13}$$

In the profit function (9), $P_i - c$ is the manufacturer's revenue from each time that consumers use the product; because of the ownership, the manufacturer undertakes the usage cost c [1]. Consumers use products adD_i times in total. Because of the pooling effect, the total number of products required is rD_i. Constraints (10) and (11) are the individual rationality constraints under a pure leasing model, and constraints (12) and (13) are the incentive compatibility constraints, which ensure two types of consumers use their respective products. Similar to the constraints under a pure selling model, the constraints from (10) to (13) describe the consumers' self-selection under leasing.

Under a pure leasing model, when the manufacturer adopts the mass-marketing strategy, the optimization problem of the manufacturer is as follows:

$$\max_{P,q_t} \quad \pi_{(L,\mathrm{mas})}\left(P, q_t\right) = \sum_{i\in\{o,g\}} \left(\left(P - c\right)adD_i - \left(c_t q_t^2 + c_e q_e^2\right)rD_i\right), \tag{14}$$

subject to

$$ad\left(v_t q_t - wP\right) \geq 0, \tag{15}$$

$$ad\left(v_t q_t + v_e q_e - wP\right) \geq 0. \tag{16}$$

The objective function (14) is the profit that the manufacturer only provides a single product with quality q_t and q_e. The constraints (15) and (16) are the individual rationality constraints.

4.3. Green Product Design under the Hybrid Model. Under a hybrid model, although the manufacturer's leasing may be aimed at ordinary consumers or green consumers, leasing is more considered a green business model in practice. For example, Daimler and other firms such as Interface, IBM, HP, and Xerox promote their leasing programs as being environmentally friendly. Therefore, we only consider a hybrid model under which the manufacturer offers a leasing model for green consumers and a selling model for ordinary consumers. When adopting the market-segmentation strategy, the manufacturer sells the products to ordinary consumers and leases the products to green consumers. The optimization problem of the manufacturer is as follows:

$$\begin{aligned}&\max_{F_o,P_g,q_t^o,q_t^g} \quad \pi_{(H,\mathrm{seg})}\left(F_o, P_g, q_t^o, q_t^g\right)\\ &= \left(F_o - c_t q_t^{o2} - c_e q_e^{o2}\right)D_o + \left(P_g - c\right)adD_g\\ &\quad - \left(c_t q_t^{g2} + c_e q_e^{g2}\right)rD_g,\end{aligned} \tag{17}$$

subject to

$$d\left(v_t q_t^o - c\right) - wF_o \geq 0, \tag{18}$$

$$ad\left(v_t q_t^g + v_e q_e^g - wP_g\right) \geq 0, \tag{19}$$

$$d\left(v_t q_t^o - c\right) - wF_o \geq ad\left(v_t q_t^g - wP_g\right), \tag{20}$$

$$ad\left(v_t q_t^g + v_e q_e^g - wP_g\right) \geq d\left(v_t q_t^o + v_e q_e^o - c\right) - wF_o. \tag{21}$$

The objective function (17) is the profit under a hybrid model. The constraints (18) and (19) indicate the consumers' utilities are nonnegative, which ensure the consumers' participation. The constraints (20) and (21) indicate the consumers prefer their respective products over the other.

Under a hybrid model, when the manufacturer adopts the mass-marketing strategy, the optimization problem of the manufacturer is as follows:

$$\begin{aligned}\max_{F,P,q_t} \quad \pi_{(H,\mathrm{mas})}\left(F, P, q_t\right) &= \left(F - c_t q_t^2 - c_e q_e^2\right)D_o + \left(P - c\right)adD_g\\ &\quad - \left(c_t q_t^2 + c_e q_e^2\right)rD_g,\end{aligned} \tag{22}$$

subject to

$$d\left(v_t q_t - c\right) - wF \geq 0, \tag{23}$$

$$ad\left(v_t q_t + v_e q_e - wP\right) \geq 0, \tag{24}$$

$$d\left(v_t q_t - c\right) - wF \geq ad\left(v_t q_t - wP\right), \tag{25}$$

$$ad\left(v_t q_t + v_e q_e - wP\right) \geq d\left(v_t q_t + v_e q_e - c\right) - wF. \tag{26}$$

The objective function (22) is the profit that the manufacturer provides a single product through a hybrid model. The constraints (23) and (24) are the individual rationality constraints. Although there is only a single product, the consumers still have two choices, i.e., to buy or to lease the products. Therefore, the incentive compatibility constraints (25) and (26) should be considered.

Solving the six optimization problems above, we obtain the optimal prices and qualities under different business models, as shown in Table 2 (see Appendix A for proof).

5. Business Model Choice and Green Product Design

In this section, we analyze the manufacturer's optimal business model choice and green product design by comparing the optimal profits and environmental qualities under different business models. For convenience, we use $\overline{q}_{t,(i,j)}$ and $\overline{q}_{e,(i,j)}$ to denote the average traditional and environmental quality under (i, j) strategy, where $i \in \{S, L, H\}$ and $j \in \{\text{mas}, \text{seg}\}$.

Proposition 1. *The manufacturer's profits are always better under the market-segmentation strategy than those under the mass-marketing strategy. The average environmental qualities are equal under both market-segmentation and mass-marketing strategies.*

Proof of Proposition 1. Under different business models, we compare the optimal profits under the market-segmentation strategy with those under the mass-marketing strategy:

$$\pi_{(S,\text{seg})} - \pi_{(S,\text{mas})} = \frac{\left(D_o + D_g\right)v_e^2 d^2 D_g}{4D_o w^2\left(c_t + c_e\right)} > 0, \tag{27}$$

$$\pi_{(L,\text{seg})} - \pi_{(L,\text{mas})} = \frac{\left(D_o + D_g\right)v_e^2 a^2 d^2 D_g}{4D_o w^2 r\left(c_t + c_e\right)} > 0, \tag{28}$$

$$\pi_{(H,\text{seg})} - \pi_{H,\text{mas}} = \frac{\left(D_o\left(a\left(v_t - v_e\right) - rv_t\right) - rv_e D_g\right)^2 d^2 D_g}{4D_o w^2 r\left(c_t + c_e\right)\left(rD_g + D_o\right)} > 0. \tag{29}$$

Therefore, the optimal profits under the market-segmentation strategy are always higher than those under the mass-marketing strategy.

Comparing the average environmental qualities under the market-segmentation and mass-marketing strategies, according to $q_t + q_e = 1$, we have

$$\overline{q}_{e,(S,\text{mas})} - \overline{q}_{e,(S,\text{seg})} = \overline{q}_{t,(S,\text{seg})} - \overline{q}_{t,(S,\text{mas})} = 0, \tag{30}$$

$$\overline{q}_{e,(L,\text{mas})} - \overline{q}_{e,(L,\text{seg})} = \overline{q}_{t,(L,\text{seg})} - \overline{q}_{t,(L,\text{mas})} = 0, \tag{31}$$

$$\overline{q}_{e,(H,\text{mas})} - \overline{q}_{e,(H,\text{seg})} = \overline{q}_{t,(H,\text{seg})} - \overline{q}_{t,(H,\text{mas})} = 0. \tag{32}$$

In equations (30)–(32), $\overline{q}_{t,(i,j)}$ and $\overline{q}_{e,(i,j)}$ represent the average traditional and environmental quality under (i, j) strategy, where $i \in \{S, L, H\}$ and $j \in \{\text{mas}, \text{seg}\}$. As there are two types of products under the market-segmentation strategy, we have $\overline{q}_{t,(S,\text{seg})} = (q_t^{o*}D_o + q_t^{g*}D_g)/(D_o + D_g)$, $\overline{q}_{t,(L,\text{seg})} = (q_t^{o*}rD_o + q_t^{g*}rD_g)/(rD_o + rD_g)$, and $\overline{q}_{t,(H,\text{seg})} = (q_t^{o*}D_o + q_t^{g*}rD_g)/(D_o + rD_g)$. Because there is only a single product under the mass-marketing strategy, $\overline{q}_{t,(i,\text{mas})} = q^*_{t,(i,\text{mas})}$. Equations (30)–(32) indicate that the average environmental qualities are equal under the market-segmentation and mass-marketing strategies.

Proposition 1 shows that the market-segmentation strategy can improve profitability but have no impact on the average environmental quality. Specifically, (i) the transition from selling to leasing cannot change the adoption of the market-segmentation strategy. For example, under both traditional selling model and the car-sharing program, car2go provides different types of vehicle including traditional and electric vehicles. (ii) The existence of green consumers cannot improve the average environmental performance of products. Although the manufacturer produces greener products for green consumers under the market-segmentation strategy, the average environmental quality cannot be improved. The reason is that the cannibalization effect limits the effect of green consumers. To be specific, the cannibalization limits the price of the greener products for green consumers, thus reducing the marginal revenue of the environmental quality.

Proposition 2. *(i) When $r < av_tD_o/((1-a)D_gv_e + D_ov_t)$, we have $\overline{q}_{e,(S,seg)} > \overline{q}_{e,(H,seg)} > \overline{q}_{e,(L,seg)}$. (ii) When $av_tD_o/((1-a)D_gv_e + D_ov_t) < r < a$, we have $\overline{q}_{e,(S,seg)} > \overline{q}_{e,(L,seg)} > \overline{q}_{e,(H,seg)}$. (iii) When $a < r < (av_t + v_e - av_e)/v_t$, we have $\overline{q}_{e,(L,seg)} > \overline{q}_{e,(S,seg)} > \overline{q}_{e,(H,seg)}$. (iv) When $r > (av_t + v_e - av_e)/v_t$, we have $\overline{q}_{e,(L,seg)} > \overline{q}_{e,(H,seg)} > \overline{q}_{e,(S,seg)}$.*

Proof of Proposition 2. Comparing the average environmental qualities under different business models, we have

$$\overline{q}_{t,(S,\text{seg})} - \overline{q}_{t,(L,\text{seg})} = \frac{(r-a)dv_t}{2wr\left(c_t + c_e\right)}, \tag{33}$$

$$\overline{q}_{t,(H,\text{seg})} - \overline{q}_{t,(L,\text{seg})} = \frac{d\left(\left((1-a)D_gv_e + D_ov_t\right)r - aD_ov_t\right)}{2wr\left(c_t + c_e\right)\left(D_o + rD_g\right)}, \tag{34}$$

$$\overline{q}_{t,(H,\text{seg})} - \overline{q}_{t,(S,\text{seg})} = \frac{dD_g\left((a-r)v_t + (1+a)v_e\right)}{2w\left(c_t + c_e\right)\left(D_o + rD_g\right)}, \tag{35}$$

because the denominators of the three fractions above are positive. According to (33), when $r < a$, we have $\overline{q}_{t,(S,\text{seg})} < \overline{q}_{t,(L,\text{seg})}$, i.e., $\overline{q}_{e,(S,\text{seg})} > \overline{q}_{e,(L,\text{seg})}$. When $r > a$, $\overline{q}_{e,(S,\text{seg})} > \overline{q}_{e,(L,\text{seg})}$. According to (34), when $r > av_tD_o/((1-a)D_gv_e + D_ov_t)$, we have $\overline{q}_{e,(H,\text{seg})} > \overline{q}_{e,(L,\text{seg})}$ and when $r < av_tD_o/((1- a)D_gv_e + D_ov_t)$, $\overline{q}_{e,(H,\text{seg})} > \overline{q}_{e,(L,\text{seg})}$. According to (35), when $r > (av_t + v_e - av_e)/v_t$, $\overline{q}_{e,(H,\text{seg})} > \overline{q}_{e,(S,\text{seg})}$ and when $r > (av_t + v_e - av_e)/v_t$, $\overline{q}_{e,(H,\text{seg})} > \overline{q}_{e,(S,\text{seg})}$. Then, we prove the relationship among the critical points. First, let $(av_t + v_e - av_e)/v_t$ be divided by $av_tD_o/((1-a)D_gv_e + D_ov_t)$, we have $((av_t + v_e - av_e)/v_t)/(av_tD_o/((1-a)D_gv_e + D_ov_t)) = (av_t + v_e - av_e)((1-a)D_gv_e + D_ov_t)/av_t{}^2D_o = 1 + ((v_e/av_t) - (v_e/v_t)) + ((D_gv_e/D_ov_t) - (aD_gv_e/D_ov_t)) + (a-1)^2D_gv_e{}^2/v_t{}^2D_oa$, where $(v_e/av_t) - (v_e/v_t) \geq 0$, $(D_gv_e/D_ov_t) - (aD_gv_e/D_ov_t) \geq 0$, and $((a-1)^2D_gv_e^2/v_t^2D_oa) \geq 0$ (because of $a \leq 1$); therefore, $((av_t + v_e - av_e)/v_t)/(av_tD_o/((1-a)D_gv_e + D_ov_t)) \geq 1$, i.e., $((av_t + v_e - av_e)/v_t) \geq (av_tD_o/((1-a)D_gv_e + D_ov_t))$. Second, subtract a from $(av_t +$

Table 2: Optimal prices and qualities.

Business model	Optimal prices	Optimal qualities
(S, seg)	$F_o^* = d(v_t q_t^{o*} t - c)/w$, $F_g^* = d(v_t - v_e)q_t^{g*} + dv_e q_t^{o*} - dc/w$	$q_t^{o*} = c_e/(c_t + c_e) + d(v_e D_g + v_t D_o)/2w(c_t + c_e)D_o$, $q_t^{g*} = c_e/(c_t + c_e) + d(v_t - v_e)/2w(c_t + c_e)$, $q_e^{o*} = 1 - q_t^{o*}$, $q_e^{g*} = 1 - q_t^{g*}$
(S, mas)	$F^* = d(v_t q_t^* - c)/w$	$q_t^* = c_e/(c_t + c_e) + dv_t/2w(c_t + c_e)$, $q_e^* = 1 - q_t^*$
(L, seg)	$P_o^* = v_t q_t^{o*}/w$, $P_g^* = (v_t - v_e)q_t^{g*} + v_e q_t^{o*}/w$	$q_t^{o*} = c_e/(c_t + c_e) + ad(v_e D_g + v_t D_o)/2rw(c_t + c_e)D_o$, $q_t^{g*} = c_e/(c_t + c_e) + ad(v_t - v_e)/2rw(c_t + c_e)$, $q_e^{o*} = 1 - q_t^{o*}$, $q_e^{g*} = 1 - q_t^{g*}$
(L, mas)	$P^* = v_t q_t^*/w$	$q_t^* = c_e/(c_t + c_e) + adv_t/2rw(c_t + c_e)$, $q_e^* = 1 - q_t^*$
(H, seg)	$F_o^* = d(v_t q_t^{o*} - c)/w$, $P_g^* = a(v_t - v_e)q_t^{g*} + v_e q_t^{o*} + (a-1)v_e/aw$	$q_t^{o*} = c_e/(c_t + c_e) + d(v_e D_g + v_t D_o)/2w(c_t + c_e)D_o$, $q_t^{g*} = c_e/(c_t + c_e) + ad(v_t - v_e)/2rw(c_t + c_e)$, $q_e^{o*} = 1 - q_t^{o*}$, $q_e^{g*} = 1 - q_t^{g*}$
(H, mas)	$F^* = d(v_t q_t^* - c)/w$, $P^* = v_t q_t^*/w$	$q_t^* = c_e/c_t + c_e + d(v_t D_o + ((1-a)v_e + av_t)D_g)/2w(c_t + c_e)(D_o + rD_g)$, $q_e^* = 1 - q_t^*$

$v_e - av_e)/v_t$ and $av_t D_o/((1-a)D_g v_e + D_o v_t)$, we have $((av_t + v_e - av_e)/v_t) \geq a \geq (av_t D_o/((1-a)D_g v_e + D_o v_t))$. Therefore, Proposition 2 is proved.

For clarity, we illustrate Proposition 2 in Figure 2.

Proposition 2 shows that the business model choice has an important impact on the average environmental quality and its impact depends on the pooling effect. Specifically, when the pooling effect is strong ($r < a$), a pure leasing and hybrid model is environmentally inferior to a pure selling model. When the pooling effect is weak ($r > a$), a pure leasing model is environmentally beneficial, and a hybrid model is environmentally beneficial only when the pooling effect is very weak ($r > (av_t + v_e - av_e)/v_t$). The underlying reason is the interaction between the pooling effect and the cannibalization effect, which leads to the pooling effect being unfavorable to the environmental quality. Specifically, the pooling reduces the marginal cost by decreasing the number of products required under leasing, thus providing an incentive to improve the product quality. However, the cannibalization effect limits the price for the green consumer (i.e., F_g or P_g) because if F_g or P_g is too high, green consumers will purchase or lease the other product at price F_o or P_o. This leads to a reduction in the marginal revenue for environmental quality. Therefore, the consequence of the interaction between the pooling effect and the cannibalization effect is not in favor of improving environmental quality.

Proposition 2 provides important managerial implications: (i) Leasing may not be environmentally beneficial. Although the pooling effect enables the manufacturer to produce fewer products, which lowers the environmental impact, the average environmental quality of products may be lower. (ii) A hybrid model is different from a pure leasing because the impact of the pooling is alleviated (because there is only one type of product provided through leasing), and the impact of the cannibalization is alleviated too (because a hybrid model increases heterogeneity of the products); therefore, the interaction between the pooling effect and the average environmental quality under a hybrid model is not as simple as the other pure business models. For example, when $r < a$, the average environmental quality under a hybrid model (i.e., $\overline{q}_{e,(H,\text{seg})}$) increases with the pooling effect. However, when $r > a$, $\overline{q}_{e,(H,\text{seg})}$ decreases with the pooling effect. As illustrated in Figure 2, when $r < a$ and if r decreases, $\overline{q}_{e,(H,\text{seg})}$ becomes better than $\overline{q}_{e,(L,\text{seg})}$, but when $r > a$ and if r decreases, $\overline{q}_{e,(H,\text{seg})}$ becomes worse than $\overline{q}_{e,(S,\text{seg})}$. This implies the duality of a hybrid model.

According to Propositions 1 and 2, the optimal strategy of green product design can be concluded. On the whole, the manufacturer has two product design strategies to choose from as follows: First, the market-segmentation strategy of focusing on traditional performance. Under this strategy, the manufacturer provides two types of products to two consumer segments and the average environmental quality of products is relatively low. Second, the market-segmentation strategy of focusing on environmental performance. Under this strategy, the manufacturer provides two types of products to two consumer segments, and the average environmental quality of products is relatively high. The adoption of green product design strategies depends on the business model and the pooling effect. According to Figure 2, when the pooling effect is strong ($r < a$), the manufacturer should adopt the market-segmentation strategy of focusing on traditional performance under leasing. When the pooling effect is weak ($r > a$), the manufacturer should focus on environmental performance under leasing.

Proposition 3. *When $c(1 - aw)/w < \min\{K_1(r), K_2(r)\}$, the manufacturer should adopt a pure selling business model; when $c(1 - aw)/w > \max\{K_1(r), K_3(r)\}$, the manufacturer should adopt a pure leasing model; and when $K_2(r) < c(1 - aw)/w < K_3(r)$, a hybrid model should be adopted ($K_1(r)$, $K_2(r)$, and $K_3(r)$ are given in the following proof).*

Proof of Proposition 3. For comparing the selling and leasing models, we subtract the profit under pure leasing from that under pure selling, and we have

$$\pi_{(L,\text{seg})} - \pi_{(S,\text{seg})} = \frac{(D_o + D_g)}{4w^2(c_t + c_e)rD_o}\Big(-4c_t c_e w^2 r^2 + \big(-v_t^2 d^2 + 4(-awc(c_t + c_e) + (av_t + c - v_t)c_e + cc_t)wd + 4c_t c_e w^2\big)r + a^2 v_t^2 d^2\big)D_o + D_g v_e^2 d^2\big(a^2 - r\big)\Big). \tag{36}$$

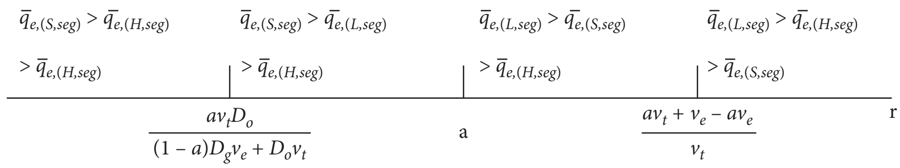

Figure 2: Comparison of the average environmental qualities.

According to (36), only when $c(1-aw)/w = K_1(r)$, we have $\pi_{(L,\mathrm{seg})} - \pi_{(S,\mathrm{seg})} = 0$, where $K_1(r)$ is as follows:

$$\begin{aligned}K_1(r) = &-\frac{1}{4w^2(c_t+c_e)rD_od}\left(a^2D_gv_e^{\,2}d^2 + D_oa^2v_t^{\,2}d^2\right.\\&+4D_oac_er\,dw\,v_t - 4D_oc_tc_ew^2r^2 - D_grv_e^{\,2}d^2\\&\left.+4D_oc_tc_ew^2r - 4c_tc_er\,dw\,v_t - D_orv_t^{\,2}d^2\right).\end{aligned} \quad (37)$$

Therefore, if $c(1-aw)/w > K_1(r)$, $\pi_{(L,\mathrm{seg})} > \pi_{(S,\mathrm{seg})}$, and if $c(1-aw)/w < K_1(r)$, $\pi_{(L,\mathrm{seg})} < \pi_{(S,\mathrm{seg})}$.

Similarly, we subtract the profit under the hybrid model from that under a pure selling and leasing model, and we have

$$\begin{aligned}\pi_{(H,\mathrm{seg})} - \pi_{(S,\mathrm{seg})} = &\frac{1}{4w^2(c_t+c_e)r}\Big(\left(v_e-v_t\right)^2\left(a^2-r\right)d^2\\&+4r\left(-acw\left(c_t+c_e\right)\left(av_t+c-v_t\right)c_e\right.\\&\left.+c_t\left(av_e+c-v_e\right)\right)wd\\&-4c_tc_ew^2r\left(r-1\right)\Big)D_g,\end{aligned} \quad (38)$$

$$\begin{aligned}\pi_{(L,\mathrm{seg})} - \pi_{(H,\mathrm{seg})} = &\frac{1}{4w^2(c_t+c_e)rD_o}\bigg(\Big(v_t^{\,2}\left(a^2-r\right)d^2\\&+4r\Big(-acw\left(c_t+c_e\right)+\left(av_t+c-v_t\right)c_e\\&+cc_t\Big)wd-4c_tc_ew^2r\left(r-1\right)\Big)D_o^{\,2}\\&+2v_eD_g\Big(v_t\left(a^2-r\right)d-2c_trw\left(a-1\right)\Big)dD_o\\&+v_e^{\,2}d^2D_g^{\,2}\left(a^2-r\right)\bigg).\end{aligned} \quad (39)$$

According to (38) and (39), when $c(1-aw)/w = K_2(r)$, $\pi_{(H,\mathrm{seg})} - \pi_{(S,\mathrm{seg})} = 0$. When $c(1-aw)/w = K_3(r)$, $\pi_{(L,\mathrm{seg})} - \pi_{(H,\mathrm{seg})} = 0$, where $K_2(r)$ and $K_3(r)$ are as follows:

$$\begin{aligned}K_2(r) = &\frac{1}{4w^2(c_t+c_e)r\,d}\Big(-a^2v_e^{\,2}d^2 + 2a^2v_tv_ed^2\\&-a^2v_t^2d^2 - 4ac_er\,dw\,v_t - 4ac_tr\,dw\,v_e + 4c_tc_er^2w^2\\&-4c_tc_erw^2 + 4c_er\,dw\,v_t + 4c_tr\,dw\,v_e + rv_e^{\,2}d^2\\&-2rv_tv_ed^2 + rv_t^{\,2}d^2\Big),\end{aligned} \quad (40)$$

$$\begin{aligned}K_3(r) = &-\frac{1}{4w^2(c_t+c_e)r\,dD_o^{\,2}}\Big(D_g^{\,2}a^2v_e^2d^2\\&+2a^2D_gD_od^2v_ev_t - 4D_gD_oac_tr\,dw\,v_e\\&+D_o^{\,2}a^2d^2v_t^{\,2} + 4D_o^2ac_er\,dw\,v_t - 4D_o^2c_tc_ew^2r^2\\&-D_g^{\,2}rd^2v_e^{\,2} + 4D_gD_oc_tr\,dw\,v_e - 2D_gD_ord^2v_tv_e\\&+4D_o^2c_tc_erw^2 - 4D_o^2c_er\,dw\,v_t - D_o^{\,2}rd^2v_t^{\,2}\Big).\end{aligned} \quad (41)$$

Therefore, when $c(1-aw)/w < \min\{K_1(r), K_2(r)\}$, the profit under a pure selling model is highest, when $c(1-aw)/w > \max\{K_1(r), K_3(r)\}$, a pure leasing is the manufacturer's best choice, and when $K_2(r) < c(1-aw)/w < K_3(r)$, a hybrid model is the best choice.

For clarity, we illustrate Proposition 3 in Figure 3. We regard the usage cost c as a dependent variable and the pooling effect parameter r as an independent variable and then draw the $K_1(r)$, $K_2(r)$, and $K_3(r)$ in Figure 3. For brevity and ease of exposition, the proofs for Characteristics of Functions, including the monotonicity and intersection point, etc., are provided in Appendix B.

Figure 3 shows the conditions under which the manufacturer adopts leasing. Generally speaking, the usage cost, the pooling effect, the consumers' price, and quality sensitivities are the determining factors for the manufacturer to choose the business models. As the consumers in the high-end market have low price sensitivity, $w < 1/a$ represents the high-end market and $w > 1/a$ represents the low-end market. Therefore, Figures 3(a)–3(d), respectively, correspond to four types of markets. Specifically, (i) in the high-end market with low environmental preference ($w < 1/a$ and $v_e < 2D_ov_t/(D_o - D_g)$), i.e., Figure 3(a), the strong pooling effect (i.e., r is small) will encourage the manufacturer to choose a pure leasing model. When the pooling effect is weak, the manufacturer should adopt the business models depending on the usage cost: if the usage cost is low, a pure selling model is the best choice, and a leasing or hybrid model is the best choice when the usage cost is high. (ii) In the low-end market with low environmental preference ($w > 1/a$ and $v_e < 2D_o v_t/(D_o - D_g)$), i.e., Figure 3(b), the manufacturer should adopt a pure leasing model when the pooling is strong. If the pooling is weak, the manufacturer should adopt a hybrid or leasing model when the usage cost is high. (iii) In the high-end market with high environmental preference (Figure 3(c)), the manufacturer should adopt a pure leasing model when the usage cost is high and a hybrid or selling models when the usage cost is low. (iv) In the low-end market with high environmental preference (Figure 3(d)), when the usage cost is low, a pure leasing is the best choice and when the usage cost is high, a pure selling or hybrid model should be adopted.

Proposition 3 provides important managerial implications: (i) the price sensitivity changes the impact of the usage cost on the business model choice. In the high-end market, the products with high usage cost should be provided through leasing. In the low-end market, the products with high usage cost are fit for a selling model. For example, electric vehicles cost less than half as much to operate as gas-powered cars (https://www.energysage.com/electric-vehicles/costs-and-benefits-evs/evs-vs-fossil-fuel-vehicles/, retrieved 22 June 2019). Therefore, gas-powered (electric) vehicles are more suitable for a leasing model in the high-end (low-end) market. (ii) The environmental quality sensitivity mainly influences the adoption of a hybrid model. The environmental quality sensitivity reflects the consumers' environmental preference. When the consumers' environmental preference is at a high level, the manufacturer adopts a hybrid model only if the pooling effect is strong. When the consumers' environmental preference is low, the manufacturer adopts a hybrid model only if the pooling effect is weak. (iii) The strong pooling is always beneficial for a pure leasing model. As illustrated in Figure 3, when the pooling effect increases, the region of pure leasing increases. However, the strong pooling may be harmful to a hybrid model, and only when the consumers' environmental preference is relatively high ($v_e > 2D_o v_t/(D_o - D_g)$), the region of a hybrid model increases with the pooling effect.

Proposition 2 shows the conditions under which leasing improves the environmental quality. Proposition 3 shows the conditions under which leasing improves the manufacturer's profit. Combining the two propositions, we have the condition under which leasing improves both environmental quality and profit.

Corollary 1. *When $c(1 - aw)/w > \max\{K_1(r), K_3(r)\}$ and $r > a$, a pure leasing model improves both profit and average environmental quality. When $K_2(r) < c(1 - aw)/w < K_3(r)$ and $r > (av_t + v_e - av_e)/v_t$, a hybrid model improves both profit and average environmental quality.*

According to Corollary 1, leasing may improve both profit and environmental quality, which depends on the pooling effect, the usage cost, and the types of markets. Combining Corollary 1 and Figure 3, we find that when the pooling effect is getting stronger, the manufacturer prefers leasing to selling (in Figure 3, the region of selling decreases with pooling effect). However, when the pooling effect is strong (i.e., $r < a$), leasing is not beneficial for the average environmental quality. Because only when $r > a$, the manufacturer could adopt the strategy focusing on environmental performance.

According to propositions and corollary above, the optimal business model and green product design strategy can be concluded; for clarity, the conclusions are shown in Table 3. Considering the practicability, we simplify the conclusion. For example, four market types correspond to Figures 3(a)–3(d). Strong pooling effect and high usage cost are relative; for example, compared with selling, leasing is more likely to be adopted under strong pooling in Figure 3(a) (i.e., when the pooling effect is weak, the region of leasing is relatively small). And compared with selling, a leasing or hybrid model is adopted under relatively high usage cost in Figure 3(a).

In Table 3, the optimal decisions on business models and product design are concluded. For example, facing a high-end market with high environmental preference, the manufacturer should make decisions depending on the usage cost and pooling effect. If the usage cost is high, a pure leasing model should be adopted. And then, the manufacturer should make decisions on the product design strategy based on the pooling effect, i.e., when the pooling is strong, the manufacturer should pay more attention to improving the traditional quality and when the pooling is weak, the manufacturer should improve the average environmental quality.

In summary, there are three main findings in this section. First, the interaction of the pooling effect and the cannibalization effect is critical for understanding the impact of leasing on green product design. That is, the pooling can decrease the marginal cost, which encourages the manufacturer to improve product quality under leasing; however, the cannibalization distorts the incentives and makes the pooling effect unfavorable to the environmental quality. Second, leasing may improve both profit and environmental quality; however, it depends on some conditions including the pooling effect, usage cost, and the types of markets. Third, the manufacturer has two types of product design strategies to choose from, including the strategy of focusing on traditional performance and the strategy of focusing on environmental performance; the business model choice has an influential impact on the adoption of product design strategy.

6. Numerical Analysis

In this section, we examine the impact of important parameters on the average environmental qualities and profits. Based on the assumption, we set the related parameters as follows: $w = 0.8$, $d = 100$, $v_t = 0.7$, $v_e = 0.6$, $D_g = 50$, $D_o = 100$, $c_e = 20$, $c_e = 90$, $r = 0.7$, $a = 0.8$, and $c = 0.1$.

6.1. Impact of Market Size. The parameters D_g and D_o represent the size of green consumers and ordinary

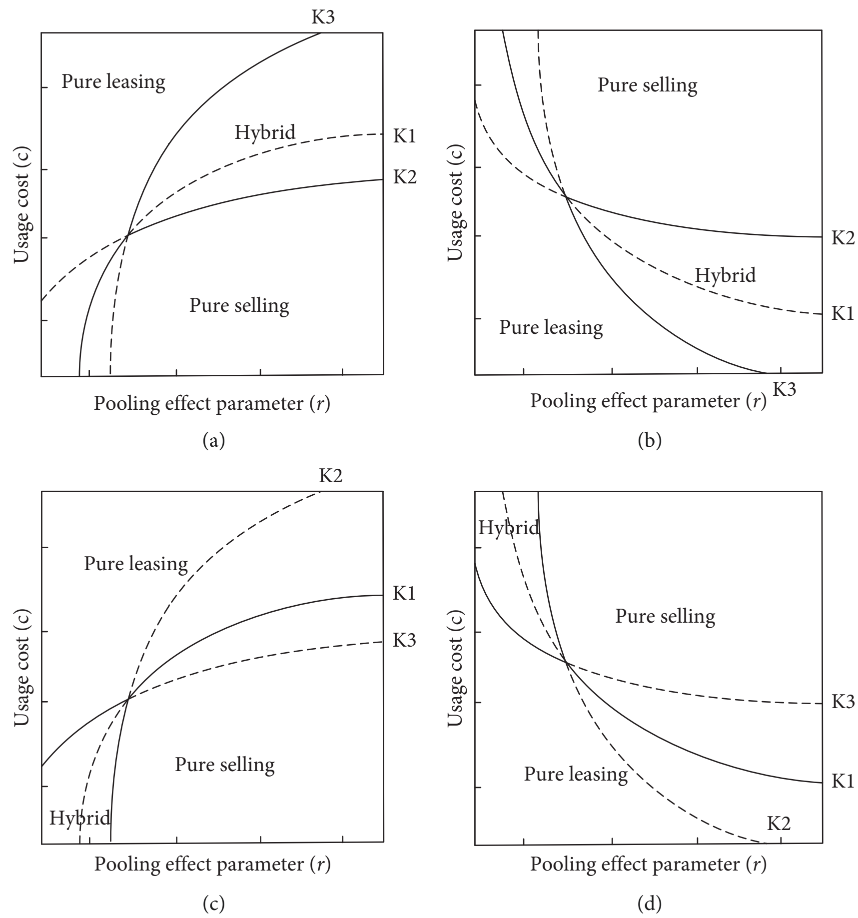

Figure 3: Optimal business model choices. (a) $w < 1/a$ and $v_e < 2D_o v_t/(D_o - D_g)$. (b) $w > 1/a$ and $v_e < 2D_o v_t/(D_o - D_g)$. (c) $w < 1/a$ and $v_e > 2D_o v_t/(D_o - D_g)$. (d) $w > 1/a$ and $v_e > 2D_o v_t/(D_o - D_g)$.

Table 3: Optimal business model choices and green product design strategies.

Types of Markets	Usage cost	Strong pooling effect	Weak pooling effect
High-end market with high environmental preference	High usage cost	Pure leasing model: the product design strategy of focusing on traditional performance	Pure leasing model: the product design strategy of focusing on environmental performance
	Low usage cost	Hybrid model: the product design strategy of focusing on traditional performance	Pure selling model: the product design strategy of focusing on traditional performance
High-end market with low environmental preference	High usage cost	Pure leasing model: the product design strategy of focusing on traditional performance	Pure leasing model or hybrid model: the product design strategy of focusing on environmental performance
	Low usage cost	Pure leasing model: the product design strategy of focusing on traditional performance	Pure selling model: the product design strategy of focusing on traditional performance
Low-end market with high environmental preference	High usage cost	Hybrid model: the product design strategy of focusing on traditional performance	Pure selling model: the product design strategy of focusing on traditional performance
	Low usage cost	Pure leasing model: the product design strategy of focusing on traditional performance	Pure leasing model: the product design strategy of focusing on environmental performance
Low-end market with low environmental preference	High usage cost	Pure leasing model: the product design strategy of focusing on traditional performance	Pure selling model: the product design strategy of focusing on traditional performance
	Low usage cost	Pure leasing model: the product design strategy of focusing on traditional performance	Pure leasing or hybrid model: the product design strategy of focusing on environmental performance

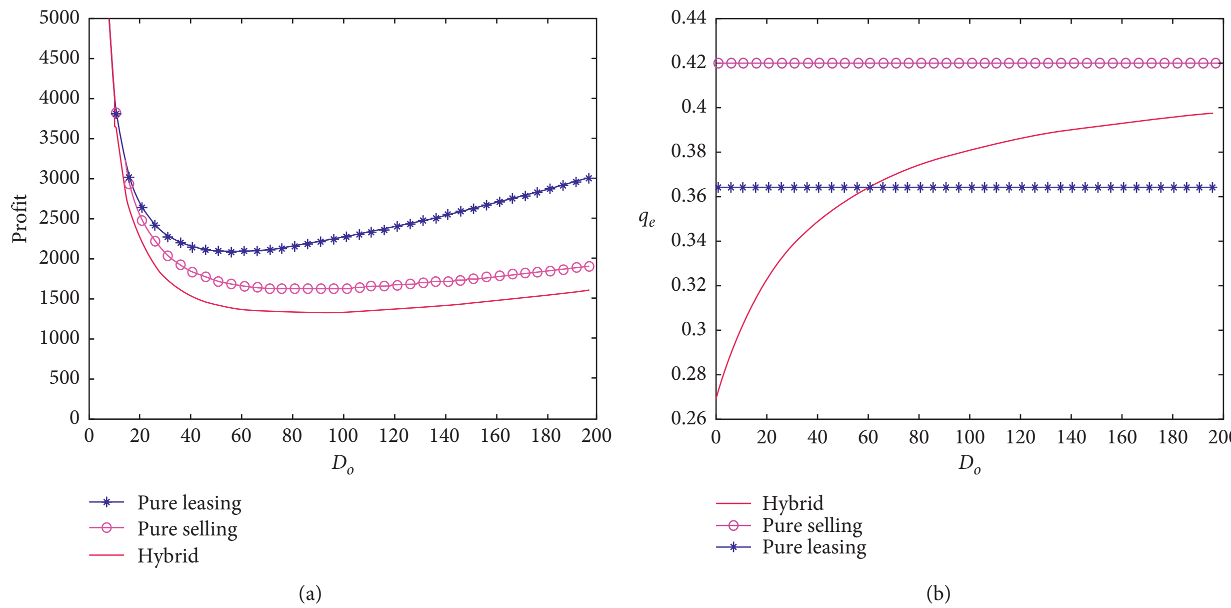

Figure 4: Impact of D_o on (a) profit and (b) environmental quality.

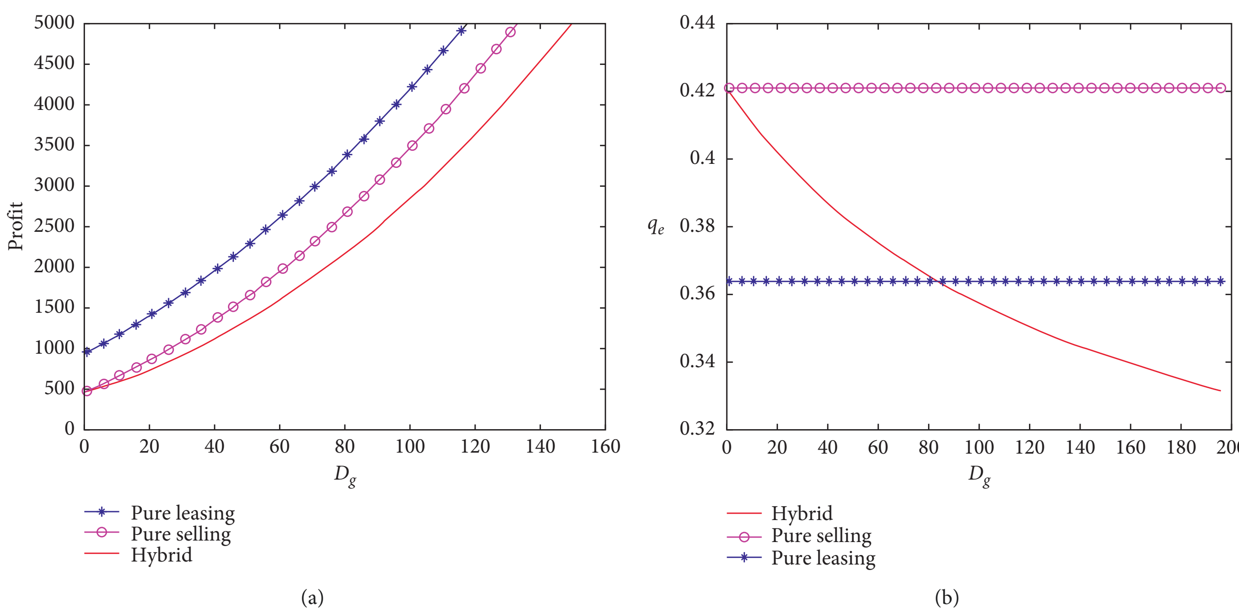

Figure 5: Impact of D_g on (a) profit and (b) environmental quality.

consumers, respectively. Figure 4 shows the impact of the ordinary consumers' size on profit and average environmental quality, with the value of D_o varying from 0 to 200. Then, we find the following: (i) The manufacturer profit decreases with D_o when D_o is relatively small, and the manufacturer profit increases with D_o when D_o is relatively large (Figure 4(a)). (ii) The average environmental quality increases with D_o only under a hybrid model, and the average environmental quality is irrelated with D_o under a pure selling and leasing model (Figure 4(b)).

With the value of D_g varying from 0 to 200, Figure 5 shows the impact of green consumers' size. We find the following: (i) The profit increases with D_g in Figure 5(a). (ii) The average environmental quality decreases with D_g under a hybrid model, while the average environmental quality under the other business models is irrelated with D_g in Figure 5(b).

From Figures 4 and 5, it is can be concluded that the growth of green consumers has a positive effect on the manufacturer's profit, while the growth of ordinary consumers may have a negative effect on profit. However, the growth of green consumers may decrease the average environmental quality while the growth of ordinary consumers may increase the average environmental quality. According to Table 2 and the proof of

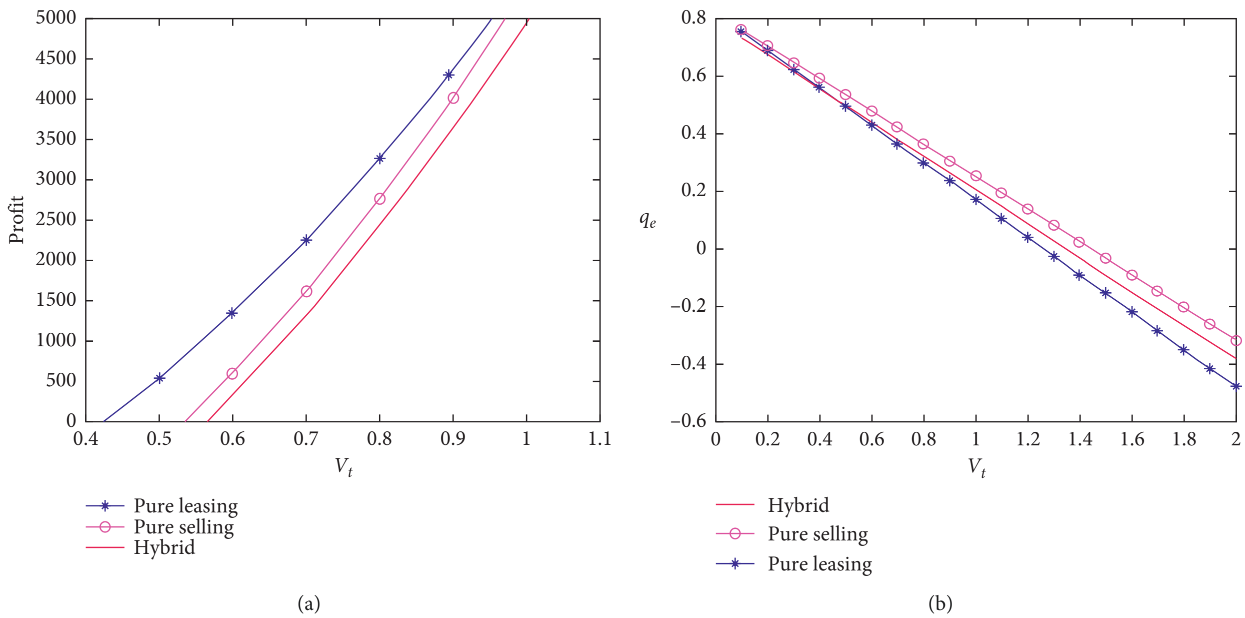

Figure 6: Impact of v_t on (a) profit and (b) environmental quality.

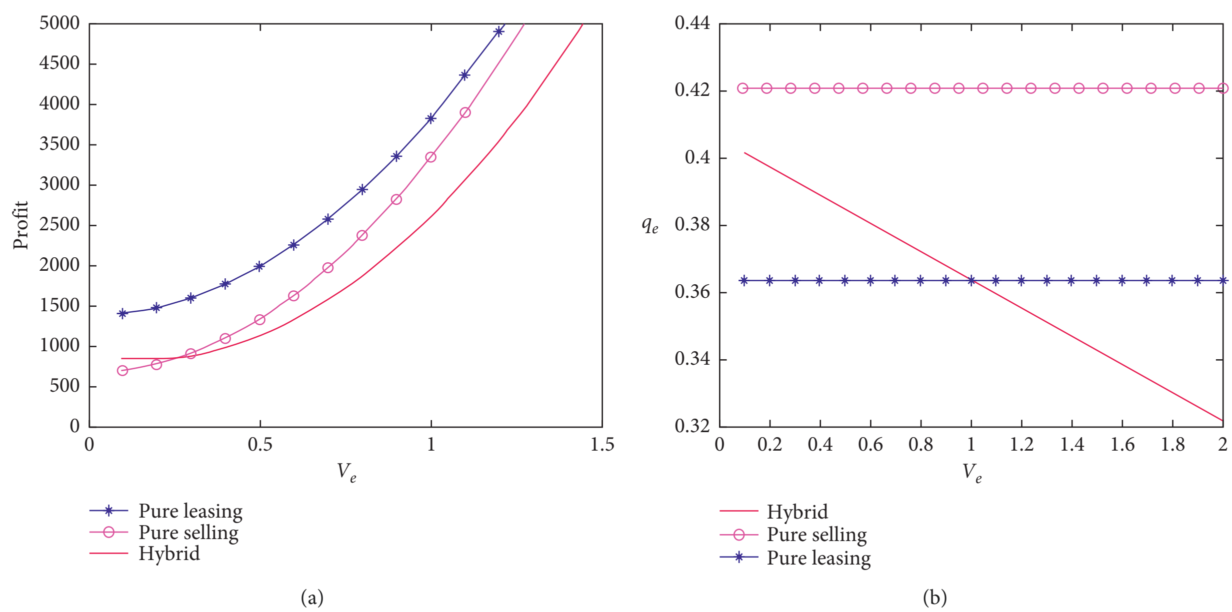

Figure 7: Impact of v_e on (a) profit and (b) environmental quality.

Proposition 1, $\overline{q}_{t,(H,\mathrm{seg})} = c_e/(c_t + c_e) + d(v_t D_o + ((1+a)v_e + a v_t)D_g)/2w(c_t + c_e)(D_o + rD_g)$; then, it is easy to find that both D_g and D_o have both positive and negative effects on the average environmental quality $\overline{q}_{t,(H,\mathrm{seg})}$. Therefore, the average environmental quality of each product may decrease.

6.2. Impact of Quality Sensitivity. v_e and v_t represent the environmental and traditional quality sensitivities, respectively. We let the value of both v_e and v_t vary from 0 to 2 in Figures 6 and 7. We find the following: (i) In Figure 6, the traditional quality sensitivity can improve the profit (Figure 6(a)) and decrease the average environmental quality (Figure 6(b)). (ii) In Figure 7, the increase of environmental quality sensitivity only improves the profit (Figure 7(a)) but cannot improve the average environmental quality (Figure 7(b)).

From Figures 6 and 7, it can be concluded that the environmental quality sensitivity can only improve the profit but cannot improve the average environmental quality. It is a surprising conclusion. Actually, Chen [18] found similar phenomenon under a pure selling model, and the reasons underlying are the same: the cannibalization limits the effect of the environmental quality sensitivity. Specifically, under the market-segmentation strategy, the high v_e increases the

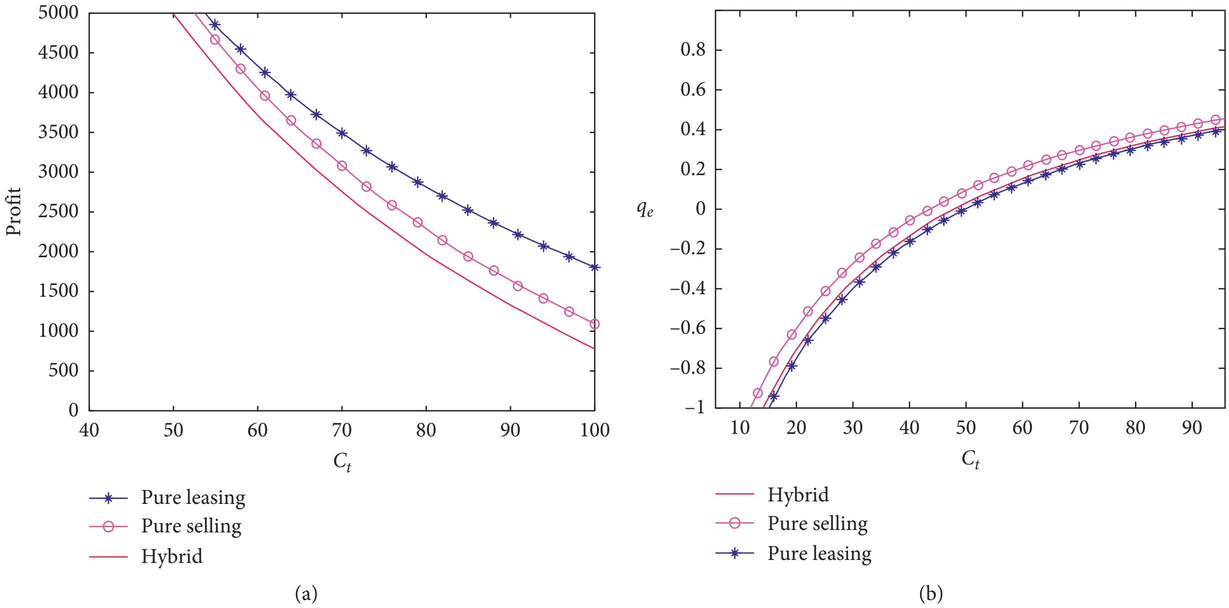

Figure 8: Impact of c_t on (a) profit and (b) environmental quality.

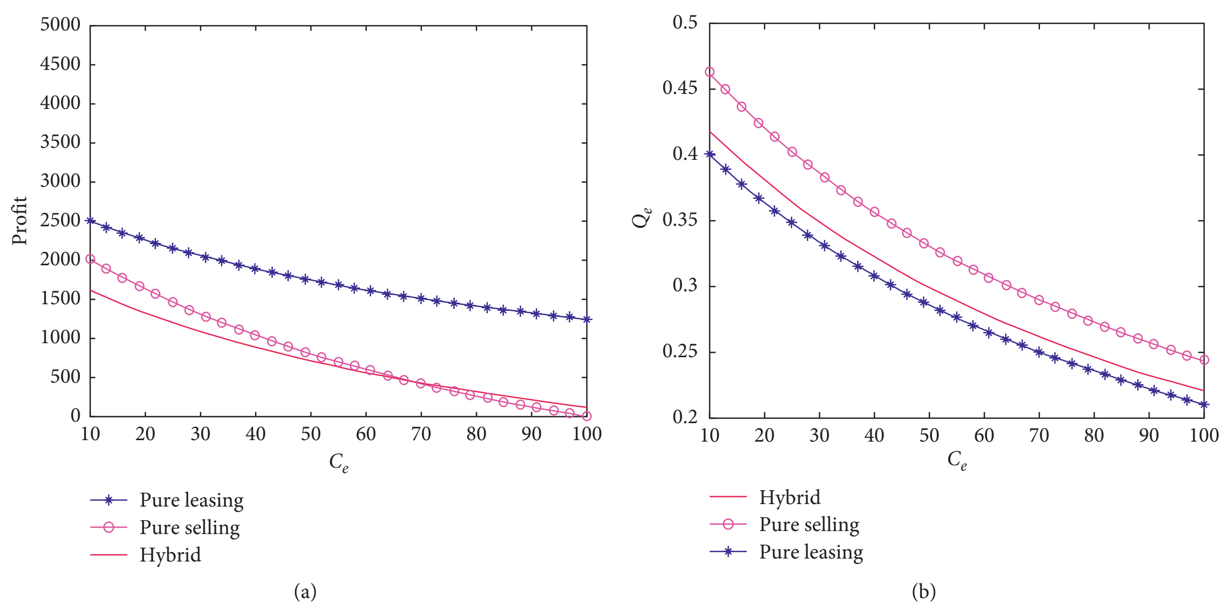

Figure 9: Impact of c_e on (a) profit and (b) environmental quality.

marginal revenue of environmental quality, thus increasing the environmental quality of product provided for green consumers (product g for short). This is a positive effect. However, the environmental quality of product provided for ordinary consumers (product o for short) is decreased because if the environmental quality of product g increases with v_e, then the product g is less attractive for ordinary consumers which allow the manufacturer to charge a higher price for product o, thus increasing the marginal revenue of traditional quality. This is a negative effect. Therefore, v_e has both positive and negative effects on the average environmental quality. According to Figure 7, under a pure leasing and selling model, the positive effect is offset by the negative effect, but under a hybrid model, the negative effect is more than the positive effect. Consequently, quality sensitivity cannot improve average environmental quality.

6.3. Impact of Production Cost. The parameters c_t and c_e represent the production cost, c_t is the cost related to the traditional quality, and c_e is the cost related to the environmental quality. Let the value of c_t and c_e vary from 0 to 100, we find the following: (i) In Figure 8, the product cost c_t has a negative impact on profit (Figure 8(a)) and a positive impact on the average environmental quality (Figure 8(b)). (ii) In Figure 9, the profit decreases with the production cost

c_e (Figure 9(a)), and the average environmental quality decreases with the production cost c_e too (Figure 9(b)).

From Figures 8 and 9, it can be concluded that the production cost related to traditional quality is beneficial to the average environmental quality, while the production cost related to environmental quality is harmful to the average environmental quality. This finding is intuitive.

In summary, while the factors from the demand side, i.e., market size and quality sensitivity, have an ambiguous or negative impact on the average environmental quality, the factors from the supply side, i.e., production cost, have a clear effect. Therefore, the reduction of the production cost related to environmental quality is more important for sustainability.

7. Conclusions

In this paper, we investigate the mechanism by which leasing affects green product design and analyze the economic and environmental consequences of leasing. We consider three business models, including a pure selling, a pure leasing, and a hybrid model. By taking the pooling effect, self-selection, and the trade-off between traditional and environmental qualities into account, we establish a mathematical model in which a manufacturer makes decisions on business models and green product design. The main findings are summarized as follows:

(i) The interaction between the pooling effect and the cannibalization effect has a significant impact on green product design under leasing. The underlying mechanism is as follows: the pooling effect decreases the marginal cost of production (because the pooling effect enables the manufacturer to provide fewer products to meet the consumer needs under leasing), thus encouraging the manufacturer to improve product quality. However, the cannibalization effect distorts the incentive (because the cannibalization decreases the marginal revenue of environmental quality). As a result, only when the pooling effect is weak, the average environmental quality under leasing is higher than that under selling.

(ii) The pooling effect, the usage cost, and the types of markets are the key factors for the manufacturer to make a decision on business models. Specifically, when the pooling is strong, the manufacturer should adopt a leasing or hybrid model in both high-end and low-end markets. When the pooling is weak, the manufacturer should adopt a leasing or hybrid model under high usage cost in the high-end market and in the low-end market, a leasing or hybrid model should be adopted when the usage cost is low.

(iii) The business model choice has an influential impact on the adoption of green product design strategy. In general, the manufacturer has two green product design strategies to choose from as follows: the market-segmentation strategy of focusing on traditional performance and the market-segmentation strategy of focusing on environmental performance. When the pooling is strong, the manufacturer should adopt the strategy of focusing on traditional performance under leasing. When the pooling is weak, the adoption of leasing makes the manufacturer choose the strategy of focusing on environmental performance.

(iv) Leasing may improve both profit and environmental quality. In general, the strong pooling is beneficial for the adoption of leasing but harmful for the average environmental quality.

There are several future research directions. In this paper, we do not consider the impact of competition on green product design under leasing. In practice, competition has an important influence on product design, but the mechanism by which competition affects green product design has not been understood sufficiently in the context of leasing. Therefore, introducing competition into our models for future research is valuable. Moreover, we do not take heterogenous customer valuations into account in this paper; as a result, demand does not change with price. Hence, modeling the relationship between price and demand could potentially generate more insights. Finally, rental platforms are adopted widely in practice and may profoundly change green product design under leasing. This is another promising direction for future research.

Appendix

A. Proof of Table 2

First, we solve the optimal price and quality decisions under (S,seg). When the manufacturer adopts the mass-marketing strategy under a selling model (i.e., (S,seg)), According to the objective function (1), we have $\delta\pi_{(S,\text{seg})}/\delta F_i > 0$, $(i \in \{o, g\})$, which means $\pi_{(S,\text{seg})}$ is increasing in F_i. Therefore, the manufacturer will set the price as higher as possible; however, F_i is limited by the constraints (2)–(5). According to the four constraints and the monotonicity of the objective function, we have

$$wF_o^* = \min\left\{d\left(v_t q_t^o - c\right), d\left(v_t q_t^o - c\right) - c\left(v_t q_t^g - c\right) + wF_g\right\}, \tag{A.1}$$

$$\begin{aligned} wF_g^* = \min\{&d\left(v_t q_t^g + v_e q_e^g - c\right), d\left(v_t q_t^g + v_e q_e^g - c\right) \\ &- d\left(v_t q_t^o + v_e q_e^o - c\right) + wF_o\}. \end{aligned} \tag{A.2}$$

According to (3) and (5), we know that constraint (3) is not binding. Because if (3) is binding, $d(v_t q_t^g + v_e q_e^g - c) - wF_g = 0$; then, we have $(d(v_t q_t^o + v_e q_e^o - c) - wF_o) \le 0$. This inequation conflicts with $d(v_t q_t^o - c) - wF_o \ge 0$ because $q_e^o \in [0,1]$. Therefore, according to (A.2), $wF_g^* = d(v_t q_t^g + v_e q_e^g - c) - d(v_t q_t^o + v_e q_e^o - c) + wF_o$, i.e., the constraint (5) is binding. In addition, the constraints (4) and (5) cannot be both binding because only when $q_t^o = q_t^g$, the constraints (4) and (5) are both binding; however, $q_t^o = q_t^g$ means the manufacturer only provides a single product, which is considered in the mass-marketing strategy.

Therefore, the constraint (4) is not binding. According to (A.1), $wF_o^* = d(v_t q_t^g - c)$. Then, we have optimal prices $F_o^* = d(v_t q_t^o - c)/w$ and $F_g^* = (d(v_t - v_e)q_t^{g*} + dv_e q_t^{o*} - dc)/w$. We take the optimal prices into the objective function (1); after solving $\delta\pi_{(S,\text{seg})}/\delta q_t^o = 0$ and $\delta\pi_{(S,\text{seg})}/\delta q_t^g = 0$, we have the optimal traditional quality $q_t^{o*} = c_e/(c_e + c_t) + (d(v_e D_g + v_t D_o))/2w(c_e + c_t)D_o$ and $q_t^{g*} = c_e/(c_e + c_t) + d(v_t - v_e)/2w(c_e + c_t)$. Then, the optimal environmental quality $q_e^{o^*} = 1 - q_t^{o^*}$ and $q_e^{g^*} = 1 - q_t^{g^*}$.

Similar to (S, seg), under (S, mas), $(\delta\pi_{(S,\text{mas})}/\delta F) > 0$. Therefore, the manufacturer will set the price as higher as possible; however, F is limited by the constraints (7) and (8). It is easy to know that the constraint (7) is binding; then, we have $F^* = d(v_t q_t^* - c)/w$. Solving $\delta\pi_{(S,\text{mas})}/\delta q_t = 0$, we have $q_t^* = c_e/(c_e + c_t) + (dv_t/2w(c_e + c_t))$.

Under (L, seg), we solve the problem by the same method under (S, seg). We have $(\delta\pi_{(L,\text{seg})}/\delta P_i) > 0$, $(i \in \{o, g\})$, and the constraints (10) and (13) are binding. Then, we have $P_o^* = v_t q_t^{o*}/w$ and $P_g^* = ((v_t - v_e)q_t^{g*} + v_e q_t^{o*})/w$. After solving $(\delta\pi_{(L,\text{seg})}/\delta q_t^o) = 0$ and $\delta\pi_{(L,\text{seg})}/\delta q_t^g = 0$, we have $q_t^{o*} = c_e/(c_e + c_t) + ad(v_e D_g + v_t D_o)/2rw(c_e + c_t)D_o$ and $q_t^{g*} = c_e/(c_e + c_t) + (ad(v_t - v_e)/2rw(c_e + c_t))$.

Under (L, mas), we have $(\delta\pi_{(L,\text{mas})}/\delta P) > 0$ and the constraints (15) are binding. Then, we have $P^* = v_t q_t^*/w$. By solving $\delta\pi_{(L,\text{mas})}/\delta q_t = 0$, $q_t^* = c_e/(c_e + c_t) + (adv_t/2rw(c_e + c_t))$.

Under (H, seg), we have $(\delta\pi_{(H,\text{seg})}/\delta F_o) > 0$ and $(\delta\pi_{(H,\text{seg})}/\delta P_g) > 0$. The constraints (18) and (21) are binding. We have $F_o^* = d(v_t q_t^o - c)/w$ and $P_g^* = a(v_t - v_e)q_t^{g*} + v_e q_t^{o*} + (a - 1)v_e/aw$. After taking the optimal prices into objective function and solving the derivatives of the profit with respect to prices, we obtain $q_t^{o*} = c_e/(c_e + c_t) + (d(v_e D_g + v_t D_o)/2w(c_e + c_t)D_o)$ and $q_t^{g*} = c_e/(c_e + c_t) + (ad(v_t - v_e)/2rw(c_e + c_t))$.

Under (H, mas), we have $(\delta\pi_{(H,\text{mas})}/\delta F) > 0$, $\delta\pi_{(H,\text{mas})}/\delta P$, and the constraints (23) and (26) are binding. In a similar way, we obtain $F^* = d(v_t q_t - c)/w$ and $P^* = v_t q_t/w$ and $q_t^* = c_e/(c_e + c_t) + (d(v_t D_o + ((1 - a)v_e + av_t)D_g)/2w(D_o + rD_g)(c_e + c_t))$.

B. Proof Related to Figure 3

First, we prove that when $1 - aw > 0$, $K_1(r)$, $K_2(r)$, and $K_3(r)$ increase with the parameter r and when $1 - aw < 0$, $K_1(r)$, $K_2(r)$, and $K_3(r)$ decrease with r.

When $1 - aw < 0$, we have $\delta K_1(r)/\delta r = (a^2 d^2 (D_g v_e^2 + D_o {v_t}^2) + 4D_o c_t c_e w^2 r^2 / 4w^2 (c_t + c_e) r^2 D_o d) > 0$, $\delta K_2(r)/\delta r = (a^2 d^2 (v_e - v_t)^2 + 4D_o c_t c_e w^2 r^2 / 4w^2 (c_t + c_e) r^2 d) > 0$, and $\delta K_3(r)/\delta r = (a^2 d^2 (D_g v_e + D_o v_t)^2 + 4D_o^2 c_t c_e w^2 r^2 / 4w^2 (c_t + c_e) r^2 d {D_o}^2) > 0$. Then, when $1 - aw < 0$, it is easy to know that $(\delta K_1(r)/\delta r) < 0$, $(\delta K_2(r)/\delta r) < 0$, and $(\delta K_3(r)/\delta r) < 0$.

Second, by solving $K_1(r) = K_2(r) = K_3(r)$, we have $r_1 = a^2 d(D_g v_e + 2D_o v_t - D_o v_e)/(4awD_o c_t + dD_g v_e - 4wD_o c_t - dD_o v_e + 2\,dD_o v_t)$; therefore, $K_1(r)$, $K_2(r)$, and $K_3(r)$ have only one intersection point.

Third, because $K_1(r) = K_2(r) = K_3(r)$ if and only if $r = r_1$, we know that, if $(\delta K_2(r)/\delta r) > (\delta K_1(r)/\delta r) > (\delta K_3(r)/\delta r)$, then we have $K_2(r) < K_1(r) < K_3(r)$ when $r = r_1$ and we have $K_2(r) > K_1(r) > K_3(r)$ when $r > r_1$. Similarly, if $(\delta K_3(r)/\delta r) > (\delta K_1(r)/\delta r) > (\delta K_2(r)/\delta r)$, we have $K_2(r) > K_1(r) > K_3(r)$ when $r < r_1$ and $K_2(r) > K_1(r) > K_3(r)$ when $r > r_1$.

Therefore, to examine the relationship among $K_1(r)$, $K_2(r)$, and $K_3(r)$, we only need to compare the derivatives as follows:

$$\frac{\delta K_2(r)}{\delta r} - \frac{\delta K_1(r)}{\delta r} = \frac{a^2 dv_e\left(D_g v_e + 2D_o v_t - D_o v_e\right)}{4w^2 r^2 (c_t + c_e) D_o}, \tag{B.1}$$

$$\frac{\delta K_3(r)}{\delta r} - \frac{\delta K_2(r)}{\delta r} = \frac{\left(D_o + D_g\right) a^2 dv_e\left(D_g v_e + 2D_o v_t - D_o v_e\right)}{4w^2 r^2 (c_t + c_e) {D_o}^2}, \tag{B.2}$$

$$\frac{\delta K_3(r)}{\delta r} - \frac{\delta K_1(r)}{\delta r} = \frac{D_g a^2 dv_e\left(D_g v_e + 2D_o v_t - D_o v_e\right)}{4w^2 r^2 (c_t + c_e) {D_o}^2}. \tag{B.3}$$

If denominators are positive, we can obtain as follows: when $v_e < (2D_o v_t/(D_o - D_g))$, $(\delta K_3(r)/\delta r) > (\delta K_1(r)/\delta r) > (\delta K_2(r)/\delta r)$ and when $v_e > (2D_o v_t/(D_o - D_g))$, $(\delta K_2(r)/\delta r) > (\delta K_1(r)/\delta r) > (\delta K_3(r)/\delta r)$. To sum up, if $1 - aw > 0$ and $v_e < (2D_o v_t/(D_o - D_g))$, we have $K_2(r) > K_1(r) > K_3(r)$ when $r < r_1$ and $K_2(r) < K_1(r) < K_3(r)$ when $r < r_1$. If $1 - aw > 0$ and $v_e < (2D_o v_t/(D_o - D_g))$, we have $K_2(r) < K_1(r) < K_3(r)$ when $r < r_1$ and $K_2(r) > K_1(r) > K_3(r)$ when $r > r_1$. If $1 - aw > 0$ and $v_e < (2D_o v_t/(D_o - D_g))$, we have $K_2(r) > K_1(r) > K_3(r)$ when $r > r_1$ and $K_2(r) > K_1(r) > K_3(r)$ when $r > r_1$. If $1 - aw > 0$ and $v_e < (2D_o v_t/(D_o - D_g))$, we have $K_2(r) > K_1(r) > K_3(r)$ when $r < r_1$ and $K_2(r) < K_1(r) < K_3(r)$ when $r > r_1$.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Acknowledgments

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