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Research Article

How Does Overconfidence Affect Decision Making of the Green Product Manufacturer?

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Overconfidence is a universal and prevalent cognitive bias affecting decision making in operation management. In this paper, overconfidence is defined as a cognitive bias in which decision makers overestimate the accuracy of demand forecasting or (and) the demand itself. We call these two behaviors overprecision and overestimation, respectively. In order to explore how overconfidence affects decision making of the green product manufacturer, we build the demand function based on the manufacturer's overconfidence and establish a newsboy-based model. Then the influence of overconfidence on product greenness, output, and profit is mainly discussed. We have several new sights as follows. First, overconfidence makes the manufacturer produce greener products than the rational manufacturer, and overestimation results in a higher greenness deviation than overprecision. Second, the influence of overconfidence on the output of green products is quite different from that of nongreen products. Specifically speaking, overestimation makes the manufacturer produce more products than the rational manufacturer, so do the overprecision manufacturer and the dual-overconfident manufacturer under the low-profit condition. But in high-profit condition, when greening investment factor is low and (or) consumers are sensitive enough to greenness, the overprecision manufacturer produces more than the rational manufacturer; when the level of overestimation exceeds a threshold, output of the dual-overconfident is greater than that of the rational manufacturer. Third, overconfidence makes the real profit of the manufacturer less than optimal profit of the rational manufacturer. There is a positive cross-effect of overprecision and overestimation in real profit of the dual-overconfident manufacturer. That is, to some extent, one kind of overconfidence can offset the decline in profit caused by the other kind of overconfidence.

1. Introduction

In the last twenty years, the unilateral pursuit of GDP economic growth in China has brought about a series of social problems such as smog and water pollution, which has seriously affected the living environment of human beings. The government is seeking solutions and has found that sustainable development can alleviate these problems. Driven by government regulations, environmental pressures, and green consumers' demand, sustainable operations have received increasing attention. Energy-saving and environment-friendly green products are favored by people, and many manufacturers are competing to develop environment-friendly products and occupying the green product markets. Some enterprises who have accurate market information and whose products correctly match the needs of green consumers have achieved good economic benefits and environmental reputation. But, some companies whose decision makers are blindly confident in the green market demand suffer a loss and even go into bankruptcy, since their products produced cannot meet the demand of green consumption very well.

Our problems are motivated by the cases of two green product manufacturers: Gree Electric Appliances Inc. of Zhuhai (GREE) and Jiangxi Saiwei LDK Solar Energy High-Tech Co., Ltd. (Saiwei). GREE is an electrical appliance manufacturer who adopted environment-friendly refrigerants and new green materials in product design and participated in drafting some industry standards and national standards in the field of home appliances. The firm explored a "Green Road" for sustainable development and has made good profits. In 2017, GREE was strongly listed on the "Green Product Leadership List" in China (http://www.sohu.com/a/206058186_610723. Retrieved April 3, 2019). The other firm, Saiwei, which produces photovoltaic products, is a new energy star manufacturer and was once the world's largest manufacturer of polysilicon wafers. Because of the founders' blind overconfidence in its product demand, a serious overcapacity led the firm to go bankrupt and restructure, and the 14 banks that provided loans for it were subjected to a total loss of 20 billion RMB (http://business.sohu.com/20160912/n468264227.shtml. Retrieved April 3, 2019). It can be seen that, as one of the most universal irrational behaviors in decision making, overconfidence has an important impact on green product manufacturers and even brings significant losses.

Plous [1] pointed out that "*no problem in judgment and decision making is more prevalent and more potentially catastrophic than overconfidence*". Therefore, it is of great practical significance to study the impact of overconfidence on decision making of the green product manufacturer. In this paper, we aim to investigate the following questions:

(a) What product greenness and output does the overconfident manufacturer choose?

(b) How does the change of greening investment factor, consumer green sensitivity, or unit product cost affect product greenness and output of the overconfident manufacturer?

(c) Does the manufacturer's overconfidence affect product greenness, output, and profit? If so, how does it affect?

We employ a newsboy-based model to study the above questions. In this setting, a manufacturer who produces and sells the only green product to consumers must decide product greenness and output before the start of a single selling season according to stochastic demand and earns net salvage value of the unsold products at the end of the season. In this paper, we find that, under the circumstances of overconfidence, there are significant differences between the operation outcomes of green products and nonproducts. The rest of the paper is organized as follows. Section 2 presents the relevant background literature of this paper. The assumptions and notation are given in Section 3. In Section 4, we establish the mathematical model and solve it. We study the effect of overconfidence on greenness, output, and profit in Sections 5 and 6, respectively. Section 7 is the conclusions.

2. Literature Review

There are three streams of research that relate to this study: theory of overconfidence, green product design, and overconfidence-based operation management. In the following section, we review literature relevant to each stream, respectively.

2.1. Overconfidence. As a psychological behavior, overconfidence has been widely studied in behavioral economic and behavioral management. For example, Camerer and Lovallo [2] used overconfidence to explain that, although the failure rate of entrepreneurship is high, the entrepreneurship rate continues to be high. Galasso and Simcoe [3] found that confidence in CEOs who are overoptimistic about the company's prospects leads to more and better innovation, and Herz et al. [4] proved theoretically and experimentally that there is a positive association between overoptimism and innovation, but a negative association between judgmental overconfidence and innovation. There are a lot of studies seeking to apply various forms of overconfidence to analyze and explain decision maker's behavior in different settings (e.g., Odean [5], Hoelzl and Rustichini [6], Bolton et al. [7], Malmendier and Tate [8], and Squintani [9]).

However, overconfidence has been studied in perplexingly different ways. Moore and Healy [10] reviewed over 350 papers covering various forms of overconfidence and summed up the three distinct types of overconfidence: overestimation, overplacement, and overprecision. In overestimation, individuals overestimate their actual ability or opportunity of success; they believe the outputs are better than reality [10, 11]. For example, students always overestimate their test scores [12], and people overestimate their ability to control [13]. In overplacement, people think that they are better than others [10, 11]. For example, it was reported that 93% of American drivers and 69% of Swedish drivers in a sample believed they were more skillful than the median driver in their own country [14]. In overprecision, people believe that their estimations about one's belief are excessive certainty than actuality; i.e., they are overconfident about the estimation of random outcomes [10, 11]. Haran [15] has proved experimentally that overprecision is the commonest type of overconfidence.

In this paper, we will capture overprecision and overestimation as a biased belief about demand distribution of green products.

2.2. Green Product Design. Green products, also known as environment-friendly products, or sustainable products, focus on the impact on environment in their life cycle. As mentioned by Securing and Muller [16], "sustainable product is the term used to comprehend all kinds of products that have or aim at an improved environmental and social quality". Many tools, such as environmental design, disassembly design, and life cycle analysis, are used to reduce the product's environmental impact [17]. Such investigation includes Zhu and Sarkis [18], Kara et al. [19], Albino et al. [20], etc. Product greenness is used to indicate the measurement of green performance and represents vertical differentiation on product features. Zhu and He [17] classified products as the development-intensive green product (DIGP) and the marginal cost-intensive green product (MIGP) based on the driving force of the product greenness. For DIGP, such as electric vehicles, R&D investment to develop new battery technologies is one of the main costs in the improvement of product greenness, and the R&D costs are almost unaffected by the production volume; hence, the driving force of greenness mainly influences the fixed costs. For MIGP, such as the gasoline-powered vehicles, the product greenness is mainly determined by elements such as materials or parts selected. Greening product to improve fuel efficiency and the emissions control system lead to additional costs in manufacturing, because this needs more advanced materials, more expensive components, and more work to do. Those additional costs are proportional to yields and therefore are variable costs. There are a substantial body of literature contributes to the issues of product design with a deterministic demand function. Zhu and He [17] discussed the problems of product design of MIGP as well as DIGP and investigated the impact of green product types (DIGP or MIGP) and the types of competition on the decision of product greenness. Ghosh and Shah [21, 22] investigated how greenness, prices, and profits were influenced by channel structures, and how greenness was affected by greening costs and consumer sensitivity. They also proposed contracts to coordinate the green channel [23]. Hong and Guo [24] analyzed and compared decisions on product greenness in several cooperation contracts under green supply chain. Li et al. [25] discussed the product greenness and pricing strategies in the single channel and dual-channel green chain supply chains. Shi et al. [26] incorporated fairness into green supply chain to study how fairness concern influenced product greenness, retail price, and profits.

Our paper differs from the existing research in that we focus on the impact of decision makers' behavior on product greenness under stochastic demand.

2.3. Overconfidence-Based Operation Management. In traditional operation literature, researchers usually assume that decision makers are completely rational and ignore the influence of psychological behavior, which leads to the decisions deviating from reality. In recent years, more and more scholars incorporate human behavior into operation management, such as fairness [27], risk-averse [28], loss-averse [29], etc. Schweizer and Cachon [30] found, even knowing the order quantity that maximizes expected profit, the newsvendor's choice still systematically deviated from the optimal value, and this bias cannot be explained by risk aversion, prospect theory, waste aversion, etc. Croson et al. [31] were the first to find the bias may be caused by overconfidence (in particular, overprecision) and presented a theoretical model to show that the overconfident newsvendor makes suboptimal decisions and earns lower profit than the well-calibrated newsvendor. Ren and Croson [32] further verified this theoretical conclusion through two experiments and used overconfidence to provide a reasonable explanation for the well-known pull-to-center effect in newsvendor experiments [30, 33]. Ren et al. [11] theoretically demonstrated that order bias is linear in the overconfidence level, and is increasing with the variance of the demand distribution. Li and Shan [34] studied the retailer's advance selling decisions when consumers were confident in product value, and found that the retailer would set a higher price in advanced selling period with overconfident consumers than that without. Jiang and Liu [35] investigated decisions on financing supply chain when supplier was overconfident and discussed the coordination issues between the supplier, the retailer, and the bank under supply chain contract. Li et al. [36] studied the effects and implications of overconfidence in a traditional competitive newsvendor setting. They found that overconfidence is a positive force for competing newsvendors, and it can lead to a better outcome than rational situation when the product's profit is high. Ma et al. [37] studied decisions on advertising and price of overconfident manufacturers in a competitive dual-channel supply chain. They found that the profits of manufactures under master-slave model are greater than that of decentralized model, while the profits of retailers are the opposite. Xu et al. [38] analyzed the impact of the retailer's overconfidence on pricing and supply chain performance. They found that the selling price charged by the retailer is increasing with the overconfidence level, and overconfidence does not necessarily damage the supply chain performance.

Different from the previous research, our model focuses on the influence of overconfidence on decisions of the green product manufacturer, especially the impact of overconfidence on product greenness, output, and profit.

To summarize, the paper contributes to the literature in two ways. First, we extend the green product design literature by incorporating the prevalent notion of overconfidence as a cognitive bias into a newsvendor based model to investigate its theoretical impact. Second, we contribute to the literature of overconfidence-based operation management by incorporating greenness as a special product nature into the decision model to investigate the operation differences between green products and nongreen products.

3. Model Assumptions

This paper considers a manufacturer who produces and sells a development-intensive product. In order to enter green product market, the manufacturer greens its products by introducing green production technology, upgrading production lines, new products R&D, and other investments. To formulate the problem, we make the following assumptions.

(1) The product greenness and output of the manufacturer are represented by g and q, respectively. According to [17], for DIGP, the greening investment is a fixed cost. We assume greening investment of the product with greenness g is $Ig^2/2$, where I is greening investment factor. The unit production cost of the green product is c, which is not affected by greening.

(2) The retail price of the green product is p, and the salvage value for the unsold products is s per unit. The parameters satisfy the inequality: $p > c > s > 0$.

(3) In [17, 21–23], the demand for green products is in a deterministic linear relationship with the retail price and greenness:

$$D(g) = a - bp + kg, \tag{1}$$

where $a, b > 0$, $a > bp$. In this equation, a is the market size; b is consumers' price sensitivity to demand; k is consumers' sensitivity to greenness. In the long run, k is gradually increasing since consumers are paying more attention to environmental protection.

In order to study the impact of overconfidence, we assume that the manufacturer faces stochastic market demand, and

Table 1: List of notations.

Decision variable	
g	greenness of the product; g_o^* is greenness selected by the overconfident manufacturer; g^* is greenness selected by the rational manufacturer
q	output of the manufacturer; q_o^* is output selected by the overconfident manufacturer; q^* is output selected by the rational manufacturer
Other symbols	
γ_1	the level of overprecision
γ_2	the level of overestimation
p	retail price
c	production cost per unit
s	salvage value for unsold product per unit
I	greening investment factor
a	the market size
b	consumers' price sensitivity to demand
k	consumers' sensitivity to greenness
ε	a continuous and non-negative random variable with mean 1 and variance σ^2
X	the standardized variable of ε
$F(\bullet)$, $f(\bullet)$	the distribution and density function of X, respectively
$F^{-1}(\bullet)$	the inverse function of $F(\bullet)$
T	a random variable, $T = 1 + \gamma_2 + (1 - \gamma_1)\sigma X$
$F_o(\bullet)$, $f_o(\bullet)$	the distribution and density function of T, respectively
$D(g)$	the deterministic linear relationship between demand and the retail price and greenness
$D(g,\varepsilon)$	the stochastic demand faced by the manufacturer
$D_o(g,\varepsilon)$	the demand that the overconfident manufacturer deems
$E\pi_o(g,q)$	expected profit that the overconfident manufacturer deems given g and q
$E\pi_o(g_o^*,q_o^*)$	the optimal expected profit that the overconfident manufacturer deems
$E\pi(g_o^*,q_o^*)$	the real expected profit of the overconfident manufacturer
$E\pi(g^*,q^*)$	the optimal expected profit of the rational manufacturer

we take the multiplicative demand case. Stochastic demand function is $D(g,\varepsilon) = (a - bp + kg) \bullet \varepsilon$, where ε is a continuous and nonnegative random variable with mean 1 and variance σ^2. Let $X = (\varepsilon - 1)/\sigma$, then X is the standardized random variable of ε, and the mean is 0 and variance is 1. The distribution and density function of X are denoted as $F(\bullet)$ and $f(\bullet)$, respectively. For $\varepsilon \geq 0$, we can get, when $x < -1/\sigma$, $f(x) = 0$ and $F(x) = 0$. Hence, the stochastic demand faced by the manufacturer can be expressed as

$$D(g,\varepsilon) = (a - bp + kg)(1 + \sigma X). \tag{2}$$

From (2), stochastic demand of the green product consists of deterministic part and random part corresponding to $a - bp + kg$ and $(a - bp + kg)\sigma X$, respectively.

(4) The manufacturer is overconfident and his overconfidence in demand is reflected in two aspects. (a) He overestimates his predictive power and his estimate of the variance of product demand is biased. Specially, the true demand distribution is more variable than the distribution which the manufacturer believes he faces. That is, the uncertainty of random part in (2) decreases. This behavior is called overprecision [11, 31, 32], and we use γ_1 $(0 \leq \gamma_1 \leq 1)$ to represent its level. (b) He overestimates the impact of retail price and greenness on demand; that is, the value of deterministic part in (2) increases. This behavior is called overestimation [10], and we use γ_2 $(0 \leq \gamma_2 \leq 1)$ to represent its level. Hence, the overconfident manufacturer deems that the demand is

$$D_o(g,\varepsilon) = (a - bp + kg)[1 + \gamma_2 + (1 - \gamma_1)\sigma X]. \tag{3}$$

For the convenience of computing, let $T = 1 + \gamma_2 + (1 - \gamma_1)\sigma X$, and the distribution and density function are $F_o(\bullet)$ and $f_o(\bullet)$, respectively. Hence, $D_o(g,\varepsilon) = D(g) \bullet T$.

To facilitate description, we make the following statement about the manufacturer: we call him a rational manufacturer when $\gamma_1 = 0$ and $\gamma_2 = 0$; we call him an overestimated manufacturer when $\gamma_1 = 0$ and $\gamma_2 > 0$; we call him an overprecision manufacturer when $\gamma_1 > 0$ and $\gamma_2 = 0$; we call him a dual-overconfident manufacturer when $\gamma_1 > 0$ and $\gamma_2 > 0$. In this paper, the overconfident manufacturer refers to the latter three cases.

In order to provide a consistent notation throughout the paper, we briefly list the notations appeared in the derivation of propositions, as shown in Table 1.

4. Modeling and Solving

The overconfident manufacturer makes decisions on product greenness and output to maximize his profit based on the belief in demand. The manufacturer deems that his profit is

$$\pi_o(g,q) = p \bullet \min(q, D_o) + s \bullet (q - D_o)^+ - cq - \frac{Ig^2}{2}. \quad (4)$$

The first part of (4) is sales revenue, the second is salvage revenue, and the third and fourth are total variable costs and greening investment, respectively. Expected profit function of the manufacturer can be expressed as

$$\begin{aligned} &E\pi_o(g,q) \\ &= p\left[\int_0^{q/D(g)} D(g)\, t f_o(t)\, dt + \int_{q/D(g)}^{\infty} q f_o(t)\, dt\right] \\ &+ s\int_0^{q/D(g)} [q - D(g)t]\, f_o(t)\, dt - cq - \frac{Ig^2}{2} \\ &= (p-s) \\ &\cdot \left[\int_0^{q/D(g)} D(g)\, t f_o(t)\, dt + \int_{q/D(g)}^{\infty} q f_o(t)\, dt\right] \\ &- (c-s)\, q - \frac{Ig^2}{2}. \end{aligned} \quad (5)$$

The Hessian matrix of $E\pi_o(g,q)$ is

$$\begin{aligned} H &= \begin{bmatrix} \dfrac{\partial^2 E\pi_o(g,q)}{\partial g^2} & \dfrac{\partial^2 E\pi_o(g,q)}{\partial g \partial q} \\ \dfrac{\partial^2 E\pi_o(g,q)}{\partial q \partial g} & \dfrac{\partial^2 E\pi_o(g,q)}{\partial q^2} \end{bmatrix} \\ &= \begin{bmatrix} -\dfrac{(p-s)k^2q^2 f_o(q/D(g))}{[D(g)]^3} - I & \dfrac{(p-s)kq f_o(q/D(g))}{[D(g)]^2} \\ \dfrac{(p-s)kq f_o(q/D(g))}{[D(g)]^2} & -\dfrac{(p-s) f_o(q/D(g))}{D(g)} \end{bmatrix}. \end{aligned} \quad (6)$$

For $|H_1| = -(p-s)k^2q^2 f_o(q/D(g))/[D(g)]^3 - I < 0$ and $|H| = (p-s)I f_o(q/D(g))/D(g) > 0$, H is negative definite. Thus, the manufacturer's expected profit function is jointly concave in g and q, and there is a maximum.

Taking the first order conditions of $E\pi_o(g,q)$ with respect to g and q, we obtain

$$\frac{\partial E\pi_o(g,q)}{\partial g} = (p-s)\,k\int_0^{q/D(g)} t f_o(t)\, dt - Ig = 0, \quad (7)$$

$$\frac{\partial E\pi_o(g,q)}{\partial q} = (p-s)\int_{q/D(g)}^{\infty} f_o(t)\, dt - c + s = 0. \quad (8)$$

For $T = 1 + \gamma_2 + (1-\gamma_1)\sigma X$, we get

$$F_o(t) = F\left(\frac{t-(1+\gamma_2)}{\sigma(1-\gamma_1)}\right), \quad (9)$$

$$f_o(t) = \frac{1}{\sigma(1-\gamma_1)} f\left(\frac{t-(1+\gamma_2)}{\sigma(1-\gamma_1)}\right). \quad (10)$$

Substituting (10) into (7) and (8) and solving simultaneously, we get the greenness and output chosen by the overconfident manufacturer:

$$g_o^* = \frac{k(p-s)}{I}\int_{-1/\sigma}^{\beta} [1+\gamma_2+(1-\gamma_1)\sigma x]\, f(x)\, dx, \quad (11)$$

$$\begin{aligned} q_o^* &= \Bigg[a - bp \\ &+ \frac{k^2(p-s)}{I}\int_{-1/\sigma}^{\beta} [1+\gamma_2+(1-\gamma_1)\sigma x]\, f(x)\, dx\Bigg] \\ &\cdot [1+\gamma_2+(1-\gamma_1)\sigma\beta], \end{aligned} \quad (12)$$

where (we can easily get $\beta > -1/\sigma$ since $F(\beta) = (p-c)/(p-s) > 0$. We use the β value to classify the green product. We define a green product as a high-profit product when $\beta > 0$ and as a low-profit product otherwise according to [30, 31])

$$\beta = F^{-1}\left(\frac{p-c}{p-s}\right). \quad (13)$$

When $\gamma_1 = 0$ and $\gamma_2 = 0$, it is easy to get the greenness and output chosen by the rational manufacturer:

$$g^* = \frac{k(p-s)}{I}\int_{-1/\sigma}^{\beta} (1+\sigma x)\, f(x)\, dx, \quad (14)$$

$$\begin{aligned} q^* &= \left[a - bp + \frac{k^2(p-s)}{I}\int_{-1/\sigma}^{\beta} (1+\sigma x)\, f(x)\, dx\right] \\ &\cdot (1+\sigma x). \end{aligned} \quad (15)$$

In the rest of this paper, we analyze and discuss the equilibrium results in order to get some valuable and innovative conclusions.

5. The Effect of Overconfidence on the Greenness and Output

Proposition 1. *The product chosen by the overconfident manufacturer is greener than that of the rational manufacturer, and the greater the level of overprecision and (or) overestimation, the higher the deviation of greenness. Moreover, overestimation results in a higher deviation than overprecision.*

Proof. In order to facilitate the description in proof, we define

$$L = \int_{\beta}^{\infty} x f(x)\, dx. \quad (16)$$

If $\beta \geq 0$ then $L > 0$. When $\beta < 0$, $L = EX - \int_{-1/\sigma}^{\beta} xf(x)dx = -\int_{-1/\sigma}^{\beta} xf(x)dx > 0$. Therefore, $L > 0$.

The deviation of greenness is equivalent to

$$\Delta g = g_o^* - g^* = \frac{k(p-s)}{I}\int_{-1/\sigma}^{\beta}(\gamma_2 - \gamma_1\sigma x) f(x)\,dx = \frac{k(p-s)}{I}[\gamma_2 F(\beta) + \gamma_1\sigma L]. \tag{17}$$

For $L > 0$, we can get $\Delta g > 0$, i.e., $g_o^* > g^*$, in the three situations involving overconfidence. Because $\partial\Delta g/\partial\gamma_1 = k\sigma(p-s)L/I > 0$ and $\partial\Delta g/\partial\gamma_2 = k(p-s)F(\beta)/I > 0$, we obtain that the deviation of greenness is increasing with the level of overprecision and (or) overestimation.

The difference between the incremental product greenness caused by overprecision and overestimation is $\partial\Delta g/\partial\gamma_1 - \partial\Delta g/\partial\gamma_2 = k(p-s)(\sigma L - F(\beta))/I = -(k(p-s)/I)\int_{-1/\sigma}^{\beta}(1+\sigma x)f(x)dx < 0$, i.e., $\partial\Delta g/\partial\gamma_1 < \partial\Delta g/\partial\gamma_2$. □

Proposition 1 shows that, compared with rational situation, a manufacturer who behaves as overprecision, overestimation, or both will make greener products to the market, and the greater the level of overprecision and (or) overestimation, the higher the greenness. For example, in the air-conditioning industry, R22 was widely used as a refrigerant in household air-conditioning, but GREE adopted a more environment-friendly new refrigerant technology R290, which made the air-conditioning get rid of the dependence on Freon and greatly reduced the destruction of the ozone layer. Due to overconfidence in the green product market, GREE continued to explore and had developed a more environment-friendly new refrigerant named R32. Its product power increased by about 3-5% and energy efficiency ratio increased by about 5% (http://www.sohu.com/a/72397376_364315. Retrieved April 3, 2019).

Although both overconfidence behaviors can lead the manufacturer to choose higher product greenness, overestimation is more likely to trigger increased greenness than overprecision. A reasonable explanation might be that the overconfident manufacturer subjectively overestimates the positive effect of greenness on market demand; he believes that market demand would increase rapidly as greenness increases, thus adopting a more radical approach to produce greener products. Overprecision makes the manufacturer more convinced that product greenness promotes demand, and demand uncertainty is also been reduced. In contrast, overestimation not only makes the manufacturer overestimate the impact of greenness on demand, but also overestimates market demand. Therefore, the effect of overestimation on greenness is greater than that of overprecision. From the perspective of environmental protection, manufacturers' overconfidence is helpful for the improvement of greenness and thus enhancing social environmental performance.

Proposition 2. *The output chosen by the overestimated manufacturer is higher than that of the rational manufacturer, and the greater the level of overestimation, the higher the deviation of the output.*

Proof. When $\gamma_1 = 0$, q_o^* is output of the overestimated manufacturer. The deviation of output between the overestimated manufacturer and the rational manufacturer is equivalent to $\Delta q_1 = q_o^* - q^* = k^2\gamma_2(1+\sigma\beta)(p-s)F(\beta)/I + \gamma_2[a - bp + (k^2(p-s)/I)\int_{-1/\sigma}^{\beta}(1+\gamma_2+\sigma x)f(x)dx]$. For $\Delta q_1 > 0$, we get $q_o^* > q^*$.

Since $d\Delta q_1/d\gamma_2 = a - bp + k^2F(\beta)(p-s)(1+\gamma_2+\sigma\beta)/I + (k^2(p-s)/I)\int_{-1/\sigma}^{\beta}(1+\gamma_2+\sigma x)f(x)dx > 0$, we obtain that the output deviation increases in the level of overestimation. □

Proposition 2 shows that the overestimated manufacturer produces more than the rational manufacturer and that the output is increasing with the level of overestimation. The reason may be that the overestimation behavior makes the manufacturer think that the market demand exceeds the actual demand. This distorted belief leads the manufacturer to increase yield to meet demand. The greater the level of overestimation is, the more deviation of the imagined demand exceeds actual demand, thus resulting in excess output.

Proposition 3. *(a) In the low-profit condition, the overprecision manufacturer produces more than the rational manufacturer. That is, if $\beta \leq 0$, then $q_o^* > q^*$. (b) In the high-profit condition, the overprecision manufacturer produces more than the rational manufacturer if $N > 1$ but produces less than the rational manufacturer if $N < 0$, and the value of N is expressed by*

$$N = 1 - \frac{I}{k^2}\bullet\frac{a-bp}{2\sigma L(p-s)} - \frac{p-c}{2\sigma L(p-s)} + \frac{1}{2\sigma\beta}. \tag{18}$$

That is, suppose $\beta > 0$; if $N > 1$ then $q_o^* > q^*$; if $N < 0$, then $q_o^* < q^*$. Moreover, in both cases, with the increase of overprecision level, the deviation of output increases.

Proof. When $\gamma_2 = 0$, q_o^* is output of the overprecision manufacturer. The deviation of output between the overprecision manufacturer and the rational manufacturer is equivalent to

$$\Delta q_2 = q_o^* - q^* = \frac{k^2\gamma_1\sigma L(1+\sigma\beta)(p-s)}{I} - \gamma_1\sigma\beta\Bigg[a - bp + \frac{k^2(p-s)}{I}\int_{-1/\sigma}^{\beta}[1+(1-\gamma_1)\sigma x]f(x)\,dx\Bigg]. \tag{19}$$

The first derivative of Δq_2 with respect to γ_1 is

$$\frac{d\Delta q_2}{d\gamma_1} = \frac{k^2\sigma L(1+\sigma\beta)(p-s)}{I} - \sigma\beta(a-bp)$$

$$
\begin{aligned}
&- \frac{k^2\sigma\beta(p-s)}{I}\int_{-1/\sigma}^{\beta}[1+(1-\gamma_1)\sigma x]f(x)\,dx \\
&- \frac{\gamma_1 k^2\sigma^2\beta L(p-s)}{I} \\
&= \frac{k^2\sigma L(p-s)}{I} - \sigma\beta(a-bp) - \frac{k^2\sigma\beta(p-c)}{I} \\
&+ \frac{2k^2\sigma^2\beta L(p-s)(1-\gamma_1)}{I}.
\end{aligned} \tag{20}
$$

(a) Suppose $\beta \le 0$, we can easily get $\Delta q_2 > 0$ and $d\Delta q_2/d\gamma_1 > 0$ from (19) and (20), respectively. That is, q_o^* is greater than q^*, and the larger the value of γ_1, the greater the $q_o^* - q^*$.

(b) Suppose $\beta > 0$, because of $\gamma_1 \in [0,1]$, if $N > 1$ then $\gamma_1 < N$. When $\gamma_2 = 0$, we get $dq_o^*/d\gamma_1 = d\Delta q_2/d\gamma_1 > 0$ from (20). That is, q_o^* and Δq_2 are both increasing with γ_1. Hence, $q_o^* > q^*$, and the larger the γ_1, the greater the $q_o^* - q^*$. If $N < 0$ then $\gamma_1 > N$. We get $dq_o^*/d\gamma_1 = d\Delta q_2/d\gamma_1 < 0$. That is, q_o^* and Δq_2 are both decreasing with γ_1. Hence, $q_o^* < q^*$, and the larger the γ_1, the greater the $q^* - q_o^*$. □

Proposition 3 shows that if the product is low-profit (i.e., $\beta \le 0$), the overprecision manufacturer will provide more products to the market, which is consistent with the existing literature in operation management research [11, 31, 32, 36]. If the product is high-profit (i.e., $\beta > 0$), it needs to be discussed separately. When greening investment factor is high (I is large) and (or) consumers are not sensitive enough to greenness (k is small), the overprecision manufacturer produces less than the rational manufacturer, since the increase of product greenness cannot cause the rapid increase of demand but requires more investment. When greening investment factor is low (I is small) and (or) consumers are sensitive enough to greenness (k is large), the overprecision manufacturer produces more than the rational manufacturer, since the increase of product greenness may cause the rapid increase of demand but requires relatively less investment. In the high-profit condition, given that demand function, retail price, per unit cost, and per unit salvage value are invariable, the influence of greening investment factor and consumers' green sensitivity on output of the overprecision manufacturer is shown in Figure 1.

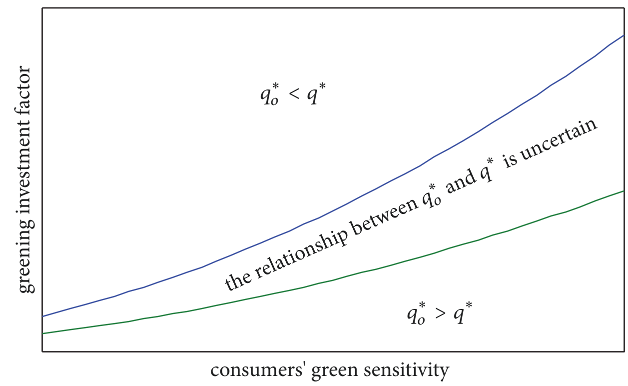


Figure 1: The influence of greening investment factor and consumers' green sensitivity on output of the overprecision manufacturer.

From Figure 1 we can see that, in the long run, with the decrease of greening investment factor and the increase of consumers' green sensitivity, the output of the overprecision manufacturer will be greater than that of the rational manufacturer.

It is worth mentioning that when k approaches 0, from (2) we see product greenness hardly affects demand as well as decision on output. From (18) we get $\lim_{k\to 0} N = -\infty$. According to Proposition 3, if the product is high-profit, then $q_o^* < q^*$, and this conclusion is consistent with Croson et al. [11, 31, 32].

Combining overprecision and overestimation, we get Proposition 4 reflecting the output relationship between the dual-overconfident manufacturer and the rational manufacturer.

Proposition 4. *(a) In the low-profit condition, the dual-overconfident manufacturer produces more than the rational manufacturer. That is, if $\beta \le 0$, then $q_o^* > q^*$. (b) In the high-profit condition, the dual-overconfident manufacturer produces more than the rational manufacturer if $\gamma_2 \ge \gamma_1\sigma\beta$. That is, suppose $\beta > 0$, if $\gamma_2 \ge \gamma_1\sigma\beta$ then $q_o^* > q^*$.*

Proof. We can get the difference in output between the dual-overconfident manufacturer and the rational manufacturer from (12) and (15):

$$
\begin{aligned}
\Delta q = q_o^* - q^* &= \frac{(1+\sigma\beta)k^2(p-s)}{I}\int_{-1/\sigma}^{\beta}(\gamma_2 - \gamma_1\sigma x) \\
&\cdot f(x)\,dx + (\gamma_2 - \gamma_1\sigma\beta)\left[a - bp + \frac{k^2(p-s)}{I}\right. \\
&\left.\cdot \int_{-1/\sigma}^{\beta}[1+\gamma_2+(1-\gamma_1)\sigma x]f(x)\,dx\right].
\end{aligned} \tag{21}
$$

Because $\beta > -1/\sigma$, if $\beta \le 0$ then $\Delta q > 0$. Suppose $\beta > 0$, if $\gamma_2 \ge \gamma_1\sigma\beta$, it is easy to get $\Delta q > 0$. □

Proposition 4 shows that, in the cases of low-profit condition, or high-profit condition satisfied $\gamma_2 \ge \gamma_1\sigma\beta$, the dual-overconfident manufacturer's output is higher than the rational manufacturer's. Although overprecision may lead to a decline in output, the output increased by overestimation exceeds the reduction caused by overprecision, which eventually results in higher output than rational situation.

As it is difficult to study the cross-effect of overprecision and overestimation on output through analytical analysis method, we present a numerical analysis to explain the result in high-profit condition. Referring to the example in [22], we set the parameters as follows: $a = 1000$, $b = 50$, $p = 8$, $c = 4$,

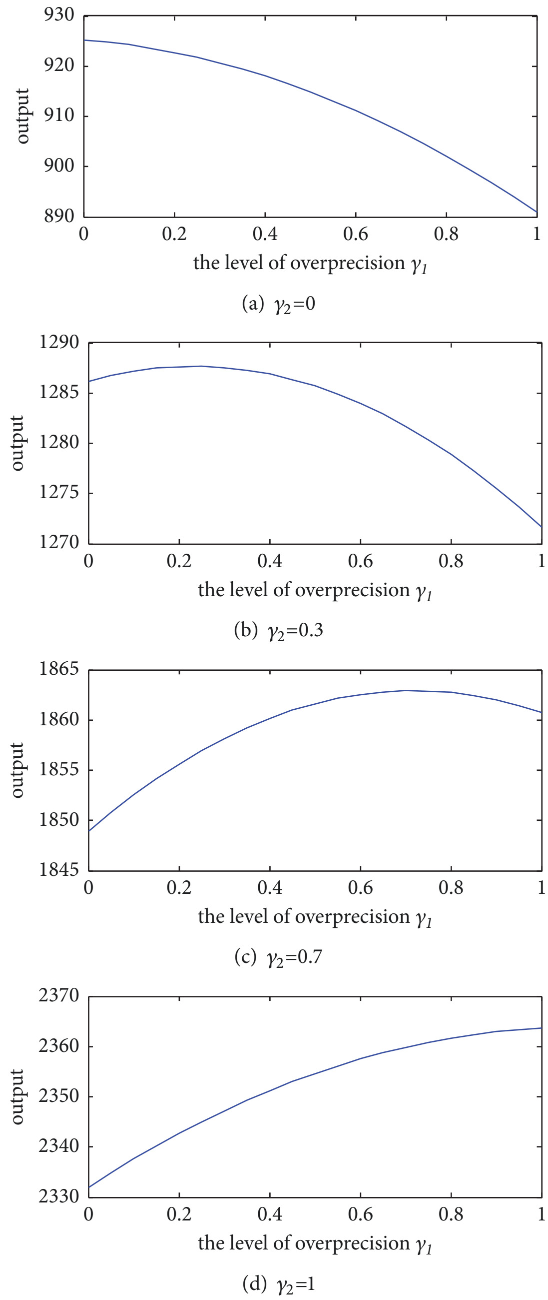


Figure 2: The cross-effect of overprecision and overestimation on output.

$s = 2$, $k = 40$, and $I = 22$. Suppose ε have a reflex normal distribution, the probability density function is

$$f_\varepsilon(x) = \begin{cases} \frac{2}{\pi} e^{-x^2/\pi}, & x \geq 0 \\ 0, & x < 0. \end{cases} \tag{22}$$

In this set up, we can obtain the value of β is 0.2813. This is the high-profit market environment. The influence of the two overconfident behaviors on output is shown in Figure 2.

In Figure 2(a), the value of N in (18) is -0.1320, and optimal profit of the rational manufacturer is 925.26. We can see output of the overprecision manufacturer is less than that of the rational situation, and the output is decreasing with the level of overprecision, which is consistent with Proposition 3. Comparing these four figures, we find that the output is increasing rapidly with the level of overestimation and that the rules of output varying with the level of overprecision differ in overestimation level. The reason is that there is a positive cross-effect of overconfidence in output, and the greater the level of overprecision, the larger the cross-effect.

Proposition 5. *Both the product greenness and output chosen by the overconfident manufacturer are increasing with the decrease of greening investment factor, the increase of consumers' green sensitivity, or decline in per unit cost. Moreover, overestimation results in a higher change rate than overprecision.*

Proof. Taking the first derivatives of g_o^* and q_o^* with respect to I, respectively, we get

$$\frac{\partial g_o^*}{\partial I} = -\frac{k(p-s)}{I^2} \cdot \int_{-1/\sigma}^{\beta} [1 + \gamma_2 + (1-\gamma_1)\sigma x] f(x)\,dx < 0, \tag{23}$$

$$\frac{\partial q_o^*}{\partial I} = -\frac{k^2(p-s)[1+\gamma_2+(1-\gamma_1)\sigma\beta]}{I^2} \cdot \int_{-1/\sigma}^{\beta} [1 + \gamma_2 + (1-\gamma_1)\sigma x] f(x)\,dx < 0. \tag{24}$$

Hence, the overconfident manufacturer's product greenness and output are increasing with the decrease of greening investment factor.

When greening investment factor is decreasing, the differences of greenness change and output change caused by overconfident between overestimation and overprecision are

$$\frac{\partial}{\partial \gamma_2}\left(\left|\frac{\partial g_o^*}{\partial I}\right|\right) - \frac{\partial}{\partial \gamma_1}\left(\left|\frac{\partial g_o^*}{\partial I}\right|\right) = \frac{k(p-s)}{I^2}\int_{-1/\sigma}^{\beta}(1+\sigma x) f(x)\,dx > 0, \tag{25}$$

$$\frac{\partial}{\partial \gamma_2}\left(\left|\frac{\partial q_o^*}{\partial I}\right|\right) - \frac{\partial}{\partial \gamma_1}\left(\left|\frac{\partial q_o^*}{\partial I}\right|\right) = (1+\sigma\beta)\int_{-1/\sigma}^{\beta}[1+\gamma_2+(1-\gamma_1)\sigma x] f(x)\,dx + \frac{k^2(p-s)}{I^2}\int_{-1/\sigma}^{\beta}(1+\sigma x) f(x)\,dx > 0. \tag{26}$$

Therefore, with the decrease of greening investment factor, changes of greenness and output caused by overestimation are greater than that of overprecision.

Taking the first derivatives of g_o^* and q_o^* with respect to k respectively, we have

$$\frac{\partial g_o^*}{\partial k} = \frac{p-s}{I}\int_{-1/\sigma}^{\beta}\left[1+\gamma_2+(1-\gamma_1)\sigma x\right] f(x)\,dx > 0, \tag{27}$$

$$\frac{\partial q_o^*}{\partial k} = \frac{2k(p-s)\left[1+\gamma_2+(1-\gamma_1)\sigma\beta\right]}{I} \cdot \int_{-1/\sigma}^{\beta}\left[1+\gamma_2+(1-\gamma_1)\sigma x\right] f(x)\,dx > 0. \tag{28}$$

Hence, the overconfident manufacturer's product greenness and output are increasing with the increase of consumers' green sensitivity.

When consumers' green sensitivity is increasing, the differences of greenness change and output change caused by overconfident between overestimation and overprecision are

$$\frac{\partial}{\partial\gamma_2}\left(\left|\frac{\partial g_o^*}{\partial k}\right|\right) - \frac{\partial}{\partial\gamma_1}\left(\left|\frac{\partial g_o^*}{\partial k}\right|\right) = \frac{p-s}{I} \cdot \int_{-1/\sigma}^{\beta}(1+\sigma x) f(x)\,dx > 0, \tag{29}$$

$$\begin{aligned}\frac{\partial}{\partial\gamma_2}\left(\left|\frac{\partial q_o^*}{\partial k}\right|\right) - \frac{\partial}{\partial\gamma_1}\left(\left|\frac{\partial q_o^*}{\partial k}\right|\right) &= \frac{2k(p-s)(1+\sigma\beta)}{I} \cdot \int_{-1/\sigma}^{\beta}\left[1+\gamma_2+(1-\gamma_1)\sigma x\right] f(x)\,dx \\ &\quad + \frac{2k(p-s)\left[1+\gamma_2+(1-\gamma_1)\sigma\beta\right]}{I} \cdot \int_{-1/\sigma}^{\beta}(1+\sigma x) f(x)\,dx > 0.\end{aligned} \tag{30}$$

Therefore, with the increase of consumers' green sensitivity, changes of greenness and output caused by overestimation are greater than that of overprecision.

In order to facilitate the description in derivation, we use function $G(\bullet)$ to represent $F^{-1}(\bullet)$. Thus, G is a monotonically increasing function, i.e., $G' > 0$ since F increases monotonously in the interval $[-1/\sigma, \infty]$. We get $\beta = G((p-c)/(p-s))$ from (13).

Taking the first derivatives of g_o^* and q_o^* with respect to c, respectively, we have

$$\frac{\partial g_o^*}{\partial c} = -\frac{k}{I} f(\beta)\, G'\left(\frac{p-c}{p-s}\right)\left[1+\gamma_2+(1-\gamma_1)\sigma\beta\right] < 0, \tag{31}$$

$$\begin{aligned}\frac{\partial q_o^*}{\partial c} &= -\left[a-bp + \frac{k^2(p-s)}{I}\int_{-1/\sigma}^{\beta}\left[1+\gamma_2+(1-\gamma_1)\sigma x\right] f(x)\,dx\right] \\ &\quad \cdot \frac{\sigma(1-\gamma_1)}{p-s} G'\left(\frac{p-c}{p-s}\right) - \frac{k^2}{I}\left[1+\gamma_2 + (1-\gamma_1)\sigma\beta\right]^2 f(\beta)\, G'\left(\frac{p-c}{p-s}\right) < 0.\end{aligned} \tag{32}$$

Hence, the overconfident manufacturer's product greenness and output are increasing with the decline in per unit cost.

When per unit cost is decreasing, the differences of greenness change and output change caused by overconfident between overestimation and overprecision are

$$\frac{\partial}{\partial\gamma_2}\left(\left|\frac{\partial g_o^*}{\partial c}\right|\right) - \frac{\partial}{\partial\gamma_1}\left(\left|\frac{\partial g_o^*}{\partial c}\right|\right) = \frac{k}{I} f(\beta)\, G'\left(\frac{p-c}{p-s}\right) \cdot (1+\sigma\beta) > 0, \tag{33}$$

$$\begin{aligned}\frac{\partial}{\partial\gamma_2}\left(\left|\frac{\partial q_o^*}{\partial c}\right|\right) - \frac{\partial}{\partial\gamma_1}\left(\left|\frac{\partial q_o^*}{\partial c}\right|\right) &= G'\left(\frac{p-c}{p-s}\right) \cdot \left\{\frac{\sigma k^2(1-\gamma_1)}{I}\int_{-1/\sigma}^{\beta}(1+\sigma x) f(x)\,dx \right. \\ &\quad + \frac{\sigma}{p-s}\left[a-bp+\frac{k^2(p-s)}{I} \cdot \int_{-1/\sigma}^{\beta}\left[1+\gamma_2+(1-\gamma_1)\sigma x\right] f(x)\,dx\right] \\ &\quad \left. \cdot + \frac{2k^2(1+\sigma\beta) f(\beta)\left[1+\gamma_2+(1-\gamma_1)\sigma\beta\right]}{I}\right\} > 0.\end{aligned} \tag{34}$$

Therefore, with the decline in per unit cost, changes of greenness and output caused by overestimation are greater than that of overprecision. □

Proposition 5 shows that when greening investment factor decreases, consumers' green sensitivity increases, or per unit cost decreases, the overconfident manufacturer will provide more and greener products to the market. The reason may be that, under the decrease of greening investment factor or decline in per unit cost, the manufacturer can make greener products in the same capital investment, thus increasing product demand; while consumers are more sensitive to green products, greener products are more prevalent, and the demand would be increased rapidly by improving the greenness. With the popularization of green production technology and increasing attention to environmental protection, the greening investment factor will decrease and the consumers' green sensitivity will increase; thus, the greenness and output have an increasing tendency, which meets the requirements of green development.

6. The Effect of Overconfidence on Profit

In this section, we analyze the impact of overconfidence on the profit. Substituting equations (11) and (12) into (5), we can get the expected profit that the overconfident manufacturer deems he earns

$$E\pi_o\left(g_o^*, q_o^*\right) = (p-s)\left[\int_0^{q_o^*/D(g_o^*)} D\left(g_o^*\right) t f_o(t)\,dt + \int_{q_o^*/D(g_o^*)}^{\infty} q_o^* f_o(t)\,dt\right] - (c-s)\,q_o^* - \frac{Ig_o^{*2}}{2} = (p-s)\,D\left(g_o^*\right) \cdot \left\{\int_{-1/\sigma}^{\beta}\left[1+\gamma_2+\left(1-\gamma_1\right)\sigma x\right] f(x)\,dx\right\} - \frac{Ig_o^{*2}}{2}. \tag{35}$$

But the real profit of the overconfident manufacturer is the expected profit based on the actual demand of (2):

$$E\pi\left(g_o^*, q_o^*\right) = p \bullet E\min\left(q_o^*, D\left(g_o^*, \varepsilon\right)\right) + s \bullet E\left(q_o^* - D\left(g_o^*, \varepsilon\right)\right)^+ - cq_o^* - \frac{Ig_o^{*2}}{2}. \tag{36}$$

We can simplify (36) to

$$E\pi\left(g_o^*, q_o^*\right) = (p-s)\,D\left(g_o^*\right) \cdot \left[\int_{-1/\sigma}^{(\gamma_2+(1-\gamma_1)\sigma\beta)/\sigma} (1+\sigma x)\,f(x)\,dx + \left[1+\gamma_2+\left(1-\gamma_1\right)\sigma\beta\right]\int_{(\gamma_2+(1-\gamma_1)\sigma\beta)/\sigma}^{\beta} f(x)\,dx\right] - \frac{Ig_o^{*2}}{2}. \tag{37}$$

Substituting $\gamma_1 = 0$ and $\gamma_2 = 0$ into (35) or (37), we can get optimal expected profit $E\pi(g^*, q^*)$ of the rational manufacturer. That is, $E\pi(g^*, q^*)$ is a special case of $E\pi(g_o^*, q_o^*)$ or $E\pi_o(g_o^*, q_o^*)$. Comparing the three profits, we can get Proposition 6 reflecting the influence of overconfidence.

Proposition 6. *Expected profits that the three overconfident manufacturers deem they earn are all greater than optimal profit of the rational manufacturer. But in actuality, the overprecision manufacturer and overestimated manufacturer earn less than the rational manufacturer. Moreover, with the increase of overconfidence (overprecision or overestimation) level, the expected profits they deem increase, but the real profits fall.*

Proof. Both $E\pi_o(g_o^*, q_o^*)$ and $E\pi(g_o^*, q_o^*)$ vary in γ_1 and γ_2, in order to simplify description, we define Z_1 and Z_2 as a function of γ_1 and γ_2, separately, and $Z_1(\gamma_1, \gamma_2) = \pi_o(g_o^*, q_o^*)$, $Z_2(\gamma_1, \gamma_2) = E\pi(g_o^*, q_o^*)$. Hence, we have $E\pi(g^*, q^*) = Z_1(0,0) = Z_2(0,0)$, and $Z_2(\gamma_1, 0)$ and $Z_2(0_1, \gamma_2)$ represent real profits of the overprecision manufacturer and the overestimated manufacturer, respectively. According to (35), taking the first derivatives of $Z_1(\gamma_1, \gamma_2)$ with respect to γ_1 and γ_2, we obtain

$$\frac{\partial Z_1\left(\gamma_1, \gamma_2\right)}{\partial \gamma_1} = \frac{\partial g_o^*}{\partial \gamma_1}\left\{(p-s) \cdot k\int_{-1/\sigma}^{\beta}\left[1+\gamma_2+\left(1-\gamma_1\right)\sigma x\right] f(x)\,dx - Ig_o^*\right\} + D\left(g_o^*\right)(p-s)\,\sigma L, \tag{38}$$

$$\frac{\partial Z_1\left(\gamma_1, \gamma_2\right)}{\partial \gamma_2} = \frac{\partial g_o^*}{\partial \gamma_2}\left\{(p-s) \cdot k\int_{-1/\sigma}^{\beta}\left[1+\gamma_2+\left(1-\gamma_1\right)\sigma x\right] f(x)\,dx - Ig_o^*\right\} + D\left(g_o^*\right)(p-c). \tag{39}$$

Substituting (10) into (38) and (39), we have $\partial Z_1(\gamma_1, \gamma_2)/\partial\gamma_1 = D(g_o^*)(p-s)\sigma L > 0$ and $\partial Z_1(\gamma_1, \gamma_2)/\partial\gamma_2 = D(g_o^*)(p-c) > 0$. Hence, $E\pi(g^*, q^*) = Z_1(0,0) < Z_1(\gamma_1, 0) < Z_1(\gamma_1, \gamma_2) = \pi_o(g_o^*, q_o^*)$. That is, expected profits that the overprecision manufacturer, the overestimated manufacturer, and the dual-overconfident manufacturer deem they earn are greater than optimal profit of the rational manufacturer, and these imagined profits increase in their overconfidence levels.

Real profit of the overprecision manufacturer is $Z_2(\gamma_1, 0)$. According to (37), taking the first derivative of $Z_2(\gamma_1, 0)$ with respect to γ_1 we obtain

$$\frac{dZ_2\left(\gamma_1, 0\right)}{d\gamma_1} = \frac{(p-s)^2 k^2 L}{I}\left\{\int_{-1/\sigma}^{(1-\gamma_1)\beta} (1+\sigma x)\,f(x)\,dx + \left[1+\left(1-\gamma_1\right)\sigma\beta\right]\int_{(1-\gamma_1)\beta}^{\beta} f(x)\,dx - \int_{-1/\sigma}^{\beta}\left[1+\left(1-\gamma_1\right)\sigma x\right] f(x)\,dx\right\} + (p-s) \cdot \sigma\beta\left\{a-bp\right.$$

$$+\frac{k^2(p-s)}{I}\int_{-1/\sigma}^{\beta}[1+(1-\gamma_1)\sigma x]f(x)\,dx\Bigg\}$$
$$\cdot\int_{\beta}^{(1-\gamma_1)\beta}f(x)\,dx. \tag{40}$$

The second derivative of $Z_2(\gamma_1,0)$ with respect to γ_1 is

$$\begin{aligned}\frac{d^2Z_2(\gamma_1,0_2)}{d\gamma_1^2}&=\frac{(p-s)^2k^2\sigma L}{I}\Bigg[-2\beta\int_{(1-\gamma_1)\beta}^{\beta}f(x)\,dx\\&-1\Bigg]+(p-s)\sigma\beta^2f((1-\gamma_1)\beta)\Bigg\{a-bp\\&+\frac{k^2(p-s)}{I}\int_{-1/\sigma}^{\beta}[1+(1-\gamma_1)\sigma x]f(x)\,dx\Bigg\}\\&<0.\end{aligned} \tag{41}$$

Hence, $dZ_2(\gamma_1,0)/d\gamma_1$ is monotonically decreasing. Because of $(dZ_2(\gamma_1,0)/d\gamma_1)|_{\gamma_1=0}=0$, we get $dZ_2(\gamma_1,0)/d\gamma_1<0$ in $(0,1]$. Thus, when $\gamma_2=0$, $E\pi(g_o^*,q_o^*)<E\pi(g^*,q^*)$. Therefore, real profit of the overprecision manufacturer is decreasing with the level of overprecision and is less than optimal profit of rational situation.

Using the same method, we get the first and second derivatives of the overestimated manufacturer's real profit with respect to γ_2:

$$\begin{aligned}&\frac{dZ_2(0,\gamma_2)}{d\gamma_2}\\&=\frac{(p-s)^2k^2F(\beta)}{I}\Bigg\{\int_{-1/\sigma}^{\beta+\gamma_2/\sigma}(1+\sigma x)f(x)\,dx\\&+(1+\gamma_2+\sigma\beta)\int_{\beta+\gamma_2/\sigma}^{\beta}f(x)\,dx\\&-\int_{-1/\sigma}^{\beta}(1+\gamma_2+\sigma x)f(x)\,dx\Bigg\}+(p-s)\\&\cdot\int_{\beta+\gamma_2/\sigma}^{\beta}f(x)\,dx\Bigg[a-bp\\&+\frac{k^2(p-s)}{I}\int_{-1/\sigma}^{\beta}(1+\gamma_2+\sigma x)f(x)\,dx\Bigg],\\&\frac{d^2Z_2(0,\gamma_2)}{d\gamma_2^2}\\&=-\frac{(p-s)^2k^2F(\beta)}{I}\Bigg[2\int_{\beta}^{\beta+\gamma_2/\sigma}f(x)\,dx+F(\beta)\Bigg]\end{aligned} \tag{42}$$

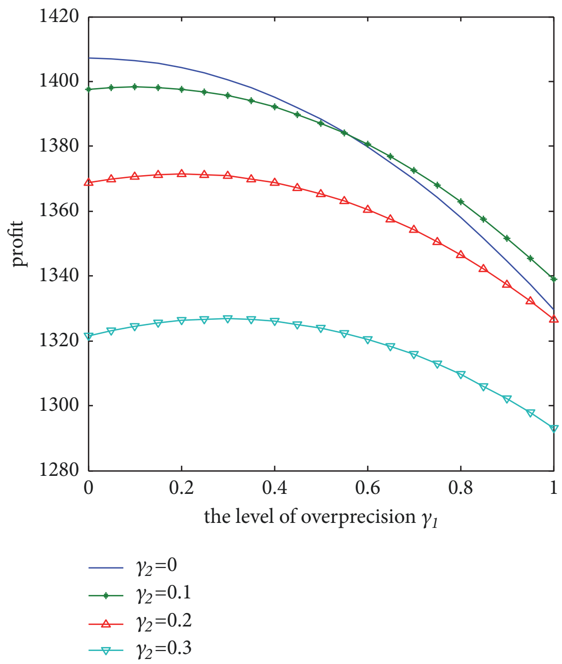
$$\begin{aligned}&-\frac{p-s}{\sigma}f\left(\beta+\frac{\gamma_2}{\sigma}\right)\Bigg[a-bp\\&+\frac{k^2(p-s)}{I}\int_{-1/\sigma}^{\beta}(1+\gamma_2+\sigma x)f(x)\,dx\Bigg]<0.\end{aligned} \tag{43}$$

Hence, $dZ_2(0,\gamma_2)/d\gamma_2$ is monotonically decreasing. Because of $(dZ_2(0,\gamma_2)/d\gamma_2)|_{\gamma_2=0}=0$, we get $dZ_2(0,\gamma_2)/d\gamma_2<0$ when $\gamma_2>0$. Thus, when $\gamma_1=0$, $E\pi(g_o^*,q_o^*)<E\pi(g^*,q^*)$. Therefore, real profit of the overestimated manufacturer is decreasing with the level of overestimation and is less than optimal profit of rational situation. □

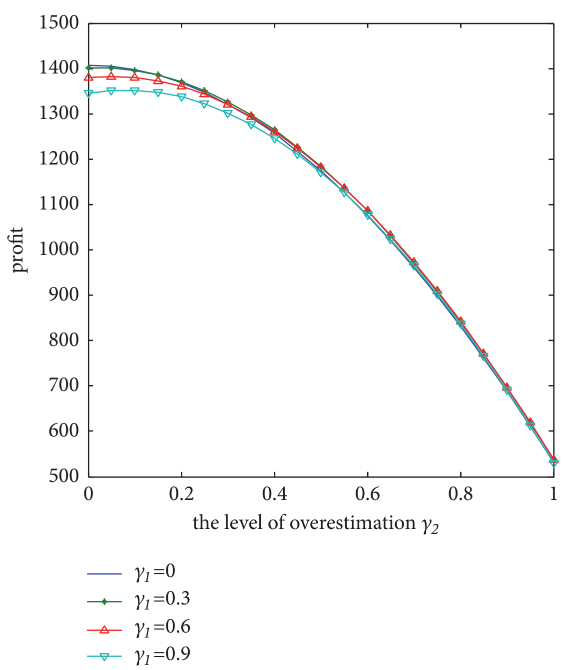
Owning to the cross-effect of overprecision and overestimation, we cannot get the influence of two behaviors on real profit of the dual-overconfident manufacturer through mathematical proof. Then we try to find new insight by using a numerical example. Assume that the parameters are $a=1000$, $b=50$, $p=8$, $c=4$, $s=2$, $k=40$, $I=65$, and ε have a reflex normal distribution with the probability density function provided by the previous example. The cross-effect of overprecision and overestimation on real profit is shown in Figure 3.

According to Figures 3(a) and 3(b), we can find that real profit of the dual-overconfident manufacturer is less than optimal profit of the rational manufacturer (in our example, the optimal profit is 1445.9). Because of the manufacturer's overconfidence, he deems that he can earn more than he indeed gets. However, overconfidence distorts the manufacturer's perception of market demand, which leads to the decisions deviating from the rational optimal value and inevitably results in the decline of the real profit. For instance, Saiwei, the industrial case cited in the introduction, realized revenue of about \$2.16 billion in the year 2011, downed 14% from the previous year, with a net loss of about \$610 million, while its net profit in 2010 was as high as \$290 million. Because of the founders' overconfidence in demand, rapidly expanding production scale had made the situation worse, with revenue falling by nearly 74%, net profit falling by 336% year-on-year and a net loss of \$169 million (http://finance.sina.com.cn/chanjing/gsnews/20120816/115812868241.shtml. Retrieved April 3, 2019.).

Although overprecision and overestimation lead to a decline in real profit separately, there is a positive cross-effect that one kind of overconfidence can affect the other's influence on the real profit. From Figure 3(a), although the real profit is lower than the optimal profit, it does not necessarily decrease with overprecision level. Because of the cross-effect, real profit of the dual-overconfident manufacturer may be greater than that of the overprecision manufacturer under the same level of overprecision (such as in Figure 3(a), in the case of $\gamma_2=0.1$ and $\gamma_1=0.8$). A similar situation also appears in Figure 3(b). Comparing Figures 3(a) and 3(b), we see that overestimation has a greater impact on real profit than overprecision. When the level of overestimation is large,



(a)



(b)

Figure 3: The cross-effect of overprecision and overestimation on real profit.

overprecision has litter effect on real profit, which is verified in Figure 3(a) (given $\gamma_2 = 0.3$, when γ_1 changes from 0 to 1, the real profit only drops from 1321.5 to 1293.1, not to mention the larger γ_2).

7. Conclusions

Making green products is becoming the mainstream of manufacturing industry in the new century, and manufacturers may be overconfident in decision making. This paper focuses on impact of the manufacturer's overconfidence on decisions. The manufacturer who produces and sells the only green product to consumers is confident about product demand. He overestimates the accuracy of demand forecasting or (and) the demand itself. We construct a newsvendor based model to study decision problems of the overconfident manufacturer and analyze the influence of overconfidence on product greenness, output and profit. Through the previous analysis, we find the operation management of green products under overconfidence is quite different from that of nongreen products. The conclusions are given below.

(1) Compared with the rational manufacturer, the overconfident manufacturer will provide greener products to the market. Under the low-profit condition, yield of the overconfident manufacturer is more than the case without overconfidence; under the high-profit condition, the overestimated manufacturer produces more than the rational manufacturer, but only when certain conditions satisfied, the overprecision and the dual-overconfident manufacturers produce more than the rational manufacturer. Hence, manufacturers' overconfidence is helpful to prompt social environmental performance.

(2) When greening investment factor is decreasing, consumers are more sensitive to green products, and (or) per unit product cost becomes lower; both the product greenness and output chosen by the green product manufacturer will increase. The increment rate under overconfidence is higher than that of the rational case, and overestimation results in a greater increment rate than overprecision.

(3) The expected profit that the overconfident manufacturer deems he earns is greater than optimal profit of the rational manufacturer. But actually, he gets less than rational situation. And as the level of overconfidence increases, he deems he earns more, but the real profit falls. There is a positive cross-effect of overprecision and overestimation; that is, one kind of overconfidence can offset to some extent the decline in profit caused by the other kind of overconfidence.

In this paper, we take the overconfidence psychological behavior into operation decisions of green products and discuss the effect of overconfidence on profit. Although overconfidence can make environmental performance improved somewhat, it may make the economic benefit worse. How to weaken or overcome the adverse effect of overconfidence will be studied in the next research.

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 regarding the publication of this paper.

Acknowledgments

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