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Supply chain informed principal model with quality uncertainty and information asymmetry in green supply chain

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Abstract. In the green supply chain, due to factors such as technical level and capital investment, quality uncertainty often occurs. At the same time, manufacturers often know more about the uncertainty than the retailers they serve. To address the concerns raised above, we apply the informed principal model and consider a two-echelon green supply chain consisting of one unreliable manufacturer and one retailer. The manufacturer, as the principal, has private information about the green degree, while the retailer only knows its prior probability. We first study the underlying model under symmetric information. Then, under the information asymmetry, we construct a low-information-density model and an interim-efficient model. Finally, the numerical comparison results show that our propositions are valid. The results show that the low-information-density model can eliminate the information asymmetry, but it imposes high signaling cost on the high-quality manufacturer. The interim-efficient model can indeed reduce the cost and the distortion of the wholesale quantity. Moreover, it is worth mentioning that there is a specific threshold for the retailer's prior probability. When the prior probability is greater than this threshold, the interim-efficient model is better than the low–information-density model; otherwise, they are equivalent. Simultaneously, the higher the prior probability, the higher the manufacturer's revenue. If the manufacturer wants to obtain more benefits, he must increase the retailer's trust by operating with integrity and building a brand effect.

Keywords: green supply chain; quality uncertainty; information asymmetry; informed principal model; low–information-density model; interim-efficient model

1. Introduction

Environmental and ecological problems continue to deteriorate, and have long become a huge challenge that the world needs to face together[1]. At the social level, many enterprises actively develop green supply chains, reduce the harmful production, use eco-friendly materials and promote global sustainable development[2]. For example, Uniqlo chooses to cooperate with green suppliers and increase the investment of green products[3]. At the government level, official forces actively guide the development of green supply chains, making people's lifestyles and consumption concepts healthier and greener[4]. Nowadays, the concept of green consumption has been gradually accepted by the public, and green products are more and more favored in the market, which in turn affects the decision-making of the supply chain[5].

Compared with the ordinary supply chain, the green supply chain also has its current shortcomings[6]. For example, there is a big gap between the green R&D capabilities of small manufacturers and large manufacturers, so the quality of the green products is quite different. Therefore, this leads to the quality uncertainty of green products in the market and destroys the interests of the supply chain. In most literature, researchers assume that retailers and manufacturers have the same information, i.e. they honestly transmit their own private information[7,8,9]. However, in the green supply chain, manufacturers have more accurate information on the quality of green products they produced and this information is not easy to be observed by retailers.

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Enterprises with private information often conceal information or even transmit false information based on their own interests, regardless of the overall interests of the supply chain, resulting in a decline in the overall interests[10]. Therefore, upstream companies with information advantages want to use information advantages to expand their own profits, even if it damages the profits of downstream companies, and downstream companies will be too conservative in their decisions and give up a lot of available market. The decision-making game will undoubtedly reduce the overall interests of the supply chain. There is no doubt that it is a “lose-lose” between them.

In this case, how to eliminate the information asymmetry between enterprises has become an urgent problem to be solved in the green chain. Currently, the literature has focused on analyzing the retailers' information screening mechanism mostly[11,12,13,14]. However, in the green supply chain, manufacturers have the responsibilities of producing green products and connecting with government agencies. They often occupy a dominant position in the supply chain. Therefore, it is more practical to study the signal transmission of manufacturers to fill the gaps in this research. We adopt a classical method, i.e., informed principal model, to achieve signal transmission. Informed principal model is an effective instrument to eliminate information asymmetry[15,16,17,18,19]. At present, the model has formed a relatively mature theoretical system, but it is rarely applied to supply chain[20]. Thus, we will expand the application of the informed principal model and guide practice through theoretical models, which will ultimately serve the actual supply chain.

Therefore, in the green supply chain with both quality uncertainty and information asymmetry, we specifically study the following research questions:

(1) How to apply the informed delegation model to this supply chain?

(2) Is the retailer willing to accept the contract and how can the retailer influence the contract?

(3) How does the wholesale quantity, the manufacturer's revenue and the retailer's revenue change between different contracts?

To answer these questions, in this paper, we study a two-echelon green supply chain consisting of an unstable manufacturer and a retailer. There are two possibilities for green products produced by this manufacturer: high quality and low quality. The manufacturer clearly knows the products’ type, but the retailer only realizes the prior probability. We first study the underlying model under symmetric information. Then, under the information asymmetry, through the informed principal model, we construct a low-information-density model and an interim-efficient model. Finally, the numerical comparison results of each model show that our propositions are valid.

The results show that the low-information-density model can eliminate the information asymmetry. But it imposes high signaling costs on the high-quality manufacturer. The interim-efficient model provides an idea to reduce the cost of signal transmission. But it follows that the retailer has a certain risk: when he is faced with the low-quality manufacturer, his earnings will be lower than the reservation profit. Moreover, it is worth mentioning that there is a specific threshold for the retailer's prior probability. When the prior probability is greater than this threshold, the interim-efficient model is better than the low–information-density model; otherwise, they are equivalent. This result organically combines the manufacturer's revenue with the retailer, i.e., the retailer can influence the manufacturer's revenue through prior probability. If the manufacturer wants to obtain more benefits, it must increase the retailer's trust by operating with integrity and building a brand effect.

2. Problem description, notations and assumptions

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Consider a two-echelon green supply chain, consisting of an unstable manufacturer and a retailer, of which the manufacturer is responsible for developing and producing green products and the retailer is responsible for selling product to the market. Manufacturers dominate the supply chain, retailers are subordinate to it. Due to the difference in technical level, capital investment and other factors, there are two possible types of green products produced by the manufacturer: high quality ($\overline{g}$) and low quality ($\underline{g}$). Correspondingly, the two types of manufacturer are referred to as high-quality and low-quality manufacturers. The manufacturer clearly knows the type of products, but the retailer's visibility of the manufacturer is relatively low, and there is no clear cognition for the type. Therefore, the retailer only knows its prior probability that the manufacturer is high-quality one, denoted as P, $P\epsilon(0,1)$. Clearly, the prior probability reflects the retailer's trust in the manufacturer.

The main symbols used herein are given by Table 1 below.

Table 1. Summary of notations

g	Green degree of products
C	Manufacturer's unit production cost
c	Retailer's unit cost of sales
w	Wholesale price of products
q	Wholesale quantity of products
p	Sales price of products
D	Products' market demand
P	The prior probability
πM	Manufacturer's revenue
πR	Retailer's revenue
Π	The supply chain's revenue
$\overline{\blacksquare}$	Corresponding symbols of high-quality manufacturers
$\underline{\blacksquare}$	Corresponding symbols of low-quality manufacturers

In order to make the analysis easy to handle, we put forward the following assumptions in this article.

Assumption 1. Both the manufacturer and the retailer are risk neutral.

Assumption 2. The manufacturer's cost includes green investment cost and manufacturing cost. The green investment cost increases exponentially with the green degree. Therefore, we assume that the green investment cost is hg2, h>0. The manufacturing cost also increases with the green degree. Suppose that the variable cost is lgq, l>0. To sum up, we assume that the manufacturer's cost is $C(q) = lgq + hg^2$.

Assumption 3. The market demand is affected by the green degree and follows the uniform distribution on (0, Q), Q is related to g. The higher the g, the higher the Q. In order to simplify the model, we assume Q = kg.

Assumption 4. The market sales price p is affected by the green degree. The higher the g, the higher the p. Similarly, we assume p= mg, m＞l.

Assumption 5. The reservation profit of the retailer is 0.

Assumption 6. Product salvage value and reputation loss cost are not considered.

Based on the above assumptions, in this green supply chain, the manufacturer dominate and design contracts. In order to win the trust of the retailer and obtain greater benefits, the manufacturer will provide selective contracts and different types of manufacturers will truthfully

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choose the corresponding types of contract options to eliminate information asymmetry. The retailer face the market and sell green products. In order to simplify the model and make it more general, we adopt wholesale price contract, and the sequence of main events in this green supply chain is shown in Figure 1.

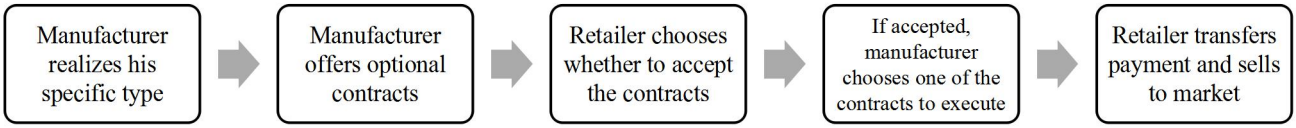

Fig. 1 sequence of events

3. Basic Models

Here we analyze the revenue functions, and the corresponding calculation process is shown as follows.

Let $S(q)$ be the expected sales, we can get

$$S(q) = \min(q,D) = \begin{cases} q, q \le D \\ D, q > D \end{cases} = q(1 - F(q)) + \int_0^q xf(x)dx = q - \frac{q^2}{2kg} \tag{1}$$

Therefore, the revenue of manufacturer is

$$\pi_M = wq - C(q) = (w - lg)q - hg^2 \tag{2}$$

The revenue of retailer is

$$\pi_R = pS(q) - (w + c)q = (mg - w - c)q - \frac{mq^2}{2k} \tag{3}$$

Thus, the expected revenue function of whole green supply chain can be written as:

$$\Pi = \pi_M + \pi_R = (mg - lg - c)q - \frac{mq^2}{2k} - hg^2 \tag{4}$$

When the information is symmetric, the retailer clearly knows the manufacturer's type, so the manufacturer directly provides a contract based on his own type. As the leader, the manufacturer needs to ensure that the retailer's profit is not less than his reservation profit. Thus, the model for the manufacturer can be established.

For the manufacturer,

$$P_1 \quad \max_{(w,q)} \pi_M = (w - lg)q - hg^2 \tag{5}$$

$$\text{s.t.} \quad \pi_R = (mg - w - c)q - \frac{mq^2}{2k} \ge 0 \tag{6}$$

where the inequality (9) is the retailer's individual rationality (IR) constraint.

It is clear that the objective function has a maximum value when the constraint is tightened. It can be seen by calculation:

$$q^s = \frac{(mg - lg - c)k}{m} \tag{7}$$

Correspondingly, the optimal wholesale price and the revenue of manufacturer are

$$w^s = \frac{mg + lg - c}{2} \tag{8}$$

$$\pi_M^s = \frac{k(mg - lg - c)^2}{2m} - hg^2 \tag{9}$$

The retailer gets only his reservation profit, i.e., $\pi_R^s = 0$.

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Thus, under symmetric information, we can obtain the following proposition.

Proposition 1. In basic model under symmetric information,

for high- and low-quality manufacturers, the selective contracts are

, and ,;

both wholesale price and wholesale quantity increase with green degree, so the optimal wholesale price and wholesale price of high-quality manufacturer are higher than those of low-quality manufacturer;

the manufacturer gets all the revenue of the supply chain, while the retailer can only get his reservation profit.

Proposition 1 shows that due to the stronger bargaining power of the manufacturer, the retailer can only maintain his reservation profit, and more earnings are owned by the manufacturer, which also gives the manufacturer greater incentives to develop green supply chain and popularize the green products in the whole society.

4. Informed principal models under asymmetric information

We now study the decision-making model under asymmetric information, that is, the retailer does not know the specific types of the manufacturers, but only knows the prior probability P. At this time, the manufacturer will provide the selective contracts $\{(\overline{w},\overline{q}),(\underline{w},\underline{q})\}$, and select one of the contract options to execute after the retailer agrees to the contracts.

It is worth noting that, from Proposition 1, the optimal wholesale price and wholesale quantity of high-quality manufacturer are higher than those of low-quality manufacturer, so if the optimal contract under symmetric information is still used, the low-quality manufacturer will imitate the high one, that is, he must choose to execute the contract $(\overline{w}^S,\overline{q}^S)$ to obtain higher revenue. As a result, retailers' profits are damaged, the market order is disturbed, and inferior products flood the market. So it is necessary to redesign the selective contracts to stop the imitation behavior.

We adopt the informed principal model and take high-quality manufacturer as the main research object to solve with the question.

4.1 Low-information-density model

The low-information-density model is a typical model of the informed principal model, which is the optimal decision-making model under the incentive compatibility constraint of the manufacturer and the profit constraint of the retailer. According to the above definition, we can establish a low-information-density model, namely

$$P_2 \quad \max_{(\overline{w},\overline{q})} \overline{\pi}_M = (\overline{w} - l\overline{g})\overline{q} - h\overline{g}^2 \tag{10}$$

$$s.t. \ \ \overline{\pi}_R = (m\overline{g} - \overline{w} - c)\overline{q} - \frac{m\overline{q}^2}{2k} \geq 0 \tag{11}$$

$$\underline{\pi}_R = \left(m\underline{g} - \underline{w} - c\right)\underline{q} - \frac{m\underline{q}^2}{2k} \geq 0 \tag{12}$$

$$(\overline{w} - l\overline{g})\overline{q} - h\overline{g}^2 \geq (\underline{w} - l\overline{g})\underline{q} - h\overline{g}^2 \tag{13}$$

$$(\underline{w} - l\underline{g})\underline{q} - h\underline{g}^2 \geq (\overline{w} - l\underline{g})\overline{q} - h\underline{g}^2 \tag{14}$$

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$$P_3 \quad \max_{(\underline{w};\underline{q})} \underline{\pi}_M = (\underline{w} - l\underline{g})\underline{q} - h\underline{g}^2 \tag{15}$$

$$s.t. \quad formulas\,(11)(12)(13)(14)$$

where the formulas (11) and (12) are the retailer's participation constraints, and formulas (13) and (14) are the incentive compatibility constraints to prevent imitation.

For low-quality manufacturer, he can still adopt the optimal contract under symmetric information ,,that is ,.

So we o,ly need to solve the optimal contract for high-quality manufacturer. Because the low-quality manufacturer adopts the optimal contract under symmetric information, the constraint equation (15) must be satisfied ($\underline{\pi}_R^s = 0$). And the high-quality manufacturer will not imitate the low-quality manufacturer, so the constraint equation (15) and (16) can be eliminated. Therefore, using the KKT condition, it can be obtained that the objective function achieves the maximum value if and only when the two constraints are tightened. At this time, we have

$$\overline{q}^{rsw} = \frac{k(m\overline{g} - l\underline{g} - c - \sqrt{(m\overline{g} - l\underline{g} - c)^2 - (m\underline{g} - l\underline{g} - c)^2})}{m} \tag{16}$$

$$\overline{w}^{rsw} = \frac{m\overline{g} + l\underline{g} - c + \sqrt{(m\overline{g} - l\underline{g} - c)^2 - (m\underline{g} - l\underline{g} - c)^2})}{2} \tag{17}$$

Therefore, we can get the following proposition 2.

Proposition 2. In low-information-density model,

the manufacturers offer the optional contracts$\left\{(\overline{w}^{rsw}, \overline{q}^{rsw}), (\underline{w}^{rsw}, \underline{q}^{rsw})\right\} =$

,,

and different types of manufacturers will truthfully choose corresponding contract options to implement according to their green degree;

the wholesale quantity and wholesale price of high-quality manufacturer are distorted from the symmetric information. That is, the wholesale quantity decreases and the wholesale price increases, $\overline{q}^{rsw} < \overline{q}^s, \overline{w}^{rsw} > \overline{w}^s$;

the revenue of high-quality manufacturer is reduced, which the revenues of the low-quality manufacturer and the retailer remain unchanged.

From the above proposition 2, we can get that under asymmetric information, low-information-density model can indeed eliminate information asymmetry. Compared with the contracts under symmetrical information, the wholesale quantity of high-quality manufacturer is distorted downward and the wholesale price is distorted upward. Obviously, the high-quality manufacturer undertakes the task of signal transmission and bears the signal cost, which leads to the reduction of his own revenue. This also brings a problem that cannot be ignored. The benefit of the great manufacturer is reduced, while the benefit of the bad manufacturer remain unchanged, which is unacceptable for high-quality manufacturer. In the long run, no manufacturer is willing to inter provincial green technology, and low-quality products will fill the whole industrial chain.

4.2 Interim-efficient model

According to the section 4.1, the revenue of the high-quality manufacturer will decrease by providing low-information-density contracts. That is, he incurs signaling cost. Clearly, only when the low-quality manufacturer obtains the revenue higher than the optimal profit under symmetric

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information, can the high-quality manufacturer obtain greater revenue and reduce the signal cost. Meanwhile, in order to enable the retailer to participate in the game, we should meet the expected profit conditions of the retailer, which is interim-efficient model.

Assume that the higher part of the rent received by low-quality manufacturers is R and the retailer's minimum loss when facing the low-quality manufacturer is L(R). Therefore, L(R) can be given by the following plan

$$P_4 \quad -L(R) = \max_{(\underline{w},\underline{q})} \left(\left(m\underline{g} - \underline{w} - c \right) \underline{q} - \frac{m\underline{q}^2}{2k} \right) \tag{18}$$

$$\text{s.t.} \quad (\underline{w} - l\underline{g})\underline{q} - h\underline{g}^2 \geq (\underline{w}^s - l\underline{g})q^s - h\underline{g}^2 + R \tag{19}$$

where equation 19 is the revenue constraint of low-quality manufacturer.

We can simply get

$$-L(R) = R \tag{20}$$

$$\underline{q}^{ie} = \underline{q}^s = \frac{\left(m\underline{g} - l\underline{g} - c \right) k}{m} \tag{21}$$

$$\underline{w}^{ie} = \underline{w}^s + \frac{R}{\underline{q}^{ie}} = \frac{m\underline{g} + l\underline{g} - c}{2} + \frac{mR}{\left(m\underline{g} - l\underline{g} - c \right) k} \tag{22}$$

It is obvious that the production quantity of low-quality manufacturer has not changed, while the increased rent R only caused the rise of wholesale price.

For the high-quality manufacturer,

$$P_7 \quad \max_{(\overline{w},\overline{q},R)} \overline{\pi}_M = (\overline{w} - l\overline{g})\overline{q} - h\overline{g}^2 \tag{23}$$

$$\text{s.t.} \quad P\left((m\overline{g} - \overline{w} - c)\overline{q} - \frac{m\overline{q}^2}{2k} \right) - (1 - P)R \geq 0 \tag{24}$$

$$(\underline{w}^s - l\underline{g})q^s - h\underline{g}^2 + R \geq (\overline{w} - l\underline{g})\overline{q} - h\underline{g}^2 \tag{25}$$

where equation 24 is the retailer's expected profit condition, and equation 25 is the incentive compatibility condition.

Using the KKT condition, it can be obtained that the objective function achieves the maximum value when the two constraints are tightened. At this time, we have

$$\overline{q}^{ie} = \frac{k(mP\overline{g} - lP\underline{g} - cP + l\underline{g} - l\overline{g})}{mP} \tag{26}$$

$$R = \frac{k(mP\overline{g} - lP\underline{g} - cP + l\underline{g} - l\overline{g})(m\overline{g} - l\underline{g} - c)}{m} - \frac{k\left(mP\overline{g} - lP\underline{g} - cP + l\underline{g} - l\overline{g} \right)^2}{2mP} - \frac{kP\left(m\underline{g} - l\underline{g} - c \right)^2}{2m} \tag{27}$$

$$\overline{w}^{ie} = P\left(m\overline{g} - c - l\underline{g} \right) + l\underline{g} - \frac{\left(mP\overline{g} - lP\underline{g} - cP + l\underline{g} - l\overline{g} \right)}{2} + \frac{P(1-P)\left(m\underline{g} - l\underline{g} - c \right)^2}{2(mP\overline{g} - lP\underline{g} - cP + l\underline{g} - l\overline{g})} \tag{28}$$

As we all know, $R > 0$. When $R \leq 0$, the above parameters will no longer be valid and the interim-efficient model will be equal to the low-information-density model, i.e., $\left\{ (\overline{w}^{ie}, \overline{q}^{ie}),\ (\underline{w}^{ie}, \underline{q}^{ie}) \right\} = \left\{ (\overline{w}^{ie}, \overline{q}^{ie}),\ (\underline{w}^{rsw}, \underline{q}^{rsw}) \right\}$.

Therefore, we summarize the following proposition 3.

Proposition 3. In the interim-efficient model,

when $R > 0$, the manufacturer provides selective contracts $\left\{ (\overline{w}^{ie}, \overline{q}^{ie}), (\underline{w}^{ie}, \underline{q}^{ie}) \right\} =$

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$$\{P\left(m\overline{g}-c-l\underline{g}\right)+l\underline{g}-\frac{\left(mP\overline{g}-lP\underline{g}-cP+l\underline{g}-l\overline{g}\right)}{2}+$$

$$\frac{P(1-P)\left(m\underline{g}-l\underline{g}-c\right)^2}{2\left(mP\overline{g}-lP\underline{g}-cP+l\underline{g}-l\overline{g}\right)},\ \frac{k\left(mP\overline{g}-lP\underline{g}-cP+l\underline{g}-l\overline{g}\right)}{mP}),\ \left(\frac{m\underline{g}+l\underline{g}-c}{2}+\frac{mR}{\left(m\underline{g}-l\underline{g}-c\right)k},\frac{\left(m\underline{g}-l\underline{g}-c\right)k}{m}\right)\};$$

when $R \le 0$, he provides $\left\{\left(\overline{w}^{ie},\overline{q}^{ie}\right),\left(\underline{w}^{ie},\underline{q}^{ie}\right)\right\}=\left\{\left(\overline{w}^{rsw},\overline{q}^{rsw}\right),\left(\underline{w}^{rsw},\underline{q}^{rsw}\right)\right\}$;

the wholesale quantity of high-quality manufacturer is less than that of symmetric information, but at least not less than that of low-information-density model, i.e., $\overline{q}^{rsw} \le \overline{q}^{ie} < \overline{q}^{s}$.

the revenue of low-quality manufacturer increases R, and the high-quality manufacturer also increases relatively (when $R > 0$);

the expected revenue of the retailer remains unchanged and still maintains his reservation profit. When facing the low-quality manufacturer, the revenue of the retailer is less than his reservation profit. On the contrary, it is greater than it;

there is a critical threshold $P^* = \frac{l\overline{g}-l\underline{g}}{\sqrt{\left(m\overline{g}-l\underline{g}-c\right)^2-(m\overline{g}-l\overline{g}-c)^2}}$. When $P > P^*$, the interim-efficient model is better than the low-information-density model, and the optimal revenue of high-quality manufacturer is improved; On the contrary, they are equal.

According to proposition 3, under certain conditions ($R > 0$), the interim-efficient model can not only eliminate information asymmetry, but also reduce the distortion of contract parameters of high-quality manufacturer and improve his revenue. However, when faced with low-quality manufacturer, his revenue will be lost. On the contrary, his revenue will increase. In further discussion, we found an interesting a priori probability threshold P*, which can determine whether manufacturer can improve his contracts. Higher priori probability can effectively improve the optimal revenue of the high-quality manufacturer. Therefore, the manufacturer must increase the trust of retailer and form a great brand effect in order to gain a better foothold in the market. And for the retailer, he needs to obtain more accurate priori probability to prevent his own loss of revenue.

5. Numerical analysis

In this section, we present a numerical example to illustrate our results. Suppose that a certain green product has a limited market size in a certain period and the market demand D obeys uniform distribution on [0, kg], k=10. Other parameters are as follows: the retailer price p=mg=5g, the manufacturer's cost constant l=2, h=0.2, the retailer's unit marginal cost c=1. To make our analysis more comprehensive, we perform numerical analysis from the following three different perspectives.

Firstly, we give certain values of the green degree and analyze the differences of parameters in different contracts. Assume that the high and low green degree is $\overline{g}=3$ and $\underline{g}=2$ respectively, and the prior probability P=0.8. Therefore, the relevant parameters of the three contracts can be obtained as shown in Table 2.

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Table 2. Different parameters in three contracts

Model type	$\overline{q}$	$\overline{w}$	$\overline{\pi}_M$	$\underline{q}$	$\underline{w}$	$\underline{\pi}_M$
Symmetric Information	16	10	62.2	10	6.5	24.2
Low-information-density	2.68	13.33	17.84	10	6.5	24.2
Interim-efficient	15	9.33	51.64	10	12	79.2

It is obvious from table 2 above that under symmetric information, products with high green degree are more popular, and high-quality manufacturer get higher revenue, which is in line with our expectations. However, in the low-information-density model, the wholesale quantity and the revenue of high-quality manufacturer are seriously distorted downward, while the interim-efficient model significantly improved this distortion. However, it is worth noting that the revenue of low-quality manufacturer has also increased by 55, which may be a psychological imbalance for high-quality manufacturer. High-quality manufacturer is required to make trade-offs. For the retailer, the expected revenue in the three cases is equal to his reservation profit.

Secondly, the difference between two green degrees has an important impact on the results, and we fix the green degree of high-quality products $\overline{g} = 3$ and change the green degree of low-quality products from 0 to 3. The change trends of the corresponding wholesale quantity and manufacturer's revenue are shown in the figures below.

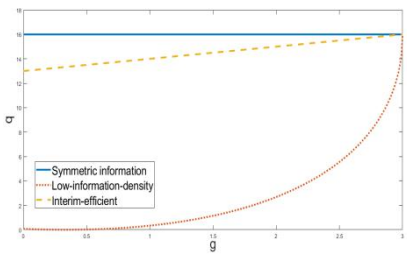

Fig. 2 The wholesale quantity

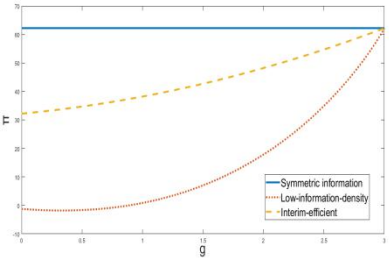

Fig. 3 The revenue

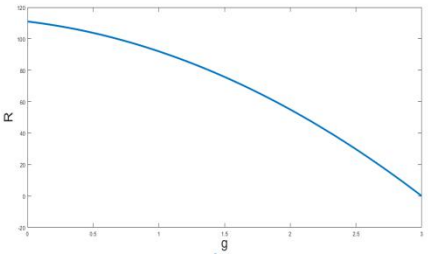

Fig. 4 The rent

Obviously, figures 2 and 3 are very similar, which further verifies the improvement efficiency of the interim-efficient model. In addition, with the increase of the difference between the two green degrees, the loss of signal transmission is also increasing, that is, the excessive quality difference increases the difficulty of signal transmission. This will significantly reduce the revenue of high-quality manufacturer. As can be seen from Figure 4, the rent R of low-quality manufacturer increases with the increase of quality difference. Naturally, the greater the difference in green degree, the greater the profit loss of retailer in the face of low-quality manufacturer, which seriously affects the market order. Thus, in order to standardize the market order of green products, we must standardize the green degree of green products and avoid the unqualified green products in the market.

Finally, we separately explore the influence of a priori probability P on the interim-efficient model. Assume that $\overline{g} = 3$ and $\underline{g} = 2$, then change the value of the prior probability P. The results are given in the following two figures.

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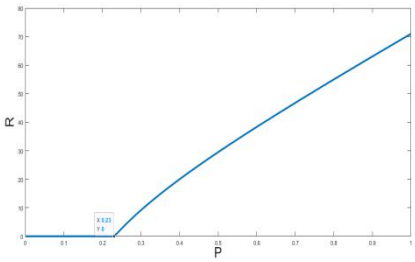

Fig.5 The low-quality manufacturer's rent

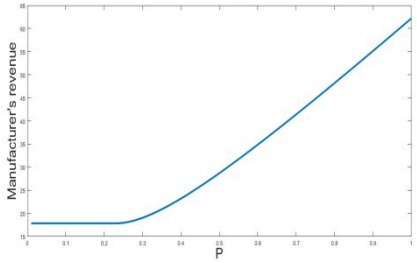

Fig. 6 The high-quality manufacturer's revenue

Figure 5 and Figure 6 verify our proposition 3, that is, there is a priori probability threshold (P = 0.23) that can distinguish the two models. With the increase of the priori probability P, the earnings of both types of manufacturers increase accordingly. It is well understood that for high-quality manufacturer, increasing retailers' trust will help to increase his revenue. For low-quality manufacturer, the high priori probability means that he deceives the retailer through their own methods, so he can get higher revenue.

6. Conclusion

Green products and green supply chains have gradually filled our lives, providing us with a healthy lifestyle. But what follows is the uneven quality of green products and quality uncertainty. At the same time, for certain green supply chain, retailers usually have low visibility of the products' green degree. That is, retailers cannot effectively distinguish different tapes of manufacturers, which will lead to a large number of low-quality products flowing into the market and eventually lead to great resistance to the establishment of a good green market order.

To solve these questions, in this paper, we use the informed principal model and study two typical models: low-information-density model and interim-efficient model. Through the comparative study of two different types of manufacturers, we get some interesting conclusions and use numerical cases to verify these conclusions.

The results show that the low-information-density model can eliminate the information asymmetry, and different types of manufacturers show their product types through different contract options. But it imposes high signaling costs on the high-quality manufacturer, making his earnings significantly lower. The interim-efficient model provides an idea to reduce the signing cost and the distortion of the wholesale quantity effectively. But it follows that the retailer has a certain risk: when he is faced with a low-quality manufacturer, his earnings will be lower than the reservation profit, and vice versa, higher than the reservation profit. In addition, high difference will result in higher signaling costs, reduce the benefits of the high-quality manufacturer and correspondingly increase the benefit of the low-quality manufacturer. Therefore, we should strictly implement the green degree quality standards, prohibit inferior products from entering the market and ensure the market order.

It is worth mentioning that there is a specific threshold for the retailer's prior probability. When the prior probability is greater than this threshold, the interim-efficient model is better than the low–information-density model; otherwise, they are equivalent. At the same time, the higher the prior probability, the higher the profit of the manufacturer. This result organically combines the manufacturer's revenue with the retailer, i.e., the retailer can influence the manufacturer's revenue through prior probability. If the manufacturer wants to obtain more benefits, it must increase the retailer's trust in him by operating with integrity and building a brand effect. Therefore, this can facilitate healthy competition among manufacturers and creates a better business environment.

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The contributions of this research are as follows:

(1) We jointly study quality uncertainty and information asymmetry in a green supply chain consisting of an unreliable manufacturer and a retailer.

(2) We introduce the informed principal model into such a supply chain, and conduct in-depth and multi-faceted model research to provide a new decision-making scheme for the quality uncertainty problem.

(3) We also explore the effect of the prior probability on the manufacturer's decision, and propose a prior probability threshold.

(4) Guide practice through theoretical models and conclusions, and promote the development of green supply chains and the formation of green consumption concepts.

There are some possible directions for future research. On the one hand, when the two product green degrees are random within a certain range, it is worth exploring whether the conclusion will change. On the other hand, in practice, more complex contracts can be applied to the informed principal model to improve supply chain efficiency.

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