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Quality Information Disclosure Strategies in a Dual-channel Supply Chain Considering Piracy

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Abstract: *This paper studied the quality information disclosure decisions of a legal manufacturer in a dual-channel supply chain with a pirated manufacturer. Only the legal manufacturer has the ability of disclosure, while pirated products can "free ride" the disclosure service. The model compared the consumers' utilities when buying legal and pirated products. We obtained the channel demand, sale price and wholesale price strategy of legal products, as well as the quality information disclosure strategy under the constraint of disclosure cost. Moreover, we analyzed the impact of piracy degree on the legal manufacturer's information disclosure decision. It is found that the retail and wholesale prices of legal products show a segmented pricing trend when considering piracy; when the wholesale price of legal products is low enough, there is no demand for pirated products; the higher the degree of piracy, the lower the bargaining power of the legal manufacturer, the lower the wholesale price that can be set; the legal manufacturer is willing to disclose information only when product quality and disclosure cost meet certain conditions at the same time.*

Keywords: *quality disclosure strategy; piracy; dual-channel supply chain*

1. INTRODUCTION

As the information age continues to evolve, the number of pirated products, such as books, software, music and other digital goods, etc., are increased rapidly via both online and offline channels. Pirated products not only take away the revenues of legal firms, but also cause long-term damage to their brand values. In addition, pirated products gain income through illegal means, which erodes the tax revenue of the state and the government in a disguised form. Although the government and relevant authorities have been cracking down on piracy and other illegal infringing products year after year, piracy still exists. Therefore, in the market where piracy is rampant, how legal manufacturers should make decisions is still an issue worth exploring.

In reality, there are two main reasons why consumers choose to buy pirated products. First, the absolute price advantage of pirated products is one of the key factors in their trade-off. Normally, pirated products bear extremely low reproduction cost. The extremely low cost but high profitability is the main reason why many firms are tempted to engage in the piracy industry. Conversely, legal products require significant investment in research and development, market research, sales and after-sales service, etc., which leads to high costs. The double marginal effect existing in supply chains makes it even more difficult to reduce the sale price. Legal manufacturers are at a disadvantage in price competition. Secondly, information asymmetry is another reason why some consumers do not choose legal products. Due to information asymmetry, consumers can't get acknowledge of the quality, service and brand value of legal products completely. Without a full understanding of the value of legal products, customers may blindly assume that the purchase experience they get from pirated products can be similar or even equivalent to that they get when purchasing legal products, and thus end up purchasing the pirated products. Although legal manufacturers can reduce the impact of information asymmetry through information disclosure, the cost of disclosure will further increase the selling price. Therefore, how should legal manufacturers respond to the disruption caused by pirated products in this situation? How should they set wholesale prices to help retailers cope with the impact of piracy? Is a low-price strategy the only way to deal with pricy for legal manufacturers? Should quality information disclosure be adopted? These are the questions that this paper seeks to explore.

This paper analyses the disclosure strategies of legal manufacturers in a dual-channel supply chain containing a pirate manufacturer. Firstly, we analyze the demand and retail pricing of legal and pirated products by weighing the consumer's utility. Furthermore, we examine the wholesale pricing strategies of manufacturers with different levels of product quality. The paper then analyses the disclosure strategies of legal manufacturers by assuming that only legal manufacturers have the ability to disclose quality information, while pirates can only do so through "free-riding".

The literature on piracy mainly studies the pricing, quality selection and anti-piracy strategy of legal products when pirated products exist. Waters (2015)[1] studied the dynamic pricing of information products sold by two terminals in the presence of piracy. Huang et al. (2017)[2] mainly focused on the impact of pirated products on the demand of traditional channels and online channels. The study found that the increase of piracy will force retailers to compete in a smaller market. Therefore, retailers with larger market share and good at maintaining a low piracy rate can obtain more revenue by setting higher prices. Chang and Walter (2015)[3] studied the pricing and quality competition between legal information product providers and pirated websites. Lahiri and Dey (2013)[4] studied the impact of piracy on the quality of information products. The study found that under specific circumstances, the less piracy, the more legal manufacturers are willing to invest in improving product quality.

Through the review of the existing literature, it can be found that the existing research on piracy mostly focuses on terminal pricing, quality selection and anti-piracy strategies, and mainly focuses on sales terminals, but few involve the impact of piracy on the supply chain, especially the wholesale pricing strategy of legal manufacturers. In addition, quality information disclosure is one of the important ways of anti-piracy, but little literature has examined the information disclosure strategies of manufacturers with pirated products. Therefore, based on the existing literature, this paper examines the wholesale pricing strategies and quality information disclosure strategies of legal manufacturers in a dual-channel supply chain containing a legal manufacturer, a retailer and a pirate manufacturer.

2. MODEL

In this paper, we consider a dual-channel supply chain consisting of a legal manufacturer (he), a retailer (it) and a pirate manufacturer (she). The legal manufacturer delivers the products with quality q to the retailer for distribution at the wholesale price w, and the retailer sets the retail price p_1 for sale. The pirate manufacturer sells a pirated product of quality n directly to consumers at a price p_2 [1]. The product quality in this paper is a broad concept, which includes not only the quality of the product, but also the brand value and after-sales service. Since pirated products are inferior to legal products in terms of quality, brand value and service, this paper assumes that $n < q \le 1$, and $n = \eta q$, where $\eta < 2/3$ [2]. η denotes the level of piracy, i.e. the difference in quality between pirated and legal products. The higher the value of η, the higher the level of piracy, and vice versa. Due to information asymmetry, consumers are unable to get full knowledge of the quality of these two types of products before purchase, and only have a prior belief in product quality $\tilde{q}$ ($\tilde{n}$). As the products' quality is the private information of the legal manufacturer, he can decide whether to disclose quality information to consumers by sending samples or advertising at a certain cost z when the product quality is high enough ($q > \hat{q}$), in order to improve sales. After information disclosed by the legal manufacturer, consumers revise their prior belief to be $\tilde{q} = q$, while when information is not disclosed, consumers revise their prior belief to be $\tilde{q} = \bar{q}$. $\bar{q}$ is the average level of product quality expected by consumers, i.e., $\bar{q} = \hat{q}/2$ [5-7].Although the pirate manufacturer has no ability to disclose information, she can indirectly disclose information through "free-riding". When the legal manufacturer discloses (don't disclose) information, consumers revise their prior belief of the quality of the pirated products to be $\tilde{n} = \eta q$ ($\tilde{n} = \eta \bar{q}$).

[1]We take piracy pricing as an exogenous variabl[4].

[2]In order to ensure that the discussion is meaningful, we only examines the situation that piracy exists in the market, which indicates $\eta < 2/3$. The analysis process is shown in conclusion 3 in the appendix. Moreover, pirated goods can't provide after-sales service, so η can't approach 1.。

The marginal cost of producing a legal product consists of the cost of reproduction and upgrading, which is normalised to 0 in this paper. The cost of upgrading is related to quality which is $cq^2/2$ [4], including the cost of later upgrades and maintenance, warranty services, etc. Since product quality is private information of the legal manufacturer, this cost is not affected by the information disclosure decision.For the pirate manufacturer, the cost of piracy is mainly the cost of reproduction, and they have few maintenance cost, so the production cost of pirated products is also normalised to zero in this paper[4].

The utility that consumers can obtain by purchasing a legal (pirated) product is $vq-p_1$ ($vn-p_2$), where v is the utility obtained by consumers when they buy products.The difference in quality and price between pirated products and legal products leads to different utility of consumers. Therefore, consumers can choose to buy legalor pirated products by trade off the utility, which will be different according to the quality and price.

As mentioned above, the game sequence of this paper is:(1) the legalmanufacturer learns the price of pirated product p_2 and decides whether to disclose quality information;(2) the legal manufacturer set the wholesale price w;(3) the retailer makes the pricing decision p_1;(4) consumers make purchase decisions.

3. DEMAND AND PRICING

3.1. Demand

The consumer's purchase decision is based on rational person and incentive compatibility constraints. Therefore, if consumers choose to purchase legal products, the utility they obtain must be non-negative, i.e., $v\tilde{q}-p_1\geq 0$, and should be higher than the utility obtained by purchasing pirated products, i.e. $v\tilde{q}-p_1\geq \eta v\tilde{q}-p_2$. Similarly, if $v\tilde{q}-p_1\geq 0$ and $\eta v\tilde{q}-p_2\geq v\tilde{q}-p_1$,customers will choose to purchase pirated products. Then we can derive the demand faced by both legal and pirate sellers, as shown in Conclusion 1.

Conclusion 1 Under different price conditions, legal manufacturers and pirated manufacturers are faced with the following requirements:

$$Q_1(p_1,\tilde{q})=\begin{cases}1-\dfrac{p_1-p_2}{(1-\eta)\tilde{q}} & if\ p_1>\dfrac{p_2}{\eta}\\ 1-\dfrac{p_1}{\tilde{q}} & otherwise\end{cases}$$

$$Q_2(p_2,\tilde{q})=\begin{cases}\dfrac{p_1-p_2}{(1-\eta)\tilde{q}}-\dfrac{p_2}{\eta\tilde{q}} & if\ p_1>\dfrac{p_2}{\eta}\\ 0 & if\ otherwise\end{cases}$$

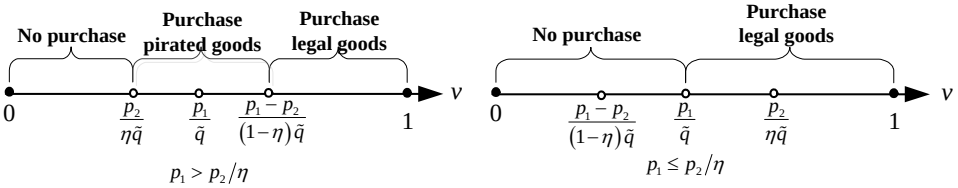


Figure1. *Customers' purchase decisions*

Figure 1 shows the consumers'trade-offs of purchasing legal and pirated goods. When $p_1>p_2/\eta$, both legal and pirated goods exist in the market. However, when the price of the legal good is sufficiently low, i.e., $p_1\leq p_2/\eta$, no consumer is willing to buy pirated products. In this situation the demand for pirated goods is 0, and the demand faced by legal goods is $1-p_1/\tilde{q}$.

3.2. Pricing Strategy of the Retailer

The retailer sets the price according to the quality of the legal products and the wholesale price given by the manufacturer, and it should make decisions to maximize its profit, i.e. $\max \pi_R(p_1,\tilde{q})=(p_1-w)Q_1$. According to conclusion 1, the demand of the legal manufacturer is $Q_1(p_1,\tilde{q})$, then the optimal pricing strategy of the retailer is $p_1^*(w)=\arg\max \pi_R(p_1,\tilde{q})$. Then we can derive Conclusion 2:

Conclusion 2 Considering piracy, the retailer adopts the following pricing strategies:

$$p_1^*(w)=\begin{cases}\dfrac{w+\tilde{q}}{2} & if\ \ w<\dfrac{2p_2}{\eta}-\tilde{q}\\ \dfrac{p_2}{\eta} & if\ \dfrac{2p_2}{\eta}-\tilde{q}\le w\le p_2\left(\dfrac{2-\eta}{\eta}\right)-(1-\eta)\tilde{q}\\ \dfrac{p_2+w+\tilde{q}(1-\eta)}{2} & if\ w>p_2\left(\dfrac{2-\eta}{\eta}\right)-(1-\eta)\tilde{q}\end{cases}$$

where, $\tilde{q}\in\left[p_2/\eta,\min\{2p_2/\eta,1\}\right]$[3].

When the manufacturer gives the retailer a lower wholesale price, i.e., $w<2p_2/\eta-\tilde{q}$, the retailer can sell products at a lower retail price $p_1^*(w)=(w+\tilde{q})/2$, and consumers can get a higher utility by buying the legal products. In this situation, the demand of pirated products is 0. When $p_1^*(w)=p_2/\eta$, there is no difference between the utility of purchasing legal and pirated products, but rational consumers prefer to buy legal products, and no one buys pirated products, either. When the wholesale price is high enough, i.e., $w>p_2(2-\eta)/\eta-(1-\eta)\tilde{q}$, the price of legal products is $p_1^*(w)=\frac{1}{2}[p_2+w+\tilde{q}(1-\eta)]$. Some consumers switch to buy pirated products due to the higher price of legal products. Therefore, the retailer can set exclusive retail prices based on the wholesale price to drive pirated goods out of the market. Corollary 1 can be obtained:

Corollary 1: when the wholesale price of legal products is low enough, i.e., $w\le p_2(2-\eta)/\eta-(1-\eta)\tilde{q}$ **, the demand of the pirated manufacturer is 0.**

When the wholesale price of legal products is $w\le p_2(2-\eta)/\eta-(1-\eta)\tilde{q}$, the retail price of legal products is $p_1^*(w)=(w+\tilde{q})/2$ or $p_1^*(w)=p_2/\eta$. In this circumstance, $p_1\le p_2/\eta$, which indicates that no consumers buy pirated products, as shown in Figure 1. Substitute $p_1^*(w)$ back to $Q_1(p_1,\tilde{q})$, the demand of legal products at different wholesale prices can be obtained:

$$Q_1^*(w)=\begin{cases}\dfrac{\tilde{q}-w}{2\tilde{q}} & if\ \ w<\dfrac{2p_2}{\eta}-\tilde{q}\\ 1-\dfrac{p_2}{\eta\tilde{q}} & if\ \dfrac{2p_2}{\eta}-\tilde{q}\le w\le p_2\left(\dfrac{2-\eta}{\eta}\right)-(1-\eta)\tilde{q}\\ \dfrac{1}{2}+\dfrac{p_2-w}{2\tilde{q}(1-\eta)} & if\ w>p_2\left(\dfrac{2-\eta}{\eta}\right)-(1-\eta)\tilde{q}\end{cases}$$

4. MANUFACTURER'S WHOLESALE PRICING STRATEGY

The previous analyse discussed the demand of legal and pirated products, and the best retail price $p_1^*(w)$ for legal products is obtained. Conclusion 2 shows that different wholesale price will lead to different price and demand, and ultimately affect the profits of the legal manufacturer. Therefore, the legal manufacturer needs to take the impact of piracy into consideration when making optimal decisions. The profit maximization problem that the legal manufacturer needs to solve is:

$$\max\ \pi_m=wQ_1-c_1q^2/2-dz$$

where $d\in\{0,1\}$. When the legal manufacturer chooses to disclose information, $d=1$, and he needs to pay the disclosure cost z. When the manufacturer hides information, i.e., $d=0$, no disclosure cost occurs. Then we can derive the legal manufacturer's profit based on the optimal demand $Q_1^*(w)$:

[3]Unless otherwise noted, the following $\tilde{q}$ is discussed under this scope.

$$\pi(\tilde{q}) = wQ_1 - cq^2/2 - dz = \begin{cases} -\dfrac{w^2 + (cq^2 - w)\tilde{q}}{2\tilde{q}} - dz & if \quad w < \dfrac{2p_2}{\eta} - \tilde{q} \\ -\dfrac{cq^2}{2} + w - \dfrac{p_2\omega}{\eta\tilde{q}} - dz & if \ \dfrac{2p_2}{\eta} - \tilde{q} \le w \le p_2\left(\dfrac{2-\eta}{\eta}\right) - (1-\eta)\tilde{q} \\ \dfrac{w - cq^2}{2} + \dfrac{w(p_2 - w)}{2\tilde{q}(1-\eta)} - dz & if \ w > p_2\left(\dfrac{2-\eta}{\eta}\right) - (1-\eta)\tilde{q} \end{cases}$$

Next, according to the different wholesale price range, we investigate the optimal wholesale pricing strategy by analyzing the legal manufacturer's profit of each segment.

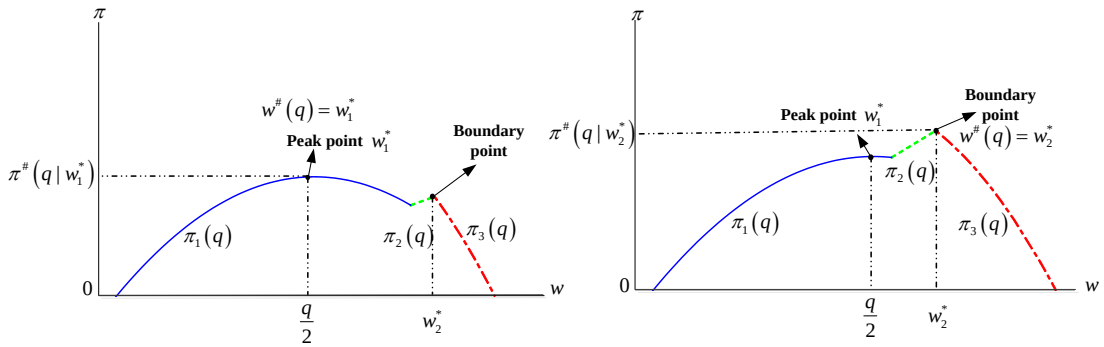
When the legal manufacturer chooses to disclose information, i.e., $d = 1$. In this situation, consumers realize the product quality and modify their prior brief as $\tilde{q} = q$. By analyzing the profits in each range, we can derive the legal manufacturer's optimal wholesale pricing strategy under information disclosure, which is shown in Conclusion 3:

Conclusion 3 In the case of information disclosure, the legal manufacturer's wholesale pricing strategy is:

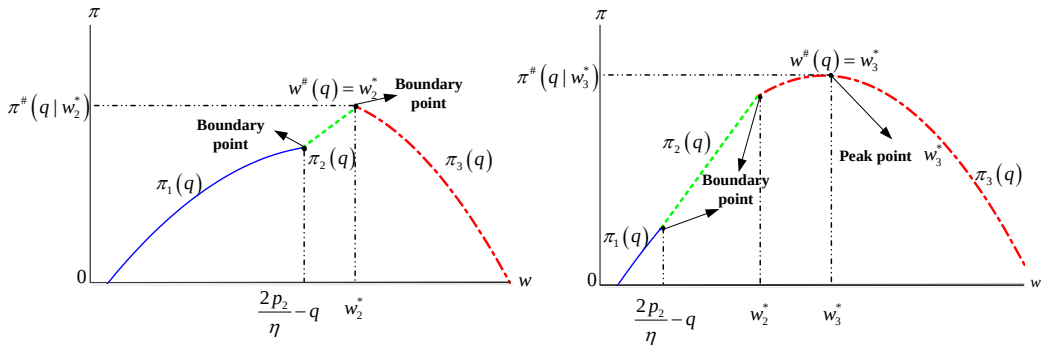
$$w^{\#}(q) = \begin{cases} \dfrac{q}{2} & if \quad \dfrac{p_2}{\eta} \le q < \dfrac{2p_2\left(6 - \sqrt{2\eta} - 4\eta\right)}{\eta(9 - 8\eta)} \\ p_2\left(\dfrac{2-\eta}{\eta}\right) - (1-\eta)q & if \quad \dfrac{2p_2\left(6 - \sqrt{2\eta} - 4\eta\right)}{\eta(9 - 8\eta)} \le q \le \dfrac{p_2(4 - 3\eta)}{3\eta(1-\eta)} \\ \dfrac{p_2 + q(1-\eta)}{2} & if \quad \dfrac{p_2(4 - 3\eta)}{3\eta(1-\eta)} < q \le \min\{2p_2/\eta, 1\} \end{cases}$$

where:

$$\min\{2p_2/\eta, 1\} = \begin{cases} 2p_2/\eta & if \ p_2/\eta < 1/2 \\ 1 & if \ 1/2 \le p_2/\eta \le 1 \end{cases}$$



(a) $\dfrac{p_2}{\eta} \le q < \dfrac{2p_2\left(6 - \sqrt{2\eta} - 4\eta\right)}{\eta(9 - 8\eta)}$ (b) $\dfrac{2p_2\left(6 - \sqrt{2\eta} - 4\eta\right)}{\eta(9 - 8\eta)} \le q < \dfrac{4p_2}{3\eta}$



(c) $\dfrac{4p_2}{3\eta} \le q \le \dfrac{p_2(4 - 3\eta)}{3\eta(1-\eta)}$ (d) $\dfrac{p_2(4 - 3\eta)}{3\eta(1-\eta)} < q \le \min\{2p_2/\eta, 1\}$

Figure2. *Wholesale pricing strategy of the legal manufacturer*

When $p_2/\eta \le q < 2p_2\left(6-\sqrt{2\eta}-4\eta\right)/\eta(9-8\eta)$, $\pi_1(q)$ can realize profit maximation at $w_1^* = q/2$. However, $\pi_2(q)$ and $\pi_3(q)$ can only realize the profit at the boundary point $w_2^* = p_2(2-\eta)/\eta-(1-\eta)q$. Now $\pi_2\left(q \mid w_2^*\right) = \pi_3\left(q \mid w_2^*\right)$. Since $\pi_1\left(q \mid w_1^*\right) > \pi_2\left(q \mid w_2^*\right) = \pi_3\left(q \mid w_2^*\right)$, the legal manufacturers will set the wholesale price as $\omega^{\#}(q) = w_1^*$ when $p_2/\eta \le q < 2p_2\left(6-\sqrt{2\eta}-4\eta\right)/\eta(9-8\eta)$, as shown in Figure 2(a). When $2p_2\left(6-\sqrt{2\eta}-4\eta\right)/\eta(9-8\eta) \le q < 4p_2/3\eta$,even though $\pi_1(q)$ can realize the optimal profit atthe peak point w_1^*, $\pi_1\left(q \mid w_1^*\right) \le \pi_2\left(q \mid w_2^*\right) = \pi_3\left(q \mid w_2^*\right)$. The legal manufacturer will set the wholesale price as $w^{\#}(q) = w_2^*$. See Figure 2(b).

When $4p_2/3\eta \le q \le p_2(4-3\eta)/3\eta(1-\eta)$, $\pi_1(q)$ can realize the optimal profit at the boundary point $w = 2p_2/\eta - q$. $\pi_2(q)$ and $\pi_3(q)$ can realize the optimal profit at the boundary point $w = w_2^*$.Now $\pi_2\left(q \mid w_2^*\right) = \pi_3\left(q \mid w_2^*\right) > \pi_1(q \mid w = 2p_2/\eta - q)$ is constant satisfied.Therefore, when $4p_2/3\eta \le q \le p_2(4-3\eta)/3\eta(1-\eta)$,the optimal wholesale price is the same, i.e., $w^{\#}(q) = w_2^*$,as shown in Figure 2(c)。

When $p_2(4-3\eta)/3\eta(1-\eta) < q \le \min\{2p_2/\eta, 1\}$, $\pi_3(q)$ can realize the optimal profit at the peak point $w_3^* = \left[p_2 + q(1-\eta)\right]/2$. Moreover, since $\pi_3\left(q \mid w_3^*\right) > \pi_2\left(q \mid w_2^*\right) > \pi_1(q \mid w = 2p_2/\eta - q)$,the optimal wholesale price is $w^{\#}(q) = w_3^*$,as shown in Figure 2(d).

It can be found that when the product quality is different, the optimal profit can be realized by the legal manufacturer is different, and the wholesale pricing strategy will change accordingly. Among all the wholesale pricing strategies, only when $w^{\#}(q) = w_3^*$, some consumers choose to buy pirated products. Therefore, the legal manufacturer can adjust the wholesale pricing strategy according to the quality of products, so as to cope with the market disruption caused by pirated products.

We can derive the impact of pirated products on the wholesale pricing strategy of legal the manufacturer based on Conclusion 3, as shown in Corollary 2:

Corollary 2 The higher the level of piracy (the greater η), the lower the bargaining power of the legal manufacturer, the lower the wholesale price that he can set (the smaller $w^{\#}$), i.e. $\partial w^{\#}/\partial\eta \le 0$.

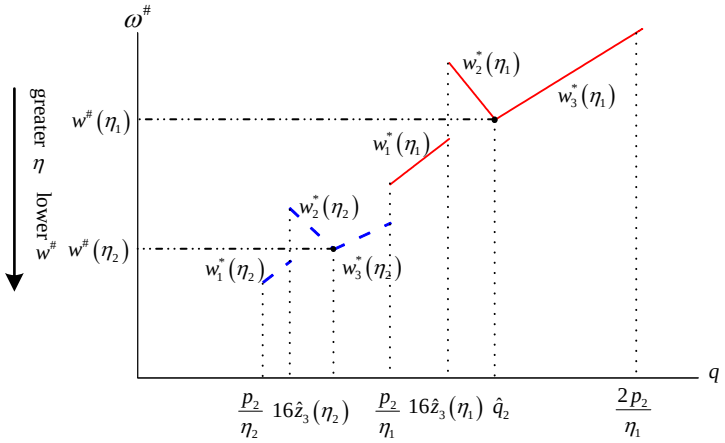


Figure3. *The Impact of piracy on wholesale prices ($\eta_1 < \eta_2$)*

Conclusion 3 gives the optimal wholesale prices of the legal products $w^{\#}(q)$ under different quality constraints under information disclosure. Moreover, the legal manufacturer's wholesale price decisions are also influenced by the level of piracy. Figure 3 shows the impact of piracy on wholesale prices. When $p_2/\eta \le q < 16\hat{z}_3$, $w^{\#}(q) = w_1^*$, $\partial w_1^*/\partial\eta = 0$. Although w_1^* is not affected directly by the level of piracy, with the increase of η, the product quality constraint required by it declines, i.e., $\partial(p_2/\eta)/\partial\eta < 0$, $\partial 16\hat{z}_3/\partial\eta < 0$, which then leads to the decline of $w^{\#}$. Thelegal manufacturer switches his wholesale pricing strategy from $w_1^*(\eta_1)$ to $w_1^*(\eta_2)$,as shown in the Figure 3. Similarly, when $16\hat{z}_3 \le q \le \hat{q}_2$, $w^{\#} = w_2^*$, and $\partial w_2^*/\partial\eta < 0$; when $\hat{q}_2 < q \le \min\{2p_2/\eta, 1\}$, $w^{\#} = w_3^*$, and $\partial w_3^*/\partial\eta < 0$. When the degree of piracy increases (η increases), the gap between pirated products and legal products will

narrow. In order to prevent piracy from encroaching the market, the legal manufacturer can only choose to lower the wholesale price to some extent, so as to reduce the cost of the retailer and encourage her to set lower sale price to compete with pirated products. At the same time, the quality constraint corresponding to the wholesale price decreases, which means the legal manufacturer makes decisions under lower product quality level. In practice, the rampant piracy behaviour greatly dampens the enthusiasm of enterprises for innovation, and they are more willing to produce "ordinary" goods than to invest a lot of costs in innovative research to improve product performance or develop new products. Therefore, pirated products have bad effects on both the legal manufacturers and the industry itself.

Similarly, the legal manufacturer do not have to pay disclosure costs,ifhe chooses to hide quality information, i.e., $d=0$. Consumers revise their prior belief of the quality of legal products, which is $\tilde{q}=\bar{q}$. By using the same analysis method, we can derive the legal manufacturer's wholesale pricing strategy if the information is not disclosed, which will not be described here.

5. QUALITY INFORMATION DISCLOSURE STRATEGY

Conclusion 3 indicates that product quality can affects the wholesale price and the legal manufacturer's profit, which will also influence disclosure strategies. When information is disclosed, the profit the legal manufacturer can obtain is $\pi_m^{\#}\left(w^{\#}(q)\right)$. Similarly, when information is not disclosed, the profit the legal manufacturer can obtain is $\pi_m^{\#}\left(w^{\#}(\bar{q})\right)$. Therefore, if and only if the profit when information is disclosed is greater than the profit when information is not disclosed, i.e. $\pi_m^{\#}\left(w^{\#}(q)\right)>\pi_m^{\#}\left(w^{\#}(\bar{q})\right)$, the legal manufacturer will disclose information. Thus, the legal manufacturer's information disclosure strategy can be obtained, as shown in Conclusion 4:

Conclusion 4 If and only if $\hat{q}_1^{\#}<q<\hat{q}_2^{\#}$, the legal manufacturer will disclose information, where:

$$\left\{\hat{q}_1^{\#},\hat{q}_2^{\#}\right\}=\begin{cases}\left\{p_2/\eta,16\hat{z}_3\right\} & if\ \ 0\le z<p_2/16\eta \\ \left\{16z,16\hat{z}_3\right\} & if\ \ p_2/16\eta\le z<\hat{z}_3\end{cases}\Bigg\}I$$
$$\Bigg\}II$$
$$\begin{cases}\left\{\hat{q}_1,\hat{q}_2\right\} & if\ \ \hat{z}_2\le z\le\hat{z}_1 \\ \left\{16\hat{z}_3,\hat{q}_2\right\} & if\ \ z>\hat{z}_1\end{cases}\Bigg\}II$$
$$\begin{cases}\left\{\hat{q}_2,\min\left\{2p_2/\eta,1\right\}\right\} & if\ \ 0\le z\le\hat{z}_4 \\ \left\{\hat{q}_3,\min\left\{2p_2/\eta,1\right\}\right\} & if\ \ z>\hat{z}_4\ \left(when\ p_2/\eta<1/2,\ z\le\hat{z}_5\ is\ required.\right)\end{cases}\Bigg\}III$$

$$\hat{q}_1=-\frac{z\eta^2-\sqrt{z^2\eta^2+2p_2{}^2\left(2-3\eta+\eta^2\right)}}{(1-\eta)\eta}\quad\hat{q}_2=\frac{p_2(4-3\eta)}{3\eta(1-\eta)}\quad\hat{q}_3=\frac{8z+\sqrt{2\left(p_2{}^2+32z^2\right)}}{(1-\eta)}$$

$$\hat{z}_1=\frac{p_2\left[30+\sqrt{2\eta}(13-12\eta)-44\eta+16\eta^2\right]}{4\eta(9-8\eta)}\quad\hat{z}_2=\frac{p_2\left(20-30\eta+9\eta^2\right)}{6\eta(4-3\eta)}\quad\hat{z}_3=\frac{p_2\left(6-\sqrt{2\eta}-4\eta\right)}{8\eta(9-8\eta)}$$

$$\hat{z}_4=\frac{p_2\left(16-24\eta-9\eta^2\right)}{48\eta(4-3\eta)}\quad\hat{z}_5=\frac{p_2\left(2-4\eta+\eta^2\right)}{16(1-\eta)\eta}$$

Conclusion 4 shows that whether to disclose information is not only related to disclosure cost, but also related to quality. Figure 4shows the legal manufacturer's quality information disclosure decisions. The shaded part in Figure 4is the area that quality information is disclosed, which consists of three parts. Area *II* consists of two parts: when $\hat{z}_2\le z<\hat{z}_1$, the legal manufacturer discloses information if $\hat{q}_1<q<\hat{q}_2$; when $z\ge\hat{z}_1$, the information disclosure condition is $16\hat{z}_3<q<\hat{q}_2$. Area *I* and Area *III* indicates information disclosure occurs only if the disclosure cost is low enough, which is also related to the level of quality. Area *I* shows that the legal manufacturer's willingness is higher, which means he can disclose information even the product quality is low, i.e. $q<16\hat{z}_3$. On the contrary, in the situation of Area *III*, the legal manufactuer discloses information only if the quality is high enough,

i.e., $\hat{q}_2$.

Conclusion 4 indicates that the legal manufacturer is willing to disclose information only if the quality of legal products meets a specific range under a specific cost of disclosure.

Two reasons may lead to such a result:(1) channel conflicts, free-riding and other factors exist in the dual-channel supply chain, so that the quality meets the disclosure condition only in a specific range, which is consistent with the conclusion of Zhou and Zhao (2016)[8]. (2) the existence of pirated products leads to the diversity of market demand, product pricing, quality, disclosure cost and wholesale price, which also makes the information disclosure decision of legal manufacturers more complicated. They have toconsider not only their own products, but also the impact caused by pirated products.

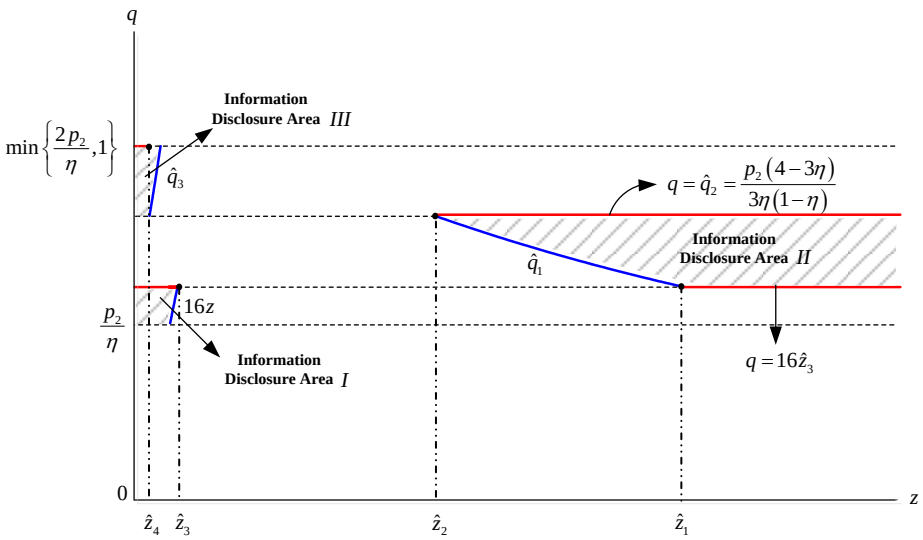


Figure4. *Disclosure strategy of thelegal manufacturer*

6. CONCLUSION

This paper investigates the demand, pricing and information disclosure strategy of legal manufacturers when there are pirate manufacturers in a dual-channel supply chain. The main conclusions are as follows: 1) due to the existence of pirated products, the retail and wholesale prices of legal products show a segmented pricing trend; 2) the degree of piracy has a negative effect on the bargaining power of legal manufacturers. In a higher degree of piracy, legal manufacturers can only set a lower wholesale price, and heneeds to make decisions at a lower level of product quality; 3) legal manufacturersdisclose information only if product quality and disclosure cost meet specific conditions.

In this paper, the analysis of information disclosure strategy of legal manufacturers when pirated products exist enriches the research of dual-channel supply chain and information disclosure. In the model studied in this paper, the price of pirated products is an exogenous variable. In the further study, it is worth to investigate if the retail price of pirated products is an endogenous variable, how the pirate manufacturers make decisions in the dual-channel supply chain to occupy the market and how the price affects the strategy of the legal manufacturers.

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APPENDIX

Proof of Conclusion 3

First of all, we analyze the optimal profit of each segment and the range it requires. Since $\pi_1(q)=-\left[w^2+\left(cq^2-w\right)q\right]/2q-z>0$, we get $w_2<w<w_1$, where $w_1=\frac{1}{2}\left(q+\sqrt{q\left(q-4cq^2-8z\right)}\right)$, $w_2=\frac{1}{2}\left(q-\sqrt{q\left(q-4cq^2-8z\right)}\right)$.As $w<2p_2/\eta-q$ have to be satisfied, $w_2<2p_2/\eta-q<w_1$, w_1 should be rejected. Therefore, when $w_2<w<2p_2/\eta-q$, $\pi_1>0$. Since $w_2<w<2p_2/\eta-q$,when $q<4p_2/3\eta$, $\pi_1(q)$ can get the highest profit at $w_1^*=q/2$。

Similarly, when $2p_2/\eta-q\le w\le p_2(2-\eta)/\eta-(1-\eta)q$, $\pi_2(q)>0$ is constant satisfied. Since $\pi_2(q)$ is increasing monotonically in w, within the scope of $p_2/\eta\le q\le\min\{2p_2/\eta,1\}$, $\pi_2(q)$ can realize the optimal value at $w_2^*=p_2(2-\eta)/\eta-(1-\eta)q$。

When $p_2(2-\eta)/\eta-(1-\eta)q<w<w_3$, $\pi_3(q)>0$,where $w_3=\frac{1}{2}\left[p_2+q-q\eta+\sqrt{4q\left(cq^2+2z\right)(\eta-1)+\left(p_2+q-q\eta\right)^2}\right]$. Then we can derive the wholesale price that maximizes $\pi_3(q)$, which is $w_3^*=\left[p_2+q(1-\eta)\right]/2$. If and only if $\left[p_2+q(1-\eta)\right]/2>p_2(2-\eta)/\eta-(1-\eta)q$,i.e., $q>p_2(4-3\eta)/3\eta(1-\eta)$, $\pi_3(q)$ can get the highest profit at w_3^*, otherwise, it can only realize the profit at w_2^*. Based on the previous analysis,only if $w>w_2^*$, i.e., $q>p_2(4-3\eta)/3\eta(1-\eta)$, there are pirated products in the market. To make the discussion meaningful, we only consider the situation when $p_2(4-3\eta)/3\eta(1-\eta)<1$i.e., $p_2/\eta<3(1-\eta)/(4-3\eta)$. Otherwise, $q>p_2(4-3\eta)/3\eta(1-\eta)$ is not satisfied, which means there are no pirated goods in the market.

Thus, we can derive the optimal wholesale pricing strategiesof the legal manufacturer by discussing q in different scopes.

- When $p_2/\eta\le q<4p_2/3\eta$:

$\pi_1(q)$ can realize the optimal value $\pi_1\left(q\mid w_1^*\right)=\frac{1}{8}\left(q-4cq^2-8z\right)$ at w_1^*. $\pi_2(q)$ can realize the optimal value at $w=w_2^*$. however, $\pi_3(q)$ can only realize the profit at the boundary point $w=w_2^*$, where $\pi_2\left(q\mid w_2^*\right)=\pi_3\left(q\mid w_2^*\right)=\left[2p_2(3-2\eta)-\eta\left[cq^2+2z+2q(1-\eta)\right]\right]/2\eta-{p_2}^2(2-\eta)/q\eta^2$.

By solving $\pi_1\left(q\mid w_1^*\right)>\pi_2\left(q\mid w_2^*\right)=\pi_3\left(q\mid w_2^*\right)$, we can get $q<2p_2\left(6-\sqrt{2\eta}-4\eta\right)/\eta(9-8\eta)$. So, when $p_2/\eta\le q<2p_2\left(6-\sqrt{2\eta}-4\eta\right)/\eta(9-8\eta)$,the legal manufacturer's optimal wholesale pricing strategy is $w^{\#}(q)=w_1^*$, and the optimal profit is $\pi_1\left(q\mid w_1^*\right)$, as shown in Figure 2(a). When $2p_2\left(6-\sqrt{2\eta}-4\eta\right)/\eta(9-8\eta)\le q<4p_2/3\eta$, $\pi_1\left(q\mid w_1^*\right)\le\pi_2\left(q\mid w_2^*\right)=\pi_3\left(q\mid w_2^*\right)$. The optimal wholesale pricing strategy is $w^{\#}(q)=w_2^*$, and the optimal profit is $\pi_2\left(q\mid w_2^*\right)=\pi_3\left(q\mid w_2^*\right)$, as shown in Figure 2(b).

- When $4p_2/3\eta\le q\le p_2(4-3\eta)/3\eta(1-\eta)$, the process of analysis is similar. For simplicity, we omit the details.

- When $p_2(4-3\eta)/3\eta(1-\eta) < q \le \min\{2p_2/\eta, 1\}$:

Firstly, consider the situation when $2p_2/\eta < 1$, i.e., $p_2/\eta < 1/2$. In order to ensure $2p_2/\eta > p_2(4-3\eta)/3\eta(1-\eta), \eta < 2/3$ is required. If $2p_2/\eta \ge 1$, $p_2/\eta \ge 1/2$ should be satisfied. Moreover, $p_2/\eta < 3(1-\eta)/(4-3\eta)$. Therefore, the range of η is $\eta < 2/3$.

$\pi_1(q)$ can only realize the profit at boundary point $w = 2p_2/\eta - q$. $\pi_2(q)$ can realize the profit at boundary points w_2^*. $\pi_3(q)$ can get the optimal profit at w_3^*. As $\pi_3(q \mid w_3^*) > \pi_2(q \mid w_2^*) > \pi_1(q \mid w = 2p_2/\eta - q)$, when $p_2(4-3\eta)/3\eta(1-\eta) \le q \le \min\{2p_2/\eta, 1\}$, the legal manufacturer's optimal wholesale price is $w^{\#}(q) = w_3^*$,as shown in Figure 2(d)。

Proof of Conclusion 4

- When $p_2/\eta \le q < 2p_2\left(6-\sqrt{2\eta}-4\eta\right)/\eta(9-8\eta)$:

The legal manufacturer's profit when information is disclosed and undisclosed is $\pi_1(q \mid w_1^*)$ and $\pi_1(\bar{q} \mid w_1^*(\bar{q}))$, respectively. If and only if the profit under information disclosure is greater than the profit the manufacturer gets when he hides information, i.e., when $\pi_1(q \mid w_1^*) > \pi_1(\bar{q} \mid w_1^*(\bar{q}))$, the legal manufacturer will disclose information.Then we can obtain the information disclosure conditions $q > 16z$.

By solving $16z > 2p_2\left(6-\sqrt{2\eta}-4\eta\right)/\eta(9-8\eta)$, we can get $z > \hat{z}_3 = p_2\left(6-\sqrt{2\eta}-4\eta\right)/8\eta(9-8\eta)$. Therefore, when $z > \hat{z}_3$, the legal manufacturer does not disclose information. When $p_2/\eta \le 16z < \hat{z}_3$, i.e., $p_2/16\eta \le z < \hat{z}_3$, $16z < q < 16\hat{z}_3$ should be satisfyied. If $16z < p_2/\eta$, i.e., $z < p_2/16\eta$, the legal manufacturer discloses information when $p_2/\eta \le q < 16\hat{z}_3$.

- When $16\hat{z}_3 \le q \le p_2(4-3\eta)/3\eta(1-\eta)$:

By comparing the profits of the legal manufacturer when information is disclosed and undisclosed, we can get the information disclosure condition $q \ge \hat{q} = \left[\bar{q}^2\eta^2(z+\eta) - \sqrt{4p_2{}^2\bar{q}^2 - p_2{}^2 + \bar{q}z - (2-\eta)(1-\eta)}\right]/2\bar{q}(1-\eta)\eta^2$. Substitute $\hat{q} = 2\bar{q}$ in the above formula, the information disclosure condition can be rewritten as $q \ge \hat{q}_1 = -\left[z\eta^2 - \sqrt{z^2\eta^2 + 2p_2{}^2(2-3\eta+\eta^2)}\right]/(1-\eta)\eta$.

Since $16\hat{z}_3 \le \hat{q}_1 \le p_2(4-3\eta)/3\eta(1-\eta)$, we have $\hat{z}_2 \le z \le \hat{z}_1$,where $\hat{z}_1 = p_2\left[30+\sqrt{2\eta}(13-12\eta)-44\eta+16\eta^2\right]/4\eta(9-8\eta)$ and $\hat{z}_2 = p_2(20-30\eta+9\eta^2)/6\eta(4-3\eta)$. Therefore, when $\hat{z}_2 \le z \le \hat{z}_1$, the disclosure conditionsis $\hat{q}_1 < q < \hat{q}_2 = p_2(4-3\eta)/3\eta(1-\eta)$. When $z > \hat{z}_1$, $\hat{q}_1 < 16\hat{z}_3$. The legal manufacturer discloses information when $16\hat{z}_3 < q < \hat{q}_2$. When $\hat{q}_1 > \hat{q}_2$, i.e., $z < \hat{z}_2$, the legal manufacturer is unwilling to disclose information.

- When $p_2(4-3\eta)/3\eta(1-\eta) < q \le \min\{2p_2/\eta, 1\}$:

Similarly, we can get $q > \hat{q}_3 = \left[8z + \sqrt{2\left(p_2{}^2 + 32z^2\right)}\right]/(1-\eta)$ by comparing the profits when information is disclosed and undisclosed. Based on the analysis above, when $p_2/\eta < 1/2$, $\min\{2p_2/\eta, 1\} = 2p_2/\eta$. If $\hat{q}_3$ satisfies $\hat{q}_2 < \hat{q}_3 \le 2p_2/\eta$, i.e., $\hat{z}_4 < z \le \hat{z}_5$[4], the information disclosure condition is $\hat{q}_3 < q \le 2p_2/\eta$. If $\hat{q}_3 > 2p_2/\eta$, i.e., $z > \hat{z}_5$, then legal manufacturer doesn't disclose information when $\hat{q}_2 < \hat{q}_3 \le 2p_2/\eta$. If $\hat{q}_3 \le \hat{q}_2$, i.e., $z \le \hat{z}_4$, information is disclosed in the range of $\hat{q}_2 < q \le 2p_2/\eta$.

When $1/2 \le 2p_2/\eta \le 1$, $\min\{2p_2/\eta, 1\} = 1$. If $\hat{q}_3$ satisfies $\hat{q}_2 < \hat{q}_3 \le 1$, i.e., $z > \hat{z}_4$, the information disclosure condition is $\hat{q}_3 < q \le 1$. If $\hat{q}_3 \le \hat{q}_2$, i.e., $z \le \hat{z}_4$, information is disclosed in the range of $\hat{q}_2 < q \le 1$.

[4] $\hat{z}_4 = p_2(16-24\eta-9\eta^2)/48\eta(4-3\eta)$, $\hat{z}_5 = p_2(2-4\eta+\eta^2)/16(1-\eta)\eta$

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