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Research Article

Research on Demand Forecasting Information Sharing Strategy of Closed-Loop Supply Chain considering Advertising Effect

Liying Li, Xinyu Hou, and Lixia Niu

College of Business Administration, Liaoning Technical University, Huludao 125105, Liaoning, China

Correspondence should be addressed to Xinyu Hou; hxyupupup@163.com

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Based on the uncertain market demand, this paper studies the sharing strategy of each main body of the closed-loop supply chain for demand prediction information and introduces the variable of advertising effect into the model. Firstly, this paper constructs a manufacturer-led Stackelberg game model based on a two-level closed-loop supply chain. Secondly, the manufacturer advertising mode and the retailer advertising mode are set up, and the influence of information sharing is discussed in each advertising mode. Finally, the conclusion and the proposition are verified by example analysis. The results show that in terms of advertising, manufacturers prefer retailers to undertake, and retailers' willingness is related to the mode of information sharing. In order to achieve a "win-win" situation by sharing information, certain conditions should be met. The advertising effect is helpful to increase product demand, retail price, advertising investment level, and profits of manufacturers and retailers and also promote recycling activities. However, the impact on wholesale price will vary with different advertising subjects.

1. Introduction

Under the pressure of resource scarcity and environment deterioration, manufacturing enterprises have gradually started to pay attention to building green supply chain and recycling and remanufacturing waste products. The closed-loop supply chain contains a reverse recovery chain, which can achieve the purpose of saving resources and reducing industrial waste by closing the flow of materials. Today, research on closed-loop supply chain has involved many aspects such as recycling channel selection and product pricing decisions. In terms of recycling channel selection, in 2004, Savaskan et al. established three recycling modes, in which the manufacturer, the retailer, and the entrusted third party assume the recycling responsibility, respectively [1]. In 2020, Huang et al. combined the third-party recyclers, manufacturers, and retailers into two new recycling modes and finally got the optimal recycling channel under the decentralized decision-making model [2]. In 2022, Wang and Qin established a mixed competitive recycling model between manufacturers and retailers and considered the impact of government subsidies on the recycling process [3]. In terms of pricing, in 2019, He et al. deduced the optimal channel structure and pricing decision of manufacturers under the three channel structures of dual-channel closed-loop supply chain and studied the influence of government subsidy policy on supply chain [4]. In 2021, Xiaotong et al. introduced the preference for online shopping and retail service influence into the closed-loop supply chain [5]. In 2022, Mondal and Giri found that government subsidies in closed-loop supply chain can improve the green level of products and thus expand sales [6].

Proper information sharing strategies can improve the operation efficiency of upstream and downstream companies in the supply chain and reduce corresponding costs. Information sharing is particularly important for the closed-loop supply chain. At present, the research on supply chain information sharing can be divided into two aspects: demand information sharing and cost information sharing. This paper studies the former. In 1981, Winkler studied the uncertainty of the market and demand and proposed to use the normal distribution of random variables to build the model [7]. In 2006, Yue et al. studied the pricing of complementary goods under asymmetric supply chain demand information using the Winkler model [8]. In 2011, Mukhopadhyay et al. discussed the pricing strategy of complementary goods using the Stackelberg game in the case of information asymmetry [9]. In 2019, Wei et al. introduced the low-carbon awareness of consumers into the information sharing study of dual-channel supply chain and proposed the model that only retailers can make predictions [10]. In 2019, Li et al. constructed a supply chain model of asymmetric demand between two manufacturers and multiple retailers and introduced the influence of substitutable products [11]. In 2019, Mingjun et al. introduced government subsidies and green input into the research of supply chain information sharing at the same time [12]. In 2021, Yu et al. used the evolutionary game to study the long-term effects of information sharing on the manufacturers using organic agriculture on the basis of profit matrix, studied the method of joint prediction to realize information sharing, and analyzed the advantages and disadvantages of information sharing [13]. In 2022, Xiaoqing et al. summarized and analyzed the research on contract design of supply chain in the environment of asymmetric demand information [14]. In 2022, Qu et al. studied the information sharing problem of virtual products from the perspective of Nash game and Stackelberg game and determined the equilibrium conditions of product pricing and quality effort decision [15].

Nowadays, there are more and more kinds of alternative products in the market, how to "stand out" from them is a difficult problem, and most enterprises will choose to expand the sales of products through advertising. Of course, advertising will inevitably bring a certain cost, and how to balance the investment of advertising and the increase of profits brought by sales is a problem that enterprises need to study. In 2011, SeyedEsfahani et al. analyzed the equilibrium solutions of Nash equilibrium, Stackelberg game, and cooperative game, respectively, using the advertising cooperation model of manufacturers and retailers [16]. In 2013, Yi studied the influence of the advertising effect on the decision making and coordination performance of closed-loop supply chain node enterprises under three decision modes: centralized, decentralized, and advertising cooperation [17]. In 2017, Xie et al. considered the level of advertising input in the study of dual-channel closed-loop supply chain and analyzed the contract coordination problem of supply chain under centralized and decentralized decision making [18]. In 2019, Minli et al. also considered advertising effect and corporate social responsibility into the study of closed-loop supply chain and discussed them through the model of manufacturers and retailers placing advertisements separately [19]. In 2020, Zhang et al. studied the influence of channel rights structure and information structure on supply chain pricing and advertising cooperation decisions [20]. In 2022, Cao et al. studied the emergency problem of closed-loop supply chain under the condition that the advertising effect is affected by emergencies, obtained the influence on product price and advertising input when the disturbance quantity of advertising effect is positive and negative, respectively, and proposed two toll system contracts to coordinate the closed-loop supply chain after disturbance [21]. In 2022, Asghari et al. studied pricing and advertising decisions in closed-loop supply chains, studied advertising schemes under different elastic effects, and solved them with improved particle swarm optimization algorithm [22].

Different from the above studies, this paper introduces the information asymmetry theory into the study of closed-loop supply chain, considering the uncertainty of market demand, and at the same time introduces the uncertainty theory into the market prediction of manufacturers and retailers, which makes the study more practical. On this basis, the influence of advertising effect is considered, and the enterprise decision of manufacturer advertising mode and retailer advertising mode is analyzed and compared, trying to explore the optimal decision mode of different supply chain subjects under different advertising modes.

2. Materials and Methods

This paper designs a two-stage closed-loop supply chain that includes manufacturers and retailers. Manufacturers are responsible for making products and wholesaling them to retailers, who are responsible for selling them to consumers. Considering the complexity of the model in this paper, it is assumed that the manufacturer is responsible for both product recycling and remanufacturing. Considering placing product advertisements, the paper sets up two advertising models in which the manufacturer or the retailer places advertisements separately. In this paper, a Stackelberg game model dominated by manufacturers is constructed, and retailers are the followers of the game.

The main symbols of the model are described as follows.

Let us say that a is the quantity demanded in the market when the price is zero and there is no advertising; q is the demand for the product; p represents the unit retail price of the product; β is the elasticity coefficient of demand to price; λ represents the sensitivity coefficient of demand to advertising (also known as advertising effect in this paper); and g is the intensity of advertising. Then, the demand function of this product can be expressed as follows:

$$q = a - \beta p + \lambda g. \tag{1}$$

Let c_m represent the unit production cost of the new product. c_r represents the unit remanufacturing cost of used products. Let $\Delta = c_m - c_r$ represent the unit cost saved in the remanufacturing link. ω represents the unit wholesale price of the product. Recovery cost consists of fixed cost and variable cost. I represents the fixed cost paid for recycling waste products, k represents the recovery efficiency of waste products, and τ represents the recovery rate of waste products. According to previous studies, $I = k\tau^2$. In this paper, $k = 1/2$, and $I = \tau^2/2$ can be obtained. The variable recovery cost is related to the unit recovery cost and recycling volume. A represents the unit recovery cost of waste products. C represents advertising input cost. According to existing studies [19], the relationship between advertising cost and advertising intensity is $g = \sqrt{\gamma C}$; for each unit level increase in advertising, the demand increases γ units, which is not only related to the production of advertising itself but also related to the market environment. To simplify the calculation, γ is assumed to be 2, so the advertising cost in this study is $C = g^2/2$. The profits of the retailer and manufacturer are denoted by π_r and π_m, respectively.

This paper assumes that the market demand is uncertain and uses random variable a to represent the market demand. According to Winkler's research [7], the market demand is composed of initial average demand a_0 and random demand ε, and then $a = a_0 + \varepsilon$ can be obtained. ε is a normally distributed random variable, used to represent the uncertainty of the market, with a mean of 0 and a variance of U. Before making a decision, manufacturers and retailers predict the market demand. In this paper, f_m and f_r are used to represent the forecast of market demand by manufacturers and retailers, respectively. Referring to existing literature, $f_m = a + \delta_m$, $f_r = a + \delta_r$. In the above equation, δ_m and δ_r are random variables subject to normal distribution. They represent the error of manufacturer's and retailer's prediction of market demand, respectively. The mean of δ_m and δ_r is 0, and the variance is V_r and V_m, respectively. Since manufacturers and retailers refer to historical data and use similar techniques to predict market demand, δ_m and δ_r can be considered to be cocorrelated, and ρ represents the correlation coefficient. The covariance matrix can be expressed as $\sum = \begin{pmatrix} V_r & V_{rm} \\ V_{rm} & V_m \end{pmatrix}$, and then the correlation coefficient can be expressed as $\rho = V_{rm}/\sqrt{V_r V_m}$.

According to Winkler's research results [7], we can know that

$$\begin{aligned}
E(\,|\,f_m) &= a_0 + t_m(f_m - a_0),\\
E(a\,|\,f_r) &= a_0 + t_r(f_r - a_0),\\
E(f_r\,|\,f_m) &= a_0 + s_m(f_m - a_0),\\
E(f_m\,|\,f_r) &= a_0 + s_r(f_r - a_0),\\
E(af_r, f_m) &= a_0 + J(f_m - a_0) + K(f_r - a_0),\\
t_m &= \frac{U}{U + V_m},\\
t_r &= \frac{U}{U + V_r},\\
s_m &= \frac{U + V_{rm}}{U + V_m},\\
s_r &= \frac{U + V_{rm}}{U + V_r},
\end{aligned}$$

$$\begin{aligned}
J &= \frac{t_m(s_r - 1)}{s_r s_m - 1},\\
K &= \frac{t_r(s_m - 1)}{s_r s_m - 1}.
\end{aligned} \tag{2}$$

This paper assumes that the decision makers of this supply chain are all economically rational. Both manufacturers and retailers aim to maximize their own profits. There is no obvious difference between new products and remanufactured products in quality and other aspects. For consumers, remanufactured products are the same as new products. In order to make the parameters and formulas of this paper meaningful, this paper assumes that $0 \le \beta \le 1$, $q \ge 0$, $a > 0$, $\lambda \ge 0$, $0 \le \rho \le 1$, $p \ge \omega \ge c_m \ge c_r$, $A \le \Delta$, $0 < \tau < 1$, $C > 0$.

3. Model Analysis

3.1. Manufacturer Advertising Model. Under this model, the advertising cost is borne by the manufacturer, and the manufacturer is also responsible for the production and recycling of the product, while the retailer is only responsible for the sale of the product. The two cases with and without information sharing are considered, respectively. The profit expressions of the manufacturer and retailer are

$$\begin{aligned}
\pi_m^M &= (\omega - c_m + \Delta\tau - A\tau)q - \frac{g^2}{2} - \frac{\tau^2}{2},\\
\pi_r^M &= (p - \omega)q.
\end{aligned} \tag{3}$$

Substitute it in equation (1) and obtain

$$\begin{aligned}
\pi_m^M &= (\omega - c_m + \Delta\tau - A\tau)(a - \beta p + \lambda g) - \frac{g^2}{2} - \frac{\tau^2}{2},\\
\pi_r^M &= (p - \omega)(a - \beta p + \lambda g).
\end{aligned} \tag{4}$$

3.1.1. No Information Sharing. In the absence of information sharing, the manufacturer only makes decisions based on f_m. However, after the manufacturer determines the advertising input and wholesale price of the product, the retailer can infer the manufacturer's prediction information from it, so the retailer makes decisions based on f_m and f_r. The following equation is the conditional expected profit function of the manufacturer and retailer based on the forecast information:

$$E\left(\pi_m^M | f_m\right)^N = E\left(\left[(\omega - c_m + \Delta\tau - A\tau)(a - \beta p + \lambda g) - \frac{g^2}{2} - \frac{\tau^2}{2}\right] | f_m\right), \tag{5}$$

$$E\left(\pi_r^M | f_m, f_r\right)^N = E\left([(p - \omega)(a - \beta p + \lambda g)] | f_m, f_r\right), \tag{6}$$

where $\partial^2 \pi_r^{MN}/\partial^2 p = -2\beta < 0$, and there is an optimal retailer profit. According to the sequence of decisions, solve the problem by backward induction, and let $\partial \pi_r^{MN}/\partial p = 0$, and we can get

$$p = \frac{B + \lambda g + \omega\beta}{2\beta}, \tag{7}$$

where $B = E(a|f_r, f_m) = a_0 + J(f_m - a_0) + K(f_r - a_0)$; substitute it into equation (5); then, find the first-order conditions for ω, τ, and g, respectively, and then simultaneous $\partial \pi_m^{MN}/\partial \omega = 0$, $\partial \pi_m^{MN}/\partial \tau = 0$, $\partial \pi_m^{MN}/\partial g = 0$ can be obtained as follows:

$$\omega^{MN*} = \frac{(B - 2B_m)\left[\beta(A + \Delta)^2 - 2\right] + c_m\left(\lambda^2 - 2\beta\right)}{(A - \Delta)^2\beta^2 - 4\beta + \lambda^2}, \tag{8}$$

$$\tau^{MN*} = \frac{\beta(2B_m - \beta c_m - B)(A - \Delta)}{(A - \Delta)^2\beta^2 - 4\beta + \lambda^2}, \tag{9}$$

$$g^{MN*} = \frac{\lambda(\beta c_m + B - 2B_m)}{(A - \Delta)^2\beta^2 - 4\beta + \lambda^2}. \tag{10}$$

Among them, $B_m = E(a|f_m) = a_0 + t_m(f_m - a_0)$, $(A - \Delta)^2\beta^2 - 4\beta + \lambda^2 < 0$. Substituting equations (8) and (10) into equation (7), we can obtain the following:

$$p^{MN*} = \frac{B_m\left[\beta^2(A - \Delta)^2 - 2\beta - \lambda^2\right] + (B - \beta c_m)\left(\lambda^2 - \beta\right)}{\beta\left[(A - \Delta)^2\beta^2 - 4\beta + \lambda^2\right]}. \tag{11}$$

Then, the conditional expected profits of the manufacturer and the retailer are as follows:

$$\begin{aligned} E\left(\pi_m^M|f_m\right)^{N*} &= \frac{-(B - 2B_m + \beta c_m)^2}{2(A-)^2\beta^2 - 8\beta + 2\lambda^2}, \\ E\left(\pi_r^{MN}|f_m, f_r\right)^{N*} &= \frac{\left\{(B - B_m)\left[(A - \Delta)^2\beta^2 + \lambda^2\right] + \beta(2B_m - 3B) + \beta^2 c_m\right\}^2}{\beta\left[(A - \Delta)^2\beta^2 - 4\beta + \lambda^2\right]^2}. \end{aligned} \tag{12}$$

In addition, the following equation can be obtained:

$$\begin{aligned} E\left(B^2\right) &= {a_0}^2 + J^2(U + V_m) + K^2(U + V_r) + 2JK(U + V_{rm}), \\ E\left({B_m}^2\right) &= {a_0}^2 + {t_m}^2(U + V_m), \\ E(BB_m) &= {a_0}^2 + Jt_m(U + V_m) + Kt_m(U + V_{rm}). \end{aligned} \tag{13}$$

$$\begin{aligned} E\left(\pi_m^M\right)^{N*} &= E\left[E\left(\pi_m^{MN}|f_m\right)\right], \\ E\left(\pi_r^M\right)^{N*} &= E\left[E\left(\pi_r^{MN}|f_m, f_r\right)\right]. \end{aligned} \tag{14}$$

The unconditional expected profit of manufacturers and retailers without information sharing under this advertising model can be obtained:

The unconditional expected profit of both parties can be obtained by the following calculation:

$$\begin{aligned} E\left(\pi_m^M\right)^{N*} &= \frac{-{a_0}^2 + 2\beta c_m a_0 - (J - 2t_m)^2(U + V_m) + 2K(2t_m - 1)(U + V_{rm}) - K^2(U + V_r) + \beta^2 c_m}{2(A - \Delta)^2\beta^2 - 8\beta + 2\lambda^2}, \\ E\left(\pi_r^M\right)^{N*} &= \frac{\left[(A - \Delta)^2\beta^2 + \lambda^2\right]^2\left[(J - t_m)^2(U + V_m) + K^2(U + V_r) + 2K(J - t_m)(U + V_{rm})\right] + \beta^2\left[(a_0 - \beta c_m)^2 + (3J - 2t_m)^2(U + V_m) + 6K(3J - 2t_m)(U + V_{rm}) + 9K^2(U + V_r)\right]}{\beta\left[(A - \Delta)^2\beta^2 - 4\beta + \lambda^2\right]^2}. \end{aligned} \tag{15}$$

3.1.2. Information Sharing. In the case of information sharing, both the manufacturer and the retailer make decisions based on f_m and f_r. The following equation is the conditional expected profit function of the manufacturer and the retailer based on the prediction information of both sides:

$$\begin{aligned} E\left(\pi_m^M|f_r, f_m\right)^I &= E\left(\left[(\omega - c_m + \Delta\tau - A\tau)(a - \beta p + \lambda g) - \frac{g^2}{2} - \frac{\tau^2}{2}\right]|f_r, f_m\right), \\ E\left(\pi_r^M|f_r, f_m\right)^I &= E\left([(p - \omega)(a - \beta p + \lambda g)]|f_r, f_m\right). \end{aligned} \tag{16}$$

The optimal retail price, wholesale price, recovery rate, and advertising investment in information sharing under the manufacturer's advertising mode are

$$\begin{aligned} p^{MI*} &= \frac{B\left[\beta(A-\Delta)^2-3\right]+c_m\left(\lambda^2-\beta\right)}{(A-\Delta)^2\beta^2-4\beta+\lambda^2},\\ \omega^{MI*} &= \frac{B\left[\beta(A-\Delta)^2-2\right]+c_m\lambda^2-2\beta c_m}{(A-\Delta)^2\beta^2-4\beta+\lambda^2},\\ \tau^{MI*} &= \frac{\beta(B-\beta c_m)(A-\Delta)}{(A-\Delta)^2\beta^2-4\beta+\lambda^2},\\ g^{MI*} &= -\frac{\lambda(B-\beta c_m)}{(A-\Delta)^2\beta^2-4\beta+\lambda^2}. \end{aligned} \tag{17}$$

Then, the conditional expected profit of the manufacturer and the retailer can be obtained:

$$\begin{aligned} E\left(\pi_m^M|f_m,f_r\right)^{I*} &= \frac{-(B-\beta c_m)^2}{2(A-\Delta)^2\beta^2-8\beta+2\lambda^2},\\ E\left(\pi_r^M|f_m,f_r\right)^{I*} &= \frac{\beta(B-\beta c_m)^2}{\left[(A-\Delta)^2\beta^2-4\beta+\lambda^2\right]^2}. \end{aligned} \tag{18}$$

Similarly, the expected profits of manufacturers and retailers without information sharing can be obtained under this advertising model:

$$\begin{aligned} E\left(\pi_m^M\right)^{I*} &= -\frac{a_0{}^2-2\beta c_m a_0+\beta^2 c_m{}^2+J^2(U+V_m)+K^2(U+V_r)+2JK(U+V_{rm})}{(A-\Delta)^2\beta^2-8\beta+2\lambda^2},\\ E\left(\pi_r^M\right)^{I*} &= \frac{\beta(a_0-\beta c_m)^2+J^2(U+V_m)+K^2(U+V_r)+2JK(U+V_{rm})}{\left[(A-\Delta)^2\beta^2-4\beta+\lambda^2\right]^2}. \end{aligned} \tag{19}$$

3.2. Retailer Advertising Model. Under this model, the advertising cost is borne only by the retailer, and the retailer is also responsible for the sale of the product, while the manufacturer is responsible for the production and recycling of the product. In this section, the two cases with and without information sharing are still considered. Under this model, the profit expressions of manufacturers and retailers are as follows:

$$\begin{aligned} \pi_m^R &= (\omega-c_m+\Delta\tau-A\tau)q-\frac{\tau^2}{2},\\ \pi_r^R &= (p-\omega)q-\frac{g^2}{2}. \end{aligned} \tag{20}$$

3.2.1. No Information Sharing. The following equation is the conditional expected profit function of the manufacturer and retailer based on the forecast information:

$$\begin{aligned} E\left(\pi_m^R|f_m\right)^N &= E\left(\left[(\omega-c_m+\Delta\tau-A\tau)(a-\beta p+\lambda g)-\frac{\tau^2}{2}\right]|f_m\right),\\ E\left(\pi_r^R|f_r,f_m\right)^N &= E\left(\left[(p-\omega)(a-\beta p+\lambda g)-\frac{g^2}{2}\right]|f_r,f_m\right). \end{aligned} \tag{21}$$

The optimal retail price, wholesale price, recovery rate, and advertising investment under the retailer advertising mode without information sharing are

$$p^{RN*}=\frac{\beta^2(A-\Delta)^2[\lambda^2(B-B_m)+\beta B_m]-\beta^2(B+2B_m)+\lambda^4(B-B_m)+\lambda^2\beta(3B_m-2B)+\beta^2c_m(\lambda^2-\beta)}{(A-\Delta)^2\beta^4-4\beta^3+2\lambda^2\beta^2},$$

$$\omega^{RN*}=\frac{\beta^2(2B_m-B)[(A-\Delta)^2\beta-2]+(B-B_m)[\beta^2\lambda^2(A-\Delta)^2+\lambda^4]+\lambda^2\beta(4B_m-3B)+\beta^2c_m(\lambda^2-2\beta)}{(A-\Delta)^2\beta^4-4\beta^3+2\lambda^2\beta^2},$$

$$\tau^{RN*}=-\frac{[\beta(B-2B_m)-\lambda^2(B+B_m)+\beta^2c_m](A-\Delta)}{(A-\Delta)^2\beta^2-4\beta+2\lambda^2},$$

$$g^{RN*}=\frac{\lambda(B-B_m)[(A-\Delta)^2\beta^2+\lambda]+\beta(2B_m-3B)+\lambda\beta^2c_m}{\beta[(A-\Delta)^2\beta^2-4\beta+2\lambda^2]}. \tag{22}$$

Obtain the conditional expected profit of the manufacturer and the retailer:

$$E(\pi_m^R|f_m)^{N*}=\frac{-[\beta(B-2B_m)+\lambda^2(B_m-B)+\beta^2c_m]^2}{2\beta^2[(A-\Delta)^2\beta^2-4\beta+2\lambda^2]},$$

$$E(\pi_r^R|f_r,f_m)^{N*}=\frac{(\beta-\lambda^2)\{(B-B_m)[(A-\Delta)^2\beta^2+\lambda^2]+\beta(2B_m-3B)+\beta^2c_m\}^2}{2\beta^2[(A-\Delta)^2\beta^2-4\beta+2\lambda^2]^2}. \tag{23}$$

Then, the unconditional expected profit of manufacturers and retailers without information sharing under the retailer advertising model can be obtained:

$$E(\pi_m^R)^{N*}=\frac{(2\beta\lambda^2-\lambda^4-\beta^2)[a_0^2+J^2(U+V_m)+K^2(U+V_r)+2JK(U+V_{rm})]+(4\beta\lambda^2-\lambda^4-4\beta^2)[a_0^2+t_m^2(U+V_m)]-\beta^4c_m^2+2\beta^3c_ma_0+(2\lambda^4-6\beta\lambda^2+4\beta^2)[a_0^2+Jt_m(U+V_m)+Kt_m(U+V_{rm})]}{2\beta^2[(A-\Delta)^2\beta^2-4\beta+2\lambda^2]^2},$$

$$E(\pi_r^R)^{N*}=\frac{(2\beta-\lambda^2)\{[a_0^2+J^2(U+V_m)+K^2(U+V_r)+2JK(U+V_{rm})][(A-\Delta\beta^4+(\lambda^2-3\beta)^2+2\beta^2(\lambda^2-3\beta)(A-\Delta)^2]+[a_0^2+t_m^2(U+V_m)][(A-\Delta)^4\beta^4+(2\beta-\lambda^2)^2-2\beta^2(A-\Delta)^2(2\beta-\lambda^2)]+[a_0^2+Jt_m(U+V_m)+Kt_m(U+V_{rm})][(A-\Delta)^4(4\beta^2-2\beta^4-2\beta\lambda^2)+2(\lambda^2-3\beta)((A-\Delta)^2\beta^2+2\beta-\lambda^2)]+\beta^3c_m(\beta c_m-2a_0)\}}{2[(A-\Delta)^2\beta^2-4\beta+2\lambda^2]^2}. \tag{24}$$

3.2.2. Information Sharing. The following equation is the conditional expected profit function of the manufacturer and the retailer based on the prediction information conditions of both sides.

$$E\left(\pi_m^R|f_r, f_m\right)^I = E\left(\left[(\omega - c_m + \Delta\tau - A\tau)(a - \beta p + \lambda g) - \frac{\tau^2}{2}\right]|f_r, f_m\right),$$
$$E\left(\pi_r^R|f_r, f_m\right)^I = E\left(\left[(p - \omega)(a - \beta p + \lambda g) - \frac{g^2}{2}\right]|f_r, f_m\right), \tag{25}$$

The optimal retail price, the optimal wholesale price, the optimal recovery rate, and the optimal advertising investment in the information sharing of the retailer advertising mode are

$$p^{RI*} = \frac{B\left[(A - \Delta)^2\beta^2 - 3\beta + \lambda^2\right] + \beta c_m\left(\lambda^2 - \beta\right)}{(A - \Delta)^2\beta^3 - 4\beta^2 + 2\lambda^2\beta},$$
$$\omega^{RI*} = \frac{B\left[(A - \Delta)^2\beta^2 - 2\beta + \lambda^2\right] + \beta c_m\left(\lambda^2 - 2\beta\right)}{(A - \Delta)^2\beta^3 - 4\beta^2 + 2\lambda^2\beta},$$
$$\tau^{RI*} = \frac{\beta(A - \Delta)(B - \beta c_m)}{(A - \Delta)^2\beta^2 - 4\beta + 2\lambda^2},$$
$$g^{RI*} = \frac{\lambda(\beta c_m - B)}{(A - \Delta)^2\beta^2 - 4\beta + 2\lambda^2}. \tag{26}$$

Obtain the conditional expected profit of the manufacturer and the retailer:

$$E\left(\pi_m^R|f_r, f_m\right)^{I*} = \frac{-(B - \beta c_m)^2}{2(A - \Delta)^2\beta^2 - 8\beta + 4\lambda^2},$$
$$E\left(\pi_r^R|f_r, f_m\right)^{I*} = \frac{(B - \beta c_m)^2\left(2\beta - \lambda^2\right)}{2\left[(A - \Delta)^2\beta^2 - 4\beta + 2\lambda^2\right]^2}. \tag{27}$$

By the same token, the unconditional expected profit of manufacturers and retailers when they share information in this advertising mode can be obtained:

$$E\left(\pi_m^R\right)^{I*} = \frac{(a_0 - \beta c_m)^2 - \left[J^2(U + V_m) + K^2(U + V_r) + 2JK(U + V_{rm})\right]}{2(A - \Delta)^2\beta^2 - 8\beta + 4\lambda^2},$$
$$E\left(\pi_r^R\right)^{I*} = \frac{\left(2\beta - \lambda^2\right)\left[(a_0 - \beta c_m)^2 + J^2(U + V_m) + K^2(U + V_r) + 2JK(U + V_{rm})\right]}{2\left[(A - \Delta)^2\beta^2 - 4\beta + 2\lambda^2\right]^2}. \tag{28}$$

3.3. Model Comparison and Analysis. According to the value range and limiting conditions of each variable, it can be known that $\beta(A - \Delta)^2 - 2 < 0$, $\beta - \lambda^2 > 0$, $(A - \Delta)^2\beta^2 - 4\beta + 2\lambda^2 < 0$, $\beta(A + \Delta)^2 - 2 > 0$, $(A - \Delta)^2\beta^2 - 2\beta + \lambda^2 < 0$.

Proposition 1. *Comparison of decision variables in different situations:*

(1) If and only if $B < B_m$, $q^{MI*} > q^{MN*}$, $p^{MI*} < p^{MN*}$, $\omega^{MI*} < \omega^{MN*}$, $\tau^{MI*} < \tau^{MN*}$, $g^{MI*} < g^{MN*}$.

(2) If and only if $B < B_m$, $q^{RI*} > q^{RN*}$, $p^{RI*} < p^{RN*}$, $\omega^{RI*} < \omega^{RN*}$, $\tau^{RI*} < \tau^{RN*}$, $g^{RI*} > g^{RN*}$.

(3) $q^{MN*} < q^{RN*}$, $p^{MN*} > p^{RN*}$, $\omega^{MN*} > \omega^{RN*}$, $\tau^{MN*} < \tau^{RN*}$, $g^{MN*} < g^{RN*}$.

(4) $q^{MI*} < q^{RI*}$, $p^{MI*} > p^{RI*}$, $\omega^{MI*} > \omega^{RI*}$, $\tau^{MI*} < \tau^{RI*}$, $g^{MI*} < g^{RI*}$.

(1) and (2) in Proposition 1 illustrate the influence of information sharing on manufacturers' and retailers' respective decision variables. When the manufacturer's market demand forecast is higher than that of the retailer, information sharing will lead to lower unit recycling, wholesale price, and retail price of the product and higher demand. The advertising effect is better when the information is not

shared in the manufacturer model, and the opposite is true in the retailer model.

(3) and (4) describe the influence of the subject of advertising on each decision variable. It can be seen that under the condition of no information sharing, the wholesale price of products in the manufacturer's advertising model is higher, but the product demand, recovery rate, and advertising investment are lower. Therefore, if the decision makers pay more attention to the increase of demand, they should choose the retailer advertising mode as much as possible. However, if it is more inclined to reduce the advertising cost, it is more suitable to choose the manufacturer advertising mode.

Proposition 2. *The comparison of manufacturers' profits under different circumstances is as follows:*

(1) *If and only if* $(B - B_m)(B_m - \beta c_m) > 0$, $E(\pi_m^M | f_m)^{I*} > E(\pi_m^M | f_m, f_r)^{N*}$; *if and only if* $U(J + K) + JV_m + KV_{rm} - t_m(U + V_m) > 0$, $E(\pi_m^M)^{I*} > E(\pi_m^M)^{N*}$.

(2) *If and only if* $(B - B_m)[\lambda^2 (B - B_m) + 2\beta B_m - 2\beta^2 c_m] > 0$, $E(\pi_m^R | f_m)^{I*} > E(\pi_m^R | f_m, f_r)^{N*}$; *if and only if* $\lambda^2 [J^2 (U + V_m) + K^2 (U + V_r) + 2JK (U + V_{rm})] + 2t_m [J(U + V_m) + K(U + V_{rm})] + t_m^2 (U + V_m)(\lambda^2 - 2\beta) > 0$, $E(\pi_m^R)^{I*} > E(\pi_m^R)^{N*}$.

Proposition 2 describes the impact of information sharing on manufacturers' profits under two advertising models. It can be seen that when different conditions are met, manufacturers can strive for greater profits through information sharing. In other words, information sharing is valuable to manufacturers only under these conditions.

Proposition 3. *The profit comparison of retailers under different circumstances is as follows:*

(1) *If and only if* $(B - B_m)[(A-)^2\beta^2 + \lambda^2 - 2\beta]\{(B - B_m)[(A - \Delta)^2\beta^2 + \lambda^2] + 2\beta(B_m - 2B) + 2\beta^2 c_m\} < 0$, $E(\pi_r^M | f_r)^{I*} > E(\pi_r^M | f_m, f_r)^{N*}$; *if and only if* $[(A - \Delta)^2\beta^2 + \lambda^2 - 2\beta]\{[J(J - 2t_m)(U + V_m) + 2K (J - t_m)(U + V_{rm}) + K^2 (U + V_r) + t_m^2 (U + V_m)] [(A - \Delta)^2\beta^2 + \lambda^2] + 2\beta[(U + V_m)(3Jt_m - 2J^2 - t_m^2) + K(U + V_{rm})(3t_m - 4J) - 2K^2 (U + V_r)]\} > 0$, $E(\pi_r^M)^{I*} > E(\pi_r^M)^{N*}$.

(2) *If and only if* $(B - B_m)[(A - \Delta)^2\beta^2 + \lambda^2 - \beta] + \beta(B_m - 2B) + \beta^2 c_m < 0$, $E(\pi_r^R | f_r)^{I*} > E(\pi_r^R | f_m, f_r)^{N*}$; *if and only if* $\beta^2 c_m - \beta a_0 < 0$, $E(\pi_r^R)^{I*} > E(\pi_r^R)^{N*}$.

Proposition 3 describes the impact of information sharing on retailers' profits under the two advertising models. Under certain conditions, retailers can achieve more profits through information sharing.

Corollary 1. *It follows from Propositions 2 (1) and 3 (1) that in the manufacturer advertising model, if and only if* $(A - \Delta)^2\beta^2 + \lambda^2 - 2\beta < 0$, $(B - B_m)[(A - \Delta)^2\beta^2 + \lambda^2] + 2\beta^2 c_m + 2\beta(B_m - 2B) > 0$, *and* $B > B_m > \beta c_m$, *manufacturers and retailers are more likely to share information when making decisions.*

Corollary 2. *According to Propositions 2 (2) and 3 (2), in the retailer advertising mode, when the following two conditions are met, manufacturers and retailers will be more inclined to share information:*

(1) $B > B_m$ *and* $(B - B_m)[(A - \Delta)^2\beta^2 + \lambda^2 - \beta] + \beta (B_m - 2B) + \beta^2 c_m < 0$.

(2) $B < B_m$, $(B - B_m)[(A - \Delta)^2\beta^2 + \lambda^2 - \beta] + \beta(B_m - 2B) + \beta^2 c_m < 0$, *and* $\lambda^2 (B - B_m) + 2\beta B_m - 2\beta^2 c_m < 0$.

Proposition 4. *The influence of advertising effect on the optimal decision variables and respective profits of manufacturers and retailers under different advertising modes and different information sharing modes is as follows:* p^{MN*}, p^{MI*}, p^{RN*}, p^{RI*}, ω^{MN*}, ω^{MI*}, g^{MN*}, g^{MI*}, g^{RN*}, g^{RI*}, τ^{MN*}, τ^{MI*}, τ^{RN*}, τ^{RI*}, q^{MN*}, q^{MI*}, q^{RN*}, q^{RI*}, π_m^{MN*}, π_m^{MI*}, π_m^{RN*}, π_m^{RI*}, π_r^{MN*}, π_r^{MI*}, π_r^{RN*}, *and* π_r^{RI*} *are positively correlated with* λ, *and* ω^{RN*} *and* ω^{RI*} *all are negatively correlated with* λ.

In this paper, λ represents the sensitivity of market demand to advertising, reflecting advertising effect. It can be seen from Proposition 4 that the demand for products is proportional to the advertising effect, which will encourage manufacturers to increase advertising efforts, and manufacturers will increase the recycling of products. Under the mode of advertising, the same quality condition, if consumers prefer to advertise products, you can increase the demand for product advertising, the influence of the retailers can improve the product at the retail level, due to the increased cost of advertising, and the retail price will increase without a decrease in demand and profits, so the wholesale price will increase and then increase the profits of manufacturers and retailers. Under the retailer advertising model, the increase in market demand will make the production of products achieve economies of scale. In order to encourage retailers to continue to vigorously advertise to increase the demand, manufacturers will reduce the wholesale price on the premise of ensuring their own profits.

4. Simulation Analysis

In order to verify the above conclusions and propositions more intuitively, this section analyzes the influence of various parameters on supply chain equilibrium results under different circumstances through simulation.

4.1. Design of the Simulation Analysis. Table 1 lists the parameter values.

4.2. The Effect of Advertising. Figure 1 shows the influence curve of the advertising effect λ on the wholesale price of products. It can be seen that the advertising effect has opposite effects on the optimal wholesale price in the two advertising modes, which are directly proportional and

Table 1: Basic value and range of the parameter.

Parameter	Base value and range of values
$\mathbf{a_0}$	120
β	0.8
$\mathbf{c_m}$	5
Δ	1.5
A	1
λ	0.8 (0-1)
U	400 (225–625)
$\mathbf{V_m}$	100 (1–256)
$\mathbf{V_r}$	81 (1–256)
$\mathbf{V_{rm}}$	0

inversely proportional, respectively, and the decreasing rate in the retailer advertising mode is smaller than the increasing rate in the manufacturer advertising mode. When the manufacturer is responsible for advertising, the increase in advertising effect will lead to the increase in product sales, which will stimulate the manufacturer to increase the advertising effort. In the absence of advertising, higher prices may result in lower sales, but if this is compensated for by increased profits from advertising, manufacturers can still increase wholesale prices. When an advertisement is placed by a retailer, at a higher advertising effect, the sales of the same advertising effect will be much more than those of the manufacturer. So, in order to encourage retailers to increase their advertising efforts, manufacturers would rather lower wholesale prices in order to achieve higher sales and profits.

Figure 2 shows the influence curve of advertising effect λ on product retail price p. It can be seen that the retail price will increase with the increase of the advertising effect under the two advertising models. When the advertising effect is less than a certain value, the retail price in the manufacturer's advertising mode is higher, and the opposite is true when the advertising effect is greater than this value. Under the same advertising effect, the advertising cost of the retailer advertising mode is higher, so even if the wholesale price decreases with increasing advertising effect, the retail price will not decrease. When the advertising effect is large, the sales volume in the retailer advertising model is more sensitive to the change of the advertising effect, which makes the retail price increase rate in this advertising model much higher than that in the manufacturer advertising model. Therefore, when the advertising effect reaches a certain value, the retail price of the retailer advertising mode will be greater than that of the manufacturer advertising mode.

Figure 3 depicts the influence curve of advertising effect λ on manufacturer's profit π_m. The manufacturer's profit is always proportional to the advertising effect. Since the retailer can know the consumer's demand more directly, it is assumed that the retailer can predict the market demand more accurately. After information sharing, manufacturers will get more accurate forecast value, which enables manufacturers to more accurately control the cost input and production scale of products, thus increasing profits. When the advertising effect is large, the retailer advertising model will maximize the profit of the manufacturer, and when the advertising effect is small, the opposite is true. Although it can be seen in Figure 1 that the wholesale price under the retailer's advertising mode is lower, the wholesale price is not the only factor that affects the manufacturer's profit. When the advertising effect reaches a certain value, the sales volume under the retailer's advertising mode will increase exponentially, offsetting the reduced profit due to the decrease of the wholesale price. In this case, the manufacturer does not have to bear the advertising cost, and the increase of advertising effect will increase the recovery rate and reduce the production cost. This is also one of the reasons why the manufacturer's profit is much higher than that when it advertises.

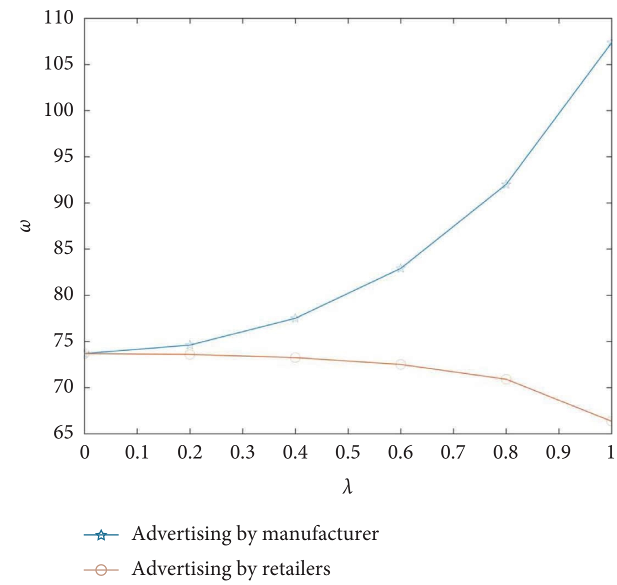

Figure 1: Impact of λ on wholesale prices.

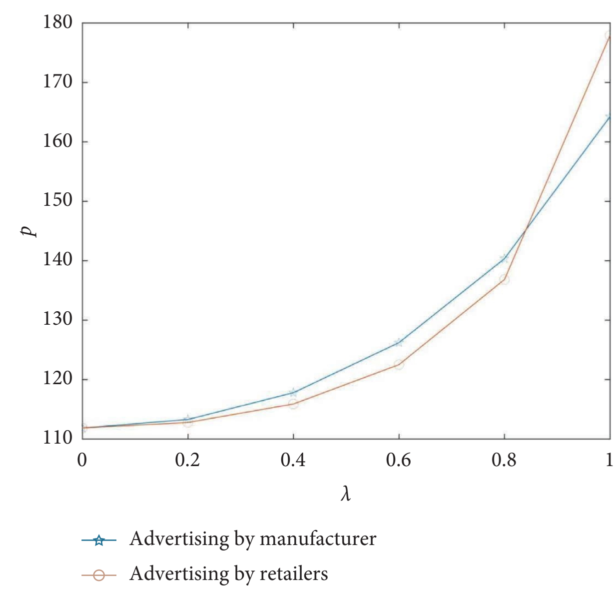

Figure 2: Impact of λ on retail prices.

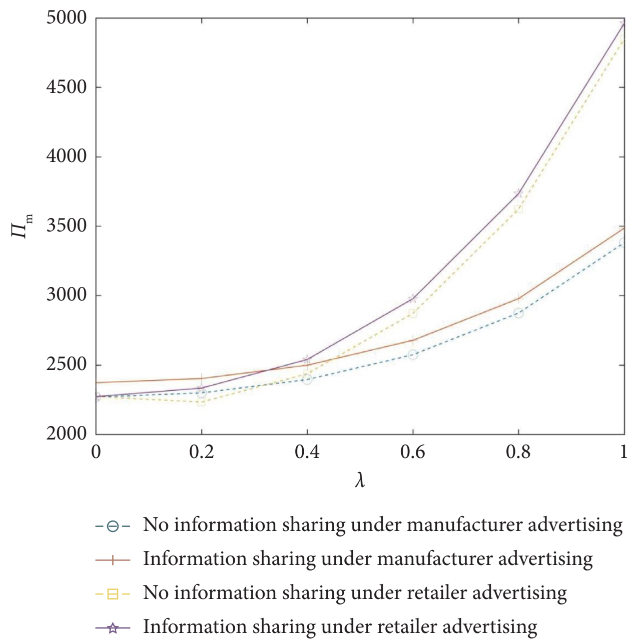

Figure 3: Impact of λ on manufacturer's profit.

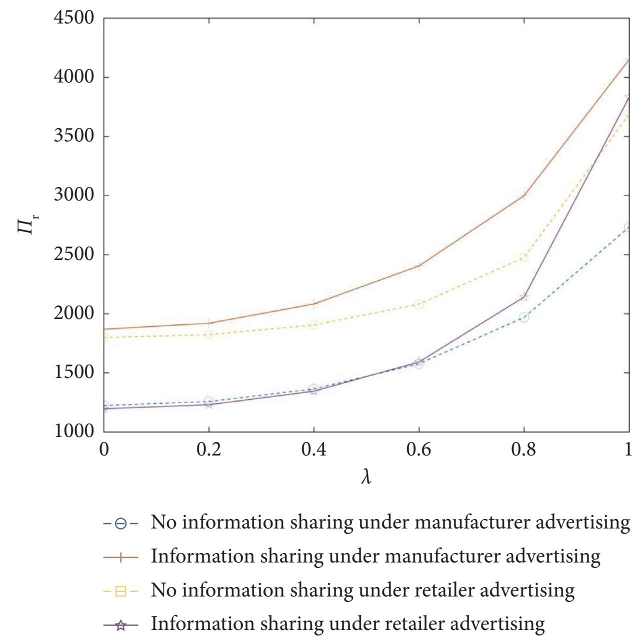

Figure 4: Impact of λ on retailer's profit.

Figure 4 shows the influence trend of the advertising effect λ on retailer's profit π_r. It can be seen that the retailer's profit is always proportional to the advertising effect. When the manufacturer is responsible for advertising, the retailer can always gain more profits under the information sharing model, but it needs to be discussed separately when the retailer is responsible for advertising. When the advertising effect is less than a certain value, retailers will gain more profits if they choose not to share information, while when the advertising effect is greater than a certain value, information sharing is more beneficial to retailers, and the rate of profit increase is larger than other cases. In the retailer advertising mode, when the advertising effect is small, the retail price is low, and the product sales are small, but the wholesale price is relatively high, resulting in low profit for the retailer. At this time, the retailer's only advantage is the high accuracy of market demand forecast. If information sharing is carried out, its advantage will be weakened, resulting in lower profits. When the advertising effect is at a large value, the wholesale price drops, and sales increase exponentially, making the profit growth rate maximum.

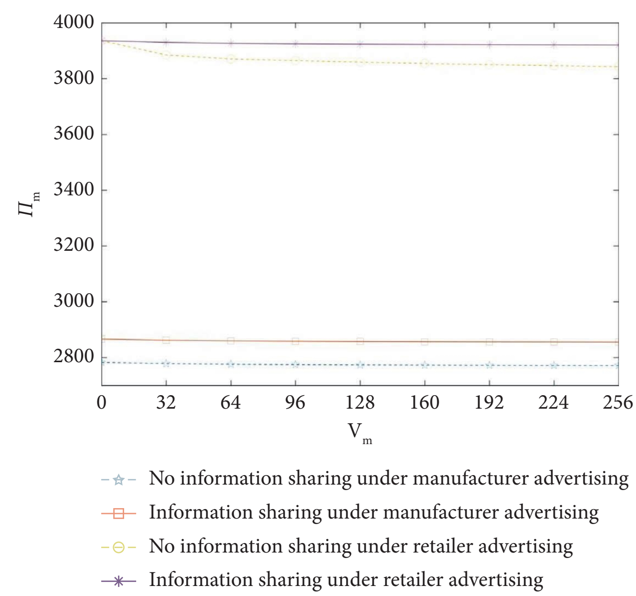

Figure 5: Impact of V_m on manufacturer's profit.

4.3. The Effect of Market Variance. Figure 5 illustrates the impact of a manufacturer's forecast variance V_m on its profit π_m. It can be seen that the profit of the manufacturer is always inversely proportional to its prediction variance, and the rate of profit decline when information is not shared is larger than that when information is shared under the same advertising mode. The larger the variance of the manufacturer's forecast is, the larger the forecast error will be, which will damage its profit, and the manufacturer will prefer the retailer's advertising model. Under the retailer's advertising mode, the manufacturer can increase the demand without bearing the advertising cost, and under the same advertising effect, the sales volume under the retailer's advertising mode can reach several times of that under the manufacturer's advertising mode, which can increase the manufacturer's profit and make up for the reduced profit due to the wholesale price.

Figure 6 shows the impact of the manufacturer's forecast variance V_m on the retailer's profit π_r. It is known that the retailer's profit is directly proportional to the manufacturer's forecast variance when information is not shared and inversely proportional otherwise. The larger the value in the manufacturer's advertising model, the lower the accuracy of the manufacturer's prediction, so the retailer can use the

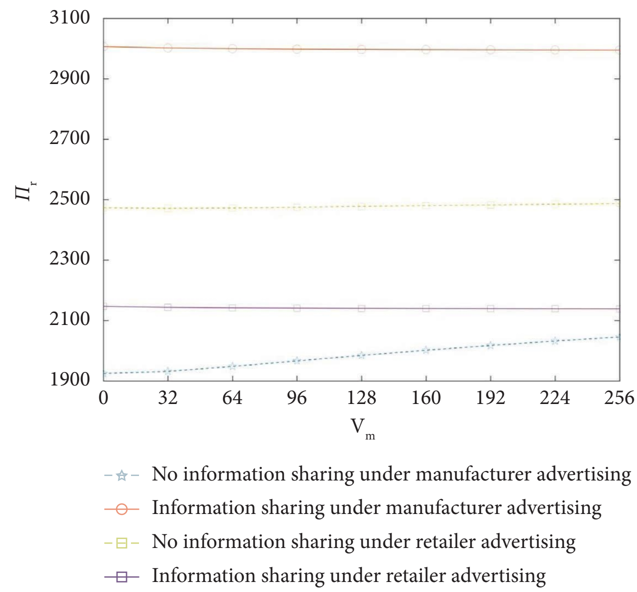

Figure 6: Impact of V_m on retailer's profit.

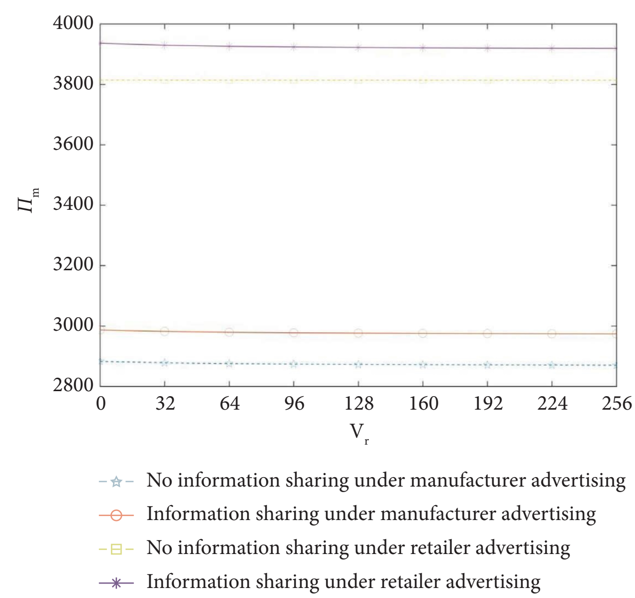

Figure 7: Impact of V_r on manufacturer's profit.

error to improve the profit. If information is not shared in the manufacturer's advertising mode, the closer the manufacturer's forecast variance to the retailer is, the greater the retailer's profit growth rate is and the smaller the retailer's profit growth rate is otherwise. It can be seen that, contrary to the retailer, the manufacturer is more inclined to the retailer's advertising mode at this time, and both parties can seek profit maximization through the coordination contract.

Figure 7 shows the influence trend of retailer's forecast variance V_r on manufacturer's profit π_m. It can be seen that under the two advertising models, the increase of retailer's forecast variance is disadvantageous to the manufacturer, and the information sharing can improve the manufacturer's profit. Other things being equal, manufacturers will prefer the retailer advertising model.

Figure 8 shows the trend of influence of retailer's forecast variance V_r on its profit π_r. It can be seen that the increase of retailer's forecast variance has a restraining effect on the increase of retailer's own profit. In the manufacturer advertising mode, retailers are more inclined to share information, but in the retailer advertising mode, they are more inclined to not share information. The larger the

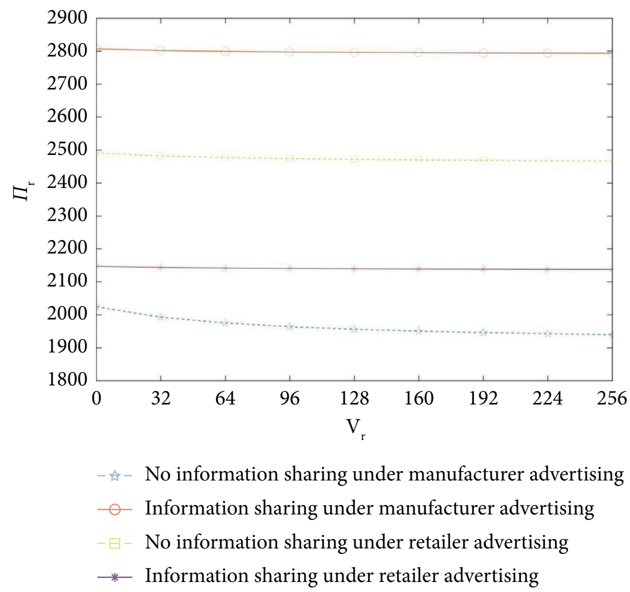

Figure 8: Impact of V_r on retailer's profit.

variance of the retailer's forecast, the more inaccurate the forecast market demand, which will damage the retailer's profit to a certain extent.

5. Conclusions and Prospects

In this paper, we construct a two-stage closed-loop supply chain, select the manufacturer recovery mode, study the demand forecast information sharing problem of the supply chain, and introduce the advertising effect into the model. This paper constructs a Stackelberg game model, discusses the problem of information sharing in the supply chain when the manufacturer is the dominant enterprise, sets up a model in which the manufacturer and the retailer put advertising separately, and analyzes the impact of advertising effect on the decision variables of the enterprise and the profit of the manufacturer and the retailer under different circumstances. The main conclusions are as follows.

The research shows that manufacturers prefer retailers to advertise whether the demand forecasting information is shared or not. Retailers prefer manufacturers to advertise when information is shared, and vice versa when information is not shared.

Under the two advertising modes, the sharing of demand forecasting information may not increase the profits of all members of the supply chain, and only when certain conditions are met can information sharing achieve a "win-win" situation. The accuracy of demand information, the size of advertising effect, the stability of market demand, and other factors will affect the decision of both manufacturers and retailers on information sharing. When information sharing can only increase the profit of one party, the other party can make some compromises, such as signing a coordination contract to make up for the loss of the other party.

Under the two advertising modes, the advertising effect has a promoting effect on the retail price, sales volume, recovery rate, advertising intensity, and the profit of manufacturers and retailers. However, the effect of advertising on wholesale price is positive only in the case of manufacturer's advertising model and reverse in the case of retailer's advertising model..

This paper also has some limitations. In terms of advertising, only manufacturers and retailers are designed to advertise separately. In future research, the mode of joint advertising can be considered. This article only compares and analyzes the results with or without information sharing under each advertising mode. In further research, the design of the contract in each mode can be considered to promote information sharing between the supply chain members and make the research more realistic.

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 they have no conflicts of interest with respect to the publication of this article.

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