Research on Drug Supply Chain Channel Strategies Considering Consumer Preferences and Medical Insurance

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Abstract. Considering the impact of consumer preferences, medical insurance, offline travel costs, and convenience of online channels on consumer purchasing behavior through different channels, a Stackberg game model for single and dual channels in the drug supply chain is constructed from the perspective of consumer utility theory to analyze the impact of consumer preferences, medical insurance, and offline channel costs on pricing and profits of drug manufacturers and retailers through different channels. Research has found that an increase in consumer preferences for online channels is more beneficial for drug manufacturers and has a smaller impact on drug retailers; The increase in the proportion of medical insurance reimbursement and the decrease in the proportion of consumer self payment are beneficial for both drug manufacturers and drug retailers, and have a greater impact on their offline channels; The gradual increase in offline travel costs for consumers will lead them to switch to drug manufacturers' online channels.

Keywords: Drug supply chain; Consumer preferences; Medical insurance; Consumer utility; Channel strategy

1 Introduction

With the adoption of the Measures for the Supervision and Administration of Drug Online Sales by the State Administration of Market Supervision in 2022, the supervision of prescription drug online sales will be more detailed and specific, further achieving the dynamic balance of drug purchasing convenience and safety supervision, and "Internet plus+medicine" will become a new market development prospect and opportunity for the pharmaceutical industry.

The coverage rate of medical insurance reimbursement is gradually expanding. According to statistics, by the end of 2022, the number of participants in basic medical insurance nationwide reached 1345.92 million, with a stable participation rate of over 95%. However, medical insurance reimbursement does not allow consumers to purchase drugs solely through offline channels, mainly due to the price difference between online and offline drugs.

Some scholars have studied the impact of medical insurance on drug supply chain channel strategies. Panos Kouvelis (2015) simulated multiple competing pharmacy benefit managers (PBMs) to provide patronage to client organizations, obtaining the optimal equilibrium price

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decision for each PBM[1].Kathleen M.（2019）evaluate the value of partnership relationships between independent individuals in different channels of the drug supply chain using mathematical models[2].Johari (2020) studied a competitive two-level pharmaceutical supply chain (PSC),obtained the optimal pricing decisions for pharmaceutical companies, and proposed a CSR cost sharing contract[3].Hou（2021）study the impact of offline medical insurance reimbursement on the dual channel strategy for drugs [4].Guan（2021）taking dual channel drug retailers as the research object, consider the effects of medical insurance, consumer risk avoidance [5].Li（2023）use cluster analysis and content analysis to explore the development status of "Internet plus+medical" services [6].

Regarding the drugs listed in the medical insurance catalog, the following questions need to be considered: What factors have a critical impact on the channel strategy of pharmaceutical companies? How can pharmaceutical companies address the pricing and channel selection issues of different channels based on consumer preferences and changes in the proportion of medical insurance reimbursement?

2 Model Assumptions and Symbolic Explanation

This article takes a drug supply chain composed of a drug manufacturer and a drug retailer as the research object. Drug manufacturers(m) can directly sell compliant drugs to consumers through online channels; It can also be wholesale to drug retailers(r), who sell drugs to consumers. The dual channel supply chain model for drugs is shown in Figure 1.

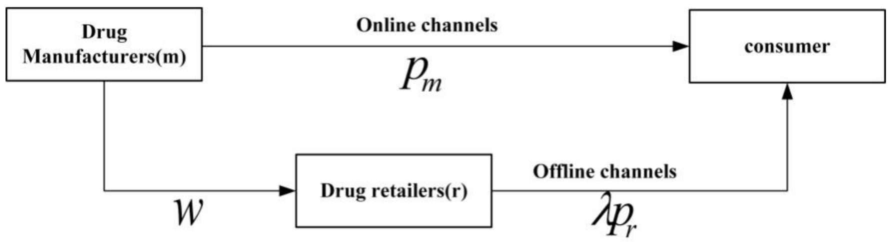

Fig. 1. Dual channel structure diagram of drug supply chain

The basic assumptions of the model are as follows:

Assumption 1: The quality and utility of drugs are consistent across different channels, and consumers are rational consumers who choose channels based on the magnitude of utility obtained. Each consumer usually chooses one channel to complete the purchase of drugs.

Assumption2：Consumers obtain utility from purchasing drugs from offline channels $U_{r(r)} = v - \lambda p_r - c_r$;The utility obtained by consumers when purchasing drugs from online channels is $U_m = \theta v - p_m$.

Assumption 3: According to the consumer utility function, the basic needs of consumers are represented, and consumers choose the purchasing channel based on the size of the channel utility. When $U_{r(r)} > U_m > 0$,Consumers purchase drugs through offline channels, and offline channel demand $q_{r(r)} = \int_{\max\left\{\lambda p_r + c_r, \frac{\lambda p_r + c_r - p_m}{1-\theta}\right\}}^{1} 1dv = 1 - \max\left\{\lambda p_r + c_r, \frac{\lambda p_r + c_r - p_m}{1-\theta}\right\}$;When $U_m > U_{r(r)} > 0$, $\frac{p_m}{\theta} < v < \frac{\lambda p_r + c_r - p_m}{1-\theta}$ Derived $0 < p_m < \theta(\lambda p_r + c_r)$, Consumers will choose to purchase medicine through online channels, and the demand for online channels is $q_m = \int_{\frac{p_m}{\theta}}^{\frac{\lambda p_r + c_r - p_m}{1-\theta}} 1dv = \frac{\lambda p_r + c_r - p_m}{1-\theta} - \frac{p_m}{\theta}$; When $U_m = U_{r(r)}$, $v_{mr} = \frac{\lambda p_r + c_r - p_m}{1-\theta}$, Consumers have equal effectiveness in purchasing drugs through two channels;When $U_m < 0$ ans $U_{r(r)} < 0$, Consumers will not purchase.From this, the demand functions of consumers in both online and offline channels of the drug supply chain can be obtained:

$$q_{r(r)} = \begin{cases} 1 - \frac{\lambda p_r + c_r - p_m}{1-\theta}, 0 < p_m < \theta(\lambda p_r + c_r) \\ 1 - \lambda p_r - c_r, p_m > \theta(\lambda p_r + c_r) \end{cases} \quad (1)$$

$$q_{(m)} = \begin{cases} \frac{\lambda p_r + c_r - p_m}{1-\theta} - \frac{p_m}{\theta}, 0 < p_m < \theta(\lambda p_r + c_r) \\ 0, p_m > \theta(\lambda p_r + c_r) \end{cases} \quad (2)$$

The model symbols in this chapter are shown in Table 1.

Table 1. Symbol Description

Symbol	Meaning
θ	Consumer preferences for purchasing drugs through online channels
v	Consumer valuation of drug value
w	Wholesale prices set by drug manufacturers
λ	Consumer drug self payment ratio
p_m	Online channel sales prices for pharmaceutical manufacturers
p_r	Drug retailers' offline channel sales prices
q_m	Consumer demand for online channels
$q_{r(r)}$	Consumer demand for offline channels
U_m	The utility that consumers obtain from online channels
$U_{r(r)}$	The utility that consumers obtain from offline channels
c_r	Travel costs
π_m	Profit of pharmaceutical manufacturers
π_r	Profit of drug retailers

3 Drug supply chain single channel strategy (S_1)

When the selling price of the drug manufacturer's online channel meets the selling price of the drug retailer's offline channel $p_m > \theta(\lambda p_r + c_r)$, Consumers choose offline channels for drug retailers.The profits of drug retailers and manufacturers are:

$$\pi_r^{S_1} = (p_r - w)\cdot q_{r(r)}^{S_1} = (p_r - w)(1-\lambda p_r - c_r) \tag{3}$$

$$\pi_m^{S_1} = w\cdot q_{r(r)}^{S_1} = w(1-\lambda p_r - c_r) \tag{4}$$

Equation (4) on the second-order partial derivative of drug retail price $\frac{\partial^2 \pi_r^{S_1}}{\partial p_r^{\ 2}} = -2\lambda < 0$,find the first partial derivative of $\frac{\partial \pi_r^{S_1}}{\partial p_r} = 1 - 2\lambda p_r + w\lambda - c_r = 0$, obtain relationship between the optimal zero selling price and wholesale price for drug retailers is:

$$p_r^{S_1}(w) = \frac{1+\lambda w - c_r}{2\lambda} \tag{5}$$

Substituting equation (5) into equation (6) yields

$$\pi_m^{S_1} = w\left(1 - \frac{1+\lambda w - c_r}{2} - c_r\right) \tag{6}$$

Find the second-order partial derivative of the wholesale price of drug manufacturers in equation (6) $\frac{\partial^2 \pi_m^{S_1}}{\partial w^2} = -\lambda < 0$, find the first order partial derivative of w, $\frac{\partial \pi_m^{S_1}}{\partial w} = \frac{1-c_r-2\lambda w}{2} = 0$, then optimal wholesale price for pharmaceutical manufacturers is:

$$w^{S_1*} = \frac{1-c_r}{2\lambda} \tag{7}$$

The optimal retail price for drug retailers is:

$$p_r^{S_1^*} = \frac{3-3c_r}{4\lambda} \tag{8}$$

The offline channel needs of consumers are: $q_{r(r)}^{S_1} = \frac{1-c_r}{4}$,The optimal profits for drug manufacturers and drug retailers are: $\pi_m^{S_1^*} = \frac{(1-c_r)^2}{8\lambda}$, $\pi_r^{S_1^*} = \frac{(1-c_r)^2}{16\lambda}$.

Proposition 1: In a single channel drug supply chain, the optimal wholesale price for drug manufacturers $w^{S_1*} = \frac{1-c_r}{2\lambda}$, The optimal selling price for offline channels of drug retailers $p_r^{S_1^*} = \frac{3-3c_r}{4\lambda}$, Consumer offline channel demand $q_{r(r)}^{S_1} = \frac{1-c_r}{4}$.

Proposition 1 indicates that in a single channel supply chain, the optimal offline drug selling price of drug retailers decreases with the increase of consumer self payment ratio, negatively correlated with consumer self payment ratio, and negatively correlated with consumer travel costs.

4 Dual channel strategy for drug supply chain (S_2)

According to the demand function of the dual channel supply chain for drugs.When $0 < p_m < \theta(\lambda p_r + c_r)$,the profit decision function of pharmaceutical companies and retailers can be expressed as:

$$\pi_m^{S_2} = w \cdot q_{r(r)}^{S_2} + p_m \cdot q_m^{S_2}$$
$$= w \cdot \left(1 - \frac{\lambda p_r + c_r - p_m}{1-\theta}\right) + p_m \cdot \left[\frac{\theta(\lambda p_r + c_r) - p_m}{\theta(1-\theta)}\right] \tag{9}$$

$$\pi_r^{S_2} = (p_r - w) \cdot q_{r(r)}^{S_2} = (p_r - w) \cdot \left(1 - \frac{\lambda p_r + c_r - p_m}{1-\theta}\right) \tag{10}$$

Find the second partial derivative of equation (10) regarding the retail price of drugs $\frac{\partial^2 \pi_r^{S_2}}{\partial p_r^{\ 2}} = -\frac{2\lambda}{1-\theta} < 0$, $\frac{\partial \pi_r^{S_2}}{\partial p_r} = \frac{1-\theta-2\lambda p_r + p_m + \lambda w - c_r}{1-\theta} = 0$ It is known that drug retailers have the optimal retail price, Solving equation (9) for the first order partial derivative can obtain the relationship between w and p_m :

$$p_r^{S_2 *} = \frac{1-\theta + p_m + \lambda w - c_r}{2\lambda} \tag{11}$$

Substitute equation (11) into (15) ,Simultaneous solution $\frac{\partial \pi_m^{S_2}}{\partial w} = 0$, $\frac{\partial \pi_r^{S_2}}{\partial p_m} = 0$, The optimal wholesale and online channel pricing for drug manufacturers can be obtained as follows:

$$w^{S_2 *} = \frac{(-1+\theta)\left[4+\theta(-1+\lambda)\right] - \left[-4+\theta(3+\lambda)\right]c_r}{(\lambda^2+6\lambda+1)\theta - 8\lambda} \tag{12}$$

$$p_m^{S_2^*} = \frac{\theta\left[(-1+\theta)(1+3\lambda) - (-1+\lambda)c_r\right]}{(\lambda^2+6\lambda+1)\theta - 8\lambda} \tag{13}$$

Solve the Hessian matrix of the profit function equation (9) for drug manufacturers based on the results of w^* and $p_m^{\ *}$:

$$H_{\pi_m^{S_2}} = \begin{bmatrix} \frac{\lambda}{\theta-1} & \frac{1+\lambda}{2-2\theta} \\ \frac{1+\lambda}{2-2\theta} & \frac{2-\theta}{(-1+\theta)\theta} \end{bmatrix} \tag{14}$$

The first-order principal sub equation of the Hessian matrix is $\frac{\lambda}{\theta-1} < 0$, The second-order order principal sub equation is $\frac{8\lambda - (\lambda^2+6\lambda+1)\theta}{4\theta(1-\theta)^2}$. When consumer preferences are met $0 < \theta < \frac{8\lambda}{\lambda^2+6\lambda+1}$, The Hessian matrix is a negative definite matrix, and the wholesale prices of drug manufacturers and online channel prices obtained above are the optimal solutions. Substitute (12) (13) into (11) ,the optimal pricing for drug retailers is:

$$p_r^{S_2^*} = -\frac{2(3-4\theta+\theta^2) + \left[-6+\theta(5+\lambda)\right]c_r}{(\lambda^2+6\lambda+1)\theta - 8\lambda} \tag{15}$$

Proposition2: In the dual channel drug supply chain, drug manufacturers' online channel drug sales prices $p_m^{S_2^*} = \frac{\theta\left[(-1+\theta)(1+3\lambda) - (-1+\lambda)c_r\right]}{(\lambda^2+6\lambda+1)\theta - 8\lambda}$, Optimal wholesale price for offline channels of pharmaceutical manufacturers $w^{S_2*} = \frac{(-1+\theta)[4+\theta(-1+\lambda)]-[-4+\theta(3+\lambda)]c_r}{(\lambda^2+6\lambda+1)\theta-8\lambda}$; Drug retailers' offline channel drug sales prices $p_r^{S_2^*} = -\frac{2(3-4\theta+\theta^2)+[-6+\theta(5+\lambda)]c_r}{(\lambda^2+6\lambda+1)\theta-8\lambda}$.

The demand for online channels of pharmaceutical companies and offline channels of pharmaceutical retailers are: $q_m^{S_2^*} = \frac{1+(-3+2\theta)\lambda-(1+\lambda)c_r}{(\lambda^2+6\lambda+1)\theta-8\lambda}$, $q_r^{S_2^*} = \frac{\lambda(-2+\theta+\theta\lambda+2c_r)}{(\lambda^2+6\lambda+1)\theta-8\lambda}$.

The profits of pharmaceutical companies through dual channels and pharmaceutical retailers are $\pi_m^{S_2^*} = \frac{(\theta-1)(1+\theta\lambda)-(-2+\theta+\theta\lambda)c_r-c_r^2}{(\lambda^2+6\lambda+1)\theta-8\lambda}$, $\pi_r^{S_2^*} = \frac{(1-\theta)\lambda(-2+\theta+\theta\lambda+2c_r)^2}{[(\lambda^2+6\lambda+1)\theta-8\lambda]^2}$.

5 Numerical Example Analysis

Using numerical analysis methods to study the effects of parameter consumer preferences θ, consumer self payment ratio λ, and offline channel costs c_r on the profits of different channel strategies in the pharmaceutical supply chain.

Set consumer self payment ratio $\lambda = 0.6$, The profit function of online channels for pharmaceutical manufacturers is shown in Figure 2. The extreme point of the profit function is $\theta \in [0.5, 0.9]$, $c_r \in [0.5, 0.9]$, Within this range, the profit growth rate is significant and ultimately reaches its maximum. This indicates that when consumers have higher preferences for online channels and higher costs for offline travel, drug manufacturers' online channel profits increase. The increase in consumer preferences for online channels and the increase in offline travel costs has a positive impact on drug manufacturers' opening up online channels.

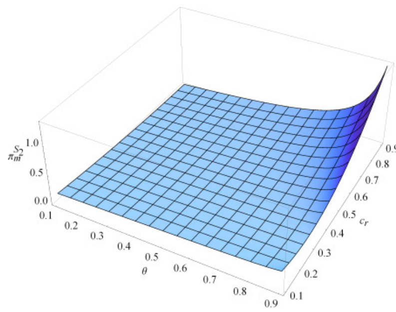

Fig .2. Profit of pharmaceutical companies in the dual channel supply chain of drugs

Analyzing offline channel strategies of drug retailers based on consumer self payment ratio and offline travel costs, and setting consumer preferences for online channels $\theta = 0.3$, The profit function of offline channels for drug retailers is shown in Figure 3. The extreme point of the profit function is $\lambda \in [0.1, 0.4]$, $c_r \in [0.1, 0.4]$ The smaller the proportion of consumer self payment, the lower the cost of offline travel, and the higher the profit of offline channels for drug retailers.

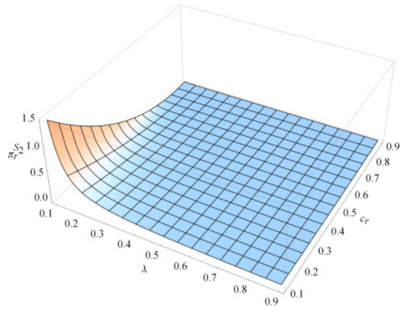

Fig.3. Profit of drug retailers in the dual channel supply chain of drugs

6 Conclusion

The research results found that: (1) an increase in consumer preferences for online channels is more beneficial for drug manufacturers, increasing their online channel demand, profits, and drug prices; Drug manufacturers need to adapt to the changes in consumers purchasing drugs through online channels, provide a convenient online purchasing experience, strengthen cooperation with e-commerce platforms, provide authentic and reliable product information and good after-sales service, to meet consumers' needs for online drug purchases. (2) The smaller the proportion of consumer self payment, the greater the proportion of medical insurance reimbursement, and the greater the profit of drug retailers. The impact of consumer self payment ratio and medical insurance reimbursement ratio on offline channels of drug retailers is greater.

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