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Enhancing customers' prevention efforts: An incentive feedback mechanism design

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Abstract: To improve the inefficient prevention caused by customers' unwillingness to adopt prevention strategies in health management, an incentive feedback mechanism that is based on game theory and contract design theory is introduced. The conditions for making customers and health maintenance organizations (HMOs) willing to participate in the proposed mechanism are given. A dual nonlinear programming model is used to identify the optimal prevention effort of customers and the pricing strategy of HMOs. Results show that to generate increased benefits, HMOs need to consider cost sharing when customers are not familiar with the proposed health services. When health services are gradually accepted, the cost sharing factor can be gradually reduced. Simulation shows that under random circumstances in which the market reaches a certain size, the proposed method exhibits a positive network externality. Motivated by network externality, HMOs only need to make their customers understand that the larger the number of participants, the greater the utility of each person. Such customers may then spontaneously invite others to purchase insurance.

Key words: customers' prevention efforts; incentive feedback mechanism; healthcare service; health pricing strategy; health service optimization

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The growth of healthcare expenditures globally has become an issue that requires effective operation modes. Healthcare costs in the US in 2017 accounted for 17% of the country's gross domestic product (GDP), and they are expected to rise to 19.9% in 2025[1]. In the same year in China, healthcare costs accounted for 6.2% of the country's GDP, thereby bringing tremendous pressure on health participants[2].

To reduce the rising health costs, health maintenance organizations (HMOs) play a significant role in health management. Health maintenance is able to reduce cost because it focuses not only on the past (previously diagnosed disease) but also on the future (disease prevention)[3]. Prevention services can reduce the future demands for diagnostic services and treatment[4]. Kaiser Permanente is a well-known HMO. Members of the Kaiser HMO include insurance companies and medical groups. The organization can provide customers with insurance that includes prevention and treatment services to control customer health[5]. Its operating mode is to bring customers and the organization together by using a fixed fee format, thereby encouraging the HMO to manage customers' health through prevention and other low-cost methods. The fixed fee payment method has become mainstream in the US[6].

In China, some HMOs have learned how to use similar operation methods to design health insurance. For example, Ping An Insurance Company of China, in cooperation with hospitals, provides child dental insurance, which includes inspections, preventive services, and accident reimbursement.

To reduce possible treatment costs, some studies[7-9] have added prevention to their investigation of health insurance options. Prevention services include three aspects. The first aspect covers disease screening, such as colonoscopies[10-11] and breast cancer screens[12]. The second aspect covers vaccinations[13-14]. The third aspect covers mechanism designs[15]. However, few of the existing studies have directly addressed how to motivate customers to participate in prevention activities. The lack of incentives for customers' prevention efforts leads to low efficiency of prevention. As customers do not engage in any prevention activity in their daily life, prevention efforts burden them. The effect of prevention depends on the efforts of HMOs and customers. The existing operation mode focuses solely on motivation for HMOs and largely ignores incentives for customers. Prevention without customer involvement leads to inefficiency[16].

In academia, two ideas have been raised to solve the aforementioned problem. On the one hand, the literature focuses on cooperation. Andritsos et al.[9] developed a health co-production model to establish joint control between patients and hospitals for readmission. Mendonça et al.[17] developed a game theory to model liver transplantation consultations involving alcohol-driven liver disease to improve patients' cooperation. Many collaborative studies have also focused on information sharing[18-19],

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asymmetric relationships[20], and trust[21]. Other works have adopted unique approaches to establish cooperation with other service fields; such approaches include cost sharing contracts[22], social networks, and behavioral models[23]. These existing methods provide theoretical support for the current work. On the other hand, the literature covers incentive mechanism design. Care et al. [24] built a computerized decision support system to document peer reviews and abnormal feedback on diagnostic results to ensure accurate diagnoses. Mehrotra et al. [25] developed multivariate regression models to study the effects of patient incentives on receiving preventive care. The preventive effects were found to remain low mainly because of inefficient incentives. The problem captured in the study requires a highly effective way to incentivize customers. To reduce hospital readmissions, Liu et al. [26] developed a delay time analysis model to identify effective checkup plans for monitoring patients. To improve prevention efficiency, the study considered customers' free time and preferences without considering how to ensure customers' cooperation. Mehta et al. [8] built a model of consumers' annual medical insurance plan decisions and periodic consumption decisions to guarantee their health. However, these existing studies passively consider customers' free time and preferences. Hence, the current study is motivated by the need to solve the aforementioned problem by strengthening customers' participation.

To mobilize customers toward prevention cooperation, this study designs a cooperative and incentive mechanism involving HMOs and customers. Different from the general health maintenance mechanism that sets a fixed price, the new mechanism adds a cost sharing fee to motivate customers. Moreover, the proposed mechanism is unlike medical insurance that provides fixed premiums and reimbursement ratios as it uses flexible pricing to target different customers.

This work presents an approach to the design of optimal incentive strategies to enhance customers' enthusiasm for prevention. As far as we know, few studies have investigated the prevention effect from the perspective of customer incentives. Relative to the passivity of waiting for treatment, the proposed method is proactive in terms of prevention.

In summary, this study aims to address the operation of the new pricing strategy for incentivizing customers to enhance their prevention engagement. First, the dual nonlinear programming model, including customer utility and HMO utility, is established. Second, the optimal strategies are calculated after verifying the existence of the optimal solution. Third, the correlation sensitivity analysis is given. Finally, the numerical study is presented.

1 Problem Statement

This work constructs an incentive feedback model with two subjects: the HMO and customers. The HMO is the leader that designs a new pricing strategy containing a fixed price P and a cost sharing rate r_{cs} to incentivize customers for their prevention effort. The customers are the followers who decide on their prevention effort strategy e_p. Our task is to find the optimal strategies for the HMO and the customers to obtain their maximum utility.

The decision sequence is as follows: In the beginning, the HMO offers an insurance plan with prevention services and possible treatment services for customers who become ill; the related effects are η_p and η_t. The price of the insurance consists of the fixed price P and cost sharing rate r_{cs}. Then, the customers pay the fixed price P to the HMO, and the organization manages the customers' health. To save costs and add benefits, the HMO provides prevention services, which help reduce the probability of customers becoming ill. When receiving the prevention services, customers need to determine their prevention effort. After the prevention period, two results are expected: First, when customers are healthy until the end of the insurance period, no additional charges are incurred. Second, when customers are sick and need treatment, they should pay the cost sharing fee $r_{cs} C_t$, where C_t is the cost of treatment and r_{cs} is the cost sharing rate given by the HMO to incentivize customers to exert prevention efforts further. Under the pressure of increased costs, customers might be more willing to cooperate through their prevention efforts. The incentive feedback mechanism is shown in Fig. 1.

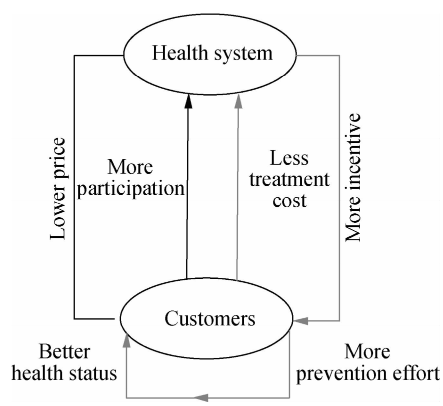

Fig. 1 Incentive feedback mechanism and plan design

For HMOs, the trade-offs lie on the cost sharing rate r_{cs} and fixed price P. On the one hand, an increase in the cost sharing rate r_{cs} increases customer cost pressure, which in turn stimulates customers to exert prevention efforts and improve their health status, thereby reducing the treatment cost of the HMO. On the other hand, an increase in r_{cs} may cause it to exceed the total price limitation. The total price limitation is set to ensure the advantage of the new pricing strategy; it is given by $P + r_{cs} C_t (1 - e_p) r_d \leqslant P_0$, where $(1 - e_p) r_d$ is the probability of illness after customer prevention efforts and r_d represents the initial probability of illness. With the consequent rise in total price, customers may refuse to participate, therefore reducing the benefits received by the HMO. If the fixed price P is too high, then customers become unwilling to pay for insurance; if the fixed price is too low, then the HMO cannot make ends meet. From the customer perspective, if customers exert negligible prevention efforts, then the cost sharing rate of their illness increases; if customers exert excessive prevention efforts, then the cost of prevention increases.

2 Model and Analysis

In this section, we construct a dual model of two subjects: the customers and the HMO. The customers determine their prevention strategies to reduce their costs and gain benefits. The HMO sets a new pricing strategy to maximize its utility. After proving the existence of the optimal solution, we obtain the relevant optimal strategy. Furthermore, we conduct sensitivity analysis and numerical simulation on the optimal strategy.

2.1 Modeling

To characterize the relationship between the degree of disease in terms of deterioration η_d and the effectiveness of prevention η_t and treatment η_p, we assume that customers can recover through prevention and treatment under ideal conditions.

$$\eta_d = \eta_t + \eta_p \tag{1}$$

Eq. (1) implies the following result: If the preventive effect increases, then the therapeutic effect can be reduced. Therefore, the cost of treatment can be reduced.

The utility of a customer who chooses the health insurance plan can be expressed as follows:

$$u(e_p) = h + (1-e_p)r_d(-\eta_d + e_p\eta_p + \eta_t) - \alpha_1(P + (1-e_p)r_d r_{cs}C_t) - \beta_1 e_p \tag{2}$$

The utility is composed of the customer's initial health status h, health control utility $(1-e_p)r_d(-\eta_d + e_p\eta_p + \eta_t)$, spending utility $P + (1-e_p)r_d r_{cs}C_t$, and health prevention cost $\beta_1 e_p$, where α_1 is the customer's price sensitivity and β_1 is the cost effect sensitivity factor for the prevention effort. The health control utility consists of the risk of illness and the health status after the intervention. Following Andritsos et al. [9], we obtain $(1-e_p)r_d$, which is the probability of illness after customer prevention efforts. Referring to the work of Mehta et al. [8], we obtain the health status after intervention $-\eta_d + e_p\eta_p + \eta_t$. If e_p is small, then the probability of disease $(1-e_p)r_d$ and the degree of disease severity $-\eta_d + e_p\eta_p$ are high. In this case, further treatment η_t is needed.

The customer's optimization can be expressed as follows:

$$\max u(e_p) = h + (1-e_p)r_d(-\eta_d + e_p\eta_p + \eta_t) - \alpha_1(P + (1-e_p)r_d r_{cs}C_t) - \beta_1 e_p \tag{3}$$

s. t.

$$e_p\eta_p + \eta_t \geqslant \beta_3\eta_d \tag{4}$$

$$0 < e_p \leqslant 1 \tag{5}$$

Eq. (4) is set to guarantee the customer's minimum health benefit. In this equation, β_3 is a constant that stands for the minimum guaranteed health rate, $\beta_3 \leqslant 1$. Eq. (5) provides the range for the variable e_p. In the model, the customer chooses his/her effort level $e_p (0 < e_p \leqslant 1)$ in terms of following the prevention advice.

Different from the customer's utility, the HMO's utility needs to consider not only the utility cost difference but also the number of customers. The number of customers participating N_{cp} depends on the fixed price and the customers' prevention efforts; it is divided into the following two parts:

$$N_{cps} = (1-e_p)r_d(a - \alpha_2 P) \tag{6a}$$

$$N_{cph} = (1-e_p)(1-r_d)(a - \alpha_2 P) \tag{6b}$$

where a is the basic market size; α_2 is the price-sensitive parameter for market size; and P is the fixed price. Eq. (6a) represents the number of customers who have been ill during the given period. Eq. (6b) represents the number of customers who are healthy during the period. The HMO's utilities from these different customers are represented as

$$U_s = P - C_{ph} - (1 - r_{cs})C_t \tag{7a}$$

$$U_h = P - C_{ph} \tag{7b}$$

Eq. (7a) presents the utility from a customer who has been ill during the period. It consists of the benefit from the fixed price P, the prevention cost C_{ph}, and the remaining treatment $(1-r_{cs})C_t$. Eq. (7b) presents the utility from the customer who is healthy during the period. It consists of the benefit from the fixed price P and the prevention cost C_{ph}. We assume that C_{ph} is part of fixed price P, that is, $C_{ph} = \beta_4 P$.

We obtain the NLP that maximizes the HMO's utility. The HMO's optimization can be expressed as follows:

$$\max U(P, r_{cs}) = U_s N_{cps} + U_h N_{cph} = (P - C_{ph} - (1-r_{cs})C_t)(1-e_p) \cdot r_d(a - \alpha_2 P) + (P - C_{ph})(1-e_p) \cdot (1-r_d)(a - \alpha_2 P) \tag{8}$$

s. t.

$$P + (1-e_p)r_d r_{cs}C_t \leqslant P_0 \tag{9}$$

$$0 < r_{cs} < 1 \tag{10}$$

$$P > C_{ph} + (1-r_{cs})C_t \tag{11}$$

Eq. (8) captures the HMO's utility from customers who choose the insurance plan. Eq. (9) indicates that the comprehensive price $P + (1-e_p)r_d r_{cs}C_t$ should not exceed the price of general insurance P_0. It is the total price limit. Eq. (10) provides the range of the cost sharing rate r_{cs}. Eq. (11) presents the range of fixed price P, which means that price P should be greater than the HMO's costs $C_{ph} + (1 - r_{cs}) C_t$. The utility of the HMO also depends on customers' prevention efforts e_p.

2.2 Optimal solutions

In this section, we calculate and analyze the optimal strategies for customers and the HMO separately and then obtain the management result.

As a precondition of this study, we analyze the conditions leading to customers' willingness to buy health insurance (the existence of customers' utility). Then, we find the conditions in which the HMO would turn to the new pricing strategy and the conditions for the HMO's optimal utility (the optimal solution for the existence of the HMO's utility). On the basis of these conditions, we obtain the equilibrium decision between customers and the HMO. In addition, we analyze the impact of other indicators under the optimal strategies.

To identify which condition leads to customers' willingness to purchase insurance, we consider two conditions: 1) The condition leading to customers' benefit ($u > 0$) when choosing the new health insurance; 2) The condition leading to the benefit of the new health insurance being greater than that of the general one ($\Delta u > 0$).

Lemma 1 shows the conditions that make $u > 0$.

Lemma 1 If $P > \frac{h + r_d\eta_d(1 - \beta_3) - \beta_1}{\alpha_1}$, $0 < r_{cs} < \frac{\beta_1 + r_d((-1 + \beta_3)\eta_d - \eta_p)}{\alpha_1 r_d C_t}$, then $u > 0$.

Lemma 1 shows that the customers' choice of health insurance depends on the fixed price P and cost sharing rate r_{cs} designed by the HMO. The aforementioned constraints relate to α_1; the bigger α_1 is, the smaller the set of constraints. Lemma 1 reveals that the more sensitive the customer is to price, the smaller the range of choices for the health organization's pricing. Therefore, the HMO should choose to cooperate with customers who are willing to exert prevention efforts.

For condition 2), we establish a comparison group $u' = u(e_p = 0)$ to analyze the condition in which customers choose the new health insurance.

$$u' = h + r_d(-\eta_d + \eta_t') - \alpha_1 P_0 \tag{12}$$

where u' stands for the customers' utility without any prevention effort. We set $\Delta u = u - u'$, $\eta_t' = \eta_t$.

Lemma 2 If $\beta_1 < (2 - e_p) r_d \eta_p$, then $\Delta u > 0$.

Lemma 2 shows that the new pricing strategy appeals to customers once the cost sharing factor β_1 is less than the customers' prevention cost constraints $(2 - e_p) r_d \eta_p$.

After assessing the conditions in which customers purchase insurance, we study the maximum customer utility under prevention effort strategies. Lemma 3 shows the results.

Lemma 3 Given the HMO's initial pricing P and r_{cs}, the customer's optimal prevention effort is

$$e_p(r_{cs}) = \frac{\alpha_1 r_d r_{cs} C_t - \beta_1 + 2 r_d \eta_p}{2 r_d \eta_p} \tag{13}$$

under which the customer's optimal utility is

$$u = h - P\alpha_1 - \beta_1 + \frac{(-\alpha_1 r_d r_{cs} C_t + \beta_1)^2}{4 r_d \eta_p} \tag{14}$$

The customer's optimal utility given in Eq. (14) has the property of $\frac{\partial u}{\partial C_{cs}} = \frac{\alpha_1(\alpha_1 r_d r_{cs} C_t - \beta_1)}{2\eta_p}$. Hence, only when the cost sharing utility that the customers must bear $\alpha_1 r_d r_{cs} C_t$ is greater than their price sensitivity to the prevention effort β_1 will their utility increase as the cost sharing rate increases. Therefore, the cost sharing rate does not always affect customers' prevention effectiveness. This result might be regarded as counterintuitive.

To satisfy the inequality $0 < e_p < 1$, we substitute Eq. (13) and find

$$\frac{\beta_1 - 2 r_d \eta_p}{r_d \alpha_1 C_t} < r_{cs} < \frac{\beta_1}{r_d \alpha_1 C_t} \tag{15}$$

Before calculating the optimal utility for the HMO, two constraints need to be considered: the constraint that makes the HMO prefer the new operation mode and the existence of the optimal strategy of the HMO.

To obtain the first constraint, we establish a comparison group $U' = U(e_p = 0, C_{ph} = 0, r_{cs} = 0)$.

$$U' = (P - C_t) r_d(a - \alpha_2 P) + P(1 - r_d)(a - \alpha_2 P) \tag{16}$$

where U' is the HMO's utility without any prevention effort. We set $\Delta U = U - U'$.

$$\Delta U = (a - P\alpha_2)((-2P + r_{cs} C_t) r_d + e_p((1 - r_{cs}) r_d C_t + P(-1 + \beta_4)) - P(-2 + \beta_4)) \tag{17}$$

Lemma 4 If $(1 + \beta_4) P < (r_{cs} + 1) C_t r_d$, then $\Delta U > 0$.

Lemma 4 shows that if the sum of the HMO's prevention cost and fixed price $(1 + \beta_4) P$ is less than the sum of the customer's cost sharing part $r_d r_{cs} C_t$ and treatment cost $C_t r_d$, then the HMO switches to the new strategy. From the above inequality, we obtain $\frac{P}{(r_{cs} + 1) C_t} < \frac{r_d}{1 + \beta_4}$. We use the control variable method to analyze the relationship between the risk of illness and the pricing ratio. We find that when the cost of prevention in the fixed price ratio β_4 is fixed, fixed price P can be set to a high value as the risk of illness r_d increases. Lemma 4 proves that the HMO switching to the new strategy depends only on the rate of the fixed price in terms of prevention advice β_4 and risk of illness r_d.

To answer the second question, we need to prove that the HSU model has an optimal solution. As the HSU model is an NLP with nonlinear constraints, we can verify which condition leads to the existence of the HSU model by proving that it is convex programming. To prove that the HSU model is convex programming, we need to verify that the maximum objective function and the larger inequality symbol constraints are concave and that the smaller inequality symbol constraints are convex.

Lemma 5 If P and r_{cs} meet the following condition:

$$4\alpha_1\alpha_2(a-P\alpha_2)(\alpha_1 r_d r_{cs} C_t-\beta_1)(1-\beta_4)-(\alpha_2\beta_1+\alpha_1(-\alpha_2((2r_{cs}+1)r_d C_t+2P(-1+\beta_4))+a(-1+\beta_4)))^2\geqslant 0$$

then the HSU model is convex programming and can achieve an optimal solution.

To solve the HSU model, we provide the optimal solutions without constraints and then introduce them to the constraints from Lemmas 1 to 5.

We obtain the optimal solution without constraints. Specifically, we solve $\frac{\partial U}{\partial P}=0$, $\frac{\partial U}{\partial r_{cs}}=0$. The HMO's optimal fixed price P and cost sharing rate r_{cs} are shown in Tab. 1.

Tab. 1 Optimal fixed price and cost sharing rate

Situation	P	r_{cs}
1	$\frac{a}{\alpha_2}$	$-\frac{a-C_t r_d\alpha_2-a\beta_4}{r_d\alpha_2 C_t}$
2	$\frac{a}{\alpha_2}$	$\frac{\beta_1}{\alpha_1 r_d C_t}$
3	$\frac{C_t r_d\alpha_1-\beta_1}{\alpha_1(1-\beta_4)}$	$\frac{\beta_1}{\alpha_1 r_d C_t}$
4	$\frac{2a\alpha_1+C_t r_d\alpha_1\alpha_2-\alpha_2\beta_1-2a\alpha_1\beta_4}{3\alpha_1\alpha_2(1-\beta_4)}$	$\frac{2\alpha_2\beta_1+\alpha_1(C_t r_d\alpha_2+a(-1+\beta_4))}{3\alpha_1\alpha_2 r_d C_t}$

Then, we introduce the above solutions to the constraints in Lemmas 1 to 5 and the participation constraint ($a>\alpha_2 P$) and ensure that the fourth solution meets all the constraints. We substitute the fourth solution into the above inequality group and obtain the following results:

Theorem 1 If the market size meets the inequalities $(1-\beta_3)\eta_d<\eta_p$,

$$\frac{\alpha_2}{\alpha_1(1-\beta_4)}\min\left\{\frac{-C_t r_d\alpha_1-(\beta_1(2-3\beta_4)-3(1-\beta_4)(h-r_d(-1+\beta_3)\eta_d))}{2}, C_t r_d\alpha_1-\beta_1+3r_d((1-\beta_3)\eta_d+\eta_p), \frac{\beta_1(3-\beta_4)+C_t r_d\alpha_1(3-5\beta_4)}{\alpha_1(3+\beta_4)}\right\}<a<\frac{\alpha_2(C_t r_d\alpha_1-\beta_1+6r_d\eta_p)}{\alpha_1(1-\beta_4)}$$

then the optimal solutions of the HSU model and customer utility (CU) model are

$$r_{cs}^*=\frac{2\alpha_2\beta_1+\alpha_1(C_t r_d\alpha_2+a(-1+\beta_4))}{3\alpha_1\alpha_2 r_d C_t} \tag{18}$$

$$P^*=\frac{2a\alpha_1+C_t r_d\alpha_1\alpha_2-\alpha_2\beta_1-2a\alpha_1\beta_4}{3\alpha_1\alpha_2(1-\beta_4)} \tag{19}$$

$$e_p^*=\frac{\alpha_1(C_t r_d\alpha_2+a(-1+\beta_4))-\alpha_2(\beta_1-6r_d\eta_p)}{6r_d\alpha_2\eta_p} \tag{20}$$

and the maximum utilities for the customer and the HMO are

$$U_{max}=\frac{(-\alpha_2\beta_1+\alpha_1(C_t r_d\alpha_2+a(-1+\beta_4)))^3}{54r_d\alpha_1^2\alpha_2^2(-1+\beta_4)\eta_p} \tag{21}$$

$$u_{max}=h-\frac{\alpha_2\beta_1+\alpha_1(-C_t r_d\alpha_2+2a(-1+\beta_4))}{3\alpha_2(-1+\beta_4)}+\frac{\beta_1(\alpha_1(a-C_t r_d\alpha_2-a\beta_4)+\alpha_2(\beta_1-6r_d\eta_p))}{6r_d\alpha_2\eta_p}+\frac{(-\alpha_2\beta_1+\alpha_1(C_t r_d\alpha_2+a(-1+\beta_4)))(\alpha_1(C_t r_d\alpha_2+a(-1+\beta_4))+\alpha_2(5\beta_1+6r_d(\eta_d-\eta_p-\eta_t)))}{36r_d\alpha_2^2\eta_p} \tag{22}$$

Theorem 1 shows that if market size a meets the above constraints, then r_{cs} and P are optimal solutions. We should note that because $(1-\beta_3)\eta_d<\eta_p$, $C_t r_d\alpha_1-\beta_1+6r_d\eta_p>C_t r_d\alpha_1-\beta_1+3r_d((1-\beta_3)\eta_d+\eta_p)$. That is, the constraint about a in Theorem 1 is not empty.

2.3 Sensitivity analysis

From the HMO's optimal solutions in Theorem 1, we have the following results: First, by differentiating α_1 and α_2 with respect to r_{cs}, we have $\frac{\partial r_{cs}}{\partial\alpha_1}<0$, $\frac{\partial r_{cs}}{\partial\alpha_2}>0$. The first inequality shows that the HMO can decrease its cost sharing when the customer's price-sensitive parameter is relatively high. Specifically, the more sensitive the customer is to the price, the more he thinks that he is paying, and the less prevention effort he is willing to make. The latter inequality implies that the HMO increases its cost sharing when the market price-sensitive parameter is high. Weisstein et al. [27] showed that because of the lack of understanding of this health service in the initial period, the price sensitivity of the market is relatively high. When customers are familiar with the health service, the market price sensitivity decreases. Intuitively, the HMO sets a low incentive to attract more customers in the initial period. However, the above inequality indicates a counterintuitive result: During the initial stage when the market price sensitivity is high, the group of customers needs more incentives to exert preventive efforts.

The managerial insight is that in the initial period, the HMO should set a relatively high cost sharing rate to reduce the negative effect of the high market price sensitivity. When the health service is sufficiently understood, the cost sharing factor can be reduced as the market price sensitivity decreases.

Second, by differentiating r_d with respect to r_{cs}, we study the relationship between the probability of illness and cost sharing. We obtain another counterintuitive result under the condition: $\frac{\partial r_{cs}}{\partial r_d} = \frac{\alpha_1 a(1-\beta_4) - 2\alpha_2\beta_1}{3\alpha_1\alpha_2 r_d^2 C_t}$; that is, when $2\alpha_2\beta_1$ is greater than $\alpha_1 a(1-\beta_4)$, $\frac{\partial r_{cs}}{\partial r_d} < 0$, the HMO should decrease the cost sharing rate as the risk of illness rises. This case can be explained by looking at the scenario in which the cost of prevention is high and the customer is not sensitive to price; in this scenario, the monetary stimulus has minimal effect on the prevention efforts of the customer.

Therefore, to obtain increased customer participation, the HMO needs to decrease the cost sharing rate when the probability of the customer being ill increases.

Third, by differentiating α_1 and β_1 with respect to P, we get $\frac{\partial P}{\partial \alpha_1} > 0$ and $\frac{\partial P}{\partial \beta_1} < 0$. The first inequality demonstrates that the HMO increases its fixed price when the customer's price-sensitive parameter is relatively high. That is, the fixed price should increase as the customer's price-sensitive parameter α_1 increases to reduce the negative effect from the customer's price-sensitive parameter. Another interesting conclusion is that the optimal fixed price and the customer's sensitivity to prevention cost effects are not independent. The second inequality shows the HMO should decrease its fixed price when the customer's prevention cost effect sensitivity parameter is high. The results show that under the constraint of the total amount, the higher the cost effect sensitivity to prevention, the higher the cost sharing rate, and the lower the optimal fixed price.

From the customer's optimal solutions, we have the following results: First, by differentiating α_2, β_4, and C_t with respect to e_p, we have $\frac{\partial e_p}{\partial \alpha_2} > 0$, $\frac{\partial e_p}{\partial \beta_4} > 0$, $\frac{\partial e_p}{\partial C_t} > 0$. The first inequality shows that the customer's optimal prevention efforts increase as the market price sensitivity increases. The second inequality shows that the customer's optimal prevention efforts should increase when the market price sensitivity is high. The third inequality shows that once the treatment cost rises, the customer's optimal prevention efforts should increase.

Second, by differentiating a with respect to e_p, we get $\frac{\partial e_p}{\partial a} < 0$. That is, as the market size increases, customers can decrease their prevention efforts, resulting in an interesting managerial insight: Customers may invite others to purchase insurance to reduce their prevention efforts while still gaining benefits. The above phenomena drive us to explore the relationship between market size a and the utilities of customers u and the HMO U. Differentiating a with respect to u and U, we cannot easily judge whether $\frac{\partial u}{\partial a}$ is greater than zero while $\frac{\partial U}{\partial a} > 0$. The results show that for customers, recommending insurance to others can reduce their optimal prevention efforts, but it does not necessarily improve customers' effectiveness in their prevention activities.

Concurrently, the HMO looks favorably on customers recommending it to others as this behavior increases the organization's utility.

2.4 Numerical study

To further study the relationship between CUs u and market size a, we use the control variable method for our simulation under random circumstances.

$$\frac{\partial u}{\partial a} = \frac{1}{36 r_d \alpha_2^2 \eta_p}(-\alpha_2\beta_1 + \alpha_1(C_t r_d \alpha_2 + a(-1+\beta_4)))\cdot (5\alpha_2\beta_1 + \alpha_1(C_t r_d \alpha_2 + a(-1+\beta_4)))\cdot \left(h - \frac{\alpha_2\beta_1 + \alpha_1(-C_t r_d \alpha_2 + 2a(-1+\beta_4))}{3\alpha_2(-1+\beta_4)} + \frac{\beta_1(\alpha_1(a - C_t r_d \alpha_2 - a\beta_4) + \alpha_2(\beta_1 - 6 r_d \eta_p))}{6 r_d \alpha_2 \eta_p}\right)$$

We find that whether $\frac{\partial u}{\partial a} > 0$ relates to the factors α_1, α_2, β_1, β_4, C_t, r_d, η_p, and a. We estimate the changes in α_1, α_2, β_1, C_t, and r_d separately and for a on CUs u. We conduct a numerical study to analyze the relationship between market size a and the customer's utility by assuming $r_d = 0.3$, $h = 100$, $\eta_p = 20$, $\eta_t = 20$, $\eta_d = 40$, $C_{ph} = 0.1P$, $C_t = 100$, $\beta_1 = 10$, $\beta_3 = 0.7$, $\beta_4 = 0.1$, $\alpha_1 = 1$, $\alpha_2 = 2$.

To rule out the impact of other factors on market size and utility, we use the control variable method in our research. Fig. 2(a) shows that the customer's utility changes with α_1 and a, where $\alpha_1 \in (0, 3]$. Fig. 2(b) shows that the customer's utility changes with α_2 and a, where $\alpha_2 \in (0, 3]$. Fig. 2(c) shows that the customer's utility changes with β_1 and a, where $\beta_1 \in [0, 40]$. Fig. 2(d) shows that the customer's utility changes with β_4 and a, where $\beta_4 \in (0, 1)$. Fig. 2(e) shows that the customer's utility changes with C_t and a, where $C_t \in [0, 200]$. Fig. 3(f) shows that the customer's utility changes with r_d and a, where $r_d \in (0, 1]$. Fig. 2(g) shows that the customer's utility changes with η_p and a, where $\eta_p \in (0, 40]$. Excluding the range of market size a in Fig. 2 of

[0, 50], the range of a in Figs. 2(a) to (g) is [0, 500].

Fig. 2(a) shows that the larger α_1 is, the more obvious the tendency of the curve between CUs u and market size a will be. The curve tendency is that as a increases, u decreases first and then increases. Fig. 2(a) indicates that when α_1 is low, customers may not urge their friends to join the HMO; when α_1 is large, the recommendation strategy is wise.

Fig. 2(b) shows that as the market size a increases, CUs u decreases first and then increases when α_2 is low. As α_2 grows, the increase in CUs u slows down. When α_2 is large enough, CUs u decreases as the market size a grows. Although the degree of bending weakens, the CUs always decreases first and then increases as the market size increases regardless of how α_2 changes. Fig. 2(b) indicates that the HMO should focus on the initial period to expand the market size because of the low α_2.

Figs. 2(c) to (f) show that regardless of the changes in β_1, β_4, C_t, and r_d, as the market size a increases, the CUs u decreases first and then increases. The differences among the figures are as follows: As β_1 and C_t increase, CUs u decreases. Meanwhile, the increase of β_4 leads to an increase in CUs u. As β_1 and C_t increase, the growth of CUs u accelerates. Figs. 2(b), (d), and (f) also show that as α_2, β_4, and r_d increase, the curve between market size a and customer utility u weakens. Different from that in the other figures, the utility of the customer in Fig. 2(g) is above zero. Similarly, η_p does not change the tendency of the u-a curve. Fig. 2(d) indicates that when the market size is large, the HMO should improve the prevention ratio in fixed price β_4. Fig. 2(f) shows that the incentive mechanism is relatively effective in cases when the probability of illness is low. Fig. 2(g) indicates that only when the market size is large enough can the prevention effect given by the HMO be effective. This result is explained as follows: When the sample size is small, the effect of prevention is not obvious. Only when the sample size is large enough, can the impact of effective prevention be easily observed.

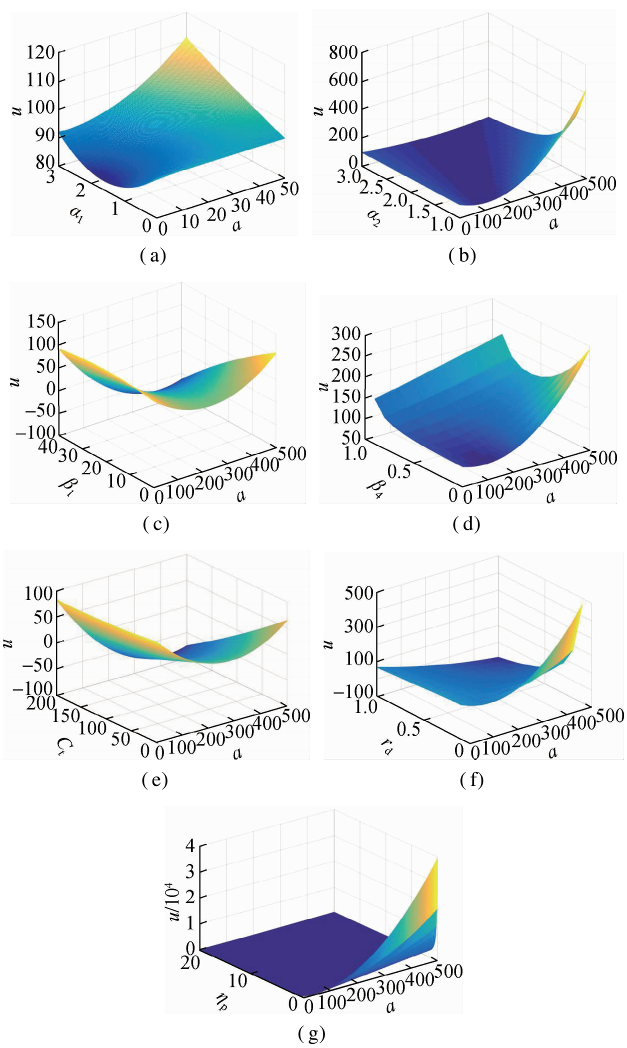

Fig. 2 Impact of factors on market size and utility. (a) CU changes with α_1 and a; (b) CU changes with α_2 and a; (c) CU changes with β_1 and a; (d) CU changes with β_4 and a; (e) CU changes with C_t and a; (f) CU changes with r_d and a; (g) CU changes with η_p and a

From Fig. 2, we conclude that customers will not recommend insurance to their friends when the market size is too small. When the market size is above the inflection point, recommending insurance to others not only benefits the customers' utility while reducing their prevention efforts but also increases the HMO's utility. These results indicate that our method is affected by positive network effects[28] when the market size reaches a certain degree.

3 Conclusions

1) To proactively defend against the rising costs of healthcare due to customers' inefficient prevention efforts, we design a mechanism for increasing the utility of customers and health organizations by stimulating customers' prevention efforts. This mechanism combines customer efforts and health advice to make prevention increasingly effective. In the proposed model, the effectiveness of prevention is improved by reducing the risk and severity of customers' illnesses. The given operation model improves not only customers' health status but also their participation.

2) This study presents the conditions under which the new mechanism is superior to the traditional health management strategy. The proposed mechanism is applicable to different customers.

3) Numerical experiments prove that the proposed method has positive network effects. That is, increased participation improves the benefits gained by customers and HMOs.

4) To cope with the increased probability of illness, HMOs need to increase their cost sharing rates. However, under the conditions in which customers are price insensitive and unwilling to pursue prevention while the

prevention costs are high, HMOs should reduce cost sharing.

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提升顾客预防努力的激励反馈机制

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摘要:为了改进健康管理中由于顾客不愿努力而造成的预防效率低的情形,引入了基于博弈论和合同设计理论的激励反馈机制,以提高顾客的预防积极性.给出了使得顾客和健康维护组织都愿意参与该机制的条件.通过非线性规划模型获得了顾客的最佳预防努力和健康维护组织的价格策略.结果表明:要产生更大的收益,健康维护组织需要在顾客不熟悉健康服务时增加成本共担系数,以激励顾客进行预防努力;当健康服务逐渐被接受以后,成本共担系数可以逐渐减小.仿真表明,在随机环境下,当市场达到一定规模后,所提方法具有积极的网络外部性.受到网络外部性的影响,健康维护组织只需要使得顾客了解参与人越多,每个人获得的效用越大,顾客就可能自发邀请朋友购买保险.

关键词:顾客预防努力;激励反馈机制;医疗服务;健康定价策略;健康服务最优化

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