Value on investment decision for internet hospitals under online/offline direct-to-patient mode

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Abstract: The Salop model was used to simulate competition after investment and development in internet hospitals (IHs) were made due to patients' selection in the medical service market. The optimal investment level and value of IHs were then derived from the total welfare decision. Results of the numerical simulation demonstrated that the investment value of the IH in the online/offline direct-to-patient mode required multi-stage and multi-investment optimization decisions and can be increased by improving patients' cognition and acceptance. Strategic insight to achieve the balance between cost payments and dynamic value is needed to decide the investment value of the IH, especially in the early stage. From the perspective of welfare, the IH should serve more patients in remote areas. The capability and maturity of creating value on investment (VOI) need to improve with the applications proportionally increasing. Furthermore, investment by a public-private partnership will mean that the IH will start up with less capital, an inclusive strategy, and create higher welfare.

Key words: internet hospital; value on investment; online/offline; direct-to-patient

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Internet hospitals (IHs) are a new approach to medical service suppliers in China[1-3], which have been developed actively by the Internet Plus Healthcare policy from 2018[4], and attracted the attention of patients, medical practitioners, and investors[5]. Internet Plus Healthcare has three categories: telemedicine, internet diagnosis and treatment (IDT), and IH. IHs can cover telemedicine and IDT, or telemedicine and IDT can be regarded as the fundamental basis for IH.

IHs are essentially business-to-customer (B2C) internet medical services. They work with approved hospitals to provide services directly to patients. It is a patient-centric approach in which the medical supplies required are prepared, packaged, labeled, and then shipped directly to the patient's or caregiver's home. Online prescriptions can be shared on the specialized platform and make it possible to deliver medicines directly to offline patients[6].

Building an IH involves investment and operation costs. Three years after the policy, only 1 600 IHs from 30 000 entity hospitals were built in China[7]. It shows that hospitals are very cautious or even hesitant to invest in the construction of an IH. On the other hand, IDT brings financial returns and increases health value and social welfare[8], and a good customer experience online can improve medical quality offline[9].

The Salop model was chosen based on previous studies. It was developed to research the spatial competition-based circle coverage market, like the scenario of this paper that two hospitals compete in a circle coverage. Han et al.[10] investigated the quality provision behavior of competing hospitals before and after a merger based on a Salop model with regulated prices. Moscone et al.[11] created a Salop framework adapted from Brekke et al.[12] to model a hospital market with both public and private providers. Li et al.[13] developed a Salop model to analyze the strategic behavior of patient welfare and hospital utility maximizations in a hospital association comprised of three hospitals in different income regions.

The Salop model started to be used to study spatial online/offline competition as the internet expanded. Shi et al.[14] elucidated the competitive equilibrium of online and offline spatial competition based on a Salop model under consumer heterogeneity. Zhang et al.[15] extended a Salop model by incorporating an extra e-tailer and heterogeneous consumer preferences to investigate strategies and decisions in online or offline channels. Ford et al.[16] researched price competition problems between online and offline stores by allowing consumers' preferences to be more favorable toward online shopping.

The reasons for choosing the Salop model for this paper can be highlighted as follows: 1) The distribution characteristic of the hospital market is the hospital-centered annular coverage, which has been proven in the literature research that was conducted to be suitable for the applicability of the Salop model. 2) The Salop model has also been proven to be suitable for online and offline integrated competition research with circular distribution characteristics. 3) As an upgrade and expansion of telemedi-

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cine, IHs in online/offline direct-to-patient mode can be studied with a Salop-type model combined with new scenarios of the emerging era.

Compared with previous studies, our work adds patients' utility based on previous research on telemedicine used by a Salop model. VOI is optimized instead of return on investment. Total welfare provides a basis for multi-agent investment decision making. Moreover, numerical experimentation is used to provide a reference for investment decisions on IHs.

1 Problem Statement

Assuming that in the medical services market, there are two hospitals: A (having an IH) and B (no IH). Hospitals A and B provide the same quality of medical services, so the utility is the same. Hospital A needs to determine the level of IH investment and the price of IH services to maximize overall welfare. This will depend on factors that affect the patient's choice of IH services, where the overall welfare means the VOI will be added to the patient surplus.

There are three options for patients to decide whether to go to a hospital or not, according to their medical utility and health needs. If they decide to seek medical care, they can choose hospital A or B. If they select hospital A, they can choose A's in-person visit or an IH consultation. The patient's value and medical costs will determine their utility as assessed by Hospital A. If the patient with mild symptoms chooses not to seek medical treatment, the utility is less than zero. When the patient chooses a hospital to seek medical treatment and the mode of medical services, the utility is greater than zero.

The model is based on the following assumptions:

1) All patients have the same perceived value of medical treatment in the circle market, although the cost is different owing to their physical condition and location.

2) Patients will choose medical treatment if their utility from medical treatment is higher than the costs.

3) Before the IH application, if the patients for hospital B turn to hospital A for treatment, hospital A is not capable of accepting all these patients.

4) After the IH application, hospital A has sufficient capacity to accept IH-preferred patients switching from hospital B.

2 Model

2.1 Impact of the IH on the market share of hospital A

Since the patient will choose the nearest hospital for medical services at any one time (in this case, hospital A), hospital B will split the market. Fig. 1 shows the market of hospital A, where both sides of the line are solid. The market of hospital B is on both sides of the dotted line. All the patients in the circle market are covered. The impact of quality on patients' utility is not considered in this paper because quality and accessibility are the main factors influencing the patient's choice of hospital, and the quality of medical services provided by A and B is the same.

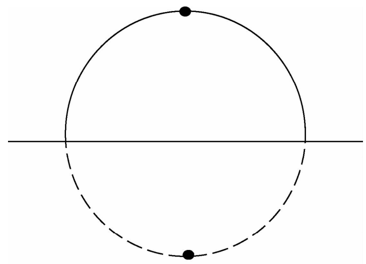

Fig. 1 Market share of hospitals A and B before A introduces an IH

Patients' medical utility in hospital A is

$$U_{\mathrm{I}}^{\mathrm{A}} = V - P_{\mathrm{I}} - tx \tag{1}$$

where V is the perceived value of treatment (a patient's highest level of willingness to pay for medical treatment); P_{I} is personal medical expenses after deduction of medical insurance associated with every in-person hospital visit; t is the perceived travel costs of an in-person visit per unit distance (including the inconvenience and discomfort to the chronically ill patient, along with time and cost of travel to hospitals); x is the distance between patients' location and the hospital.

Patients' medical utility in hospital B is

$$U_{\mathrm{I}}^{\mathrm{B}} = V - P_{\mathrm{I}} - t\left(\frac{1}{2} - x\right) \tag{2}$$

when $x = \frac{1}{4}$; $U_{\mathrm{I}}^{\mathrm{B}} \geqslant 0$; the range of perceived value of treatment V is

$$V \geqslant P_{\mathrm{I}} + \frac{t}{4} \tag{3}$$

According to regulations, the patients who choose an IH (after it is put to use) should receive service in hospital A for the first time, establish the initial doctor-patient relationship, and then contact hospital A's doctor for an IH consultation. In the subsequent treatment process, the patient must also go to the hospital for a physical examination according to their physical condition. The proportion of patients who conduct a remote consultation with hospital A's doctor at home in the IH setting is w, and the number of patients in the market is normalized to 1; therefore, $w \in [0, 1]$.

When the patient chooses an IH service for treatment in hospital A, the cost of transportation will be reduced. There is no difference in the quality of diagnostic accuracy between online and offline because all patients served by an IH who have common and chronic diseases will be subsequent visitors to hospital A. Therefore, it is assumed that the perceived value is the same whether in IH mode or in-person mode.

For patients whose location is x from hospital A, the utility of the IH is given by the following:

$$U_{\mathrm{T}}^{\mathrm{A}} = V + \gamma m - wP_{\mathrm{T}} - (1-w)(P_{\mathrm{I}} + tx) - S \tag{4}$$

where γ is the influence coefficient of IH investment on patient utility; m is the IH investment level; P_{T} is personal medical expenses after deducting medical insurance associated with every IH visit; S is the set-up cost incurred in the IH service model (including initial preparation costs, such as hardware and software equipment costs, and patients' unwillingness to move to an IH visit).

Taking derivatives of the above functions about x, the following formula is produced:

$$\frac{\partial U_{\mathrm{T}}^{\mathrm{A}}}{\partial x} = -(1-w)t \tag{5}$$

Obviously, as x increases, the patient's treatment utility in hospital A through an IH consultation is diminishing. Therefore, when $U_{\mathrm{T}}^{\mathrm{A}} = 0$, the farthest distance where patients are willing to choose hospital A's IH services is

$$x_{\mathrm{T}}^{\mathrm{A}} = \frac{V + \gamma m - S - P_{\mathrm{I}} - wP_{\mathrm{T}} + wP_{\mathrm{I}}}{t(1-w)} \tag{6}$$

where γm is expressed as the utility of the patient's medical experience in an IH consultation and is related to the investment level in the IH. According to Grube et al. [17], although IHs require initial cost investment, when a patient's access to medical care increases, the waiting time for medical treatment reduces. Here, γm shows patients' increasing medical utility compared with an in-person visit, while γm also reflects the current recognition level of an IH. When IHs have higher acceptance, patients will have more utility.

In hospital A, when patients are indifferent to an in-person visit and an IH consultation, that is $U_{\mathrm{I}}^{\mathrm{A}} = U_{\mathrm{T}}^{\mathrm{A}}$, the location $x_{\mathrm{IT}}^{\mathrm{A}}$ is given by the following:

$$2\left(\frac{1}{2} - x_{\mathrm{IT}}^{\mathrm{AB}}\right) = \frac{-2\gamma m + 2wP_{\mathrm{T}} - 2wP_{\mathrm{I}} + (1-w)t + 2S}{(2-w)t} \tag{7}$$

The location of neutral patients is

$$x_{\mathrm{IT}}^{\mathrm{A}} = \frac{wP_{\mathrm{T}} - wP_{\mathrm{I}} - \gamma m + S}{wt} \tag{8}$$

when patients are indifferent to an in-person visit to hospital B and an IH consultation with hospital A, which is $U_{\mathrm{I}}^{\mathrm{B}} = U_{\mathrm{T}}^{\mathrm{A}}$, the location $x_{\mathrm{IT}}^{\mathrm{AB}}$ is given by

$$V - P_{\mathrm{I}} - t\left(\frac{1}{2} - x\right) = V + \gamma m - wP_{\mathrm{I}} - (1-w)(P_{\mathrm{I}} + tx) - S \tag{9}$$

then $x_{\mathrm{IT}}^{\mathrm{AB}}$ can be written as

$$x_{\mathrm{IT}}^{\mathrm{AB}} = \frac{\gamma m - wP_{\mathrm{T}} + wP_{\mathrm{I}} + \frac{t}{2} - S}{(2-w)t} \tag{10}$$

When $\frac{1}{4} \leqslant x_{\mathrm{IT}}^{\mathrm{AB}} \leqslant \frac{1}{2}$ is satisfied, introducing an IH by hospital A can bring additional market share, and the constraint condition can be obtained as follows:

$$0 < \gamma m - S - wP_{\mathrm{T}} + wP_{\mathrm{I}} + \frac{1}{4}wt \leqslant \frac{1}{2}t - \frac{1}{4}wt \tag{11}$$

After entering formula (3), it satisfies $x_{\mathrm{IT}}^{\mathrm{A}} < \frac{1}{4}$.

Therefore, hospital A's market share after IH services can be achieved, as shown in Fig. 2 below.

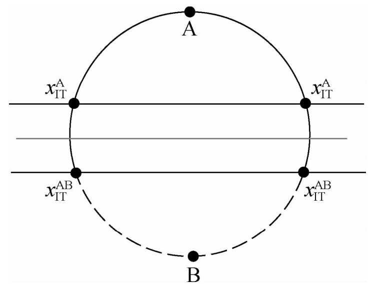

Fig. 2 Market share map of hospitals A and B after the introduction of an IH by hospital A

Following this, the market share of an in-person visit to hospital A is $2x_{\mathrm{IT}}^{\mathrm{A}}$, as shown below:

$$2x_{\mathrm{IT}}^{\mathrm{A}} = \frac{2wP_{\mathrm{T}} - 2wP_{\mathrm{I}} - 2\gamma m + 2S}{wt} \tag{12}$$

The market share of hospital A's IH services is $2(x_{\mathrm{IT}}^{\mathrm{AB}} - x_{\mathrm{IT}}^{\mathrm{A}})$ as follows:

$$2(x_{\mathrm{IT}}^{\mathrm{AB}} - x_{\mathrm{IT}}^{\mathrm{A}}) = \frac{4gm + wt - 4wP_{\mathrm{T}} + 4wP_{\mathrm{I}} - 4S}{tw(2-w)} \tag{13}$$

The total market share of hospital A is $2x_{\mathrm{IT}}^{\mathrm{AB}}$, and hospital B's market share is $2\left(\frac{1}{2} - x_{\mathrm{IT}}^{\mathrm{AB}}\right)$ as demonstrated in this formula:

$$2\left(\frac{1}{2} - x_{\mathrm{IT}}^{\mathrm{AB}}\right) = \frac{-2\gamma m + 2wP_{\mathrm{T}} - 2wP_{\mathrm{I}} + (1-w)t + 2S}{(2-w)t} \tag{14}$$

2.2 Formulation of IH's investment decision-making model in hospital A

Assuming that the total number of patients on the circle market is n, d is used to express the value created by the IH. It is similar to incremental revenue created by increased patient satisfaction and care plan adherence. This is additional to a return by service charge directly, and d

$=(\beta nw)^2$, which underlyingly means that those visits online have a proportion switching to offline when necessary. I is used to express the investment cost for an IH, and $I=\frac{1}{2}\delta m^2$. The patients' surplus in hospital A is

$$U_A = 2n\int_0^{x_{IT}^A}(V-P_I-tx)\,dx + 2n\int_{x_{IT}^A}^{x_{IT}^{AB}}(V-wP_T-(1-w)(P_I+tx)+\gamma m-S)\,dx \quad (15)$$

The VOI of hospital A is

$$\pi_A = n[2x_{IT}^A(P_I-C_I)+2(x_{IT}^{AB}-x_{IT}^A)((wP_T-wC_T)+(1-w)(P_I-C_I))]-I-d \quad (16)$$

The total welfare W is expressed as the patients' surplus in hospital A and the sum of the profits of hospital A:

$$W_A=\pi_A+U_A \quad (17)$$

The first-order partial derivative of the IH investment m and the IH cost P_T in Eq. (9), can be obtained as follows:

$$\frac{\partial W}{\partial P_T}=\frac{1}{t(w-2)^2}nw(8C_T+8P_I-8P_T+2S+t-4V+2C_I(w-2)-w(4C_T+6P_I-6P_T+t-2V)-2m\gamma) \quad (18)$$

According to the first-order partial derivative of the IH investment, m, and the IH cost, the Hessian matrix is as follows:

$$\boldsymbol{H}(m,P_T)=\begin{bmatrix}\frac{\partial U}{\partial m^2} & \frac{\partial U}{\partial m} \\ \frac{\partial U}{\partial P_T \partial m} & \frac{\partial U}{\partial P_{T^2}}\end{bmatrix}=\begin{bmatrix}\frac{-2n(w-4)\gamma^2}{t(w-2)^2 w}-\delta & \frac{-2nw\gamma}{t(w-2)^2} \\ \frac{-2nw\gamma}{t(-2+w)^2} & \frac{nw(6w-8)}{t(w-2)^2}\end{bmatrix} \quad (19)$$

The first order of the main formula $\frac{-2n(w-4)\gamma^2}{t(w-2)^2 w}-\delta<0$ is established.

When the second-order determinant is greater than zero, the Hessian matrix is negative, and there is a unique restraint that needs to be satisfied:

$$8n\gamma^2+tw\delta(3w-4)<0 \quad (20)$$

Let W be the first-order partial derivative of the IH investment level m, and the IH cost P_T equals zero. The formula is constructed as follows:

$$m^*=\frac{n(8S-(4C_I-8C_T+t+4V)w)\gamma}{8n\gamma^2+tw\delta(3w-4)} \quad (21)$$

$$\pi=\frac{1}{2}n(P_I-C_I)=105\ 000$$

$$P_T^*=\frac{1}{16n\gamma^2+2tw\delta(3w-4)}\cdot(2n\gamma^2(-4C_I+8C_T+8P_T+t-4V)+tw(4C_I-8C_T-8P_I-2S-t+4V+(-2C_I+4C_T+6P_I+t-2V)w)\delta) \quad (22)$$

Constraints on the IH's impact on hospital A's market share are shown as Eq. (5); substituting into m^* and P_T^*, while $V\geqslant P_I+\frac{t}{4}$, then it obtains the following constraint:

$$\left.\begin{aligned}&V\geqslant P_I+\frac{t}{4}\\&2n\gamma^2+tw\delta\left(\frac{3}{4}w-1\right)<2n\gamma^2+\\&w(-2S-t+(C_I-2C_T+t+V)w)\delta\leqslant 0\end{aligned}\right\} \quad (23)$$

Restricted by these conditions, considering m^* and P_T^*, the total welfare W^* is

$$W^*=\frac{1}{4(8n\gamma^2+tw\delta(3w-4))}(n(-2n(8C_I+t-8V)\gamma^2+(-16S^2+4S(4C_I-8C_T+t+4V)w+w(t(8C_I+t-8V)-(4C_I^2+16CT^2+(t-2V)^2+8C_I(V-2C_T+t)-4C_T(t+4V))w))\delta)) \quad (24)$$

The market share of hospital A M_A^* is

$$M_A^*=\frac{4n\gamma^2+w(4S+t(w-2)-2(C_I-2C_T+V)w)\delta)}{8n\gamma^2+tw\gamma(3w-4)} \quad (25)$$

3 Numerical Simulation

Based on a representative example[18], it is assumed that the number of patients in the circle is 3 000, i. e., $n=3\ 000$. Before the IH services are available in hospital A, service costs P_I is 150 yuan, and the unit cost of treatment C_I is 80 yuan. The cost C_T is also 80 yuan after the IH is operational.

3.1 The impact of the IH's use

Let $S=200$, $t=1\ 000$, $\delta=25$, $\beta=1/3$, and $\gamma=0.5$, and to discuss the effect of the IH use ratio w respectively on the total welfare, the total surplus of patients radiated by hospital A, the profit of hospital A, and the optimal decision m^*, P_T^*.

In this case, the range of V is $V\geqslant 400$, assuming V is 450, and the range of w satisfying the optimal solution is $w>0.06$ according to the previous constraint. At this time, the two-dimensional image is used to describe the effect of the IH uses ratio w in the interval [0, 1] on the total benefit of the total welfare, patients' surplus, the profit of hospital A, and the optimal decision, as shown in Fig. 3.

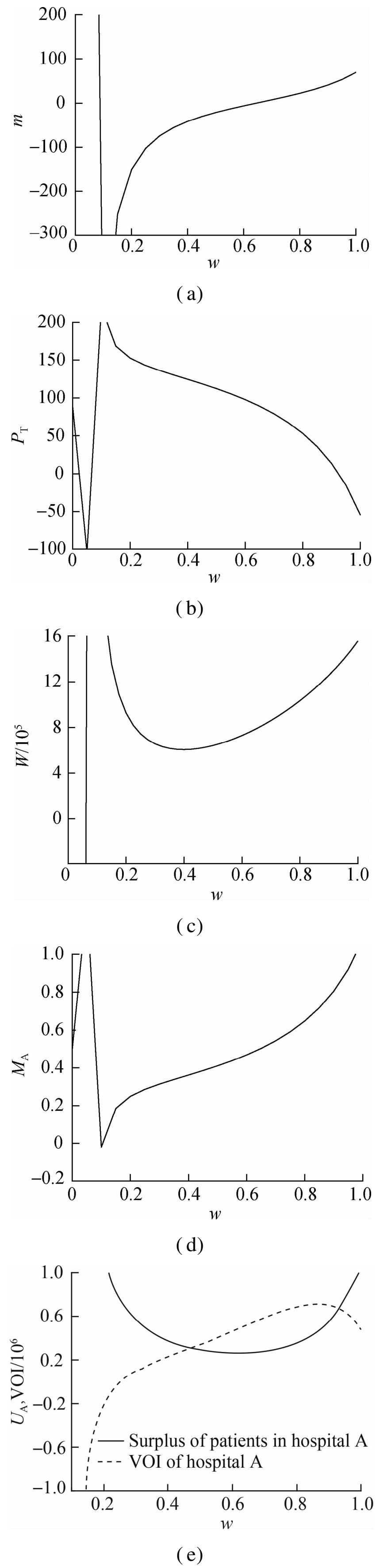

Fig. 3 Impact of the IH use ratio w. (a) The level of IH investment m; (b) The price of IH P_T; (c) Total welfare W; (d) Hospital A's market share M_A; (e) Hospital A's patients' surplus U_A and VOI

The first four graphs in Fig. 3 show the range of w of the optimal solution for the decision variable, i. e., $w > 0.06$. According to constraint (5), the ranges that can make a difference to hospital A's market share when A introduces an IH are $0.645 < w < 0.977$.

It can be seen from Fig. 3 that, IH expenses are gradually reduced while the level of IH investment and w increase, which means that the proportion of online consultations at home increases during the entire process of treatment. Patients choosing an IH can bring greater utility to them and reduce medical expenses. It means that increasing IH investment can serve more remote patients and also improve the accessibility of medical care, thereby increasing the utility of the patients.

When $w = 0.8$, before hospital A introduces an IH, the utility of patients in the range of (0, 0.324) and (0.676, 1) in the circle market can be seen in the following formula:

$$U = 2n\left(\int_0^{1/4}(V - P_I - tx)\,\mathrm{d}x + \int_{1/4}^{0.324}\left(V - P_I - t\left(\frac{1}{2} - x\right)\right)\mathrm{d}x\right) = 301\ 013 \tag{26}$$

And VOI of hospital A is

$$\pi = \frac{1}{2}n(P_I - C_I) = 105\ 000$$

Patients' surplus added to the hospital's profit is

$$W = U + p = 406\ 013$$

It can be seen from Tab. 1 that the market share of A has been improved, and the total utility of patients who choose to use the IH has increased, which combines to bring about the increase of the aggregate welfare with the VOI of hospital A also increasing.

Tab. 1 Data comparison before and after the introduction of IH when $w = 0.8$

Item	M_A	U_A	π_A	W_A
Before IH	0.5	301 013	105 000	406 013
After IH	0.6	350 093	683 992	1 034 085

Therefore, the hospital can choose to reduce the price of IH usage to attract patients, especially those with chronic diseases, as the new medical service offers online/offline mode in order to obtain patients' recognition by improving patients' utilization. IHs can monitor these patients (especially the elderly) at home all day, remind them to take medication on time, provide other health guidance to help them stabilize their physical conditions, and reduce their travel to the hospital. By increasing IH investment, hospitals can bring new care access to more patients and increase their medical utility. At the same time, the hospital needs to set lower IH prices to attract patients, which results in lower profitability for a while, but more profit in a longer term due to attracting more patients. Meanwhile, the value created by IHs will grow consistently until the service proportion capability is limited by the maturity of creating VOI.

3.2 Influence coefficient of IH investment on patient utility

Let $t=1\ 200$, $w=0.5$, $S=150$, $\delta=80$ to discuss the effect of coefficient γ of IH investment on patient utility on total welfare, the total utility of patients served by hospital A, hospital A's VOI, and the optimal decision m^*, P_T^*.

Assume that the value of V is 500 while the range of V is $V \geqslant 450$, and the range of γ satisfying the optimal solution is $0<\gamma<2.145$, according to the previous constraint. At this time, the influence coefficient of IH investment on the utility of the patient is described by the two-dimensional image in the interval [0, 4] for the total benefit, the total utility of the patient served by hospital A, the VOI of the hospital A, and the optimal decision. This is shown in Fig. 4.

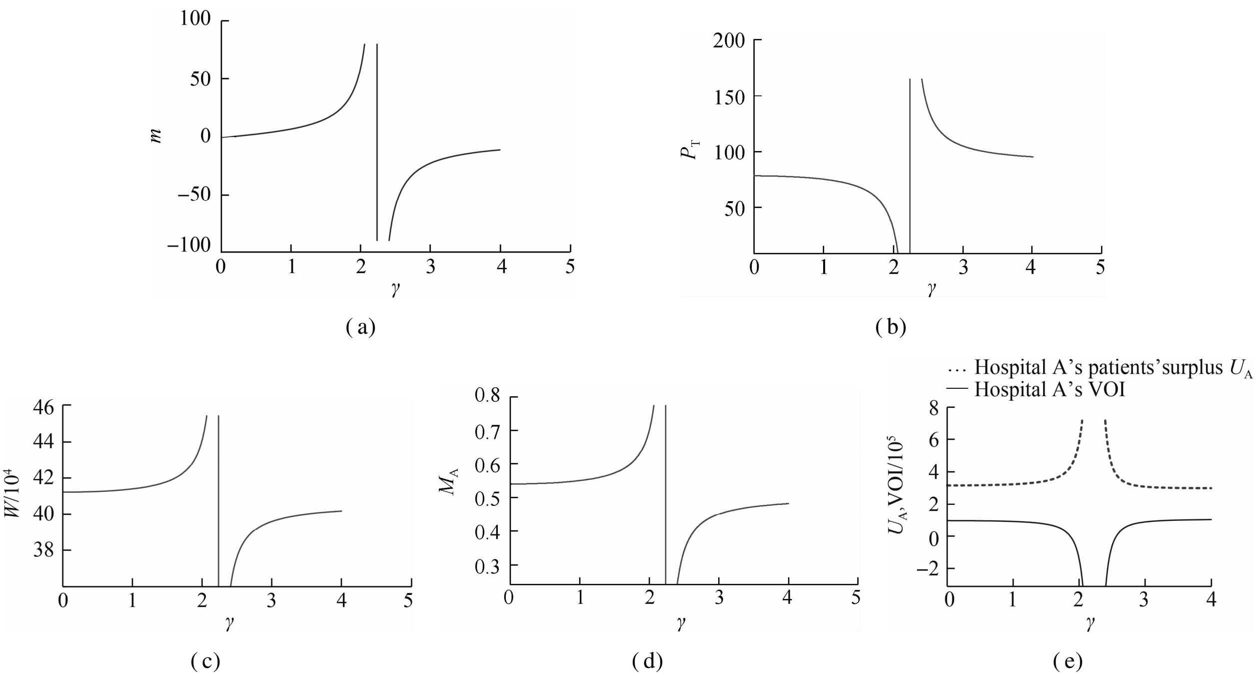

Fig. 4 Influence coefficient of IH investment on patient utility. (a) Level of IH investment m; (b) Price of IH P_T; (c) Total welfare w; (d) Hospital A's market share M_A; (e) Hospital A's patients' surplus and VOI

According to constraint (5), the range of γ that can affect hospital A's market share is $0<\gamma<2.236$, which corresponds to the vertical line shown in the first four figures of Fig. 4. Considering the range of γ when the optimal value of the decision variable exists, it can be seen in Fig. 4 that the dependent variables represented by the y-axis are not infinitely increased (or reduced), and their maximum (or minimum) is limited to $\gamma=2.145$.

Fig. 4 also demonstrates that the IH cost is gradually decreasing, and the level of IH investment is increasing, with the increase of γ in the range of $0<\gamma<2.236$. The impact of IH investment on patients can be seen from two aspects. At the social level, the patient's acceptance of the IH generally improves, so the investment in the IH can increase the patient's medical utility effectively. On this basis, the patients feel that the investment of the IH simplifies the medical process and reduces the waiting time and cost of medical treatment. The greater the value of γ, the greater added utility for the patients. As shown in Fig. 4 (a), the area between the curve of the investment level and the horizontal axis represents the value of added utility because of the investment of the IH in the range of $0<\gamma<2.145$. When γ is larger, the effect of hospital A's per unit of IH investment on the patients' utility is larger. Thus, the hospital will naturally increase investment and reduce the price of the IH to attract more patients to expand its market share. It will increase patients' surplus and overall welfare, with more patients choosing IH services. When γ is within a small value range, the increase in m and the reduction in the price of IH services have little effect on patient utility, hospital VOI, and total surplus. When γ increases to about 1.5, its effect on all dependent variables suddenly increases. At this time, increasing investment and reducing the cost of services will greatly impact the market share and the total welfare.

Therefore, hospitals should first enhance the patient's psychological awareness and recognition of IHs and reduce or even eliminate the patient's concerns that IHs may violate privacy. It makes them aware of the efficiency of IH treatment and is as good as the in-person treatment before introducing them to an IH. At the same time, IHs can increase accessibility to healthcare. Patients with chronic diseases can feel better about the reduction in waiting time and expense, so the hospital can invest in an IH to produce more benefits with less effort.

3.3 Effect of IH investment on patient utility at different values of parameters

Let $S = 150$, $\delta = 80$, and the effect of IH investment on the ratio of patients' utility γ, under different levels of perceived travel cost t and the IH using the ratio w, can be shown.

When the value of perceived travel cost t is small, and set $t = 400$, then the range of perceived value V is $V \geqslant 250$. Assuming that the value of V is 380, and the range of γ satisfies constraints (5) and (10) is $0 < \gamma < 1.323$, $0.75 < w < 1$, taking $w = 0.8$, then the range of γ is $0 < \gamma < 1.222$.

When the perceived travel cost t is large, the range of perceived value V is $V \geqslant 450$ when $t = 1\ 200$. Assuming that the value of V is 500, and the range of γ satisfying constraints (5) and (10) is $0 < \gamma \leqslant 2.141$, $0.416 < w < 0.926$, or $2.141 < \gamma < 2.15$, $0.416 < w < 0.509$, or $\gamma = 2.15$, set $w = 0.463$, $w = 0.5$ and 0.8, respectively. When $w = 0.5$, the range of γ satisfying the optimal solution is $0 < \gamma < 2.145$, and the range of γ satisfying that IH investment works in hospital A, then $0 < \gamma < 2.236$. When $w = 0.8$, the range of γ satisfying the optimal solution is $0 < \gamma < 1.475$, and the range of γ satisfying that the introduction of an IH influences hospital A, then $0 < \gamma < 2.263$.

It can be seen from the constraint analysis that when the perceived travel cost t is small, under the restricted value of perceived value V, the higher level of IH use ratio w can influence hospital A when introducing IH, but when t is larger, under the condition of satisfying V, the middle level of w can also bring an impact to hospital A. For patients with larger t, reducing travel frequency increases their utility greatly.

With different levels of perceived travel cost t and the IH use ratio w, the effect of the influencing ratio of the investment on IH and patients' utility γ with investment level m is shown in Fig. 5.

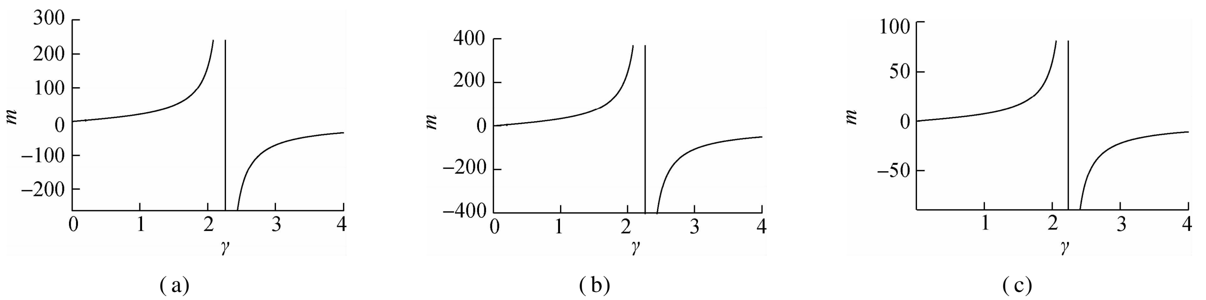

Fig. 5 Effect of γ on m with levels of t and w. (a) γ's influence on m under low-level t and high-level w, $t = 400$, $V = 380$, $w = 0.8$; (b) γ's influence on m under high-level t and high-level w, $t = 1\ 200$, $V = 500$, $w = 0.8$; (c) γ's influence on m under high-level t and middle-level w, $t = 1\ 200$, $V = 500$, $w = 0.8$

In Figs. 5(a) to (c), when γ takes the value of 1 or in the vicinity of the maximum constraint range, the values of m are shown in Tab. 2.

Tab. 2 Impact of γ on m under levels of t and w

Parameter	γ	γ maximum values	m
$t = 400$, $w = 0.8$	1	1.22	56
$t = 1\ 200$, $w = 0.8$	1	1.47	69
$t = 1\ 200$, $w = 0.5$	1	2.14	153

As can be seen from Tab. 2, when γ is the same and the perceived travel cost t is high enough, while the IH use ratio w and the IH investment is small, the hospital's investment will naturally increase as both t and w increase. When t is small, even if w is large, the effect of the IH on patient utility is small, and when t increases, even if w is small, the impact of the IH investment on patient utility increases. However, the IH's impact on patient utility is limited to a range and cannot be infinitely increased. At the same time, there is a limit to the investment in the IH under the maximum total welfare. Additional investment is futile when the impact of IH investment on patient utility reaches its maximum.

Therefore, in the early stage of IH investment, the hospital can focus on patients in remote areas or who are located less conveniently and gradually increase the IH investment to increase the proportion of IH consultations, w. When w becomes larger, broader types of patients will be served, such as those with convenient travel but who need to visit the hospital frequently, while providing even more benefit for patients whose perceived travel cost is high.

3.4 Impact of proportion and maturity on VOI

With the advancement of information technology and internet operations, the creation and development of IHs have a gradual promotion and maturation process. The impact of these factors on value investment needs to be analyzed for decision making at different stages.

As shown in Fig. 6(a), the initial stage is the set-up investment period and technical service iteration period, and IH's maturity (service experience, function realization) is low. The proportion of patients is low ($w < 0.2$), and the VOI of the hospital is less than zero, which means that it should prepare the necessary resources and capital investment, yet not enough VOI is created.

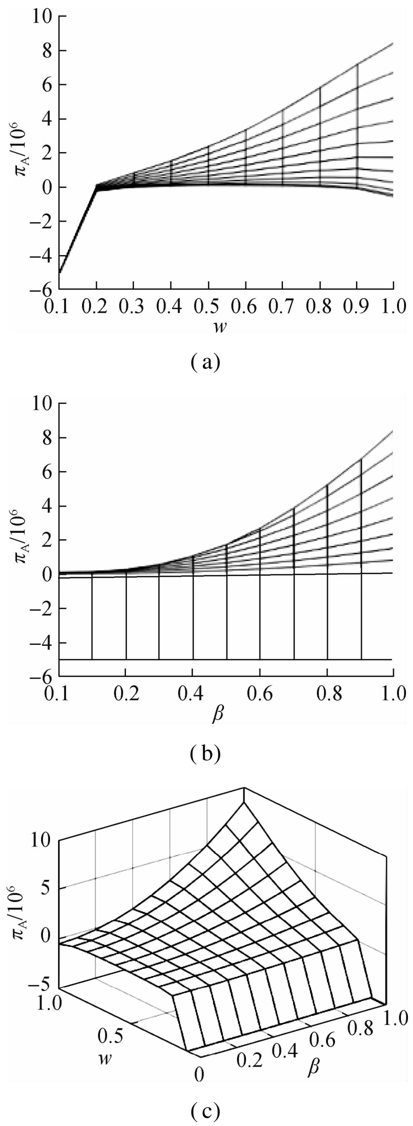

Fig. 6 Impact of factors on VOI. (a) Proportion; (b) Maturity; (c) Proportion and maturity

If the maturity of IH has been at a low level, as shown in Fig. 6(b), the increase in the proportion of patients will not bring positive VOI; even when the proportion of patients is high, there will be negative growth. It is suggested that IH should not blindly promote and increase the number of patients. The improvement of service and technology should be paid more attention to in the set-up stage.

As shown in Fig. 6 (c), it is suggested that the maturity of the IH and the proportion of patients have a synergistic relationship (positive correlation); that is, the maturity needs the accumulation of the number of users to continue to improve, and the higher maturity can attract more patients, too.

When the development and the proportion of users reach a certain level, the VOI will double the absolute value, indicating that the performance model has a cumulative snowball effect. It is suggested that long-term plans need to make for large-scale development. In reality, the maturity experience of online medical services cannot reach the offline level. The change in the slope of the curve on both sides shows that IH cannot collaborate with physical hospitals to achieve optimal ratio sharing.

In summary, managerial insight can be improved based on numerical simulation: 1) IH investment, whether for hospitals, patients or the overall welfare, is a positive benefit for operation, management and performance improvement. 2) IH investment means higher cost and lower profit in the early stage when the technology is not yet mature, and customer awareness is not yet enough. The investment value needs to be decided from a strategic insight. 3) IH is not simple construction work but needs a complex, systematic and long-term operation. It is necessary to balance the cost of payments and dynamic value. 4) From the perspective of welfare, IHs should serve more patients in remote areas, reduce repeated long-distance travel, and seek medical treatment on time.

4 Conclusions

1) The Salop model is applicable to build the competition model of IH investment, taking total welfare maximization as the goal, with the optimal level of IH investment and the IH price obtained.

2) Results of a numerical simulation show that the investment value of IHs in the online/offline direct-to-patient mode requires multi-stage and multi-investment optimization decisions and can be increased by improving patients' cognition and acceptance.

3) The investment value of IHs needs to be decided from strategic insight to balance between cost payments and dynamic value, especially in the early stage. From the perspective of welfare, IHs should serve more patients in remote areas.

4) The capability and maturity of creating VOI need to improve spontaneously with the proportion of applications increasing. Furthermore, investment by a public-private partnership mode will start up IHs with less capital and inclusive strategy and create higher welfare.

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线上/线下直达患者模式下的互联网医院价值投资决策

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摘要:通过建立Salop模型对互联网医院投资发展后医疗服务市场的变化进行仿真研究,并分析患者选择的结果,然后从总体福利决策中推导出互联网医院的最优投资水平和健康福利价值.数值模拟结果表明,线上/线下直达患者模式下的互联网医院投资价值需要多阶段、多投资主体的优化决策,提高患者对互联网的认知和接受程度,有助于增加互联网医院的投资价值.互联网医院的投资需要战略规划,尤其是在建设前期,应做到成本支付与动态价值的平衡.从社会福利的角度来看,互联网医院应该服务于更多偏远地区的患者.随着使用患者比例的增加,需要提高投资价值的创建能力与成熟度.此外,应探索公私合营模式,以较少的低成本和惠民战略启动互联网医院,并更加注重社会福利增值.

关键词:互联网医院;价值投资;线上/线下;直达患者

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