Research on Evolutionary Game of Information Sharing with Online Health Community

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Abstract. Online health community has become an important way for patients to share information and has received more and more attention. Based on the theory of evolutionary game theory, this paper establishes a game model of information sharing of online health community members, and studies the factors that affect the information sharing among patients. Results show that the information sharing behavior of the online health community can evolve into a good state and can also be "locked" in a bad state. Online health community managers need to improve the information sharing revenue coefficient, reduce information sharing risk cost, and promote the sustainable information sharing of online community patients.

1. Introduction
With the development of science and technology, patients actively use online platforms to participate in their own health management[1], discuss the problems encountered during the diagnosis and treatment, integrate various resources[2], carry out information sharing, create a unique online health community value creation model[3]. The development of Internet technology and mobile communication technology has enabled the communication between members of online healthy communities not to be affected by time, space and social status[4], providing necessary support for information exchange between patients[5]. Patients join online health communities to seek information, emotional support and opportunities to communicate with others[6]. Experiential knowledge helps all members of the community get the information they want to better fight their own disease[7]. However, because information sharing has certain risks[8], and information provided by patients with community may be wrong or misleading[9], not all patients will share information. Combined with the evolutionary game theory, this paper builds online health information sharing community evolution game model, analyzes the influencing factors of online health community information sharing, to improve the value of online health community, promote the information sharing level and sustainable development of community patients.

The rest of this paper is organized as follows. Section 2 builds an online health community information sharing base model and analyzes its evolution stabilization strategy. The differences of online health community patients will be considered in Section 3. Finally, the results of the two models are compared and suggestions for information sharing are proposed.

2. Basic model of online health community information sharing behavior

2.1. Benefit Matrix
Online health community information sharing is a complex and dynamic system[10]. There are two strategies of information sharing and information monopoly. When information is shared, the patient gains the benefit of self-efficacy. If both parties share information, they will benefit from the complementary and superposition of information. At the same time, information sharing needs to pay a certain cost. Suppose the parties involved in information sharing are patient A and patient B. The probability of patient A actively participating in information sharing is $x$, and the probability of information monopoly is $1-x$. Similarly, the probability that patient B actively participates in information sharing is $y$, and the probability of information monopoly is $1-y$. The information sharing benefit matrix is shown in Table 1.

Table 1. Information sharing strategy and benefit matrix of online health community

| Patient | Information sharing(x) | Information monopoly(1-x) |
|---------|-------------------------|---------------------------|
| Patient A | $a-c,a-c$ | $b-c,p$ |
| Information sharing(y) | $0,0$ |

$c$ is the cost of information sharing, when the two parties share information, the benefit of information synergy is $a$. When one patient shares information, another monopolizes information, the benefits obtained by the information sharer is $b$, and the benefits obtained by the information monopolist is $p$.

The expected benefits $U_a^{11}$ of information sharing, expected benefits $U_a^{12}$ of information monopoly and the average benefits $\overline{U}_a$ of patient A are respectively:

$$U_a^{11} = y(a - c) + (1 - y)(b - c)$$

(1)

$$U_a^{12} = y \ast p$$

(2)

$$\overline{U}_a = xU_a^1 + (1 - x)U_a^2$$

(3)

The expected benefits $U_b^{11}$ of information sharing, expected benefits $U_b^{12}$ of information monopoly and the average benefits $\overline{U}_b$ of patient B are respectively:

$$U_b^{11} = x(a - c) + (1 - x)(b - c)$$

(4)

$$U_b^{12} = xp$$

(5)

$$\overline{U}_b = yU_b^1 + (1 - y)U_b^2$$

(6)

According to the dynamic equation of Malthusian, the replication dynamic equation of information sharing of patient A and patient B is respectively:

\[
\begin{align*}
\frac{dx}{dt} &= x(U_a^{11} - \overline{U}_a) = x(1-x)[y(a-p-b) + b-c] \\
\frac{dy}{dt} &= y(U_b^{11} - \overline{U}_b) = y(1-y)[x(a-b-p) + b-c]
\end{align*}
\]

(7)

2.2. Equilibrium Points and Stability Analysis
When $x = 0 \cdot y = 0$, the dynamic equation of replication is solved, and 5 local equilibrium points of the system $(0,0),(0,1),(1,0),(1,1),(G,Q)$ are obtained. $G = \frac{c-b}{a-b-p}$, $Q = \frac{c-b}{a-b-p}$. The equilibrium points of dynamic equation is not necessarily the evolutionary stability strategy of the system. According to Friedman's method, the evolution stabilization strategy of differential equation system can be derived from the local stable analysis of the Jacobson matrix. The Jacobson matrix

$$J = \begin{pmatrix}
\frac{\partial x}{\partial x} & \frac{\partial x}{\partial y} \\
\frac{\partial y}{\partial x} & \frac{\partial y}{\partial y}
\end{pmatrix} = \begin{pmatrix}
a_{11} & a_{12} \\
a_{21} & a_{22}
\end{pmatrix}
$$

(8)

Among them,

$$\begin{cases}
a_{11} = (1-2x)[y(a-b-p)+b-c] \\
a_{12} = x(1-x)(a-b-p) \\
a_{21} = y(1-y)(a-b-p) \\
a_{22} = (1-2y)[x(a-b-p)+b-c]
\end{cases}
$$

(9)

When the following two conditions are met, the local equilibrium points of the system will become the evolutionary stability strategy (ESS).

$$\det J = \begin{vmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{vmatrix} = a_{11}a_{22} - a_{12}a_{21} > 0$$

(10)

$$\text{tr} J = a_{11} + a_{22} < 0$$

(11)

The values of $a_{11}$, $a_{12}$, $a_{21}$ and $a_{22}$ of 5 local equilibrium points of the system are shown in table 2.

| Equilibrium | $a_{11}$ | $a_{12}$ | $a_{21}$ | $a_{22}$ |
|-------------|----------|----------|----------|----------|
| (0,0)       | b-c      | 0        | 0        | b-c      |
| (0,1)       | a-p-c    | 0        | 0        | c-b      |
| (1,0)       | c-b      | 0        | 0        | a-p-c    |
| (1,1)       | p+c-a    | 0        | 0        | p+c-a    |
| (G,Q)       | 0        | D        | W        | 0        |

Note: $D = \frac{(a-p-c)(c-b)}{a-b-p}$, $W = \frac{(a-p-c)(c-b)}{a-b-p}$

It is clear that $a_{11} + a_{22} = 0$ at the point (G,Q), which does not meet the condition 2, so the local equilibrium points is certainly not an evolutionary stabilization strategy.

2.3. Results Discussion

(1) When $c > b, a < p + b$, the local stability analysis of the system equilibrium points is shown in table 3. At this point, (0,0) is the system stability point. When the cost of information sharing is higher than benefits of information sharing, all members of the community will not share information.

| Equilibrium | trJ | det J | Stability |
|-------------|-----|-------|-----------|
| (0,0)       | -   | +     | ESS       |

Table 2. Values of $a_{11}$, $a_{12}$, $a_{21}$ and $a_{22}$ at the local equilibrium point

Table 3. Local stability analysis of system equilibrium point
(2) When \( a - p < c < b \), local stability analysis of the system equilibrium points is shown in Table 4.

At this point, \((0, 1)\) and \((1, 0)\) is the system stability point. When the cost of information sharing is lower than the benefits of information sharing, higher than the difference of the collaborative benefits of information sharers minus benefits of information monopolists, information sharing members in the community will always keep information sharing, and information monopolists will keep the information monopoly.

**Table 4. Local stability analysis of system equilibrium point**

| Equilibrium | trJ  | det J | Stability  |
|-------------|------|-------|------------|
| (0, 0)      | +    | +     | Instability point |
| (0, 1)      | -    | +     | ESS        |
| (1, 0)      | -    | +     | ESS        |
| (1, 1)      | +    | +     | Instability point |
| (G, Q)      | +    | 0     | Instability point |

(3) When \( b < c < a - p \), local stability analysis of the system equilibrium points is shown in Table 5.

At this point, \((1, 1)\) is the system stability point. When the cost of information sharing is lower than the difference of the collaborative benefits of information sharers minus benefits of information monopolists, eventually members of the community will share information.

**Table 5. Local stability analysis of system equilibrium point**

| Equilibrium | trJ  | det J | Stability  |
|-------------|------|-------|------------|
| (0, 0)      | +    | +     | Instability point |
| (1, 0)      | +    | +     | Instability point |
| (1, 1)      | -    | +     | ESS        |
| (G, Q)      | +    | 0     | Instability point |

3. **Online health community information sharing model based on individual differences**

3.1. **Benefit Matrix**

Information sharing in online health communities varies with the subject of information sharing. Each information sharer's information reserve, information expression ability and information absorbing ability are different, and the benefits and costs of information sharing are different. Considering the individual differences of information sharing among online health communities, information sharing game model in online health community based on individual differences is constructed. \( I \) is information levels of patients. \( K \) is the information absorptive capacity coefficients. \( F \) is information transfer capacity coefficients. \( R \) is the benefit of information sharing. \( C \) is the cost coefficient of information sharing. The benefit matrix of information sharing is shown in Table 6.

**Table 6. Information sharing strategy and benefit matrix of online health community**

| Patient B | Information sharing \((x)\) | Information monopoly \((1 - y)\) |
|-----------|-------------------------------|---------------------------------|
| Patient A | Information sharing \((x)\)   | Information sharing \((1 - y)\) |
|           | \( I_a R_a + I_b F_b K_a - I_a C_a \) | \( I_a R_a - I_a C_a \) |
|           | \( I_b R_b + I_b F_b K_b - I_b C_b \) | \( I_b F_b K_b \) |
|           | Information                   | \( I_a F_a K_a \) |
|           | \( I_b R_b - I_b C_b \)       | \( I_b F_b K_b \) |
|           | 0, 0                          | 0, 0                            |
The expected benefits of information sharing $U_{a}^{21}$, expected benefits of information monopoly $U_{a}^{22}$ and the average benefits $\overline{U_{a}^2}$ of patient A are respectively:

$$U_{a}^{21} = y(I_aR_a + I_bF_aK_a - I_aC_a) + (1 - y)(I_aR_a - I_aC_a)$$  \hspace{1cm} (12)

$$U_{a}^{22} = y*I_aF_aK_a$$  \hspace{1cm} (13)

$$\overline{U_{a}^2} = xU_{a}^{21} + (1 - x)U_{a}^{22}$$  \hspace{1cm} (14)

The expected benefits of information sharing $U_{b}^{21}$, expected benefits of and information monopoly $U_{b}^{22}$ and the average benefits $\overline{U_{b}^2}$ of patient B are respectively:

$$U_{b}^{21} = x(I_bR_b + I_aF_bK_b - I_bC_b) + (1 - x)(I_bR_b - I_bC_b)$$  \hspace{1cm} (15)

$$U_{b}^{22} = xI_aF_bK_b$$  \hspace{1cm} (16)

$$\overline{U_{b}^2} = yU_{b}^{21} + (1 - y)U_{b}^{22}$$  \hspace{1cm} (17)

According to the dynamic equation of Malthusian, the replication dynamic equation of information sharing of patient A and patient B is respectively:

$$\begin{align*}
  \frac{dx}{dt} &= x(U_{a}^{21} - \overline{U_{a}^2}) = x(1 - x)(U_{a}^{21} - U_{a}^{22}) = x(1 - x)(I_aR_a - I_aC_a) \\
  \frac{dy}{dt} &= y(U_{b}^{21} - \overline{U_{b}^2}) = y(1 - y)(U_{b}^{21} - U_{b}^{22}) = y(1 - y)(I_bR_b - I_bC_b)
\end{align*}$$

3.2. Equilibrium Points and Stability Analysis

The evolution stabilization strategy of differential equation system can be derived from the local stable analysis of the Jacobson matrix. The Jacobson matrix

$$J = \begin{pmatrix}
\partial x \\
\partial y \\
\partial x \\
\partial y
\end{pmatrix} = \begin{pmatrix}
a_{11} & a_{12} \\
a_{21} & a_{22}
\end{pmatrix} = \begin{pmatrix}
(1 - 2x)(I_aR_a - I_aC_a) & 0 \\
0 & (1 - 2y)(I_bR_b - I_bC_b)
\end{pmatrix}$$

(19)

The values of $a_{11}$, $a_{12}$, $a_{21}$ and $a_{22}$ of 4 local equilibrium points of the system are shown in table 7.

| Equilibrium | $a_{11}$ | $a_{12}$ | $a_{21}$ | $a_{22}$ |
|-------------|----------|----------|----------|----------|
| (0,0)       | $I_aR_a - I_aC_a$ | 0        | 0        | $I_bR_b - I_aC_b$ |
| (0,1)       | $I_aR_a - I_aC_a$ | 0        | 0        | $I_bC_a - I_aR_b$ |
| (1,0)       | $I_aC_a - I_aR_a$ | 0        | 0        | $I_bR_a - I_bC_b$ |
| (1,1)       | $I_aC_a - I_aR_a$ | 0        | 0        | $I_bC_b - I_aR_b$ |

When $I_aR_a < I_aC_a$, $I_bR_b < I_aC_b$, local stability analysis of the system equilibrium points is shown in table 8. When $I_aR_a < I_aC_a$, $I_bR_b > I_aC_b$, local stability analysis of the system equilibrium points is shown in table 9. When $I_aR_a > I_aC_a$, $I_bR_b < I_aC_b$, local stability analysis of system equilibrium points is shown in table 10. When $I_aR_a > I_aC_a$, $I_bR_b > I_aC_a$, local stability analysis of system equilibrium points is shown in table 11.
Table 8. Local stability analysis of the system equilibrium point

| Equilibrium | trJ | det J | Stability |
|-------------|-----|-------|-----------|
| (0,0)       | -   | +     | ESS       |
| (0,1)       | Indeterminate | - | Instability point |
| (1,0)       | Indeterminate | - | Instability point |
| (1,1)       | +   | +     | Instability point |

Table 9. Local stability analysis of the system equilibrium point

| Equilibrium | trJ | det J | Stability |
|-------------|-----|-------|-----------|
| (0,0)       | Indeterminate | - | Instability point |
| (0,1)       | -   | +     | ESS       |
| (1,0)       | +   | +     | Instability point |
| (1,1)       | Indeterminate | - | Instability point |

Table 10. Local stability analysis of the system equilibrium point

| Equilibrium | trJ | det J | Stability |
|-------------|-----|-------|-----------|
| (0,0)       | Indeterminate | - | Instability point |
| (0,1)       | +   | +     | ESS       |
| (1,0)       | -   | +     | Instability point |
| (1,1)       | Indeterminate | - | Instability point |

Table 11. Local stability analysis of the system equilibrium point

| Equilibrium | trJ | det J | stability |
|-------------|-----|-------|-----------|
| (0,0)       | +   | +     | Instability point |
| (0,1)       | Indeterminate | - | Instability point |
| (1,0)       | Indeterminate | - | Instability point |
| (1,1)       | -   | +     | ESS       |

Table 8-11 show that when the income coefficient is less than the risk coefficient, the community ends up with no information sharing; when the income coefficient is greater than the risk factor, the community patients will eventually share information. If income coefficient of some patients in community is less than the risk coefficient, income coefficient of other patients is greater than the risk coefficient, the former will not share information and the latter will always share information.

4. Conclusion

Compare the above two evolutionary game model of information sharing, found that the differences of patients in online health community, namely information conversion coefficient, absorption coefficient and patient information reserve, have no direct impact on the development of community information sharing, and the income coefficient and risk coefficient of information sharing determine the development of information sharing. Therefore, to protect patients' privacy, reduce the cost of information sharing, and give information sharing incentives, it is the key to enhance the value of online health community and promote the continuous information sharing of community patients.

References

[1] A. F. Payne, K. Storbacka, P. Frow, "Managing the co-creation of value", Journal of the Academy of Marketing Science, vol.36, 2008, pp. 83-96.
[2] S. L. Vargo, R.F. Lusch, "It's all B2B and beyond: toward a systems perspective of the market", Industrial Marketing Management, vol.40, 2011, pp.181-187.
[3] J. R. McColl-Kennedy, S.L. Vargo, T.S. Dagger, et al. "Health care customer value cocreation practice styles", Journal of Service Research, vol.15, 2012, pp.370-389.
[4] S. A.King, D.Moreggi, "Internet Self-Help and Support Groups"[M] Psychology and the Internet. 2007.

[5] J.Preece, "Etiquette online: from nice to necessary", Communications of the ACM,vol.47, 2004, pp. 56-61.

[6] U.Josefsson, "Coping with illness online: the case of patients' online communities "The Information Society: An International Journal, vol. 21, 2005, pp. 133-141.

[7] J.Zhao, K.Abrahamson, J. G.Anderson, S.Ha, R.Widdows, "Trust, empathy, social identity, and contribution of knowledge within patient online communities", Behaviour & Information Technology, vol. 32, 2013, pp.1041-1048.

[8] M.Etgar, "A descriptive model of the consumer co-production process", Journal of the Academy of Marketing Science, vol. 36, 2008, pp. 97-108.

[9] E. J.Madara, "The mutual-aid self-help online revolu-tion", Social Policy, vol. 27, 1997, pp.20-26.

[10] Chaohua Deng, Jiang Meng. Research on knowledge sharing behavior of online medical health community, National conference on computer simulation and information technology. 2015.