Analysis on the Cooperation Mechanism between CDC and Medical Community at County Level in China: From the Perspective of Evolutionary Game Theory

Chan Wang¹, Yimeng Zhang², Junli Wei³, Haiqiang Dai⁴*

¹Institute of Medical Information, Chinese Academy of Medical Sciences, Beijing, China
²The Second Affiliated Hospital of Nantong University, Nantong, Jiangsu Province, China
³Beijing Friendship Hospital of Capital Medical University, Beijing, China
⁴School of Social Development and Public Policy, Beijing Normal University, Beijing, China

#All authors contributed equally to this manuscript.

*Correspondence to: Haiqiang Dai, School of Social Development and Public Policy, Beijing Normal University, No. 19, Xinjiekouwai Street, Beijing, 100875, China; Email: daihaiqiang@sina.com

Abstract

Objective: Using evolutionary game theory to explore the conditions for in-depth cooperation between county-level Center for Disease Control and Prevention (CDC) and Medical Community, and to raise policy recommendations.

Methods: The basic assumptions of the evolutionary game model were set through the information collected from focus group interview and individual interview, then the basic model was established by constructing the payment matrix and the replicator dynamic equation. The condition of in-depth cooperation was deduced by stable equilibrium analysis.

Results: To improve cooperation effectiveness, the following conditions should be met: total income of CDC and Medical Community after the cooperation increased, additional benefit to CDC from the cooperation increased, effort level of the cooperation increased, psychological cost of CDC and Medical Community from the cooperation decreased. Thus the Medical Community and CDC were more inclined to cooperate and setup cooperation network.

Conclusion: To setup in-depth cooperation, it is suggested: 1) government administrative intervention to push forward the cooperation as the initial and external impetus; 2) unified or dual leadership to drive the prevention-and-treatment network as internal support; 3) in-depth resources sharing to foster organizational and structural interdependence as the basis of cooperation; 4) objective interdependence to push self-improvement of cooperation as continuous self-driven force.

Keywords: evolutionary game theory, CDC, medical community, prevention-and-treatment, cooperation mechanism

1 INTRODUCTION

Many factors combined together affect population’s health [1], such as lifestyle, genetics, social status, natural environment, and medical conditions, among which medical conditions often has a less impact [2], and other determinants, especially Social Determinants of Health (SDOH), play important roles in health promotion [3]. The latter can be intervened by prevention, and this is why prevention has been emphasized by the health department of most countries and by many scholars [4-7]. Moreover, it will greatly expand the intervention effectiveness to reduce the impact of health risk actors if
prevention and treatment can be organically integrated to form a whole-cycle service and comprehensive health intervention\cite{8,9}. Cooperation between the organizations responsible for health prevention or treatment will help to form a socioecological network of health intervention, thereby achieving positive result through synergistic effects\cite{10-13}. However, many countries including China are facing a common and practical problem when conducting prevention-and-treatment integrated primary care services\cite{14}: if without sufficient incentives, the healthcare institutions providing primary care appear to lack motivation in performing preventive functions. Large portion of cooperations between prevention and treatment only stay at the planning or policy-making stage, and concrete work is hard to be delivered and organizational and operational mechanisms between institutions are difficult to be established, and this is the focus of this paper.

In consideration of the vast population covered by primary care services at county level and the faster pace in medical reform at this level, this paper will confine its scope to healthcare behavior at the county level. In China, the main healthcare institutions involving in prevention and control at primary care level and their functions are: county hospital which provides treatment, county CDC which provides prevention, and township healthcare centers which provide both basic treatment and basic prevention services. Meanwhile, in order to raise clinical capacity and build up an integrated healthcare system, China is promoting Medical Community, a model to build an alliance with a leading county hospital and several township healthcare centers to provide diagnosis and treatment on common diseases\cite{15,16}. Under the Medical Community model, the entities will retain their administrative nature and management affiliation, but share human resources, funding and materials\cite{17}. This model is becoming the major efforts at county level in the overall healthcare reform.

As for basic prevention service, the healthcare centers are mainly working on the establishment of health files, health education, vaccination, management of the health of children, the pregnant and patients of major chronic diseases, management of severe mental disorders and tuberculosis, reporting of infectious diseases occurrence, prevention and treatment of endemic as well as monitoring major diseases factors\cite{18}. The CDCs usually focus on the public health service at population level which include controlling epidemic, endemic and parasites, monitoring health risks, screening high-risk population and conducting intervention, doing surveillance of public health emergencies and reporting, conducting laboratory testing, and conducting health education, etc. In consideration of the organizational relationships and administration levels (in China the county CDC and county Medical Community are parallel entities under the administration of county government) (Figure 1), this paper will choose county CDC and county Medical Community as the research objects and analyze the conditions for the effective cooperation between county Medical Community and county CDC and interpretate the pathway to build it.

![Figure 1. Illustration of Prevention and Treatment Network at Primary Care Level.](image)

**Figure 1. Illustration of Prevention and Treatment Network at Primary Care Level.**

### 2 LITERATURE REVIEW

#### 2.1 Treatment and Prevention Cooperation in Primary Care Settings

Prevention is an effective means for disease intervention, which has increasingly become a consensus\cite{19,20}. In counties where primary care is making up the backbone of the health care system, primary care institutions provide both preventive service and medical care, including the primary, secondary and tertiary prevention and basic treatment of chronic diseases such as diabetes, hypertension, renal disease, mental illness and AIDS. Serving as patients’ primary point of contact with the health care system and bearing the advantages of communicating easily with community, being multi-specified and cost-effective, primary care institutions have prominent advantages in targeting high-risk population, managing health disorders, screening for risky signals, conducting long term follow-up, providing continuous care, monitoring health outcomes, and conducting health education and counselling, all of which play fundamental roles in health promotion and disease prevention and treatment\cite{21-25}. Thus primary care institutions are very suitable for the integration of provision of prevention and treatment, therefore many chronic disease prevention programs position the primary care institutions as the leading implementer, such as The Berlin Declaration (Global)\cite{26}, The National Diabetes Prevention Program (USA)\cite{27}, Multi-sectoral Partnerships to Promote Healthy Living and Prevent Chronic Disease
and technology guidance to the healthcare centers of the leading hospital only provides management with Village Clinic, etc. Among all these, Medical Alliance that connects several county maternal and children health entities. At County Level in China, several modalities of cooperation between institutions can trigger internal motivation, cooperation mechanism at management, funding, and personnel level, etc. can trigger internal motivation, which is relatively strong, firm, deep and effective. Compared with ostensible cooperation, substantial organization’s capacities like many existing networks do. Compared with ostensible cooperation, substantial ones with structural interdependence and has cooperation mechanism at management, funding, and personnel level, etc. can trigger internal motivation, which is relatively strong, firm, deep and effective.

2.2 Cooperations Among Healthcare Institutions at County Level in China

To provide whole-cycle and comprehensive healthcare services and to address service needs at county level, several modalities of cooperation between healthcare institutions have been deployed, including County Maternal and Children Health Specialty Service Alliance that connects several county maternal and children health entities. Hospital Trusteeship with Village Clinic, etc. Among all these, Medical Community is the most officially acknowledged. Medical Community could be classified into two modes: the loose mode and the tight mode. In the loose mode, the leading hospital only provides management and technology guidance to the healthcare centers without financial and personnel exchange. In the tight mode, a closer alliance is formed that: close linkage of medical resources could be setup in the forms including deployment of healthcare personnel, salary distribution and information sharing, etc. and as a whole to form a cooperative network though with unchanged administrative affiliation and financial investment channels. Resources interdependence is key to organizational interdependence and the essence of resources sharing is resources internalization which helps to enhance innovation performance in the continuous process of exploration, transformation and development. Thus compared with the loose mode, the tight mode which involves the in-depth resources sharing of human resources and funding has shown significant advantages in terms of efficiency for patient referral, enhancement of the ability of physicians in healthcare centers, the development of healthcare center itself, and the raised satisfaction of residents in the local area. Therefore, the tight mode is becoming the leading Medical Community model in China, and this is the reason why this paper will focus on the tight mode Medical Community rather than the loose mode, and will provide reference for the establishment of sector cooperation mechanism between county Medical Community and county CDC (referred to as Medical Community and CDC afterwards).

2.3 Cooperation between Medical Community and CDC at County Level in China

In China, cooperation between Medical Community and CDC is promising. Firstly the Medical Community has human resources and technical advantages in treatment and management of chronic diseases, while CDC has strengths in detection and prevention of infectious diseases, health risk factor monitoring, and health education by leveraging its complete operational information system. Thus the foundation for cooperation is already in place. Secondly due to the prevailing treatment-oriented medical model, CDCs are facing a lot of difficulties in recent years such as government investment shortage, human resources run-off, and shrinking of working scope. The voices to cooperate and integrate with Medical Community to develop CDC itself are emerging from within CDCs. Thirdly, the public health function has been marginalized compared to medical service in Medical Community previously and with the increasing needs on integrated healthcare services, it will exert pressure on Medical Community to provide better public health services. Thus the cooperation with CDC should be welcome as it will reinforce the capacity of the Medical Community in this aspect.

In this regard some pilots are being explored to accumulate experience to bring CDC and tight-model...
Medical Community together and to establish cooperation mechanism to integrate management and resources. In Shanxi province, CDCs are incorporated into comprehensive county-level healthcare reform plans and the directors of CDC is concurrently appointed as the vice president of the local Medical Community so as to manage public health and clinical treatment as a whole. The healthcare center within the Medical Community is jointly managed by the Medical Community and CDC. Thus the Medical Community and the CDC share their organizational leadership, service standards and performance appraisal method (The Dual Leadership Model). By leveraging the rapid and efficient deployment of local medical and public health resources, the response has been significantly improved in dealing with COVID-19 epidemic. In Pingluo County of Ningxia Autonomous Region, the local CDC was incorporated into its Medical Community and adopts unified management requirements, including administration, personnel, funding, workscope, performance, and medical equipment management to form cooperation network as a tight mode Medical Community. These innovations have been acknowledged and encouraged by national healthcare authorities. Scholars and researchers also have positive attitudes towards this kind of cooperation in forming a tight network between CDC and Medical Community as it can effectively integrate prevention and treatment to improve the overall effectiveness of health intervention.

However, due to lack of internal motivation and incentive mechanisms, many geographical areas are taking a watch-and-see position and a large portion of the cooperation has not yet reached in-depth resources sharing in terms of leadership and financial resources. Many experts consider the conditions for successful cooperation need to be studied in terms of the trigger point of integration, clarifying of respective functions, unification of performance assessment, and clarifying of funding allocation.

3 METHODS

The research mainly used qualitative research method (focus groups and in-depth interviews) to collect information. Informed consent was obtained in advance for individual interview and all the info of institutional and individual participants are treated anonymously.

3.1 Counties for Research

Judgment sampling was used based on the different levels of cooperation status (well, moderate or not well) between Medical Community and CDC, and 6 provinces were enrolled into research based on previous evaluation by experts of National Health Commission. Among the six provinces, Shanxi and Ningxia were categorized as “well” as they had issued official notice for the cooperation network establishment. Shandong and Hebei were categorized as “moderate” as they had formulated workplans or set up Public Health Division in public hospitals. Guangxi and Hainan were categorized as not well” as they had not taken any concrete actions. The research team then used judgment sampling and convenience sampling to identify 21 counties for field investigation (Table 1).

3.2 Information Collection

Information collection included two stages:

Stage 1 was focus group interview. The interviewees were leaders of county-level authorities deeply involved in the cooperation establishment between Medical Community and CDC, including: County Governor/ Vice Governor in charge of healthcare, Director/ Deputy Director/Division Director of the county Health Bureau, Director/Deputy Director/technical staff of Medical Community and county CDC cooperation network, administrators of other county government departments relevant to healthcare reform such as Medical Security Bureau etc.

Stage 2 was in-depth face-to-face interviews with the principal grass-roots implementers. According to the semi-structured interview design, the interviews mainly focused on the background, progress, services allocation, attitude and reasons, advantages and disadvantages, challenges and problems of cooperation, as well as suggestions on how to improve. The field visits aimed to further understand the performance of the cooperation and confirm the information gathered from the field investigations. The research team also collected relevant materials during the field visits and interviews. All the materials were analyzed with the method of grounded theory.

3.3 Evolutionary Game Theory

Evolutionary game theory was used to establish an analytical framework and deduce the conditions for in-depth and effective cooperation. The basis of evolutionary game theory is the traditional game theory where players seek their optimal strategy to achieve an equilibrium, combined with the view of survival of the fittest in Darwinian evolution in situation of non-full rationality and non-perfect information. When applying the evolutionary game theory, it is necessary to set parameters and make some basic assumptions. In this research, these parameters and assumptions were based on the information acquired through the investigations. The investigations mainly focus on the cost and benefits derived from the cooperation and the findings were analyzed under the
game theory. The cost and benefits were then used to setup the payment matrix and evolutionary game model. The dynamic equilibrium point of cooperative/non-cooperative choice was then identified. The final strategic selection of cooperation was made based on the dynamic equilibrium point. Meanwhile, according to the dynamic equilibrium point, the specific conditions for the cooperation are verified.

4 RESULTS
4.1 Results of Qualitative Analysis

Based on the interviews, the following results are obtained:

(1) The anticipated effect of the in-depth cooperation between Medical Community and CDC is positive as it can incur cost reduction, improvement of health outcome and enhanced development of CDC. China has a big burden from chronic diseases which accounts for more than 70% of the overall disease burden and BMI (Basic Medical Insurance) has covered more than 95% of total population. With CDC carrying out the disease prevention function, the disease cycle and the patients’ number can be handled and loss from late-stage disease and complications can be greatly reduced, and the overall health care performance can be improved. “It is a good thing to have this kind of reform. The integrity of treatment and prevention has been proposed for so many years, and this is a good starting point. (if successful) Local residents can enjoy better disease prevention services, and the population health will be improved in the long run” (Deputy Director of County Health Bureau, S).

The short-term desire of the CDC to raise income. Due to the difference of funding sources, the income of Medical Community mainly comes from BMI funding, and a small part from government financial subsidies and patients’ out-of-pocket expenses, while CDC’s revenue comes mainly from financial disbursement and patients’ out-of-pocket expenses, while CDC’s revenue comes mainly from financial disbursement from the local government. Most CDCs surveyed had less financial investment and less staff than hospitals at parallel level, nearly all CDC respondents complained about their low-salary and currently are less-paid than hospital doctors. “I have a classmate. He is a clinical doctor. After graduation, he went to the county hospital. Although he is more tired, his salary is much higher than mine, and his salary belongs to the top level in our little county.” (Technical staff in county CDC, IIIP).

(2) The main motivation for in-depth cooperation are the followings:

Intentional push and arrangement from the government. The cooperation between county CDC and Medical Community is usually the government’s administrative deployment to fulfill the comprehensive objective to integrate healthcare system and to reform the disease control system. For example, the integration of prevention and treatment in Shanxi is relying on the government initiative to integrate healthcare institutions at county and township levels. In this process, a Dual Leadership Model that fully integrates prevention and treatment is setup. Another example is that the Ningxia Autonomous Region Government deploys the exercise from the perspective of comprehensive county-level reform and initiates the integration of all the healthcare institutions including the CDC, the Maternal and Children Health Center and other clinical institutions. “At present the foundation of cooperation is weak, it needs the government to take actions first by issuing official document to achieve a nominal cooperation.” (Deputy Director of County Health Bureau, S).

The short-term desire of the CDC to raise income. Due to the difference of funding sources, the income of Medical Community mainly comes from BMI funding, and a small part from government financial subsidies and patients’ out-of-pocket expenses, while CDC’s revenue comes mainly from financial disbursement from the local government. Most CDCs surveyed had less financial investment and less staff than hospitals at parallel level, nearly all CDC respondents complained about their low-salary and currently are less-paid than hospital doctors. “I have a classmate. He is a clinical doctor. After graduation, he went to the county hospital. Although he is more tired, his salary is much higher than mine, and his salary belongs to the top level in our little county.” (Technical staff in county CDC, IIIP). “Now the county hospital and township hospitals (healthcare centers) have formed an alliance. The wages of staff in township hospitals have also climbed up. Their wages were originally higher than
ours, and now much higher…” (Technical staff in County CDC, IIN). Most of them are optimistic about the salary raise after in-depth cooperation with the Medical Community. “The design of the reform is good, so that the income of our unit will enter a healthy growth, and we will not rely so much on the financial allocation of the local government, and both individual and unit will develop better than before” (Deputy Director of County CDC, II).

The long-term desire of the county CDC to develop and improve overall status. To balance the prevention and treatment will raise the feasibility for CDC on laboratory construction, work-scope expansion and capacity building as well as to acquire more funding. This brings hope to overcome the problem of under-development due to lack of funding and encouragement. “In the past years, CDC has experienced under-development and personnel run-off as prevention is not the focus of healthcare service thus not enough resources is allocated. It is anticipated such kind of situation could be improved by the reform to combine prevention and treatment.” (Director of County CDC, VR).

(3) The main challenges for the in-depth cooperation are:

Leadership and coordination with other government sectors, including ability to allocate resources, coordinate with other government sectors to get support. “After establishing a unified cooperation network, the medical insurance fund can only reimburse medical services according to the health care insurance law, which is a new problem. (Director of County Medical Insurance Bureau, VIU). Despite merging nominally, some low-income sort of health education campaigns and high-risk HIV/AIDS prevention and treatment works still lack the strong support and cooperation from the Medical Community. Our II vaccination were outraged for a time on the initial stage of the network established” (Director of County CDC, IH).

The psychological gap of CDC. As for CDC, the main concerns include the sense of stability is reduced with the change of staff identity and the concerns on breaking the vertical management linkage (that is constituted by different levels of CDCs). “The weight of CDC’s status may be reduced (after in-depth cooperation with Medical Community), thus undermining the policy goal that strengthens CDCs system and keeps the CDCs’ network intact” (Director of County CDC, IIL). According to some CDC leadership, if the CDC setup in-depth cooperation with Medical Community and were to be incorporated into, the CDC staff would have a psychological letdown as CDC belongs to Class I public institutions and Medical Community belongs to Class II public institutions. “We used to have the government’s job security in our hands, but now we feel like (the government) is pushing us away and leaving us alone” (Technical staff of County CDC, IIN).

The concerns from the Medical Community to lose resources. Compared with CDC, the Medical Community has advantages in funding, personnel and projects. Some staff show concerns to the potential loss of such resources after the sharing with CDC. “The CDC has a vaccination clinic and mainly makes profit from the YH Vaccination Point which can feed 60 people from its vaccination work. But with the abolishment of the changing right of the CDC, all the medical institutions are unwilling to integrate with the clinic except the YH Point.” (Director of County CDC, ID).

\[(4\gamma(\Phi+\Pi)'+ec><\Phi+\Pi+\Pi+\Pi+\Pi)\] The depth of cooperation determines the effectiveness of the cooperation. Among the investigated provinces, Ningxia Autonomous Region has carried out in-depth resources sharing in 5 aspects including personnel, capital, business, information and equipment, which is equivalent to incorporate CDC into the management of Medical Community on the basis of maintaining its original unit nature. In Shanxi Province, the director of CDC also serves as the party committee member and vice president of Medical Community, which strengthens the sharing of leadership resources. Other provinces have weaker structural interdependence and resources sharing. “To promote a unity game, the unified deployment of protective materials and personnel solved the problem of increment (under the condition of material shortage) during the (COVID-19) epidemic” (Director of Primary Health Office in County Health Bureau, VS). In the cooperation network where the medical treatment and prevention are being preliminarily integrated, as the performance and financial distribution mechanism had not been unified, the phenomena that poor welfare package of staff and serious staff run-off in CDCs were still difficult to change. The cooperation is ostensible as the original profit distribution, incentive mechanism has not been innovatively established between CDC and other medical entities. Thus, the cooperation network has not formed perfect integrated mechanism to perform treatment and prevention with respective interests and priorities. “CDC staff hope to increase wages; hospital staff do not want to reduce their treatment(mainly an income cut). Therefore, the deadlock will not be broken in a short time without new investment and allocating mechanism, which will certainly affect the effect of reform” (Director of County Health Committee, IIP).

4.2 Results from the Evolutionary Game Theory and Its Process

4.2.1 Parameter and Hypothesis

Based on the result from the qualitative interviews
Coordination cost of Medical Community with $P_1 - \theta$-Based on interview result

Additional benefit of CDC after cooperation, the exptect return under different Coordination cost of county CDC with unilateral $Ph+Pc$ Artificially defined

Based on interview result: the short-term desire of the county CDC to develop and improve overall status

Based on interview result: Medical Community’s concerns to lose resources Based on the literature [49,51,52]

Table 2. Parameters of the Equation and Their Sources

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Notion</th>
<th>Basis of setup</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_h$</td>
<td>Income of Medical Community before cooperation</td>
<td>Artifcially defined</td>
</tr>
<tr>
<td>$P_c$</td>
<td>Income of CDC before cooperation</td>
<td></td>
</tr>
<tr>
<td>$\gamma \theta (P_s+P_c)'$</td>
<td>Income of Medical Community after cooperation</td>
<td>Based on interview result: the short-term desire of the CDC is to raise income</td>
</tr>
<tr>
<td>$\gamma (1-\theta)(P_s+P_c)'$</td>
<td>Income of county CDC after cooperation</td>
<td>Based on interview result: the long-term desire of the county CDC to develop and improve overall status</td>
</tr>
<tr>
<td>$e_c$</td>
<td>Additional benefit of CDC after cooperation</td>
<td>Based on interview result:</td>
</tr>
<tr>
<td>$C_p$</td>
<td>Psychological cost of CDC after cooperation</td>
<td>Based on interview result: CDC’s psychological gap</td>
</tr>
<tr>
<td>$C_h$</td>
<td>Psychological cost of Medical Community after cooperation</td>
<td>Based on interview result:</td>
</tr>
<tr>
<td>$C_{hc}$</td>
<td>Coordination cost of county CDC with unilateral cooperation</td>
<td>Based on the literature [49,51,52]</td>
</tr>
<tr>
<td>$C_{inh}$</td>
<td>Coordination cost of Medical Community with unilateral cooperation</td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Exptect Return under Different Situations

<table>
<thead>
<tr>
<th>Medical Community</th>
<th>CDC</th>
<th>Cooperation</th>
<th>Non-cooperation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperation</td>
<td>$\gamma \theta (P_s+P_c)' - C_{nh}$</td>
<td>$P_s - C_{nh}, P_c$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\gamma (1-\theta)(P_s+P_c)' + e_c - C_c$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-cooperation</td>
<td>$P_{nh}, P_{c} - C_{nc}$</td>
<td>$P_{nh}, P_{c}$</td>
<td></td>
</tr>
</tbody>
</table>

that in-depth cooperation between CDC and Medical Community is more effective, we define the cooperation in the Theory as the in-depth collaboration involving sharing of finance, personnel and leadership. Meanwhile, we setup the parameter of the evolutionary game theory based on the findings from the qualitative interviews.

4.2.2 Non-Cooperation

Before the in-depth cooperation between CDC and Medical Community, it is assumed that the income of Medical Community is $Ph$ and that of CDC is $Pc$.

4.2.3 In-depth Cooperation between CDC and Medical Community to Form a Network

If in-depth cooperation is setup towards the expected results, the overall revenue of Medical Community and CDC will be $(P_s+P_c)'$. Then $(P_s+P_c)'$ will be allocated to Medical Community and CDC as a whole according to their cost and contribution in the network. Assume Medical Community will get $\theta (P_s+P_c)'$, and CDC will get $(1-\theta)(P_s+P_c)'$. According to the general analysis of the interviews, there is an additional impediment unrelated to the revenue generated by CDC and Medical Community, that could be attributed to a psychological cost as $C_c$ and $C_h$ of CDC and Medical Community. Assigning efforts level of cooperation to $\gamma(\gamma \leq 1)$. Under ideal conditions, a linear relationship can be assumed between $\gamma$ and cooperation effect, that is, if the total revenue is $\gamma(Ph+Pc)'$; that of Medical Community and CDC will be $\gamma(P_s+P_c)'$ and $\gamma (1-\theta)(P_s+P_c)'$ respectively. The research team found that along with the increasing of cost-benefit in health intervention after in-depth cooperation, this will eventually lead to a concentration of health care resources towards prevention work [70], an extra benefit of CDC will generate as etc.

When the total benefit of Medical Community becomes more, the total cost is less than that in non-cooperation or unilateral-dominant cooperation, and so are those of CDC, in-depth cooperation between the two sides happens.

4.2.4 Unilateral - Dominant Cooperation

If Medical Community or CDC choose unilateral-dominant cooperation, it means that the cooperation has not been achieved. Both sides’ revenue remain unchanged compared with non-cooperation model, and the side of unilateral-dominant cooperation will spend a coordination cost as $C_{nh}$ or $C_{nc}$ [49,51,52] (Table 2).

4.3 Model

In Table 3, the exptect return under different situations were shown.

4.3.1 Replicator Dynamic Equation

Applying replicator dynamic equation to stimulate the repeated comparison and learning process of the insiders in a multi-round game is the most common-sensed and widely-used stimulation method. Individuals in the group choose the strategy of the next round of the game by comparing their own utility with the average utility of the whole group.

Assuming $x(0 \leq x \leq 1)$ is the proportion among the Medical Community to choose cooperation while $1-x$ is the proportion choose not to cooperate. The same method is assigned to CDCs as $Y (0 \leq y \leq 1)$ and $1-y$.
At this point, in the case of cooperation or non-cooperation, the expected utility and the average utility of the Medical Community are:

\[ u_{1h} = y[y\theta(P_h + P_c') - C_h] + (1 - y)(P_h - C_{nh}) \]
\[ u_{2h} = yP_h + (1 - y)P_c \]
\[ \bar{u}_h = xu_{1h} + (1 - x)u_{2h} \]

At this point, in the case of cooperation or non-cooperation, the expected utility and the average utility of the CDC are:

\[ u_{1c} = y[y(1 - \theta)(P_h + P_c') + e_c - C_c] + (1 - x)(P_c - C_{nc}) \]
\[ u_{2c} = xP_c + (1 - x)P_c \]
\[ \bar{u}_c = yu_{1c} + (1 - y)u_{2c} \]

The replicator dynamic equation of Medical Community is

\[ F(x) = \frac{dx}{dt} = x(u_{1h} - \bar{u}_h) = x(1 - x)[y\theta(P_h + P_c') - (1 - y)C_{nh} - y(C_h + P_h)] \]

The replicator dynamic equation of CDC is

\[ F(y) = \frac{dy}{dt} = y(u_{1c} - \bar{u}_c) = y(1 - y)[y(1 - \theta)(P_h + P_c') - (1 - x)C_{nc} - x(C_c + P_c - e_c)] \]

### 4.4 Steady-state and Stability

A two-dimensional dynamic system is obtained through the above two simultaneous equation:

\[ \frac{dx}{dt} = x(1 - x)[y\theta(P_h + P_c') - (1 - y)C_{nh} - y(C_h + P_h)] \]
\[ \frac{dy}{dt} = y(1 - y)[y(1 - \theta)(P_h + P_c') - (1 - x)C_{nc} - x(C_c + P_c - e_c)] \]

And the equilibrium points of the equilibrium game between Medical Community and CDC are (0,0), (1,1), (0,1), (1,0), and

\[ (1 - \theta)(P_h + P_c') + e_c + C_{nc} - C_c - P_c - \theta(\theta(P_h + P_c') + C_{nc} - C_h - P_h) \]

The Jacobian matrix is:

\[ J = \begin{bmatrix} \frac{\partial x}{\partial x} & \frac{\partial x}{\partial y} \\ \frac{\partial y}{\partial x} & \frac{\partial y}{\partial y} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \]

Then the following equations are obtained:

\[ a_{11} = (1 - 2x)[y\theta(P_h + P_c') - (1 - y)C_{nh} - y(C_h + P_h)] \]
\[ a_{12} = x(1 - x)[y\theta(P_h + P_c') - C_{nh} - C_h - P_h] \]
\[ a_{21} = y(1 - y)[y(1 - \theta)(P_h + P_c') + e_c + C_{nc} - C_c - P_c] \]
\[ a_{22} = (1 - 2y)[y(1 - \theta)(P_h + P_c') - (1 - x)C_{nc} - x(C_c + P_c - e_c)] \]

If (1) \( a_{12} + a_{21} < 0 \) (matrix trace requirements, the value as trJ), (2) \( \frac{a_{11}}{a_{21}} = \frac{a_{12}}{a_{22}} = a_{11}a_{22} - a_{12}a_{21} > 0 \) (Jacobian determinant requirements, the value as detJ), the equilibrium point of the replication dynamic equation is (gradual) locally stable, which is the evolutionary stability strategy (ESS).

After bringing (0,0) (1,1) (0,1) (1,0), and

\[ \gamma(1 - \theta)(P_h + P_c') + e_c + C_{nc} - C_c - P_c - \theta(\theta(P_h + P_c') + C_{nc} - C_h - P_h) \]

into (1) and (2), it can be found that the condition of (0,0) and (1,1) when \( y(P_h + P_c') + e_c > P_h + P_c + C_c - C_s \) are ESS.

There are two situations:

**Situation I:** when \( y(P_h + P_c') + e_c < P_h + P_c + C_c - C_s \) the system is convergent to (0,0) which means both sides tend not to cooperate (Figure 2A).

**Situation II:** when \( y(P_h + P_c') + e_c > P_h + P_c + C_c - C_s \) the system is convergent either (0,0) or (1,1) which means both sides tend not to cooperate or cooperate (Figure 2B), which path the system eventually tends to adopt and stabilizes depends on the initial state of Medical Community and CDC, which is the size of the segmentation area of S_{AMCO}.

To achieve in-depth cooperation between CDC and Medical Community, situation II would be the focus to continue the analysis. When \( S_{AMCO} < S_{AMCB} \), the probability that the system converges to (0,0) is more than that converges to (1,1), that is, CDC and the Medical Community are less likely to cooperate with each other. When \( S_{AMCO} > S_{AMCB} \), the probability that the system converges to (0,0) is less than that converges to (1,1), that is, CDC and the medical community...
are more likely to cooperate with each other. Solving
\[ S_{MCG} = 1 - \frac{1}{2} \left( \frac{c_{NC}}{\gamma(P_{h}+P_{c})^3+c_{NC}+e_{C}-c_{h}\gamma(P_{h}+P_{c})^3+c_{NC}+e_{C}-c_{h}} - \frac{c_{h}}{\gamma(P_{h}+P_{c})^3+c_{NC}+e_{C}-c_{h}} \right), \]

it can be found that the evolution path of the system is related to
\[ \gamma(P_{h}+P_{c})^3+c_{NC}+e_{C}-c_{h}\gamma(P_{h}+P_{c})^3+c_{NC}+e_{C}-c_{h} \]
the smaller \( C_{NC} \) and \( P_{h} \), \( P_{c} \) (\( C_{h}+C_{c} \)) are, the larger \( \gamma \), \( (P_{h}+P_{c}) \) are, the more players including both CDCs and the medical communities would like to choose to cooperate, until all the players choose to cooperate, which is consistent with the condition of situation II \( \gamma(P_{h}+P_{c})^3+c_{NC}+e_{C} > P_{h}+P_{c}+C_{h}+C_{c} \).

Consequently we will conduct in-depth analysis on \( (C_{h}+C_{c}), (P_{h}+P_{c}), e, \gamma \) from 4 perspectives including intervention from the government, leadership, resources interdependence and objective interdependence.

### 5 DISCUSSION

In China, the goal of integration of treatment and prevention at county level needs to be achieved jointly by CDC and Medical Community to enhance interdependence. Such interdependence will increase the uncertainty and unpredictability of an organization, so it requires cooperation through coordination and the establishment of interdependent structures which involves key elements of government intervention, leadership, resources interdependence and objective interdependence\(^ {71-73} \). When fulfilling the roles that these elements paly, we will further discuss the parameters derived from the evolutionary game theory and make clear their relationship with the elements.

What’s more, though both CDC and Medical Community are public institution, the difference is that CDC is Class I public institution and Medical Community is Class II and this will bring difference or conflicts in terms of the organization goals and management mechanism etc. This should also be taken into account.

#### 5.1 Intervention from the Government

In China, the integration of prevention and treatment is advocated and implemented on the call from the government, thus administrative intervention is important to push forward the cooperation. On the one hand, the government needs to bear long-term views and a broad concept of health notion and is willing to push the integration of treatment and prevention and deliver them through administrative tools such as strategic plannings and policies. In the provinces surveyed, majority have developed detailed plannings and policies. Ningxia and Shanxi even incorporated the integration of prevention and treatment into relevant laws and regulations. The concrete procedures and implementors as well as the time framework were also made clear. Fei County in Shandong Province adopted the model that Director of the county Health Bureau should take position as Party Secretary in the cooperation networks, which is also adopted in Ningxia Autonomous Region. These methods are quite effective in the Chinese public sectors with bureaucracy characteristic and this forms the momentum to initiate the cooperation. On the other hand, the intervention to make the overall environment to be suitable for the integration is important to serve as security from macro level. The environment mainly involves corresponding reform at institutional level to balance the asymmetrical relationship between CDC and Medical Community which influences \( (C_{h}+C_{c}) \) in the equations derived from evolutionary game theory. CDC is in a weak position when cooperating with Medical Community because it lacks vitality with the nature of ClassI public institution, the closure of legitimacy to charge on social service after 2017\(^ {24} \), and the nature that prevention efforts need a long period to show effect\(^ {70} \), all lead to its risk to be marginalized by the Medical Community in the cooperation and this has happened in many provinces. To address this, Ningxia Autonomous Region applied to CDC the same principle of Maintain Class I nature but Manage as Class II entity which was originally applied to healthcare centers, and gave CDC more flexibility in funding use and CDC could find legitimacy to share cash encouragement with Medical Community. Meanwhile like some provinces, opening up CDCs’ social services reasonably and seeking the support of medical insurance can also improve CDCs’ income and stimulate their staff. Last but not the least, full government investment is still the basic guarantee for CDCs’ operation and development. All the measures above help to fulfill the development of CDC and raise their weight and voice in the cooperation network and lower the concerns of the Medical Community to lose resources due to cooperation.

#### 5.2 Leadership

If intervention from the government is the external force to push integration and cooperation, then leadership is the force embedded in the network. A leader is the controller and allocator of the resources in an organization, and also the decision maker in the innovation and development of an organization, which influences \( \gamma \) and \( (P_{h}+P_{c}) \) in the equations. With the expansion of the understanding of leadership from individual level to organizational level, leadership based on the influence of network and social interaction plays an increasingly prominent role, and the concept of innovative and cooperative leadership is emphasized\(^ {70} \). It is important to empower the director of the cooperation network who is in charge of prevention or the integration of prevention and treatment, and this will improve the effect of integration significantly. The intention of Ningxia Autonomous Region to incorporate CDC into Medical Community
is to establish unified leadership to consolidate prevention and treatment. If unified leadership cannot be strengthened, good cooperative performance can also be achieved through the dual leadership which is cooperation between leaders of both sides. The dual leadership of prevention and treatment can balance prevention and treatment or even give more attention to prevention effectively. The practice of Shanxi Province that the Director of CDC took charge of the cooperation network as its Vice Party Secretary was a good example. Either of the unified leadership and dual leadership will achieve the same good effect. On the one hand it helps to overcome the info dissymmetry between prevention and treatment, and encourage the professional people to do the professional things to make the right decisions. For example, in Ningxia and Shanxi, both emphasized more on CDCs’ function and work than before, and their infrastructure in almost all the immunization and vaccination centers had been significantly improved through innovative development strategy and the cooperation with Medical Community. On the other hand, it helps to resolve the conflicts between prevention and treatment timely and effectively by seeking a manner of dynamic balance management[77]. “This kind of leadership framework adopted by us could make it easier to handle conflicts as the communication is quite smooth and convenient. Under this circumstance, we can easily build up norms that could be acknowledged by all to align our behaviors and mitigate impact of conflicts and even avoid them.” (Director of County Medical Community, IF)

5.3 Resources Interdependence

The cooperation between Medical Community and CDC is more of a vertical cooperation which is based on the distribution of complementary resources and function along the medical service chain. It will have an impact on the partners’ value and incur risk due to the exchange. As this kind of cooperation is more difficult to operate than horizontal cooperation in which same resources and functions are shared, it is necessary to increase the inputs for the integration at the starting or ending stage of the industrial chain[78]. Meanwhile this brings opportunity for CDC and Medical Community to share resources. On the one hand the integration involving the aggregation and allocation of resources will help CDC and Medical Community to share the common interests and form the force to drive the cooperation from institutional level[79], which is linked to cooperation performance as \((P_i + P_j)^2\) of the equation. In Yanchi County and Pingluo County of Ningxia Autonomous Region, CDC personnel who took part in the work of chronic disease prevention and treatment would get rewards from the basic public health project under the same performance appraisal indicators with Medical Community. Though this kind of benefit distribution is not too much, it played a very important role in rationalizing the cooperation mechanism and establishing a cooperative orientation for both sides, which greatly raised the motivation to and satisfaction with the cooperation. “Getting involved in the family doctor affairs could give us more performance and most of us are willing to join” (Director of County CDC, VT). On the other hand, vertical cooperation involves the sharing of complementation resources which helps to raise the performance level through co-efforts[72], which is linked to cooperation performance as \(y\) of the equation. For example, in the management of chronic diseases, professional public health physicians from CDC participate in the family doctor team from Medical Community in the whole course of service in many provinces. Fox example chronic disease management centers in Ningxia Autonomous Region have been established with technical staff from both healthcare centers and CDC to prevent chronic diseases, such as hypertension, diabetes, brucellosis and tuberculosis. Physicians from the healthcare centers take charge of locating and follow-up of chronic disease patients, while public health physicians are responsible for the quality control and assessment of disease information collection. “Our control of chronic diseases is quite good and the management indicators are above the national average and this is also acknowledged by the local residents” (Director of County Medical Community, VS). In terms of infectious diseases prevention, the epidemic database in hospitals is needed to support situation assessment by CDC. In-depth cooperation in Ningxia Autonomous Region and Shanxi Province had facilitated efficient resources mobilization during COVID-19 prevention and treatment, helping to respond promptly and mobilize for such public health emergency. “In this year no large-scale epidemic occurred in our region and several incipient events were terminated due to our quick response and this was praised by the provincial authorities” (Director of Disease Control Office in county Health Bureau, IC).

5.4 Objective Interdependence

Objective interdependence means the alignment of organizational objective of CDC and Medical Community and cooperation objective and both sides well understand and acknowledge the objectives. Compared with resources interdependence, it is the internal driving force to push cooperation and could help to reduce the interventions from external environment and then achieve the high-effort and continuous self-driven status[80,81], which is linked to cooperation performance as \(y\) of the equation. At the same time, this high effort behavior helps to promote the further deepening of structural and organizational interdependence, and has a significant positive impact on the improvement of cooperation performance[82]. At present, the integration of prevention and treatment in China is deeply compromised by the traditional concept
of treatment-oriented healthcare service. Since from the short-term perspective, the benefit from providing treatment is obvious, the more cases treated, the more profits hospital will make. This inevitably leads to that Medical Community is inclined to invest a lot of resources in treatment and pay little attention to prevention thus making prevention work marginalized. Although the prevention and treatment integration in Ningxia and other places can develop to resources-sharing level and produce certain performance, when CDC or Medical Community meets conflicts due to work alienation, the cooperation will often slow down or even get broken, and the interaction will transform from positive to negative, and high effort is likely to become low, thus affecting the stability and effectiveness of the cooperation network. "Because of the dispute on who leads the project, the two sides (CDC and Medical Community) have a conflict and either side deems itself reasonable, so such a conflict is not easy to solve, and will seriously affect everyone’s enthusiasm... In my opinion, this is actually a matter of perception, and it is easy to solve the conflict when we unify our thoughts, and we all need to find common interests. In addition, it is necessary to rely on education and guidance, but without establishing a common perception, education alone is not effective" (Director of Medical Reform Office in County Health Bureau, VS). It is necessary to establish the objective interdependence so that both sides can truly agree on the concept of prevention-oriented and the importance of integration of prevention and treatment. To establish the objective interdependence, the opportunity maybe lies with the reform of medical insurance payment. The government is adjusting the Fee-for-Service model to DRG and global budget. This requires the Medical Community to pay more attention to primary and secondary prevention which is more cost-effective, and integration of prevention and treatment and integration of services from CDC and healthcare centers will be helpful in this process and will help to reshape medical concepts and behavior.

6 CONCLUSION

In consideration of current situation of CDC and Medical Community, the in-depth cooperation is a very efficient way to realize the integration of treatment and prevention, which mainly involves intervention from the government, leadership, resources interdependence and objective interdependence. These are crucial for implementing cash incentives between CDC and Medical Community, realizing high effort in cooperation, and building equal relationship in cooperation to make the cooperation equation valid. These require policy intervention, institutional guidance, and ultimately the government’s efforts to implement them into specific decisions. At the same time, the reform at county-level on comprehensive health system, is also very important to realize the reform to integrate prevention and treatment. It is a good opportunity to achieve the goal of integrated prevention and treatment by promoting the in-depth cooperation between CDC and Medical Community.

As this is a research on the conditions of cooperation, the samples are chosen only based on the progress of in-depth cooperation. However, different in-depth cooperation modes are formed based on different cooperation mechanism in different regions after a period of exploration, thus what kind of mode is suitable for what kind of condition in the region and whether it can be implemented in similar regions is still to be explored. Apart from the interference due to different exogenous factors, whether cooperation performances produced by different modes of in-depth cooperation have differences or which one is better, these questions still need to be further discussed, which will be the next step of further studies in the future.

Acknowledgements

This research is supported by National Social Science Fund Major Special Project (No. 18VZL011) and the Key Research Projects of the National Health Commission.

Conflicts of Interest

The authors declared that there is no conflict of interest.

Author Contribution

Wang C and Zhang Y was responsible for the investigation and writing of the original draft. Wei J contributed to the investigation. Dai H provided supervision and project administration, and contributed to the writing, review, and editing processes. All authors have made substantial contributions to the manuscript and have approved the final version for submission.

Abbreviation List

CDC, Center for Disease Control and Prevention

References

[7] World Bank, People, Pathogens and our Planet: The Economics of...
Ilyés I, Jancsó Z, Simay A. Trends and current questions of
Hobbs FR, Erhardt L. Acceptance of guideline recommendations
Kumanyika S, Brownson RC. Handbook of Obesity Prevention A
Lang T, Rayner G. Overcoming policy cacophony on obesity: an
transform health care important?.
Kumanyika S, Brownson RC. Handbook of Obesity Prevention A
Kumanyika S, Brownson RC. Handbook of Obesity Prevention A
Kumanyika S, Brownson RC. Handbook of Obesity Prevention A
Kumanyika S, Brownson RC. Handbook of Obesity Prevention A
Kumanyika S, Brownson RC. Handbook of Obesity Prevention A
Kumanyika S, Brownson RC. Handbook of Obesity Prevention A
Kumanyika S, Brownson RC. Handbook of Obesity Prevention A
Kumanyika S, Brownson RC. Handbook of Obesity Prevention A
Among the 21 counties (cities/districts), Gaoping, Dingzhou, and Pingluo County Party Committee & government. Implementation Plan of the Pilot Work on Comprehensive Medical Reform in Pingluo County. 2018


Pinghuo County Party Committee & government. Implementation Plan of the Pilot Work on Comprehensive Medical Reform in Pinghuo County. 2018


Among the 21 counties (cities/districts), Gaoping, Dingzhou, Qionghai are county-level cities. Cheng, Xiaodain, Changan, Xinhu, Xixia are county-level districts (usually in urban area). Others are counties (usually in rural area).


Sumaila UR, Apaloo J. A selected survey of traditional and evolutionary game theory. Chr. Michelsen Institute, 2002. Available at: [Web]


Based on the principle of anonymity, the interviewees are coded. Deputy Director of County Health Bureau is the title of the interviewees. I represents province and I is the county.

He W. Health insurance should support the purchase of prevention services. Beijing Daily (Special Report on the NPC and CPPCC in 2020), 2020.


Chen Z. China’s multi-sectoral CDC system is exemplary. 21st Century Business, 2020.


Gupta AK, Smith KG, Shalley CE. The interplay between exploration and exploitation. Aca Mange J, 2006; 49: 693-706.[DOI]


Johnson DW, Johnson RT, Ortiz AE et al. The impact of positive goal and resource interdependence on achievement, interaction, and attitudes. J Gen Psychol, 1991; 118 341-347.[DOI]