An Evolutionary Game Analysis on the Establishment of a Stable Anti-Poverty Mechanism

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Abstract: 2020 is the decisive year of poverty alleviation. China has made remarkable achievements in poverty alleviation, but how to prevent the phenomenon that poor households return to poverty after poverty alleviation is a very urgent research topic at this stage. Under the theory of evolutionary game, this paper establishes a game model between the governments and the families out of poverty, and solves the evolutionary stability strategy. The results show that: without constraints, the outcome of the evolutionary game will evolve in two different directions. One is the rational state we desire, that is, governments are incentive and poor households are positive, the other is an unreasonable state, that is, the governments are non-incentive and poor households are negative. Finally, suitable suggestions are put forward to make the game evolve to a reasonable result by analyzing the relevant parameters.

Keywords: poverty alleviation, poverty return, evolutionary game, replicator dynamic equation, evolutionary stability strategy (ESS).

INTRODUCTION

Since General Secretary Xi put forward the concept of "targeted measures in poverty alleviation" in 2013, China has made significant progress in tackling poverty. At present, it has entered a stage of decisive victory from poverty alleviation. While achieving comprehensive poverty alleviation, the phenomenon of poverty return has occurred from time to time. Therefore, how to establish a long-term mechanism for stabilizing poverty alleviation is the focus of current poverty alleviation work. At the same time, it can also provide decisive reference for china to solve the problem of return to poverty after poverty alleviation, and to build a moderately prosperous society in all respects.

At present, many domestic and foreign scholars have studied the problem: The 2019 Nobel Prize in Economics was awarded to three scientists, Abigail Banerjee, Esther Dufourjoy and Michael Kramer, for their contributions to the use of experimental methods in global poverty alleviation. Zhou Di et al. innovatively proposed the theory of vulnerability to poverty, explained the internal logic of the phenomenon of returning to poverty and further demonstrated how to reduce and prevent return to poverty after poverty alleviation, and finally concluded that asset endowment can prevent the phenomenon of returning to poverty.[3] By constructing a three-party evolutionary game model of the government, enterprises and poor households, Huang Haitang proposed that poverty alleviation funds allocated by the government, the income obtained by the enterprise's poverty alleviation, and the remuneration received by the poor households from the poverty alleviation are important factors that affect the participants' strategic choices.[4] Yuan Fang et al. studied the relationship between farmers’ entrepreneurship and poverty alleviation, and concluded that entrepreneurship can significantly reduce the probability of return to poverty after poverty alleviation[4] ; Wang Jiamei et al. analyzed the 221 research papers on poverty alleviation included in CNKI from 1989 to 2019, and intuitively showed the evolution trend and development direction of poverty alleviation in the past 30 years of china[5]; The research group of the National Development Institute of Wuhan University on poverty alleviation believes that the market mechanism should play a greater role and reduce the overreliance of poverty reduction industry development on poverty reduction policies[6]; In the context of Supply-side Structural Reforms, Qi Taotao discussed governments cooperation behavior in poverty alleviation under different circumstances, and concluded that reducing costs and risks would promote cooperation between the two parties[7]; Wu Xiongzhou concluded that government subsidies can change the strategy choices of poor households through research on...
competitive and synergistic behaviors of poor households, and there is an optimal threshold for subsidies\(^8\); Wang Zhihe et al. proposed to guide and encourage people to participate in the work on accurate identification of poor objects, increase social supervision, and avoid corruption\(^9\); Yin He et al. analyzed the evolutionary game model between financial institutions and poor households, and proposed that increasing the awards and punishment can solve the problem of poor households’ untrustworthiness\(^10\); Under the reward and punishment mechanism, Fu Jiangyue studied the evolutionary game between enterprises and poor households and proposed that a scientific supervision mechanism can promote the implementation of poverty alleviation projects\(^11\); Sun Quan proposed that the social credit system and commercial insurance system in rural areas should be improved as soon as possible\(^12\); Zheng Shuyao et al. discussed the evolutionary game of ecological poverty alleviation strategies among local governments with and without the constraint mechanism, and proposed that increasing penalties and increasing the weight of ecological environment quality indicators in the performance evaluation can increase the enthusiasm of local governments for ecological poverty alleviation\(^13\).

The above literature discusses the reasons for return to poverty after poverty alleviation from different angles and makes recommendations for preventing it. However, the governments, the enterprises, and the poor households are individuals with limited rationality, when they receive different information or interference from external factors, they will make strategies that are different from or even contrary to the previous ones. According to construct an evolutionary game model between the governments and the escaping-poverty households, this paper solves the evolutionary stability strategy (\(\text{ESS}\)), and searches the reasons for returning to poverty through the analysis of dynamic phase diagrams and related parameters, and puts forward effective suggestions for consolidating the results of poverty alleviation.

**MODEL CONSTRUCTION AND ANALYSIS**

**Model construction:**
To accomplish the targeted poverty alleviation work excellently, the game between governments and poor households should evolve to a reasonable state. After poverty alleviation, the poor households have a certain economic foundation, but to prevent various subjective or objective reasons that cause poverty return, it is necessary to build an evolutionary game model of the interests of both parties, work out the evolutionary stability strategy (\(\text{ESS}\)), and explore effective ways to consolidate the results of poverty alleviation.

Assuming that governments and poor households are the main players of the game, the participants of both parties are finitely rational in their strategic choices. The government pursues the maximization of social welfare, aimed to enhance people's sense of happiness and sense of achievement. The government needs to consider how to achieve the best poverty alleviation effect at the least cost; the poor households desire to maximize their own interests.

Suppose that the governments have two behavioral strategies in the process of poverty alleviation: incentive and non-incentive, which are denoted as \(S_1, S_2\); poor households have two behavioral strategies for positive and negative poverty alleviation, denoted as \(P_1, P_2\). When the income of poor households cannot reach the poverty alleviation standard, the government will take measures to help the poor households escape poverty.

The government’s incentive cost is \(C\) (including expenditures on the social welfare system such as education and medical care). \(W_1\) is The income of poor households when governments are incentive and they are positive in poverty alleviation. (Assuming that the income \(W_1\) reaches the national poverty line standard, which is enough to make the poor households escape poverty, that is, \(W_1 > K\), local governments do not need to provide poverty alleviation funds to support poor households). \(W_2\) is the income of poor households when the governments do not motivate them and they are positive in poverty alleviation. (Assuming that the income \(W_2\) cannot reach the national poverty line standard, that is, \(W_2 < K\)). The government will provide poverty-relief funds \(K - W_2\) to the poor households. At this...
time, the income of the poor households is from positive poverty alleviation \( W_2 \) and the government’s poverty alleviation subsidy \( K - W_2 \), so the final income of the poor households is \( K \). When the poor households negatively escape poverty, they can only rely on the government’s poverty alleviation funds and have no other income. When positively escaping poverty, in addition to basic living needs, poor households also need to spend on upgrading their skills, children’s education, and buying insurance, etc., which is denoted as \( E_1 \). When negatively escaping poverty, poor households only assumes the expenditures of basic life, which is denoted as \( E_2 \), and \( E_1 > E_2 \). When the governments do not incentive and the poor households negatively escape poverty, the local governments need to provide a part of the funds to support the poor households, whose revenue is \(-K\), and the poor households receive this part of the poverty alleviation funds (assuming that the government funds can cover all poor households).

Suppose that in the government group, the probability of incentive is \( x \), and the probability of non-incentive is \( 1 - x \); in the poor household group, the probability of positive poverty alleviation is \( y \), and the probability of negative poverty alleviation is \( 1 - y \), \( 0 < x < 1, 0 < y < 1 \).

Based on the above assumptions, the game income matrix of both parties is obtained as follows:

### Table 1. Game matrix of decision-making behavior

| Poor households | positive (\( P_1 \)) | negative (\( P_2 \)) |
|------------------|----------------------|----------------------|
| incentive (\( S_1 \)) | \(-C, W_1 - E_1\) | \(-C - K, K - E_2\) |
| non-incentive (\( S_2 \)) | \(W_2 - K, K - E_1\) | \(-K, K - E_2\) |

**Model analysis:**

Through the table 1, calculate the expected revenue of governments:

\[ U_x = yK - C - K - \left[ x(yK - C - K) + (1 - x)(yW_2 - K) \right] \]

Calculate the expected revenue of poor households:

\[ V_y = x(W_1 - E_1) + (1 - x)(K - E_1) = xW_1 - xK + K - E_1 \]

\[ V_{1-y} = x(K - E_2) + (1 - x)(K - E_2) = K - E_2 \]

The replicator dynamic equation:
\[ \dot{y} = V, \quad \dot{V} = xW_i - xK + K - E_1 - \left[ y(xW_i - xK + k - E_1) + (1-y)(K - E_1) \right] \]

From the above calculation and analysis, we can establish the replication dynamic equation as follows:

\[
\begin{cases}
F(x) = \dot{x} = x(1-x)(yK - yW_2 - C) \\
G(y) = \dot{y} = y(1-y)(xW_i - Kx - E_1 + E_2)
\end{cases}
\]

Let \( F(x) = 0, G(y) = 0 \), obtain the five equilibrium points of the above evolutionary game system in the plane area \( Q \).

\[ Q = \{(x, y). 0 \leq x \leq 1, 0 \leq y \leq 1\} \]

\[ O(0,0), A(1,1), B(0,1), C(1,0), S\left(x^*, y^*\right) \]

\[ x^* = \frac{E_i - E_2}{W_i - K}, \quad y^* = \frac{C}{K - W_2} \]

The Jacobian matrix \( J \) of the system:

\[
J = \begin{bmatrix}
(1 - 2x)(yK - yW_2 - C) & x(1-x)(K - W_2) \\
y(1-y)(W_i - K) & (1 - 2y)(xW_i - Kx - E_1 + E_2)
\end{bmatrix}
\]

The determinant of Jacobian matrix \( J \):

\[
\det J = (1 - 2x)(yK - yW_2 - C)(1 - 2y)(xW_i - Kx - E_1 + E_2) - x(1-x)(K - W_2)y(1-y)(W_i - K)
\]

The trace of Jacobian matrix \( J \):

\[
TrJ = (1 - 2x)(yK - yW_2 - C) + (1 - 2y)(xW_i - Kx - E_1 + E_2)
\]

The stability analysis of the equilibrium point is as follows:

| equilibrium point | \( \det J \) | \( TrJ \) | Result |
|-------------------|--------------|----------|--------|
| \( (0,0) \)      | \( CE_1 - CE_2 \) | +        | \( -C - E_1 + E_2 \) | ESS    |
| \( (0,1) \)      | \( (K - W_2 - C)(E_1 - E_2) \) | -        | \( K - W_2 - C + E_1 - E_2 \) | Instability |
| \( (1,0) \)      | \( C(W_i - K - E_1 + E_2) \) | -        | \( C + W_i - K - E_1 + E_2 \) | Instability |
| \( (1,1) \)      | \( (K - W_2 - C)(W_i - K - E_1 + E_2) \) | +        | \( W_i - W_2 - C - E_1 + E_2 \) | ESS    |
| \( (x^*, y^*) \) | 0            |          | Saddle point |

The comprehensive dynamic evolution phase diagram is as follows:
According to the analysis of the above figure 1, When the initial state is in the area $A$ (The area on the lower left), the system will converge to the point $(0,0)$, that is, governments will adopt a non-incentive strategy, and poor households will adopt a negative strategy; When the initial state is in area $B$(The area on the upper right), the system will eventually converge to the point $(1,1)$, that is, governments will adopt incentive strategies and poor households will adopt positive strategies.

Under unconstrained conditions, it can be seen that the outcome of the evolutionary game will evolve in two different directions. One is the rational state we desire, that is, governments are incentive and poor households are positive, the other is an unreasonable state, that is, the governments are non-incentive and poor households are negative. Therefore, both states are $ESS$. In any state, participants who adopt another strategy will be eliminated.

Let’s analyze the parameters of the model and try to find out its impact on the evolutionary game, and then adjust it as possible to make the game evolve in an optimum direction.

**Parameter Analysis and Regulation:**

Assume that the initial conditions of the system are random and uniformly distributed in the plane $Q=\{(x,y):0 \leq x \leq 1,0 \leq y \leq 1\}$ . The purpose of analyzing the parameters is to reduce the area $A$ in the phase diagram and increase the area $B$ by changing the parameters, that is, moving saddle point $S$ to the lower left, so that the system can finally reach $ESS(1,1)$.

The following discusses the impact of several parameter changes on the evolution of the game model and the possible control methods:

1. $C$: Government incentive cost

   Government incentive costs are mainly in education, medical care, social welfare, business support, entrepreneurial subsidies and other aspects. At the saddle point, $\frac{\partial x^*}{\partial C}=0, \frac{\partial y^*}{\partial C}>0$. In the case where other quantities remain unchanged, when the government incentive cost $C$ increases, the abscissa $x_*$ of the saddle point $S$ does not change, and the ordinate $y_*$ increases, that is, the saddle point $S$ moves upward and the area $B$ decreases; Conversely, when the cost of government incentives decreases, the saddle point moves downward and the area $A$ decreases. It can be seen from this that when the governments encourage, appropriately reducing and controlling the cost of incentives can enhance the poor households’ enthusiasm in poverty alleviation, thereby improve the profits of both parties.

2. $W_1$: The income of poor households when governments are incentive and they are positive in poverty alleviation.

   At the saddle point, $\frac{\partial x^*}{\partial W_1}<0, \frac{\partial y^*}{\partial W_1}=0$. In the case where other quantities remain unchanged, when $W_1$ increases, the saddle point moves to the left. The area $A$ decreases and the area $B$ increases; conversely, the area $A$ increases and the area $B$ decreases. It follows from this that when income is increased by various means, both game parties will evolve to a favorable state, that is, the governments encourages poverty alleviation, and the poor households positively escape poverty.

3. $W_2$: The income of poor households when the governments do not motivate them and they are positive in poverty alleviation.

   At the saddle point, $\frac{\partial x^*}{\partial W_2}=0, \frac{\partial y^*}{\partial W_2}>0$. In the case where other quantities remain unchanged, when $W_2$ increases, the saddle point moves upward. The area $A$ increases and the area $B$ decreases; conversely, the area $A$ decreases and the area $B$ increases. It follows from this that when the governments do not incentivize, it will crack down on the enthusiasm of the poor households for production. Even if the income increases for a short period of time, they will eventually tend to negatively escape poverty for other reasons.
(4) $E_1$: Expenditure of poor households when they are positive.

At the saddle point $\frac{\partial x^*}{\partial E_1} < 0$, $\frac{\partial y^*}{\partial E_1} = 0$. In the case where other quantities remain unchanged, when $E_1$ increases, the saddle point moves to the left, the area $A$ decreases, and the area $B$ increases; conversely, the area $A$ increases and the area $B$ decreases. It can be concluded that when poor households are positively escape poverty, more investment in education, medical insurance, and entrepreneurship can promote the evolution of the game to a favorable state and achieve a "win-win" situation.

(5) $E_2$: The expenditure of poor households when they are negative.

At the saddle point $\frac{\partial x^*}{\partial E_2} > 0$, $\frac{\partial y^*}{\partial E_2} = 0$. In the case where other quantities remain unchanged, when $E_2$ increases, the saddle point moves to the right, that is, the area $A$ increases and the area $B$ decreases; conversely, the area $A$ decreases and the area $B$ increases. It can be concluded from this that when poor households spend more on indulgence, the game will evolve towards $ESS(0, 0)$, which will eventually lead to a "double-lost" situation. Through the above analysis, the strategies of the both game sides can be adjusted according to the relevant parameters to ensure that the anti-poverty war is won.

CONCLUSION AND POLICY IMPLICATIONS

Combining the actual situation and the analysis of model parameters, the recommendations are as follows:

(1) **Education Boost:**

Family members with a high level of education can have more social resources and the ability to earn income, so that the basic survival needs of the family can be guaranteed. It is mentioned in the book "The Essence of Poverty" that an extra year of average schooling raises incomes by 8% [1]. In order to stop the intergenerational transmission of poverty, the education of children is essential. The uneven level of education resources in urban and rural areas is also an important cause of poverty. The government has invested a lot of money in basic education to escape poverty, but the effect is not significant, and the number of school dropouts in rural compulsory education is still high. The government has attached importance to improving the basic hardware facilities of rural schools, but the problems of the input of teachers and the change of parents' concepts have not been completely resolved. The Banaji concluded that spending 100 dollars, adding a teacher can increase education time of a child by 1.7 years, providing lunch can increase by 2.8 years, and educating parent will increase education time of a child by 40 years [1]. Therefore, it is indispensable to use legal mandatory intervention to change the concept of parents. In terms of the input of teachers, it is feasible to improve the remuneration of rural teachers, attract better teachers to the countryside or encourage university graduates to find employment in the countryside.

(2) **Medical Insurance:**

At present, the medical and health conditions in poverty-relief areas are gradually improving. The government must not only protect the basic medical conditions of poor households, but also prevent medical resources from being occupied. At the same time, the government's investment in medical security is also very important, on the one hand, providing medical insurance ensures that poor can afford the cost of disease, on the other hand, increasing public health governance enables to prevent the occurrence of diseases, such as investment in drinking water and diet health, community disease prevention, health knowledge popularization, and favorable lifestyle, etc.

(3) **Social Welfare:**

In case of natural disaster, such as meteorological disasters, crop harvests have been reduced, biological disasters have caused the death of livestock, and geological disasters have caused losses to residential houses, factory machinery, vehicles and personal health, which will inevitably cause additional expenditures. This will compress other living expenses and cause a series of problems. The government needs to ensure that the social welfare system is supported by other external resources, which will improve the ability of assets against resist risks. The government needs to build a complete social welfare system, such as medical care, social security and disaster subsidies. These measures can play the "safety net" role of assets to help families withstand the impact of unexpected risks.
(4) Entrepreneurship Support:
Some scholars have found that the rural poverty return rate can be reduced by 0.76% when entrepreneurial rate is increased by 10%, and the poverty return rate can be reduced by 0.10% when entrepreneurial income is increased by 10% [4]. The government should vigorously optimize the entrepreneurial environment, energetically encourage qualified people in rural areas to start businesses, and actively carry out the measures of cities feeding rural areas and industries feeding agriculture. In addition, they need to cultivate new types of professional farmers, give certain support to township and village enterprises, and drive local people to work. Combining the two will help to prevent farmers from returning to poverty and promote the implementation of rural revitalization strategies. It should be noted that different policies should be adopted to support initiatives of poverty-relief at different stages of development.

(5) Use Of Wealth:

When the country provides policy support to poor areas, benefits of the poor are getting smaller and smaller, while the benefits of the rich are getting bigger and bigger (the Gini coefficient in 1978 was 0.21, and the Gini coefficient in 2019 was 0.47). Although the government has devoted to opportunity to obtain wealth fair, due to the limitation of capital, such a result is caused. Poor people’s lives are full of risks, as shown in Figure 2 above, once they fall into the poverty trap, and become poorer. Due to the lack of attention to education, physical examination, and financial management, the risk of poor households returning to poverty after poverty alleviation increases. In addition, encountering fraud will make poor households return to poverty after poverty alleviation. Therefore, it is essential to introduce relevant policies to control and tackle these phenomena.

According to statistics from the National Poverty Alleviation Office, affected by the coronavirus pneumonia, about 2 million people are at risk of returning to poverty, and 3 million are at risk of leading to poverty. Therefore, it is a huge test to complete the all-round poverty alleviation as scheduled. We must first eliminate absolute poverty, and then gradually eliminate relative poverty in the development process. On the one hand, the development of productive forces can make the "cake" of people's well-being ever bigger. On the other hand, reasonable policies can separate the "cake" well. To achieve comprehensive poverty alleviation, everyone has a responsibility to work hard jointly.

The work of targeted measures in poverty alleviation involves many stakeholder groups, and this article researches the evolutionary game relationship between the government and poor households, rather than consider other concerned stakeholder groups such as enterprises and village collectives. In future research, the influence of the behavior of different subjects on the effectiveness of poverty alleviation should be considered.

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