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Research on the Slope Green and Environment Protection Using Dynamical Game Theory

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Abstract: This study aims to investigate the slope green and environment protection in China. In ecological slope protection, the plant roots can achieve the ecological vegetation restoration of the slope surface. Hence the slope environment can be protected significantly. However, there is still lack of efficient policy to support the implementation of nationwide slope green program to facilitate the development of slope green and environment protection technologies. Hence, the reasonable relationship between the slope green and environment protection and the national policy is very important. Literature review indicates that very little work has been done to address this issue. In order to investigate the relationship between the slope green and environment protection and the national policy, this study presents a new analysis method based on the dynamical Game theory. The game between the slope green and environment protection and the national policy can be regarded as a dynamical economic process, the optimized implementation strategy for the slope green and environment protection under the national support can be obtained by the use of dynamical game analysis. The stability analysis and the balance analysis have been discussed for the proposed game model. The analysis result shows that the government should increase financial support as well as establish corresponding punishment mechanism to encourage different policies and practices for slope green and environment protection and hence a win-win situation can be achieved

Keywords: Dynamical game theory, environment protection, national policy, slope green

INTRODUCTION

The slope green is a new kind of ecological slope protection method that can effectively realize ecological vegetation restoration of the slope surface and protect the environment. China is a mountainous country and the slope green is very suitable and important to protect the slope environment from damages. The slope green can also prevent the landslides. As a result, the slope green has received great development in the last decade and many slope green technologies have been proposed. Wang (1999) proposed the hydraulic spray seeding technology; (Li, 1999) introduced the hydropower spray seeding technology; (Du, 2000) introduced the earth spray seeding technology; (Yang *et al*., 2013) presented the vegetation concrete technology. There also other slope green methods (Yin *et al*., 2004). These existing slope green methods have been widely used in practice. However, there is still lack of efficient policy to support the implementation of nationwide slope green program to facilitate the development of slope green and environment protection technologies.

The implementation of the slope green is marked as a new milestone for the environment protection in the modern society. How to guide the society to participate in and share the benefit of the slope green is a formidable task for the government. Pressure comes from the construction of environment protection. The proper environment protection strategy can improve implementation of the slope green. However, literature review indicates that there is very few work has been done to address this issue. The solution to the national policy to support the slope green and environment protection has not been answered by the government. Therefore, it is very urgent to investigate the national policy construction to fulfill the requirements of the slope green and environment protection.

In general, how to balance the slope green and environment protection and the national policy is very important for a proper guidance of the development of advanced slope green technologies (Hines, 2002; Zhang, 2010). On the one hand, the government would like to establish brand new strategies to develop advanced slope green technologies to protect the environment. However, the financial support is the bottleneck. On the other hand, the development of advanced slope green technologies needs sufficient support to keep moving forward. Thus, contradiction arises. A suitable optimization is needed to balance the interests of them and hence to fully drive the

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development of advanced slope green technologies forwards.

In order to investigate the relationship between the slope green and environment protection and the national policy, a new method is proposed in this study based on the dynamical Game theory. A dynamical game model for the national policy construction has been established and the Nash balance solutions have been discussed. The analysis results demonstrate that the government should increase financial support as well as establish corresponding punishment mechanism to encourage different policies and practices for slope green and environment protection and hence a win-win situation can be achieved.

DYNAMIC GAME MODEL

For the purpose of a comprehensive understanding of the game information and action, four different models can be used to represent the non-cooperative game Papageorgiou (2009), Donald *et al*. (2010), Johannes *et al*. (2010), Richey *et al*. (2010) and Danuta and Artur (2011):

- Static game model with complete information
- Static game model with incomplete information
- Dynamic game model with complete information
- Dynamic game model with incomplete information. Generally, it is assumed that the players know complete information while in conventional Game theory complete information is necessary. However, in practice it is hardly to obtain complete information. As a result, conventional Game theory is not suitable for the analysis of games with incomplete information (Papageorgiou, 2009; Donald *et al*., 2010; Johannes *et al*., 2010; Richey *et al*., 2010; Danuta and Artur, 2011). In this study, the relationship between the slope green and environment protection and the national policy belongs to incomplete information case. Hence, the dynamic game theory is adopted in this study.

Dynamic Game Theory (DGT) is a combination of static game theory and Darwin's evolutionary theory. It aims to deal with games with incomplete information. In static games, as mentioned, the players are suggested to know complete information. The players are also rational. However, the DGT is different from the conventional game theory. DGT can map dynamics information into the game model, where the changes of information over time can be efficiently described in this dynamic model. Hence, DGT can overcome the limitations of static games and provide solutions to the dynamic games with incomplete information (Johannes *et al*., 2010).

In DGT, the game costs are the fitness of individuals of the population and the solutions are evolved dynamically (Finke *et al*., 2009). In the dynamic games, an individual knows its own group but do not know other individuals' groups. However, an individual can observe others' behavior to infer their groups and characteristics. Then, according to the judgments from previous actors, the following individuals can tune their behavior to make the optimized actions. In contrast, the previous actors know that their information will be used by the followings; they will protect themselves by transferring information that may be mostly favorable to themselves. Hence, the whole process is not only the selection of game actions, but also the correction of participants' belief (Finke *et al*., 2009). In this process, similar to Nash equilibrium, EGT uses the perfect Nash equilibrium, i.e., the Evolutionary Stable Strategy (ESS) to resist to both internal mutation and external perturbation. That means, the mutation by some players will not influence the game outcome. Compared with the optimized payoffs for individuals in traditional games, the dynamic games focus on the sustainability or persistence of solutions from generation to generation. The ESS can maintain sustainable or survivable solutions for generations.

ANALYSIS OF THE SLOPE GREEN AND ENVIRONMENT PROTECTION USING DGT

The static game models often suffer from rationality and complete information assumption. To overcome these shortcomings, the Dynamic Game Theory (DGT) adopts the dynamic evolution conception to further develop the game model that can model the dynamic information. To address the game between the slope green and environment protection and the national policy, the DGT is used in this study.

In the game analysis, the dynamic game with incomplete information is assumed. To simplify the balance in this specific issue, i.e. the game between the slope green and environment protection and the national policy, we mainly focus the financial support of the government and the responds of the development in the technology innovation of slope green.

Dynamic game analysis model: The financial support on the implementation of the slope green and environment protection is the main problem in the national policy to the agreement of strong support of this activity. Up to date, the technology innovation of slope green relies on individuals. Due to the lack of financial support, revolutionary innovation is hardly to achieve. Only small improvements could be made to add new materials into the slope green technologies. Hence, technology innovation of slope green will need sufficient funding to construct the new technologies. In

Table 1: The cost between the government and individuals

		Individuals	
	Contribution	Non-contribution	
Government	Increase	(A, B)	(C, D)
	Non-increase	(0, 0)	(0, D)

Table 2: Local stability analysis of the dynamic game model

Balance points	Determinant of Jacobian	Trace of Jacobian	Local stability
(0, 0)	$C * (-D)$ (+)	$C - D$ (–)	ESS
(0, 1)	$A * D$ (+)	$A + D$ (+)	Instability
(1, 0)	$(-C)*(B - D)$ (+)	$-C + B - D$ (+)	Instability
(1, 1)	$(-A) * (-B + D)$ (+)	$-A - B + D$ (–)	ESS

this game, there are two strategies for government to manage the implementation of the slope green and environment protection. One is to increase financial support and the other is keeping the current financial support level. Assuming: F is the basic profit acquired from the implementation of the slope green and environment protection; E is the financial support of the government; I is the basic input for the slope green and environment protection; p is the probability of individuals in current technology innovation of slope green; q *is* increase rate of financial support in the implementation of the technology innovation of slope green; R is the profit of government acquired from the new slope green technologies; s is the probability of individuals in the technology innovation of slope green when the financial support increases. Then, the expected profit for government is $[F+ (1–s)\, pR–E–qI]$ when the financial support increases; Otherwise, the profit is F.

Assuming t is the rate of the financial support increase and O is the cost of the technology innovation of slope green when the financial support increases. The expected profit for environment protection is $\{p[(1 - s)(1+q)\, RI] + (1–p)\, I - (1–t)\, O\}$; Otherwise, the return is $(I+tO)$.

Dynamic analysis: Herein the dynamics between the slope green and environment protection and the national policy is analyzed. Parameter x is defined as the probability of government to increase the financial support and y is defined as the probability of individuals increase technology innovation of slope green. The cost table between them is listed in Table 1. In the table:

$A = [F + (1 - s)\, pR - E - qI]$, $B = \{p[(1 - s)(1 + q)RI] + (1 - p)I - (1 - t)O\}$, $C = E$, $D = tO$ and $B > D$, $|C| > D$.

In the dynamic games of incomplete information, use $H\,(1, x)$ and $H\,(0, x)$ to represent the desired profit for the government in increase and non-increase of the financial support. Then, use $J(y,\, 0)$ and $J(y,\, 1)$ to represent the desired profit for the individuals in choosing contribution and non-contribution for the technology innovation of slope green. Hence, the desired profit function is:

$$H(1,x) = y[(1-s)pP - E - qI] + (1-y)E = yA - (1-y)C \quad (1)$$

$$H(0,x) = 0 \quad (2)$$

$$J(y,1) = x\{p[(1-s)(1+q)I] + (1-p)R - (1-t)O] + (1-x)*0\} = xB \quad (3)$$

$$J(y,0) = x(tO) + (1-x)(tO) = D \quad (4)$$

Stability analysis: The evolution in the dynamic games between the slope green and environment protection and the national policy can be derived by the use of the dynamic system:

$$x' = x(1-x)[yA - (1-y)C] \quad (5)$$

$$y' = y(1-y)[xB - D] \quad (6)$$

For this purpose of investigating the ESS stability in this dynamic system, the Jacobian information should be calculated. Herein the Jacobian information is:

$$\text{Jacobian} = \begin{bmatrix} x(1-2x)[yA-(1-y)C] \\ x(1-x)[A-C] \\ y(1-y)B \\ (1-2y)[xB-D] \end{bmatrix} \quad (7)$$

The local stability analysis has been carried out using the Jacobian information and the stability is shown in Table 2.

From Table 2 it can be seen that:

- The larger is the punishment when the government increase the financial support, the more comes from the technology innovation of slope green
- The less is the profit of the government gained by increasing the financial support for the implementation of the slope green and environment protection, the larger is the probability of individuals increase technology innovation of slope green
- If individuals do not increase technology innovation of slope green, the government will decrease the financial support as a kind of punishment.

Balance point analysis: It can be seen from the above dynamical game model that three conditions should be inspected to achieve balanced strategy. In the first stage, when H(1, x) >0 & J(y, 0) >0 or H(0, x) <0 & J(y, 1) <0, the dynamical game model reaches balance. In this situation, the cost of financial support increase is less than punishment and the gain of individuals by non-contribution in the technology innovation of slope green is less than punishment under financial support increase. In this condition, individuals will choose contribution. In the second stage, when H(1, x)<0 & J(y, 0)<0 or H(0, x) >0 & J(y, 1)>0, the dynamical game model reaches balance. In this situation, the government gives up financial support increase because the profit is less than the cost while individuals choose contribution because the gain is more than punishment. In the third stage, when H(1, x) >0 & J (y, 0)<0 or H(0, x) <0 & J(y, 1)<0, the dynamical game model reaches balance. In this situation, individuals cost more than gain when choosing contribution and the profit of government choosing financial support increase is less than non-increase. Thus, to facilitate the technology innovation of slope green, it should carry out rigorous punishment police; at the same time improve the incentives.

As for the mixed stages, the government enhances the financial support at the probability of (I-E)/F and individuals contribute at the probability of (I-E)/F. Then, it can be seen that the punishment is relative large and the contribution probability is relative low, which will lead to large cost of the government and low efficiency of the technology innovation of slope green. In this situation, proper solution should be proposed to promote the efficiency of both the government and individuals.

CONCLUSION

The relationship between the slope green and environment protection and the national policy, as being a game model, have been modeled in this study and been analyzed for the pursuit of a win-win event for the environment protection. Punishment or similar stimulation strategies seem not to be good solutions to improve the relationship between the slope green and environment protection and the national policy. To receive the benefits of the implementation of the technology innovation of slope green, it suggests that feasible incentive and restraint mechanisms should be established. The suitable incentive mechanism is also necessary. Moreover, a punishment mechanism is needed. Most important, the government need increase the financial support. For one thing, this requires improve the quality of technology innovation of slope green. For the other, this is to mobilize social pressure to construct new slope green technologies.

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