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DEVELOPMENT OF DECISION-MAKING MODEL FOR ADOPTING RENEWABLE ENERGY BASED ON TRIPARTITE EVOLUTION GAME THEORY ANALYSIS

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ABSTRACT

For the adoption of renewable energy to buildings that consumes a lot of fossil fuel-based energy, the government, environmental service company, and consumers have organized for the Private-Public-Partnership (PPP) project encouraging private building to install renewable energy generators. However, the majority of building owner is unwilling to install renewable energy generators to their buildings because of high initial investment cost, low rate of return, and long payback period. Most of the previous studies analyzed the economic benefits of PPP projects for adopting the renewable energy generators in residential buildings, but they rarely present any decision-making model to support choosing an appropriate strategy and the optimal incentive and penalty rate. To fill the gap, this study aims to construct the decision-making model for implementing PPP projects from three-participant perspective through evolutionary game theory. This study firstly collected background costs and benefits information related to renewable energy adoption PPP projects. Secondly this study analyzed the evolutionarily stable strategy of each participants. Finally, the decision-making model was proposed to support choosing an appropriate strategy for accomplishing win-win solution from each stakeholder.

Keywords: *Renewable energy*, *Public-Private partnership*, *Evolutionary game theory*, *Financial Incentive*, *Penalty*

1. INTRODUCTION

Greenhouse gas (GHG) emissions and environmental pollution from the immersive use of fossil fuels has been considered the significant problem in the history of mankind [1-3]. Also, GHG emissions have continued to accelerate global climate change. Many countries were trying to attend the United Nations Framework Convention on Climate Change (UNFCCC) every year to discuss these global issues [4]. The main agenda of the convention was the reduction of carbon dioxide emissions and the increase in the renewable energy usage. In particular, many energy policies and measures were proposed for promoting the use of renewable energy. Traditional policies mainly aimed at a second-party relationship between the government and consumers, by subsidizing incentives or penalizing fines on consumers to adopting renewable energy. However, the government's total budget was not sufficient, but limited. For example, the government could not afford the additional budget, such as the cost of installing renewable energy, R&D, and promoting renewable energy. The majority of consumers was unwilling to install renewable energy generators to their buildings because of high initial investment cost, low rate of return, and long payback period. Furthermore, the unclear policy of adopting renewable energy to consumers led to duplication or absence of environmental protection. This policy failures resulted in low efficiency of renewable energy adoption.

Due to changes in government functions, the market plays an important role in adopting renewable energy. Recently, a new alternative has been proposed to attract third parties through carrying out Public-Private Partnership (PPP) project [5]. A PPP project refer to cooperative relationship between the government and private entities to facilitate privately finance projects. In this study, a PPP project involved three participants: (i) government; (ii) environmental service companies (ESCOs) and (iii) consumers. The government, as the principal stakeholder, induced involvement of the other participants through incentives and penalties. An amount of incentives and penalties determined the probability that ESCOs and consumers could invest or participate to the project. Evolutionary game theory (EGT) has been widely used to analyze the PPP project's decision process, by using replicated dynamic mechanism [6]. This study aimed to construct a decision process model of PPP project focusing on adopting renewable energy using evolutionary game theory. First, many parameters were assumed for benefits and costs used in the EGT model. Second, we defined the replicated dynamic equation using a payoff matrix, which depended on the strategy selected by each participant. Finally, we found an Evolutionary stable strategy (ESS) that all three participants were satisfied with. Through this study, optimal ratio of incentives and penalties would allow all participants to involve in the PPP project.

2. METHOD

2.1 Model assumption

An EGT was an optimal strategy searching process by adapting classical game theory into the context of biological evolution and replication [7]. EGT used the dynamic evolution process analysis to understand changes in a population through interaction with different participants according to their own strategies. The purpose of the EGT was explaining how strategies affect each other over time, and why participants come into being its current status. This study constructed a decision- making model on a PPP project targeting renewable energy adoption. Therefore, the best strategy of three parties were based on *bounded rationality*, it means that the game participants may adopt any strategy for maximizing their benefits [8]. The government paid more attention to social utilities, ESCOs more pursue in monetary profits, and the consumers more pursued the energy savings. In order to construct the three-party EGT specifically, related parameters and the basic assumptions are as follows.

- *Assumption 1*: For the government's position, assume that the probability of government selecting the "supervise" strategy was x ($0<x<1$), then the probability of selecting the "non-supervise" strategy was $1-x$. For the ESCO's position, assume that the probability of ESCOs selecting the "invest" strategy was y ($0<y<1$), then the probability of selecting the "non-invest" strategy was 1-y. and, for the consumers position, assume that the probability of selecting "participate" strategy was z ($0<z<1$), then the probability of selecting the "non-participate" strategy was $1-z$.
- *Assumption 2*: In the case that the government selected "supervise" strategy, the government could receive basic revenues (R_1) such as incentive tax. At the same time, it is expected that environmental problems would be alleviated when consumers use renewable energy. So, the government could receive additional revenues (R_2) from environmental improvement. Moreover, if ESCOs and consumers did not "invest" and "participate" the PPP project, the government could penalize fines from them. R_3 referred to ESCOs' fines for government when ESCOs did not invest to the PPP project; R_4 referred to consumers' fines for government when consumers did not participate the PPP project. However, it needed to pay various costs. The government needed to pay basic expenditures (E_1) such as technical innovation (R&D) costs, supervision costs etc. At the same time, the government needed to pay environmental burdens (E_2) when consumers used traditional fossil-fuel energy, not renewable energy. Moreover, if ESCO "invest" the PPP project, the government should subsidize ESCOs as much as financial incentive cost (E_3). For example, depending on the amount of incentives, ESCOs could provide low-cost devices than market prices and promote renewable energy adoption for more consumers. Also, for consumers, the government needed to pay financial incentive (E_4) such as the expenditure paid by the government for resolving the high energy consumption and pollution.
- *Assumption 3*: In the case that ESCOs selected "invest" strategy, ESCOs could obtain basic profits (P_1) such as operating incomes when consumers used renewable energy. As companies' social image changes positively, it is expected that ESCOs receive financial compensation such as tax benefits and government' support. So, ESCOs could obtain additional profits (P_2). At the same time, ESCOs could obtain incentive profits (P_3) which is the same amount as E_3. However, it needed to pay incremental costs. C_1 referred to ESCOs' operating cost of installing energy systems and investigating new technologies; C_2 referred to ESCOs' tax costs by obtaining the incentive profit. On the other hand, in the

case that ESCOs selected "non-invest" strategy, ESCOs need to pay a fine cost (C_3) to the government, which is the same as R_3.

- *Assumption 4*: In the case that the consumers selected "participate" strategy, energy savings by using renewable energy could help the consumers benefit as much as B_1. In addition, there were consumers' relative gains (B_2) that could be obtained from contracting with ESCOs rather than with other companies. At the same time, consumers could obtain incentive benefit (B_3) which is the same amount as E_4. In the case that the consumers selected "non-participate" strategy, the consumers needed to pay a fine cost (S_1) to the government, which is the same as R_4.

2.2 *The payoff function and replicated dynamics equation*

In reference to four assumptions and related parameter mentioned above, In EGT model, replicated dynamic equation stands for a dynamic differential equation that expressed the proportion of a particular strategy selected in a population as follows:

- *The replicated dynamics equation of the government aspect*: Let U_{x1} represents an expected payoff of the government if it selects "supervise" strategy, and U_{x2} represents an expected payoff of the government if it selects "non-supervise" strategy. U_x represents the average expected payoff of the government. U_{x1}, U_{x2}, and U_x are as follows:

$$U_{x1} = yz(R_1 + R_2 - E_1 - E_3 - E_4) + y(1 - z)(R_1 + R_3 - E_1 - E_2 - E_3) + (1 - y)z(R_1 + R_2 + R_4 - E_1 - E_4) + (1 - y)(1 - z)(R_1 + R_3 + R_4 - E_2) \quad [1]$$

$$U_{x2} = yz(R_2) + y(1 - z)(-E_2) + (1 - y)z(0) + (1 - y)(1 - z)(-E_2) \quad [2]$$

$$U_x = xU_{x1} + (1 - x)U_{x2} \quad [3]$$

Thus, the replicated dynamic equation of the government can be expressed:

$$F(x) = \frac{dx}{dt} = x(U_{x1} - U_x) = x(1 - x)[R_1 + R_3 + R_4 - y(E_3 + R_4) + z(R_2 - E_4 - R_3) - yzR_2] \quad [4]$$

- *The replicated dynamics equation of the ESCOs aspect*: Let U_{y1} represents an expected payoff of the ESCOs if it selects "invest" strategy, and U_{y2} represents an expected payoff of the ESCOs if it selects "non-invest" strategy. U_y represents the average expected payoff of the ESCOs. U_{y1}, U_{y2}, and U_y are as follows:

$$U_{y1} = xz(P_1 + P_2 + P_3 - C_1 - C_2) + x(1 - z)(P_2 + P_3 - C_1 - C_2) + (1 - x)z(P_1 - C_1) + (1 - x)(1 - z)(0) \quad [5]$$

$$U_{y2} = xz(-C_3) + x(1 - z)(P_2 - C_3) + (1 - x)z(0) + (1 - x)(1 - z)(0) \quad [6]$$

$$U_y = yU_{y1} + (1 - y)U_{y2} \quad [7]$$

Thus, the replicated dynamic equation of the ESCOs can be expressed:

$$F(y) = \frac{dy}{dt} = y\left(U_{y1} - U_x\right) = y(1 - y)[-C_1 + x(P_3 - C_2 + C_3) + z(P_1) + xz(P_2)] \quad [8]$$

- *The replicated dynamics equation of the consumers aspect*: Let U_{z1} represents an expected payoff of the consumers if it selects "participate" strategy, and U_{z2} represents an expected payoff of the consumers if it selects "non-participate" strategy. U_z represents the average expected payoff of the ESCOs. U_{z1}, U_{z2}, and U_z are as follows:

$$U_{z1} = xy(B_1 + B_2 + B_3) + x(1 - y)(B_1 + B_3) + (1 - x)y(B_1) + (1 - x)(1 - y)(B_1) \quad [9]$$

$$U_{z2} = xy(-S_1) + x(1 - y)(-S_1) + (1 - x)y(0) + (1 - x)(1 - y)(0) \quad [10]$$

$$U_z = zU_{z1} + (1 - z)U_{z2} \quad [11]$$

Thus, the replicated dynamic equation of the consumers can be expressed:

$$F(z) = \frac{dz}{dt} = z(U_{z1} - U_z) = z(1 - z)[B_1 - x(B_3 + S_1) + y(B_2) + xy(B_2)] \quad [12]$$

2.3 *The payoff function and replicated dynamics equation*

The utopia point of evolutionary stable strategy (ESS) has the following characteristics: when one player's probability (*x*) diverges from stable point, *x**, the replicated dynamic equation tend to *x* to *x** unconditionally. In other words, if *x* lower than *x**, F(*x*) should be greater than 0; if *x* higher than *x**, F(*x*) should be less than 0. According to these replicated dynamic equations, it can be obtained the dynamic system was a three-dimensional system with three participants. In addition, the probability of the different strategies is depending on time step. If $F(i) = 0$ and $\frac{dF(i)}{di} < 0$ is satisfied, we can obtain optimal stable points that represents the ESS selected by local stability analysis of the Jacobian matrix. ESS of the evolution strategies of each participant's aspect were as follows:

- *The ESS of the evolution strategies of the government aspect*

According to Eq. (4), the *x** of the stable point should satisfy F(*x*) = 0 and $(dF(x))/dx < 0$. $(dF(x))/dx$ are expressed as follows:

$$(dF(x))/dx = (1 - 2x)[R_1 + R_3 + R_4 - y(E_3 + R_4) + z(R_2 - E_4 - R_3) - yzR_2] \quad [13]$$

1. If $z = \frac{y(E_3+R_4)-R_1-R_3-R_4}{R_2-E_4-R_3-yR_2}$, $F(x) \equiv 0$, it represents that the boundary of the stable state. Regardless of the probability that the government select "supervise" strategy, stable strategy will not change over time.
2. If $z \neq \frac{y(E_3+R_4)-R_1-R_3-R_4}{R_2-E_4-R_3-yR_2}$, $F(x) \equiv 0$, we can obtain two stable points (*x* = 0 and *x* = 1).
3. If $z > \frac{y(E_3+R_4)-R_1-R_3-R_4}{R_2-E_4-R_3-yR_2}$, $\left.\frac{dF(x)}{dx}\right|_{x=1} < 0$, $\left.\frac{dF(x)}{dx}\right|_{x=0} > 0$; thus, *x* = 1 is the stable point, and the government will select to a "supervise" strategy.
4. If $z < \frac{y(E_3+R_4)-R_1-R_3-R_4}{R_2-E_4-R_3-yR_2}$, $\left.\frac{dF(x)}{dx}\right|_{x=1} > 0$, $\left.\frac{dF(x)}{dx}\right|_{x=0} < 0$; thus, *x* = 0 is the stable point, and the government will select to a "non-supervise" strategy.

Under the constraints of $z > \frac{y(E_3+R_4)-R_1-R_3-R_4}{R_2-E_4-R_3-yR_2}$, the three-participants evolutionary game strategy moves to *x*=1, it is shown that when the probability of the government selecting "supervise" strategy is higher than the boundary of the stable state. In addition, if other participants select positive strategy (*y*=*z*=1), we can obtain the parameter's relationship ($R_1 > E_3 + E_4$). Only when basic revenues (R_1) are higher than total sum of expenditures by financial incentive to other participants ($E_3 + E_4$), the government will select the "supervise" strategy.

▪ *The ESS of the evolution strategies of the ESCOs aspect*

According to Eq. (8), the *y** of the stable point should satisfy F(*y*) = 0 and $(dF(y))/dy$ < 0. $(dF(y))/dy$ is expressed as follows:

$$(dF(y))/dy = (1-2y)[-C_1 + x(P_3 - C_2 + C_3) + z(P_1) + xz(P_2)] \quad [14]$$

1. If $x = \frac{zP_1-C_1}{C_2-C_3-P_3-zP_2}$, $F(y) \equiv 0$, it represents that the boundary of the stable state. Regardless of the probability that the ESCOs select "invest" strategy, stable strategy will not change over time.
2. If $x \neq \frac{zP_1-C_1}{C_2-C_3-P_3-zP_2}$, $F(y) \equiv 0$, we can obtain two stable points (*y* = 0 and *y* = 1).
3. If $x > \frac{zP_1-C_1}{C_2-C_3-P_3-zP_2}$, $\left.\frac{dF(y)}{dy}\right|_{y=1} < 0$, $\left.\frac{dF(y)}{dy}\right|_{y=0} > 0$; thus, *y* = 1 is the stable point, and the ESCOs will select to a "invest" strategy.
4. If $x < \frac{zP_1-C_1}{C_2-C_3-P_3-zP_2}$, $\left.\frac{dF(y)}{dy}\right|_{y=1} > 0$, $\left.\frac{dF(y)}{dy}\right|_{y=0} < 0$; thus, *y* = 0 is the stable point, and the ESCOs will select to a "non-invest" strategy.

Under the constraints of $x > \frac{zP_1-C_1}{C_2-C_3-P_3-zP_2}$, the three-participants evolutionary game strategy moves to *y*=1, it is shown that when the probability of the ESCOs selecting "invest" strategy is higher than the boundary of the stable state. In addition, if other participants select positive strategy (*x*=*z*=1). We can obtain the parameter's relationship ($P_1 + P_2 + P_3 > C_1 + C_2 + C_3$). Only when total sum of profit ($P_1 + P_2 + P_3$) are higher than total sum of cost ($C_1 + C_2 + C_3$), the ESCOs will select the "invest" strategy.

▪ *The ESS of the evolution strategies of the consumer's aspect*

According to Eq. (12), the *z** of the stable point should satisfy F(*z*) = 0 and $(dF(z))/dz$ < 0. $(dF(z))/dz$are expressed as follows:

$$(dF(z))/dz = (1-2z)[B_1 - x(B_3 + S_1) + y(B_2) + xy(B_2)] \quad [15]$$

1. If $y = \frac{x(B_3+S_1)-B_1}{(x+1)B_2}$, $F(z) \equiv 0$, it represents that the boundary of the stable state. Regardless of the probability that the consumers select "participate" strategy, stable strategy will not change over time.
2. If $y \neq \frac{x(B_3+S_1)-B_1}{(x+1)B_2}$, $F(z) \equiv 0$, we can obtain two stable points (*z* = 0 and *z* = 1).
3. If $y > \frac{x(B_3+S_1)-B_1}{(x+1)B_2}$, $\left.\frac{dF(z)}{dz}\right|_{z=1} < 0$, $\left.\frac{dF(z)}{dz}\right|_{z=0} > 0$; thus, *z* = 1 is the stable point, and the consumers will select to a "participate" strategy.
4. If $y < \frac{x(B_3+S_1)-B_1}{(x+1)B_2}$, $\left.\frac{dF(z)}{dz}\right|_{z=1} > 0$, $\left.\frac{dF(z)}{dz}\right|_{z=0} < 0$; thus, *z* = 0 is the stable point, and the consumers will select to a "non-participate" strategy.

Under the constraints of $y > \frac{x(B_3+S_1)-B_1}{(x+1)B_2}$, the three-participants evolutionary game strategy moves to *z*=1, it is shown that when the probability of the consumers selecting "participate" strategy is higher than the boundary of the stable state. In addition, if other participants select positive strategy (*x*=*y*=1), we can obtain the parameter's relationship ($B_1 + B_3 - 2B_2 > S_1$).

2.4 Stability of Evolutionary strategies analysis

Using Eq. (4), (8), and (12), we can compose 3x3 matrix, which express as $X = (\frac{dx}{dt}\ \frac{dy}{dt}\ \frac{dz}{dt})^T$. For obtaining global stable point of the government, the

ESCOs, and consumers, the X equal to 0. In dynamic process, the stability of the strategy combination of three participants can be analysed through the Jacobian matrix, *J*. The Jacobian matrix can be expressed as:

$$J=\begin{bmatrix}\frac{\partial F(x,y,z)}{\partial x} & \frac{\partial F(x,y,z)}{\partial y} & \frac{\partial F(x,y,z)}{\partial z}\\ \frac{\partial G(x,y,z)}{\partial x} & \frac{\partial G(x,y,z)}{\partial y} & \frac{\partial G(x,y,z)}{\partial z}\\ \frac{\partial H(x,y,z)}{\partial x} & \frac{\partial H(x,y,z)}{\partial y} & \frac{\partial H(x,y,z)}{\partial z}\end{bmatrix} \quad [16]$$

According to the research result of Rizberger and Weibull, stable point can be obtained local equilibrium point, which are $D_1(0,0,0)$, $D_2(1,0,0)$, $D_3(0,1,0)$, $D_4(0,0,1)$, $D_5(1,1,0)$, $D_6(1,0,1)$, $D_7(0,1,1)$, $D_8(1,1,1)$. Adjusting the initial conditions cannot evolve toward the expected stable equilibrium. The reason is that the probability value of x, y and z change from time to time in the evolution process, and the equilibrium of this evolutionary game is not robust against the small changes of x, y and z. This study focuses on promoting renewable usage through the PPP project. That is, three participants need to select positive strategy (i.e., x = y = z = 1): a strict supervising of the government, a lavish investment of the ESCOs, and will to participation of the consumers. Therefore, only the stable point of $D_8(1, 1, 1)$ is analysed. The Jacobian matrix corresponding to D_8 can be expressed as:

$$J=\begin{bmatrix}E_3+E_4-R_1 & 0 & 0\\ 0 & C_1+C_2+C_3-P_1-P_2-P_3 & 0\\ 0 & 0 & 2B_2-B_1-B_3-S_1\end{bmatrix} \quad [17]$$

The characteristic roots of D_8 are $E_3+E_4-R_1$, $C_1+C_2+C_3-P_1-P_2-P_3$, and $2B_2-B_1-B_3-S_1$. According to Lypunov's first method, the characteristic roots need to be less than 0 (negative value).

3. NUMERICAL SIMULATION

In order to directly show the evolution process on behaviours of the three participants, and to analyse the impact of changes in parameters, this study carried out numerical simulation by combining constraints and replicated dynamic equations. Under the evolution process, x_0, y_0, z_0 respectively represent the initial probability of the three participants' strategy. This study sets the initial value of the parameters as R_1=7, R_2=1, R_3=C_3=3, R_4=S_1=3, E_1=7, E_2=2, E_3=P_3=3, E_4=B_3=3, P_1=10, P_2=1, C_1=8, C_2=1, B_1=10, B_2=6. At the initial stage of evolution process, x_0, y_0, z_0 are set as 0.5. In addition, the study depicted each participant's evolution curve according to ratio of incentive to penalty: Each ratio is as follows: (i) incentive: penalty = 1:1; (ii) incentive: penalty = 1:1.5; and (iii) incentive: penalty = 1.5:1.

- *Evolution process of the government under different ratio of incentive to penalty*

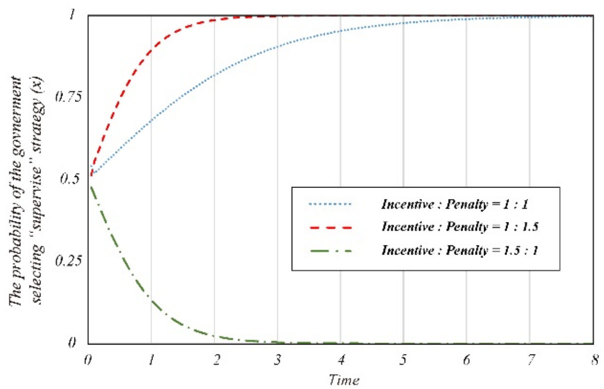
For the initial probability (x_0) to move to ideal stable point, it needs to be satisfied $\mathrm{A}= R_1+R_3+R_4-y(E_3+R_4)+z(R_2-E_4-R_3)-yzR_2>0$. From a random initial value of *y* and z, the evolution curve can be expressed as *x* ($x=\frac{1}{e^{-At}+1}$). At the initial stage of evolution process, y_0, z_0 are set as 0.5. In the government's payoff, the expenditures by incentive to other participants are E_3+E_4 and the revenues by penalizing fines are R_3+R_4. As shown Figure 1(a), the probability value (*x*) increases over time with the strategy supervised by the government when the incentive and the penalty are the same ratio. In addition, the probability value converges to 1 even if the penalty is greater than the incentive. However, if the incentive is higher than the penalty, the probability value converges to 0. In other words, the probability that the government select "supervise" strategy is more dependent on penalty, which is collected from ESCOs and consumers.

- *Evolution process of the ESCOs under different ratio of incentive to penalty*

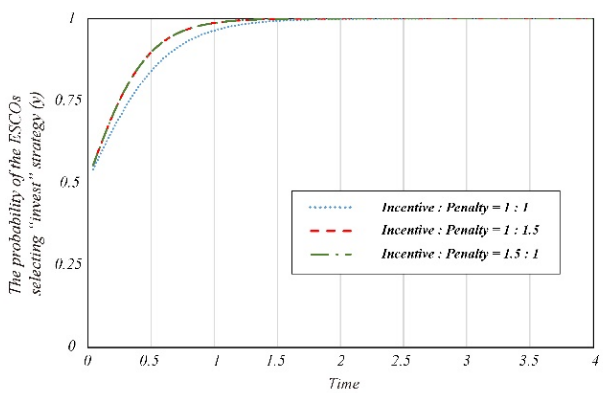
For the initial probability (y_0) to move to ideal stable point, it needs to be satisfied $\mathrm{B}= -C_1+x(P_3-C_2+C_3)+\mathrm{z}(P_1)+xz(P_2)>0$. From a random initial value of *x* and z, the evolution curve can be expressed as *y* ($y=\frac{1}{e^{-Bt}+1}$). At the initial stage of evolution process, x_0, z_0 are set as 0.5. In the ESCOs' payoff, the incentive profits are P_3 and the revenue by fine costs are C_3. As shown Figure 1(b), the probability value (*y*) increases over time with the strategy invested by the ESCOs regardless of the ratio of incentive and penalty. In other words, the assumption of parameters in the PPP projects is in favour of ESCOs.

- *Evolution process of the consumers under different ratio of incentive to penalty*

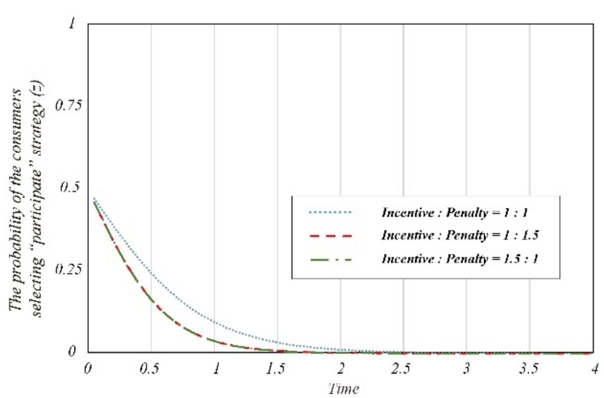
For the initial probability (z_0) to move to ideal stable point, it needs to be satisfied $\mathrm{B}= B_1-x(B_3+S_1)+\mathrm{y}(B_2)+xy(B_2)>0$. From a random initial value of *x* and y, the evolution curve can be expressed as *z* ($y=\frac{1}{e^{-Ct}+1}$). At the initial stage of evolution process, x_0, y_0 are set as 0.5. In the consumers' payoff, the incentive benefits are B_3 and the revenue by fine costs are S_1. As shown Figure 1(c), the probability value (*z*) decrease over time with the strategy participated by the consumers regardless of the ratio of incentive and penalty. In other words, the probability that consumers select "participate" strategy the project depends on other parameters. For example, benefits from generating renewable energy and lower installation costs through ESCOs exists. Therefore, in order to promote consumers involved in the project, more emphasis should be placed on economic factors such as an amount of renewable energy generation and installation costs than policy factors such as incentives and penalties.



(a) Evolution curve of the x value under different ratio of incentive to penalty



(b) Evolution curve of the y value under different ratio of incentive to penalty



(c) Evolution curve of the z value under different ratio of incentive to penalty

Fig. 1. Evolution curve under different ratio of incentive to penalty

4. CONCLUSION

This study aimed to construct a decision process model of Private-Public partnership (PPP) project focusing on adopting renewable energy using evolutionary game theory. First, many parameters were assumed for the benefits and costs used in the Evolutionary Game Theory (EGT) model. Second, we defined the replicated dynamic equation using a payoff matrix, which depends on the strategy selected by each participant. Finally, we found an Evolutionary stable strategy (ESS) that all three participants were satisfied with. To validate the EGT model, a numerical simulation carried out. Through the results of this study, the policymaker can determine the optimal rate of incentives and penalties, at the same time encouraging the other two participants to participate in the PPP project.

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REFERENCE

[1] Stork, J. (1975). Middle East oil and the energy crisis.
[2] Hill, M. K. (2010). Understanding environmental pollution. Cambridge University Press.
[3] Nordhaus, W. D., & Boyer, J. (2000). Warming the world: economic models of global warming. MIT press.
[4] Rhodes, C. J. (2016). The 2015 Paris climate change conference: COP21. Science progress, 99(1), 97-104.
[5] Klijn, E. H., & Teisman, G. R. (2003). Institutional and strategic barriers to public—private partnership: An analysis of Dutch cases. Public money and Management, 23(3), 137-146.
[6] Dou, W. (2015). Research on the three-party evolutionary game model among the government, enterprises and the society in corporate social responsibility. Mathematical modelling of Engineering Problems, 2(4), 29-34.
[7] Hofbauer, J., & Sigmund, K. (2003). Evolutionary game dynamics. Bulletin of the American mathematical society, 40(4), 479-519.
[8] Simon, H. A. (1997). Models of bounded rationality: Empirically grounded economic reason (Vol. 3). MIT press.