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Analysis of Private Investors Conduct Strategies by Governments Supervising Public-Private Partnership Projects in the New Media Era

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Abstract: Private investors and governments need to cooperate in public–private partnership (PPP) projects but the private investors may be in pursuit of their own profit by conducting defaulting behaviors which causes various environmental problems and economic risks. However, the information asymmetry between them makes it difficult to supervise the behaviors of private investors. The development of internet and social media creates new environment for the information spread and people are using new media increasingly in the current society, providing an inexpensive and viable way for the public to participate in PPP projects. We constructed a dynamic evolutionary model to analyze the behaviors strategies of governments and private investors in the new media era and then analyzed how important factors influence the behavior trends of governments and private investors. These findings could provide meaningful insight to improve supervision status by using the new media environment and predict the behaviors of governments and private investors in PPP projects, which would be conductive for the governments to supervise the private investors in PPP projects more efficiently.

Keywords: PPP scheme; private investors conduct strategies; supervision behaviors of government; new media era; evolutionary simulation

1. Introduction

Public-private partnership (PPP) scheme has been applied in transportation [1–5], water industry [6–10], power supply [11], waste management [12] and other infrastructure projects [13]. PPPs promote economic growth, improve the living environment [14] and meanwhile reduce the pressure of infrastructure construction on the tightening fiscal budget [15–17]. PPP, as a unique financing scheme, has been adopted to procure infrastructure and provide public services in some countries [18,19], but it has also currently been plagued with controversy in recent years because of a number of unsuccessful cases in some countries, for example, Edinburgh Trams in the UK and Sothern Cross Railway Station and Latrobe Regional Hospital in Victoria, Australia [20]. As a key participant in PPP

projects, the governments play an important role in PPP projects, so good governance is a vital factor for the success of PPP [17,21,22].

However, the private investors are mainly concerned with their own interest and may not necessarily have the public interest as a primary goal [23,24]. In pursuit of maximizing their own profit, private investors may conduct defaulting behaviors which violate laws, regulations and contracts and should be punished once discovered by the governments (such as bribery, cut corners, low quality service, etc.). A lot of defaulting behaviors has been discovered in PPP projects and poses a huge threat to the sustainable development of the society. For example, in a sewage treatment project of Wuda industrial park, the sewage treatment quality was not up to standard and even some untreated sewage was drained to the Yellow River. One of the key issues for governments in PPPs is the extent to which the governments can overcome inherent conflicts of interest between their partners [25]. When the defaulting behaviors conducted by private investors in PPP projects are not known by the governments, the private investors can obtain unjust benefit at the expense of undermining the public benefit. Because it is difficult for the governments to access accurate information about the behaviors of private investors [26,27], the information asymmetry between the two parties poses a challenge for the governments, the leading party in the supervision of PPP projects. PPP projects concern infrastructure and public services [28] and public products or services provided by PPP projects are closely related to social and public interest. Therefore, the defaulting behaviors in PPP projects impair the public benefit and even cause potential dangers to the society, such as major accidents and environmental pollutions. The governments play a key role in the supervision of PPP projects and thus have to pay high attention on how to improve the supervision efficiency. The rapid development of the internet and social media (such as Weibo, Weixin, Twitter, Facebook) creates platforms for the public to express their opinions conveniently. New media are types of media that formulated after the traditional media (such as books, magazines, newspaper, television), while new media mainly rely on computers and internet [29,30]. New media have promoted the public engagement in supervision of food security [31], environmental protection [32], anti-corruptions [33] and so forth and have achieved fruitful results. New media have irreplaceable position in current information society [34]. The information can spread online expeditiously and thus more and more people begin to use the new media, which provides an inexpensive and convenient way for the public to participate in PPP projects. New media should be used more to improve the public engagement in construction projects [35]. In the supervision of PPP projects, when some citizens find the defaulting behaviors, they can expose the phenomena through new media and this type of news always raises high attention from the governments and the public. The public participation in supervision of PPP projects can help the governments to supervise the private investors better.

Due to the importance of governments in PPP projects, some previous studies [22,36,37] have been conducted on the governance issues and put forward a lot of recommendations for the governments. Most of the previous studies mainly focused on the governance factors affecting the success of PPP project based on survey or case analysis. However, on the one hand, very few scholars have conducted research on behaviors or decision-making strategies for the parties in supervision of PPP projects. On the other hand, there is no paper published on how new media influence the supervision of PPP projects. This paper aims to explore the behavior strategies of the governments and private investors when making decision on defaulting behaviors in the new media era and predict the long-term behavior trend of both parties in the supervision in PPP projects. It will provide meaningful reference for the governments to analyze the private investors conduct strategies in the current new media era. This paper is organized as follows. The Section 2 is the literature review which analyzes the studies related to the supervision, new media and evolutionary game. Section 3 firstly describes the problem of defaulting behaviors supervision, selects important factors based on the literature review and explains the reason why the evolutionary game theory is chosen as the method in this paper. Then the selected factors are used to establish an evolutionary game for defaulting behavior in PPP projects. Section 4 analyzes the different scenarios derived from the built dynamic evolutionary

model. In Section 5, a numerical simulation is adopted to analyze how the important factors influence the behavior strategies of governments and private investors in PPP projects. Based on the findings, we discuss further how to improve the supervision efficiency in Section 6 and put forward some policy recommendations in Section 7.

2. Literature Review

2.1. Governmental Supervision of PPP Projects

Governments act not only as a contracting party but also as a regulating authority in PPP projects [38]. The capacities, expertise and commitment level of governments are usually reflected in structuring and implementing process of PPP projects [36]. Thus, good governance has been perceived as an essential element for PPPs by many previous researchers [21,39,40]. The roles and involvement of the governments are greatly different depending on the legal environment of the host countries [41]. Petersen compared the supervision mechanism of PPP projects in Denmark and Ireland and found that the supervision mechanism of PPP projects has obvious distinctions under different political and economic systems [42]. Lohmann and Rötzel used the survey data on PPPs of the German Armed Forces to prove that to align objectives of the government and private investors can reduce the opportunism behaviors in renegotiations and draw a conclusion that effective supervision could reduce the opportunism behaviors in PPP projects [43]. Shash pointed out that unreasonable risk allocation would lead to an increase in opportunism behaviors and thus a reasonable incentive mechanism is significant for the design of construction contract [44]. Liu et al. conducted research on the opportunism behaviors in the operational period of PPP projects and believed that there was a periodic change in the opportunism behaviors [45].

In terms of the position and responsibility of governments in PPP projects, power and resources are delegated by citizens to the governments in order to provide public services for citizens and thus governments are generally regarded as the representative of the public in PPPs [46], so the governments have the responsibility to supervise the behaviors of private investors so as to protect the public benefit. Kumaraswamy and Zhang conducted research on governmental supervision and management in the PPP projects and argued that the success of PPP projects should not be completely guaranteed by the conscious behaviors of private investors [47], implying that the governments should take their responsibility of supervision in PPP projects. Hofmeister and Borchert stated that insufficient understanding of each other's position, or political behaviors by governments, could jeopardize the PPP overall and suggested that some basic system of PPP governance supervision needed to include behavioral rules for the partners, which should encompass appropriate sanctions and penalties within the contract. Their point was supported by Friend [23]. Wu et al. contended that governments of PPPs were responsible for ensuring the quality of public service and efficiency of public resources consumption in order to satisfy the asset end-users and general population respectively [48].

2.2. Use of New Media in Construction Industry

New media are playing a significant role in the current society [34] and are changing the model of communication in construction industry. The new medial makes workers willing to show their feelings, a lot of construction workers use new media to make contact with their friends and express their emotions about their lives (including their family, work, etc.) and many construction workers also browse online construction-relevant information. More and more construction companies are applying new media in order to enhance visibility and raise brand awareness [49]. Russell et al. [50] put forward that construction companies could use Twitter, Facebook, Googleþ and other social media to present their work and develop relationships with their clients. Minsker et al. [51] stated that social media could be adopted to show input or rate design concepts and to assess stakeholders' opinions about sustainable and resilient infrastructure. Jiang et al. [52] used data collected from Weibo.com to analyze the published words in order to assess the public attitude toward the Three Gorges project,

providing a feasible method to explore the public feeling in large projects. Leung et al. [35] suggested that new media should be used more in construction development projects so as to increase public participation. Wang and Taylor [53] used the human mobility data collected from Twitter to analyze important urban civil engineering problems and proved that human mobility data could be adopted by researchers to study the interdependence relationship between and civil infrastructure and human activity. Tang et al. [54] collected data from Twitter and conducted sentiment analysis, topic modeling, link analysis, geolocation analysis and timeline analysis and then found that the messages posted by four clusters had different characteristics. Jiao et al. [55] analyzed how to use new media to communicate information related to project management, such as schedules, progress monitoring data and work assignments. The method proposed in this paper was useful to integrate useful project data with BIM (Building Information Modeling) and thus was useful to enhance the digital management level of projects.

2.3. Use of Evolutionary Game Theory in Construction Industry

Some studies in construction industry have been conducted based on evolutionary game theory in recent years. Eid, et al. [56] used evolutionary game theory to analyze the balance between post disaster insurance plans purchased by resident families, types of plans sold by insurance companies and ex-post disaster relief plans provided by governments. Shi, et al. [57] built an evolutionary game model to find the cooperation tendency of suppliers in the prefabrication construction supply chain and identify its critical influencing factors. Guo, et al. [58] conducted research on the quality supervision activities among construction stakeholders by using evolutionary game theory. Li [59] constructed a mathematical model to enhance cooperation among stakeholders in PPP mega-infrastructure projects. Sun [60] constructed a model for construction employers, workers and government to analyze their attitudes towards vocational skills trainings. Feng et al. [61] studied the partnership between prefabricated producers using an evolutionary game theory so as to strengthen the cooperative relationship between them and proved that reasonable punishment and incentive mechanisms can help to reduce the cost in the supply chain of prefabricated construction. Guo and Li [62] built a three-party game model for the old community renovation based on the evolutionary game theory and conducted evolutionary path for each participant.

3. Problem Description and Model Establishment

3.1. Problem Description

The governments and the private investors need to cooperate in PPP projects but the private investors may conduct defaulting behaviors with the intent of pursuing the maximization of their own profits [23,24], which makes the governmental supervision of private investors indispensable. However, the informational asymmetry makes the supervision difficult for the governments [26,27]. In the current new media era, various new media are used increasingly by citizens to obtain information and communicate with others, so the new media provide a viable way for the public engagement in PPP projects.

In the supervision of PPP projects, governments play a leading role in this model and the public participation makes the governmental supervision more efficient. When the governments discover the defaulting behaviors of the private investors, there will be punishment on the private investors. When one or more citizens discover the defaulting behaviors which have not discovered or published by the governments, they can use new media to publish news related to the discovered defaulting behaviors. In this way, the governments and the public will know the defaulting behaviors in PPP projects and the governments will punish the private investors for the discovered defaulting behaviors. When the defaulting behaviors are found by neither the governments nor any citizen, the governments cannot punish the private investors.

3.2. Evolutionary Game Theory between Government and Private Investors

Game theory is regarded as a powerful tool to address strategic interaction and analyze competition, conflict, or cooperation between multiple entities [63]. Game theory has already been applied in biology, economics, political science, computer science and other areas to deal with strategic interaction problems between individuals, organizations and countries [56,64]. Evolutionary game theory originates from biological evolutionism [65] and meanwhile combines the essence of game theory. The players in traditional game theory are assumed to be completely rational, while evolutionary game theory assumes that the players in the game are boundedly rational and adapt their selection through their continuous learning activities, which will generate a dynamic change of the probability of each selected strategy [66]. There are two core concepts in evolutionary game theory, namely Evolutionary Stable Strategy (ESS) and replicator dynamic equation. Its theory is similar to "survival of the fittest" which was put forward by Darwin. Players with better-than-average payoffs are more likely to survive in the game, while other players with less-than-average payoffs adjust their strategic choices by observing and imitating the other players who have obtained better-average payoffs [67].

The activities in PPP projects can be considered as games between governments and private investors [68]. The governments and the private investors are both boundly rational, so they have trouble choosing the optimal strategies at the beginning. Meanwhile, they are both continuous leaning parties in PPP projects and always adjust their own strategies to optimize their benefit according to the experiences accumulated as times goes on [69]. All of these make the supervision process of defaulting behaviors in the whole projects become a dynamic game between the governments and private investors and the public participation makes the supervision more complicated. If the governments can take advantage of the new media to involve public supervision in PPP projects, the supervision will be more efficient. The evolutionary game theory, as a typical dynamic evolutionary theory, provides a useful method to analyze the dynamic game between the different parties. In this paper, we chose incentive mechanism [44,70], punishment measure [45], supervision cost [45], discovering probability, public participation [35] and new media exposure as the main factors influencing strategies on the defaulting behaviors in order to construct a dynamic evolutionary model in the next section to analyze the behavior strategies of the governments and private investors in PPP projects.

3.3. Model Establishment

Assumption 1: The two participating groups in the game model are governments and private investors and both of them are bounded rational groups. The governments' strategy set is (weak supervision, strong supervision); while the private investors' strategy for defaulting behaviors set is (default, no to default). As it is known to all, behaviors which default laws, regulations and contracts exert negative impact on the outcome of PPP projects. Players from both groups make independent decisions based on their own judgments after comparing the values of different strategies. During the entire game process, players make adjustments to their strategy choices.

Assumption 2: R is assumed as the project output of private investors when the private investors do not conduct defaulting behaviors, the income of the private investors is expressed as $F_0 + iR$, where F_0 means subsidy and fixed payment given by the governments when certain basic conditions are satisfied. i means the sharing ratio of project output for private investors and $0 \leq i < 1$. In some PPP projects, apart from the fixed payment, the private investors can also gain a certain sharing ratio of the output of projects. Therefore, the output assigned to the governments is $(1-i)R$. It should be noticed that when only fixed payments is included and no income sharing is offered to the private investors in the signed contracts, i is 0 here.

Assumption 3: If private investors conduct defaulting behaviors, the governments may discover them in supervision, or may not. If the defaulting behaviors are known by the governments, the private investors will be punished. However, because of the informational asymmetry, it is possible that

the governments may never discover the defaulting behaviors which have been conducted by the private investors.

s is assumed as the profit that the private investors gain by conducting defaulting behaviors in PPP projects and the damage coefficient is h. The output of private investors in the project will decrease by hs because of defaulting behaviors and therefore the output of private investors can be expressed as $R' = R - hs$.

Assumption 4: Consider the incomes of both parties when the private investors conduct defaulting behaviors. When defaulting behaviors conducted by private investors are not known by the governments, the income of private investors is $F_0 + iR' + s = F_0 + i(R - hs) + s$. However, it is also possible that the governments find the defaulting behaviors of private investors in some way. In such case, the income of private investors in this project can be expressed by $F_0' + iR' + s - khs = F_0' + i(R - hs) + s - khs$, where k represents the penalty coefficient of the defaulting behaviors and F_0' is a new but lower subsidies or payments offered by the governments after discovering defaulting behaviors. It can be easily known from the practice that $F_0' \leq F_0$, indicating that there is a penalty on the private investors for the defaulting behaviors discovered by the governments. This parameter in the model can be set as different values as needed. When F_0' is smaller than F_0, there exists a fixed penalty on the fixed payment. However, when the penalty is only related to the damage of defaulting behaviors to the output of PPP project (hs) and the penalty coefficient (k), F_0' is equal to F_0 and the penalty of defaulting behaviors is khs.

Assumption 5: When the governments strengthen supervision in PPP projects, the probability of discovering defaulting behaviors by the governments should be higher but in the meanwhile the strong supervision cause an increase in the supervision cost (including the human, physical and financial cost). Suppose that the governmental supervision cost under weak supervision is C_g, the cost under strong supervision is C_g' and that $C_g' > C_g$.

Assumption 6: It is assumed that strong supervision may generate additional benefits for the governments as a result of hard work, such as some certain subsidies, award, or higher work efficiency which will bring other material or spiritual rewards, higher recognition and even promotion opportunities. Here, M means the sum of the encouragement for strong supervision, including all sorts of material and spiritual reward and subsidies. If there is no reward or subsidy, M should be set as 0. Generally speaking, M is not equal to 0 in reality.

When the private investors do not conduct defaulting behaviors and the governmental supervision is weak, the income of the governments is $(1 - i)R - F_0 - C_g$. While the supervision of the governments is strong and the private investors choose not to perform defaulting behaviors, there will be no defaulting behavior discovered, so the income of the governments will be $(1 - i)R - F_0 - C_g' + M$.

Assumption 7: The discovering probability of defaulting behaviors is closely related to the governments' supervisory measures. The different discovering probabilities of defaulting behaviors under weak governmental supervision and strong governmental supervision are respectively assumed as p_1 and p_2 and it is obvious that p_1 is smaller than p_2.

Assumption 8: The public participation in supervision is also considered in this model. The probability of the defaulting behaviors discovered by some citizens is assumed as p_3. When some citizens find the defaulting behaviors, they will use new media to publish news related to the discovered defaulting behaviors so as to expose the private investors and protect the public benefit and then the governments and the public will also know the defaulting behaviors. The private investors will also be punished. Only if the defaulting behaviors are neither discovered by the governments nor published by the new media, the private investors will not be punished.

According to the **Assumptions 7 and 8**, it can be derived that when the private investors conduct defaulting behaviors and the governments conduct weak supervision, the probability that both of the governments and citizens fail to discover defaulting behaviors is $(1 - p_1)(1 - p_3)$, representing that the conducted defaulting behaviors are not found, there will be no punishment on private investors. Under such situation, private investors successfully make unjust benefit. If there is no

defaulting behavior discovered under weak supervision, the income of the governments is expressed as $(1-i)(R-hs)-F_0-C_g$.

On the contrary, if the defaulting behaviors are found by the governments, various measures will be taken to punish the private investors. When the defaulting behaviors are discovered first by some citizens, after they publish news though new media, the governments and the public will know the defaulting behaviors from the news. The possibility of this case under weak supervision is $(1-p_1)p_3$, representing that the public knows the defaulting behaviors first from the new media rather than governments. At this time, the public will be skeptical about the supervision efficiency of the governments, so it will impair the reputation and public trust of the governments. The reputation lost value is assumed as L. After discovering the defaulting behaviors, the governments will punish private investors and publish relevant news and the income of the governments under weak supervision will be $(1-i)(R-hs)-F_0'-C_g+khs-L$. If the governments find and expose the defaulting behaviors not later than the new media, there will be no reputation lost. The possibility of this situation is p_1 and the income of the governments under weak supervision is $(1-i)(R-hs)-F_0'-C_g+khs$. According to the above analysis, when the defaulting behaviors are performed by private investors under weak governmental supervision and public supervision, the mean income of governments is expressed as $(1-i)(R-hs)-F_0'-C_g-(F_0-F_0')(1-p_1)(1-p_3)+(p_1+p_3-p_1p_3)khs-(1-p_1)p_3L$. Similarly, under strong governmental supervision and public supervision, the mean income of governments is $(1-i)(R-hs)-F_0'-C_g'+M-(F_0-F_0')(1-p_2)(1-p_3)+(p_2+p_3-p_2p_3)khs-(1-p_2)p_3L$.

When the private investors conduct defaulting behaviors under weak governmental supervision and public supervision, it can be derived that the expected income of private investors is $F_0+i(R-hs)+s+(F_0'-F_0)(p_1+p_3-p_1p_3)-khs(p_1+p_3-p_1p_3)$ and that the expected income of private investors when conducting defaulting behaviors under strong governmental supervision and public supervision is $F_0+i(R-hs)+s+(F_0'-F_0)(p_2+p_3-p_2p_3)-khs(p_2+p_3-p_2p_3)$.

Assumption 9: In addition, x and $1-x$ respectively mean the proportions of strong governmental supervision and weak governmental supervision. y is the proportion that private investors do not carry out defaulting behaviors in PPP projects and therefore the probability of conducting defaulting behaviors is $1-y$. It can be known from the definitions of x and y that $0\le x\le 1$ and $0\le y\le 1$.

Based on the above analysis, the mean incomes of both governments and private investors can be analyzed when different strategies are adopted. When making the decisions about supervision strategy, the governments do not know whether private investors will carry out defaulting behaviors. Therefore, each of the two strategies is likely to be chosen. If strong supervision is adopted, the governments can discover private investors' defaulting behaviors with a higher probability. Penalties on private investors can compensate for the loss caused by the defaulting behaviors to some extent. However, it is also possible that after strengthening supervision and paying higher supervision costs, the governments still do not discover the defaulting behaviors of the private investors in this project. Suppose that $\overline{V_1}$ represents the expected income when the governments choose weak supervision, $\overline{V_2}$ indicates the expected income of the governments under strong supervision and the overall mean income of governments is $\overline{V}$. The three parameters can be respectively calculated by Equations (1)–(3).

$$\begin{aligned}\overline{V_1} &= [(1-i)R-F_0-C_g]y+[(1-i)(R-hs)-F_0'-C_g-\\ &(F_0-F_0')(1-p_1)(1-p_3)+(p_1+p_3-p_1p_3)khs-(1-p_1)p_3L](1-y)\\ &= (1-i)R-F_0'-C_g-(F_0-F_0')y-(1-i)(1-y)hs-\\ &(F_0-F_0')(1-p_1)(1-p_3)(1-y)+(p_1+p_3-p_1p_3)(1-y)khs-\\ &(1-y)(1-p_1)p_3L\end{aligned} \tag{1}$$

$$\begin{aligned}\overline{V_2} &= [(1-i)R-F_0-C_g'+M]y+[(1-i)(R-hs)-F_0'-C_g'+M\\ &-(F_0-F_0')(1-p_2)(1-p_3)+(p_2+p_3-p_2p_3)khs-(1-p_2)p_3L](1-y)\\ &= (1-i)R-F_0'-C_g'-(F_0-F_0')y-(1-i)(1-y)hs-\\ &(F_0-F_0')(1-p_2)(1-p_3)(1-y)+(p_2+p_3-p_2p_3)(1-y)khs-\\ &(1-y)(1-p_2)p_3L+M\end{aligned} \tag{2}$$

$$\overline{V} = (1-x)\overline{V_1} + x\overline{V_2} \tag{3}$$

The private investors are in pursuit of maximization of personal profits, which motivates the private investors in the PPP project to obtain unjust profits by engaging in defaulting behaviors. Meanwhile, private investors also know that the governments will supervise their behavior but on one hand the private investors are not sure whether the governments will adopt weak supervision or strong supervision; and on the other hand, even if the governments adopt strong supervision, it is possible that the defaulting behaviors are not discovered. If the governments discover the defaulting behaviors, there will be punishment on the private investors. When the defaulting behaviors are not discovered, the private investors can benefit from the defaulting behaviors, so the private investors may still have a fluky psychology to perform defaulting behaviors. Suppose that $\overline{U}_1$ denotes the expected income of private investors that can be obtained when not conducting defaulting behaviors, $\overline{U}_2$ is the expected income of private investors when conducting defaulting behaviors and $\overline{U}$ represents the overall mean income of private investors. $\overline{U}_1$, $\overline{U}_2$ and $\overline{U}$ can be calculated according to Equations (4)–(6).

$$\overline{U_1} = (F_0 + iR)(1-x) + (F_0 + iR)x = F_0 + iR \tag{4}$$

$$\begin{aligned}\overline{U_2} = {} & [F_0 + i(R-hs) + s - (F_0 - F_0')(p_1 + p_3 - p_1p_3) - khs(p_1 + p_3 - p_1p_3)](1-x) \\ & + [F_0 + i(R-hs) + s - (F_0 - F_0')(p_2 + p_3 - p_2p_3) - khs(p_2 + p_3 - p_2p_3)]x \\ = {} & F_0 + i(R-hs) + s - [(F_0 - F_0') + khs][(1-p_3)(p_1 - p_1x + p_2x) + p_3]\end{aligned} \tag{5}$$

$$\overline{U} = y\overline{U_1} + (1-y)\overline{U_2} \tag{6}$$

The dynamic changes in the proportions of different strategies chosen by the both parties throughout the entire process are the core of the evolutionary game theory. The change rates of proportions can represent the main feature of the dynamic change. The replicator dynamic equation that determines the proportion of strong governmental supervision can be expressed as Equation (7), where t denotes time and $\frac{dx}{dt}$ means the change rate of proportion of strong supervision chosen by the governments (x).

$$\begin{aligned}F(x) = \tfrac{dx}{dt} = {} & x(\overline{V_2} - \overline{V}) = x(1-x)[C_g - C_g' + M + \\ & (F_0 - F_0')(p_2 - p_1)(1-y)(1-p_3) + khs(p_2 - p_1 - p_2p_3 + p_1p_3)(1-y) \\ & + (p_2 - p_1)(1-y)p_3L]\end{aligned} \tag{7}$$

Likewise, as for the private investors, the replicator dynamic equation that determines the change in the proportion of not conducting defaulting behaviors is expressed as Equation (8).

$$\begin{aligned}\mathrm{G}(y) = \tfrac{dy}{dt} = {} & y(\overline{U_1} - \overline{U}) = y(1-y)\{ihs - s + [(F_0 - F_0') + khs] \\ & [(1-p_3)(p_1 - p_1x + p_2x) + p_3]\}\end{aligned} \tag{8}$$

Based on the above analysis, a two-dimensional dynamic system can be derived, as shown in Equation (9).

$$\begin{cases} \frac{dx}{dt} = x(\overline{V_2} - \overline{V}) = x(1-x)[C_g - C_g' + M + \\ (F_0 - F_0')(p_2 - p_1)(1-y)(1-p_3) + khs(p_2 - p_1 - p_2p_3 + p_1p_3)(1-y) \\ + (p_2 - p_1)(1-y)p_3L] \\ \frac{dy}{dt} = y(1-y)[ihs - s + (F_0 - F_0' + khs) \\ [(1-p_3)(p_1 - p_1x + p_2x) + p_3] \end{cases} \tag{9}$$

4. Equilibrium Points and Stability Analysis

4.1. Equilibrium Points Analysis

The five local equilibrium points of the above system are respectively E_1 (0, 0), E_2 (0, 1), E_3 (1, 0), E_4 (1, 1) and E_5 (x^*, y^*), where

$$x^* = \frac{s - ihs - p_3(F_0 - F_0' + khs)}{(F_0 - F_0' + khs)(1 - p_3)(p_2 - p_1)} - \frac{p_1}{p_2 - p_1} \tag{10}$$

$$y^* = 1 - \frac{C_g' - C_g - M}{(F_0 - F_0')(p_2 - p_1)(1 - p_3) + khs(p_2 - p_1 - p_2p_3 + p_1p_3) + p_3L(p_2 - p_1)} \tag{11}$$

When the conditions $C_g' - C_g - M \geq 0$, $ihs - s + (F_0 - F_0' + khs)[(1 - p_3)p_1 + p_3] \leq 0$ and $ihs - s + (F_0 - F_0' + khs)[(1 - p_3)p_2 + p_3] \geq 0$ are satisfied, E_5 exists. Otherwise, E_5 does not exist here.

The equilibrium points obtained from replicator dynamic equation may not be ESS in the system. According to the method proposed by Friedman [71], the stability of the evolutionary equilibrium points can be analyzed from the local stability of the Jacobian matrix. The Jacobian matrix of the system built here is

$$J = \begin{bmatrix} \frac{\partial F}{\partial x} & \frac{\partial F}{\partial y} \\ \frac{\partial G}{\partial x} & \frac{\partial G}{\partial y} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \tag{12}$$

The values of a_{11}, a_{12}, a_{21} and a_{22} differ in each local equilibrium point and jointly determine the evolutionary process of the system. Among the above equilibrium points, the points where the following two conditions Equations (13) and (14) are both satisfied are the ESS.

$$\text{tr}\, J = a_{11} + a_{22} < 0 \tag{13}$$

$$\det J = \begin{vmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{vmatrix} = a_{11}a_{22} - a_{12}a_{21} > 0 \tag{14}$$

4.2. Stability Analysis

Based on the method proposed by Friedman [71], it can be concluded that the system's ESS point varies significantly under different conditions. The evolution path of this system can be summarized as the following 9 scenarios.

Scenario 1: When $C_g - C_g' + M + (F_0 - F_0')(p_2 - p_1)(1 - p_3) + khs(p_2 - p_1 - p_2p_3 + p_1p_3) + (p_2 - p_1)p_3L < 0$, $ihs - s + (F_0 - F_0' + khs)(p_1 - p_1p_3 + p_3) < 0$, $ihs - s + (F_0 - F_0' + khs)(p_2 - p_2p_3 + p_3) > 0$ and $C_g' - C_g - M > 0$, (0, 0) is the ESS. The stability analysis of local equilibrium points and the phase diagram under *Scenario 1* are respectively shown in Figure 1 and Table 1.

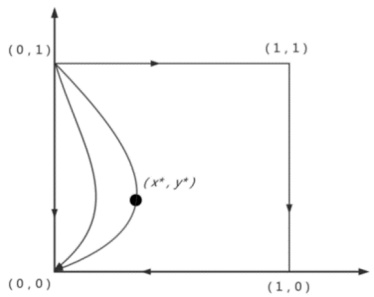


Figure 1. Phase diagram under Scenario 1.

The conditions of *Scenario 1* mean that (1) with the help of new media, the cost difference between the strong governmental supervision and the weak governmental supervision is larger than increase in the expected income (including the penalty of defaulting behaviors and reputation from the public)

when the governments adopts the strong supervision; (2) the income gained from the defaulting behaviors is larger than the expected loss under weak governmental supervision; (3) the income of the defaulting behaviors is smaller than the expected loss under strong governmental supervision; (4) additionally, the increase in the strong governmental supervision cost is larger than the sum of subsides and rewards of hard work. Therefore, the governments lack enough motivation to adopt strong supervision, so the probability of strong supervision will decrease. Meanwhile, the possibility that private investors can benefit from defaulting behaviors is relatively high, so the defaulting behaviors will be conducted more in PPP projects.

Table 1. Stability analysis of local equilibrium points under *Scenario 1*.

LEP	tr$J$	det$J$	Stability
(0, 0)	−	+	ESS
(0, 1)	Uncertain	−	Saddle point
(1, 0)	+	+	Instable point
(1, 1)	Uncertain		Saddle point
(x^*, y^*)	0	+	Central point

Scenario 2: When $C_g - C_g' + M + (F_0 - F_0')(p_2 - p_1)(1 - p_3) + khs(p_2 - p_1 - p_2p_3 + p_1p_3) + (p_2 - p_1)p_3L < 0$, $ihs - s + (F_0 - F_0' + khs)(p_2 - p_2p_3 + p_3) < 0$ and $C_g' - C_g - M > 0$, (0, 0) is the ESS. The stability analysis of local equilibrium points and the phase diagram under *Scenario 2* are respectively shown in Figure 2 and Table 2.

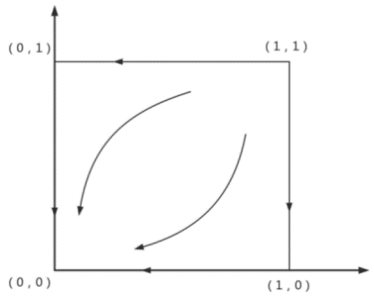


Figure 2. Phase diagram under *Scenario 2*.

The conditions of *Scenario 2* mean that (1) with the help of new media, the increase in supervision cost when adopting the strong supervision is larger than the increase in expected income increase; (2) the income obtained from the defaulting behaviors is larger than the expected loss even under strong governmental supervision; (3) the cost increase in governmental supervision caused by strong supervision is larger than the sum of subsides and rewards of hard work. Under these conditions, even if the governments adopt strong supervision, it is still hard to find the defaulting behavior and meanwhile the low subsidies and rewards make the governments unwilling to adopt strong supervision. Therefore, governments are more inclined to adopt weak supervision and the probability of the defaulting behaviors conducted by private investors will increase as well.

Table 2. Stability analysis of local equilibrium points under *Scenario 2*.

LEP	tr$J$	det$J$	Stability
(0, 0)	−	+	ESS
(0, 1)	Uncertain	−	Saddle point
(1, 0)	Uncertain	−	Saddle point
(1, 1)	+	+	Instable point
(x^*, y^*)	Meaningless		

Scenario 3: When $C_g - C_g' + M + (F_0 - F_0')(p_2 - p_1)(1 - p_3) + khs(p_2 - p_1 - p_2p_3 + p_1p_3) + (p_2 - p_1)p_3L < 0$, $ihs - s + (F_0 - F_0' + khs)(p_1 - p_1p_3 + p_3) > 0$ and $C_g' - C_g - M > 0$, the ESS is (0, 1). The stability analysis of local equilibrium points and the phase diagram under *Scenario 3* are respectively shown in Figure 3 and Table 3.

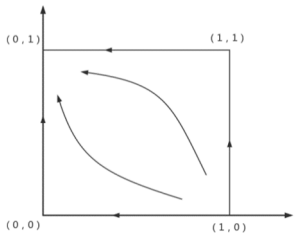


Figure 3. Phase diagram under *Scenario 3.*

The conditions of *Scenario 3* require that (1) with the help of new media, the increase in supervision cost when choosing the strong governmental supervision is larger than increase in the expected income; (2) the income obtained from the defaulting behaviors is smaller than the expected loss even if weak governmental supervision is implemented; (3) the increase in governmental supervision cost caused by strong supervision is larger than the sum of subsides and rewards of hard work. Under these conditions, even if the governments adopt weak supervision, the expected income of conducting defaulting behaviors is still lower than the expected loss, so the probability of conducting the defaulting behaviors will become lower. Low subsidies and reward for the governments cannot compensate the hard word caused by strong supervision and therefore the governments are unwilling to adopt strong supervision.

Table 3. Stability analysis of local equilibrium points under *Scenario 3.*

LEP	tr*J*	det*J*	Stability
(0, 0)	Uncertain	−	Saddle point
(0, 1)	−	+	ESS
(1, 0)	+	+	Instable point
(1, 1)	Uncertain	−	Saddle point
(x^*, y^*)	Meaningless		

Scenario 4: When $C_g - C_g' + M + (F_0 - F_0')(p_2 - p_1)(1 - p_3) + khs(p_2 - p_1 - p_2p_3 + p_1p_3) + (p_2 - p_1)p_3L > 0$, $ihs - s + (F_0 - F_0' + khs)(p_1 - p_1p_3 + p_3) < 0$, $ihs - s + (F_0 - F_0' + khs)(p_2 - p_2p_3 + p_3) > 0$ and $C_g' - C_g - M > 0$, there is no ESS. The stability analysis of local equilibrium points and the phase diagram under *Scenario 4* are respectively shown in Figure 4 and Table 4.

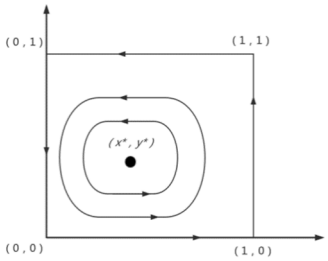


Figure 4. Phase diagram under *Scenario 4.*

The conditions of *Scenario 4* mean that (1) with the help of the new media, the cost difference between the strong governmental supervision and the weak governmental supervision is smaller than the increase in the expected benefit caused by the strong supervision; (2) the income of the defaulting behaviors is larger than the expected loss under weak governmental supervision; (3) the income of

the defaulting behaviors is smaller than the expected loss under strong governmental supervision; (4) the increase in governmental supervision cost is larger than the sum of subsides and rewards of hard work. Under such conditions, the defaulting behaviors still are alluring for some private investors. When the private investors find the signal that the governments are intensifying the supervision, the probability of defaulting behaviors will decrease. When the private investors believe that the governments are adopting weak supervision, the probability will be higher. Thus, there is no ESS under this scenario.

Table 4. Stability analysis of local equilibrium points under *Scenario 4.*

LEP	tr*J*	det*J*	Stability
(0, 0)	Uncertain	−	Saddle point
(0, 1)	Uncertain	−	Saddle point
(1, 0)	Uncertain	−	Saddle point
(1, 1)	Uncertain	−	Saddle point
(x^*, y^*)	0	+	Central point

Scenario 5: When $C_g - C'_g + M + (F_0 - F'_0)(p_2 - p_1)(1 - p_3) + khs(p_2 - p_1 - p_2p_3 + p_1p_3) + (p_2 - p_1)p_3L > 0$, $ihs - s + (F_0 - F'_0 + khs)(p_2 - p_2p_3 + p_3) < 0$ and $C'_g - C_g - M > 0$, the ESS is (1, 0). The stability analysis of local equilibrium points and the phase diagram under *Scenario 5* are respectively shown in Figure 5 and Table 5.

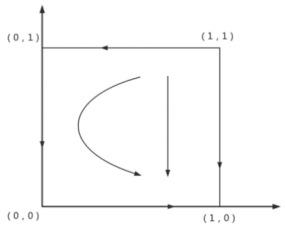


Figure 5. Phase diagram under *Scenario 5*.

The conditions of *Scenario 5* require that (1) with the help of the new media, the cost difference between the strong supervision and the weak supervision is smaller than the increase in the expected income caused by the strong governmental supervision; (2) the income of the defaulting behaviors is larger than the expected loss even when the governments adopt strong supervision; (3) the increase in governmental supervision cost is larger than the sum of subsides and rewards for hard work. Under such conditions, the defaulting behaviors still are every alluring for the private investors. The private investors know that even under strong governmental supervision, the expected income is still high, so the probability of defaulting behaviors will increase in PPP projects. The governments can gain a positive expected net income (including the material and spiritual encouragement) for strengthening supervision even if they do not find defaulting behaviors, so the strategy of strong supervision will be chosen increasingly.

Table 5. Stability analysis of local equilibrium points under *Scenario 5.*

LEP	tr*J*	det*J*	Stability
(0, 0)	Uncertain	−	Saddle point
(0, 1)	Uncertain	−	Saddle point
(1, 0)	−	+	ESS
(1, 1)	+	+	Instable point
(x^*, y^*)	Meaningless		

Scenario 6: When $C_g - C'_g + M + (F_0 - F'_0)(p_2 - p_1)(1 - p_3) + khs(p_2 - p_1 - p_2p_3 + p_1p_3) + (p_2 - p_1)p_3L > 0$, $ihs - s + (F_0 - F'_0 + khs)(p_1 - p_1p_3 + p_3) > 0$ and $C'_g - C_g - M > 0$, the ESS

is (0, 1). The stability analysis of local equilibrium points and the phase diagram under *Scenario 6* are respectively shown in Figure 6 and Table 6.

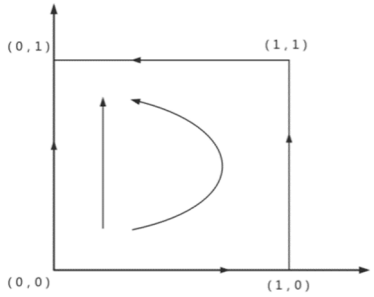


Figure 6. Phase diagram under *Scenario 6*.

The conditions of **Scenario 6** mean that (1) with the help of the new media, the increase in governmental supervision cost is smaller than increase in the expected income when the governments strengthen supervision; (2) the income obtained from the defaulting behaviors is smaller than the expected loss under governmental supervision; (3) additionally, the increase in governmental supervision cost is larger than the sum of subsides and rewards of hard work. The private investors will realize that it is dangerous to conduct defaulting behaviors even if the governments adopt weak supervision and then the defaulting behaviors will be conducted less. The governments lack enough motivation to adopt strong supervision, so the probability of strong supervision will decline.

Table 6. Stability analysis of local equilibrium points under *Scenario 6*.

LEP	tr$J$	det$J$	Stability
(0, 0)	+	+	Instable point
(0, 1)	−	+	ESS
(1, 0)	Uncertain	−	Saddle point
(1, 1)	Uncertain	−	Saddle point
(x^*, y^*)	Meaningless		

Scenario 7: When $C_g - C_g' + M + (F_0 - F_0')(p_2 - p_1)(1 - p_3) + khs(p_2 - p_1 - p_2p_3 + p_1p_3) + (p_2 - p_1)p_3L > 0$, $ihs - s + (F_0 - F_0' + khs)(p_1 - p_1p_3 + p_3) < 0$, $ihs - s + (F_0 - F_0' + khs)(p_2 - p_2p_3 + p_3) > 0$ and $C_g' - C_g - M < 0$, the ESS is (1, 1). The stability analysis of local equilibrium points and the phase diagram under *Scenario 7* are respectively shown in Figure 7 and Table 7.

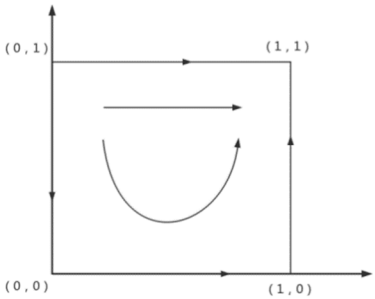


Figure 7. Phase diagram under *Scenario 7*.

The conditions of *Scenario 7* mean that (1) with the help of the new media, the increase in governmental supervision cost is smaller than increase in the expected income when the governments strengthen supervision; (2) the income obtained from the defaulting behaviors is larger than the expected loss under weak governmental supervision; (3) the income of the defaulting behaviors is smaller than the expected loss under strong governmental supervision; (4) additionally, the increase

in governmental supervision cost is smaller than the sum of subsides and rewards of hard work. Therefore, the governments have enough motivation to adopt strong supervision, so the probability of strong supervision will increase. Meanwhile, when the private investors notice that the probability of strong supervision is increasing and the expected net income under strong supervision is negative, the defaulting behaviors will be performed less.

Table 7. Stability analysis of local equilibrium points under *Scenario 7*.

LEP	tr$J$	det$J$	Stability
(0, 0)	Uncertain	−	Saddle point
(0, 1)	+	+	Instable point
(1, 0)	Uncertain	−	Saddle point
(1, 1)	−	−	ESS
(x^*, y^*)	Meaningless		

Scenario 8: When $C_g - C_g' + M + (F_0 - F_0')(p_2 - p_1)(1 - p_3) + khs(p_2 - p_1 - p_2p_3 + p_1p_3) + (p_2 - p_1)p_3L > 0$, $ihs - s + (F_0 - F_0' + khs)(p_2 - p_2p_3 + p_3) < 0$ and $C_g' - C_g - M < 0$, the ESS is (1, 0). The stability analysis of local equilibrium points and the phase diagram under *Scenario 8* are respectively shown in Figure 8 and Table 8.

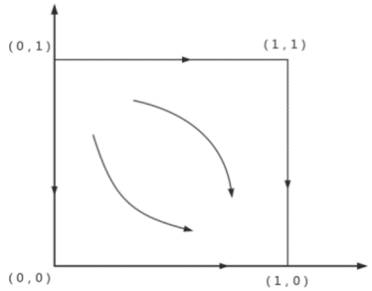


Figure 8. Phase diagram under *Scenario 8*.

The conditions of *Scenario 8* represent that (1) with the help of the new media, the increase in governmental supervision cost is smaller than increase in the expected income when the governments adopt strong supervision; (2) the income of conducting the defaulting behaviors is larger than the expected loss under governmental supervision, even if the governments adopt strong supervision; (3) additionally, the cost increase in governmental supervision is smaller than the sum of subsides and rewards for hard work. Therefore, the governments are highly motivated to adopt strong supervision, so the probability of strong supervision will increase. However, the probability of defaulting behaviors in PPP projects is still increasing, because the expected net income of conducting defaulting behaviors is positive even when the strong governmental supervision is adopted.

Table 8. Stability analysis of local equilibrium points under *Scenario 8*.

LEP	tr$J$	det$J$	Stability
(0, 0)	Uncertain	−	Saddle point
(0, 1)	+	+	Instable point
(1, 0)	−	+	ESS
(1, 1)	Uncertain	−	Saddle point
(x^*, y^*)	Meaningless		

Scenario 9: When $C_g - C'_g + M + (F_0 - F'_0)(p_2 - p_1)(1 - p_3) + khs(p_2 - p_1 - p_2p_3 + p_1p_3) + (p_2 - p_1)p_3L > 0$, $ihs - s + (F_0 - F'_0 + khs)(p_1 - p_1p_3 + p_3) > 0$ and $C'_g - C_g - M < 0$, the ESS point is (1, 1). The stability analysis of local equilibrium points and the phase diagram under *Scenario 9* are respectively shown in Figure 9 and Table 9.

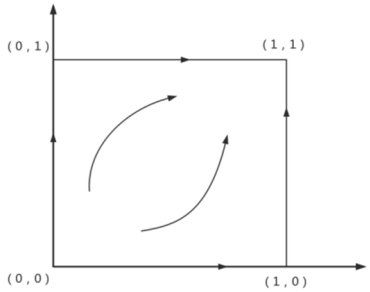


Figure 9. Phase diagram under *Scenario 9*.

The conditions of *Scenario 9* mean that (1) with the help of the new media, the increase in governmental supervision cost is smaller than the expected income increase when the governments strengthen supervision; (2) the income of conducting defaulting behaviors is smaller than the expected loss under weak governmental supervision; (3) the increase in governmental supervision cost is smaller than the sum of subsides and rewards for hard work. Therefore, the governments are enthusiastic to adopt strong supervision, so the probability of strong supervision will increase. Meanwhile, when the private investors find that even if the governments adopt weak supervision, the income of defaulting behaviors is still lower than the expected loss, implying that the risk of defaulting behaviors is relatively high, so the probability of defaulting behaviors will decrease.

Table 9. Stability analysis of local equilibrium points under *Scenario 9*.

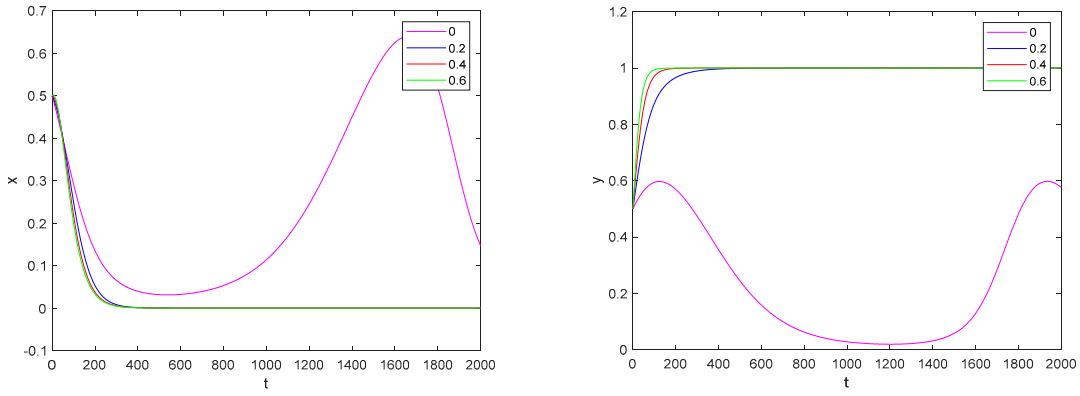
LEP	tr*J*	det*J*	Stability
(0, 0)	+	+	Instable point
(0, 1)	Uncertain	−	Saddle point
(1, 0)	Uncertain	−	Saddle point
(1, 1)	−	+	ESS
(x^*, y^*)	Meaningless		

5. Influences of Important Parameters

Through comparing the different scenarios, it can be seen that the ESS and the evolutionary speed are influenced by the important factors, for example, incentive mechanism, the punishment of defaulting behaviors, the supervision strategy of governments, the exposure of new media, the cost of different supervision strategies and so forth. In order to identify how the important parameters affect the evolutionary behaviors of the governments and private investor, MATLAB R2008a was used to conduct numerical simulations under different conditions.

Set $C_s = 0.1$, $C'_s = 0.15$, $F_0 = 0.5$, $F'_0 = 0.44$, $p_1 = 0.3$, $p_2 = 0.5$, $L = 0.2$, $i = 0.1$, $k = 1.1$, $h = 1.2$, $s = 0.05$, $M = 0.03$ and the initial point is (0.5, 0.5). With the above parameter fixed, Figure 10 depicts the influence of p_3 (the possibility that defaulting behaviors are discovered by some citizens and exposed on the new media) on the defaulting behaviors of private investors. p_3 = 0 means that the public does not participate in the supervision of defaulting behaviors in PPP projects, while $p_3 \neq 0$ means that the public is participating in the supervision of the defaulting behaviors. If some citizens find the defaulting behaviors, they will expose them on the new media and then the public and the governments know defaulting behaviors. When the value of p_3 becomes larger, the behavior choice and the evolutionary speed both change. It can be found in Figure 10b that when p_3 = 0, there is no ESS but when p_3 = 0.2, 0.4 or 0.6, the evolutionary result of private investors becomes "not to default". It is

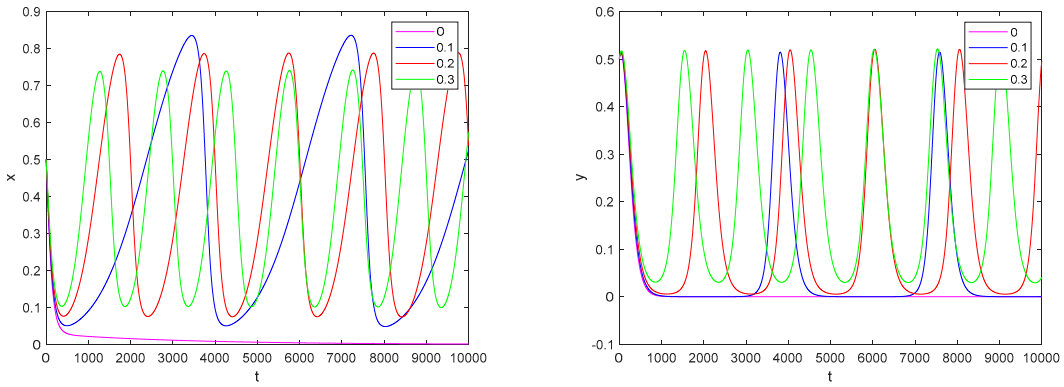
proved that the public participation in supervision can reduce the probability of defaulting behaviors in PPP projects. The public participation increases the discovering probability of defaulting behaviors and the risk of defaulting behavior will be higher for the private investors. The expected net income of conducting defaulting behavior becomes lower, so the defaulting behaviors are less attractive to the private investors. The public participation in PPP projects can also help the governments discover the defaulting behaviors as soon as possible. As depicted in Figure 10a, p_3 also exerts influence on the governmental supervision. When the value of p_3 is respectively set 0, 0.2, 0.4 and 0.6, the public participation in supervision increases the possibility of discovering the defaulting behaviors, so the evolutionary strategy of the governments changes from "no ESS" to "weak supervision".



(**a**) (**b**)

Figure 10. (**a**) Influence of p_3 on governmental supervision; (**b**) Influence of p_3 on defaulting behaviors.

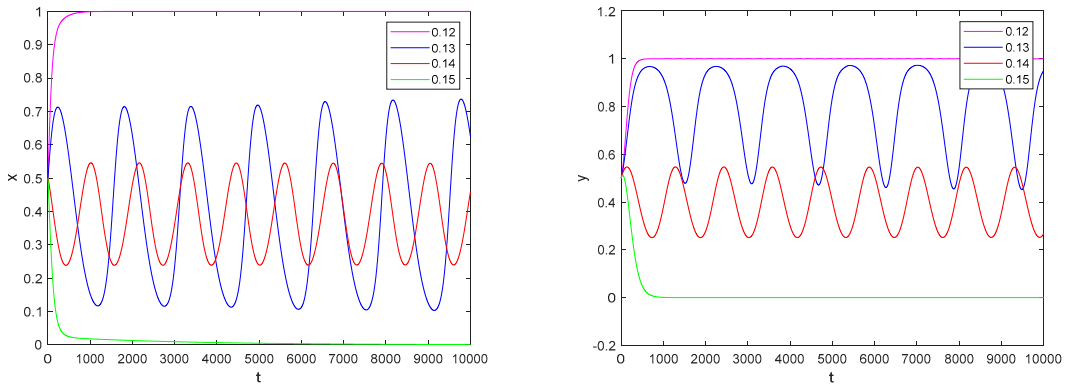
Set $C_s = 0.1$, $C_s' = 0.15$, $F_0 = 0.5$, $F_0' = 0.44$, $p_1 = 0.2$, $p_2 = 0.4$, $p_3 = 0.1$, $i = 0.1$, $k = 1.1$, $h = 1.2$, $s = 0.05$, $M = 0.027$ and the initial point is (0.5, 0.5). With the above parameter fixed, Figure 11a depicts the influence of L (the reputation lost) on the supervision strategy of governments. When $L = 0$, the governments do not consider the reputation loss, or the public pays no attention to the governmental affairs. The development of new media provides a convenient way for all citizens to express their opinions to the public. When $L \neq 0$, the public are concerned with the governmental affairs and the reputation and credibility are considered by the governments. When L increases from 0 to 0.3, evolutionary strategy of the governments changes from "weak supervision" to "no ESS" and the evolutionary speed also changes, indicating that the reputation effect from the public can increase the probability of strong governmental supervision. PPP projects always raise high attention from the public. When a lot of defaulting behaviors are exposed on the new media, the public will be unsatisfied with the governments acting as the representative of the public and the main supervisor in PPP projects. Thus, the reputation effect stimulates the governments to strengthen the supervision. Meanwhile, the evolutionary strategy of the private investors changes from "to default" to "no ESS", as shown in Figure 11b. New media make it more convenient for the citizens to express their opinions and the public is paying unprecedented attention to the governmental affairs, which is also a type of supervision on the governments. More measures should be taken to encourage the public to participate in the PPP projects so as to reduce the defaulting behaviors of private investors.



(**a**) (**b**)

Figure 11. (**a**) Influence of L on governmental supervision; (**b**) Influence of L on defaulting behaviors.

Set $C_s = 0.1$, $F_0 = 0.5$, $F_0' = 0.44$, $p_1 = 0.2$, $p_2 = 0.4$, $p_3 = 0.1$, $L = 0.1$, $i = 0.1$, $k = 1.1$, $h = 1.2$, $s = 0.05$, $M = 0.025$ and the initial point is (0.5, 0.5). With the above parameter fixed, Figure 12a depicts the influence of C_g' (the cost of strong supervision) on the supervision strategy of governments. When C_g' increases from 0.12 to 0.15, the evolutionary strategy changes greatly, implying that the cost of strong governmental supervision is a significant influencing factor when choosing supervision strategy. Figure 12a describes that when the cost of strong supervision gets higher, the governments are less willing to choose it, so the probability of strong governmental supervision becomes lower. Meanwhile, the decrease in the probability of strong supervision will cause an increase in the probability of defaulting behaviors conducted by the private investors, as depicted in Figure 12b. If strong supervision is very expensive, the governments will choose strong supervision less and the risk of discovering defaulting behaviors will be lower for the private investors, so the private investors will conduct more defaulting behaviors to gain high profit in PPP projects.



(**a**) (**b**)

Figure 12. (**a**) Influence of C_g' on governmental supervision; (**b**) Influence of C_g' on defaulting behaviors.

Set $C_s = 0.1$, $C_s' = 0.15$, $F_0 = 0.5$, $F_0' = 0.44$, $p_1 = 0.2$, $p_3 = 0.1$, $L = 0.1$, $i = 0.1$, $k = 1.1$, $h = 1.2$, $s = 0.05$, $M = 0.027$ and the initial point is (0.5, 0.5). With the above parameter fixed, Figure 13a demonstrates the influence of p_2 (the discovering possibility of defaulting behaviors under strong supervision) on the supervision strategy of governments. The evolutionary result changes obviously when p_2 increases from 0.3 to 0.6, showing that the discovering possibility of defaulting behaviors under strong supervision is a significant influencing factor for defaulting behaviors. Figure 13b indicates that the higher the discovering possibility of defaulting behaviors under strong supervision is, the more risk defaulting behaviors takes, so the probability of conducting defaulting behaviors becomes lower. When the defaulting behaviors are discovered by the governments, the private investors will be punished according to the relevant agreement, rules or laws, so the relatively high

probability of discovering defaulting behavior may make private investors conduct fewer defaulting behaviors in PPP projects. The discovering probability is very critical factor for the defaulting behavior. It can also be proved in Figure 13a that the increase in probability of discovering defaulting behaviors under strong supervision can encourage the governments to adopt strong supervision and thus improve the probability of strong supervision.

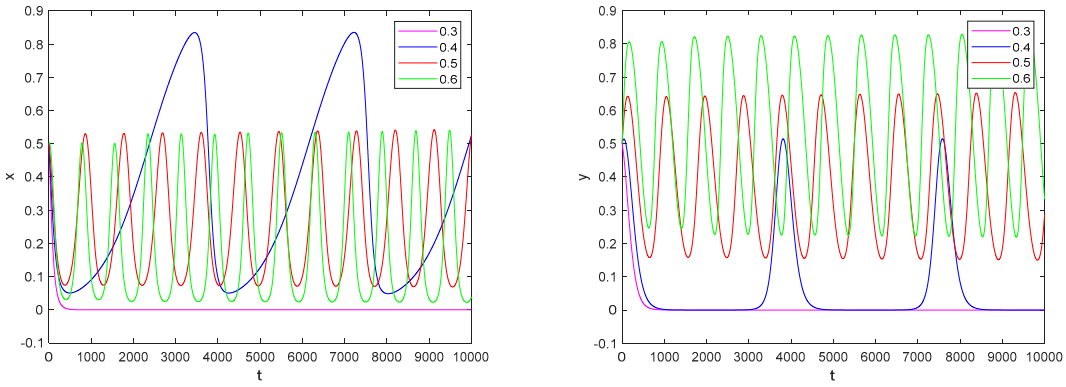


Figure 13. (**a**) Influence of p_2 on governmental supervision; (**b**) Influence of p_2 on defaulting behaviors.

Set $C_s = 0.1$, $C_s' = 0.15$, $F_0 = 0.5$, $F_0' = 0.44$, $p_1 = 0.2$, $p_2 = 0.6$, $p_3 = 0.1$, $L = 0.1$, $k = 1.1$, $h = 1.2$, $s = 0.05$, $M = 0.027$ and the initial point is (0.5, 0.5). With the above parameter fixed, Figure 14b shows the influence of i (the output sharing ratio of private investor) on the probability of defaulting behaviors. When $i = 0$, the private investors just get fixed income and do not share outputs of PPP projects. When $i \neq 0$, the private investors share a certain ratio of outputs in PPP projects and the incomes of private investors vary with the outputs of PPP projects. The output sharing scheme in PPP projects can transfer some risks of output to the private investors and can align the objective of the both parties to some extent, so the private investors will work hard to improve the output. A high output sharing ratio will lead to a larger output sharing loss when the private investors conduct defaulting behaviors. As depicted in Figure 14b that increase in the output sharing ratio of private investors leads to decrease in the probability of defaulting behaviors. Figure 14a describes the evolutionary strategies of the governmental supervision strategy when the value of i is respectively set 0, 0.1, 0.2 and 0.3, implying that the output sharing ratio exerts great effects on the supervision strategy of the governments.

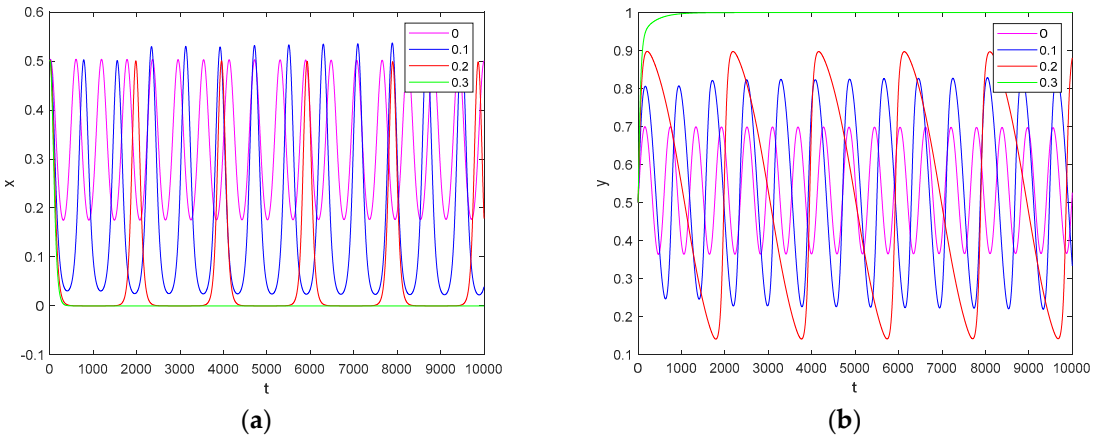
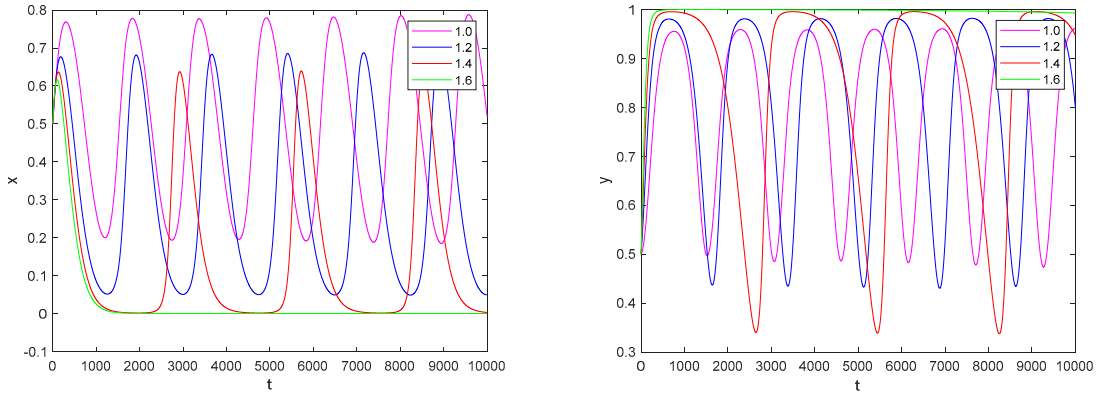


Figure 14. (**a**) Influence of i on governmental supervision; (**b**) Influence of i on defaulting behaviors.

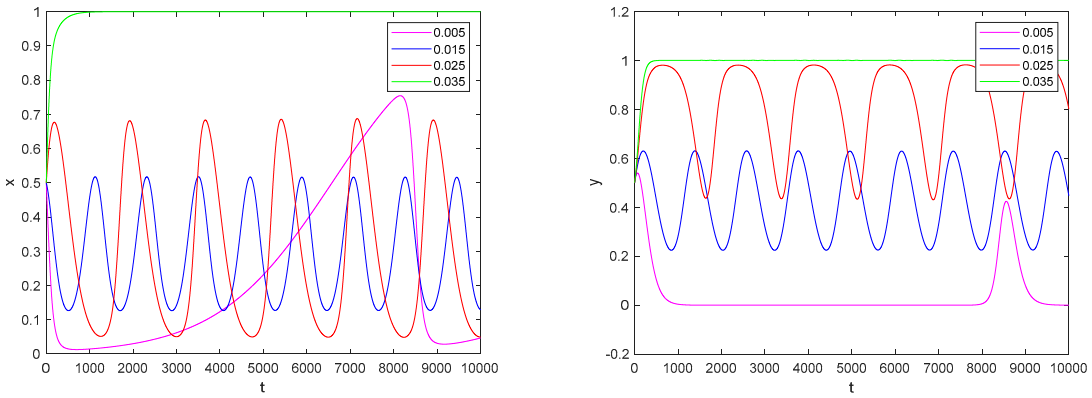
Set $C_s = 0.1$, $C_s' = 0.13$, $F_0 = 0.5$, $F_0' = 0.44$, $p_1 = 0.2$, $p_2 = 0.4$, $p_3 = 0.1$, $L = 0.1$, $i = 0.1$, $h = 1.2$, $s = 0.05$, $M = 0.025$ and the initial point is (0.5, 0.5). With the above parameter fixed, Figure 15b shows the influence of k (the punishment coefficient of defaulting behaviors) on the probability of defaulting behaviors. When k increases from 1.0 to 1.6, the evolutionary result of defaulting behaviors changes from "no ESS" to "not to default", which indicates that the punishment of defaulting behaviors can reduce the defaulting behaviors of private investors to some extent. When the punishment measures for the discovering defaulting behaviors are severer, the expected net income of conducting defaulting behaviors will be lower, so the probability of conducting defaulting behavior will be smaller. The severe punishment measures make the defaulting behaviors less alluring to the private investors. Figure 15a shows that the increase in k also changes the evolutionary strategy of the governmental supervision from "no ESS" to "weak supervision".



(**a**) (**b**)

Figure 15. (**a**) Influence of k on governmental supervision; (**b**) Influence of k on defaulting behaviors.

Set $C_s = 0.1$, $C_s' = 0.13$, $F_0 = 0.5$, $F_0' = 0.44$, $p_1 = 0.2$, $p_2 = 0.4$, $p_3 = 0.1$, $L = 0.1$, $i = 0.1$, $k = 1.1$, $h = 1.2$, $s = 0.05$ and the initial point is (0.5, 0.5). With the above parameter fixed, Figure 16a depicts the influence of M (the rewards and subsidies of strong supervision) on the probability of strong supervision. When M increases from 0.005 to 0.035, the evolutionary result of defaulting behaviors changes from "no ESS" to "strong supervision" in Figure 16a, which indicates that the material and spiritual subsidies can promote the strong supervision of governments. When the material and mental subsidies of strong supervision is improved, the governments are more willing to adopt strong supervision and the probability of strong supervision is relatively larger. Figure 16b shows the evolutionary strategy of defaulting behaviors changes from "no ESS" to "not to default" when M gets larger, indicating that the increase in M can also reduce the probability of defaulting behaviors. The high material and mental subsidies stimulate the governments to adopt the strong supervision in PPP projects, which makes the probability of discovering defaulting behaviors larger. Therefore, the private investors will conduct fewer defaulting behaviors. In order to increase the subsidies of strong supervision, some measures can be taken, such as various material subsidies, honorary title, evaluation and promotion based on the work performance.



(**a**) (**b**)

Figure 16. (**a**) Influence of M on governmental supervision; (**b**) Influence of M on defaulting behaviors.

6. Discussion

The evolutionary results of the numerical simulation demonstrate that the important parameters are influencing the evolutionary paths of the governments and the private investors, including the evolutionary speeds and the ESS. Under different scenarios, the behaviors of the governments and private investors present different change trends, so PPP projects cannot be guaranteed by the conscious behaviors of private investors [47]. To judge which scenarios PPP projects are under can help the governments to predict the behaviors of private investors. If some important parameters change, the evolutionary results may change accordingly. To control the important parameters can help the governments to change the behavior trend in PPP projects, so effective supervision could reduce the defaulting behaviors in PPP projects [43]. The main implications for the industry are put forward here as follows:

(1) The public participation in PPP projects is at a low level and its cost is very expensive [72]. In the new media era, the citizens have various methods to express their opinions and browse relevant news. If the public participation in supervision of PPP projects is improved, the probability of discovering defaulting behaviors will be larger and then the defaulting behaviors will be reduced. The new media provide an inexpensive and viable way to involve the public in PPP projects. The government should take various measures to encourage the public participation in PPP projects. Likewise, we suggest that new media should be used more in construction projects in order to increase public engagement [35]. There are a lot of measures that can encourage the public participation in PPP projects. The government can release information about the PPP projects online as much as possible, including the contracts, the updated progress, the main members, the detailed cost and so forth. Some government workers should be arranged to browse the news published on the new media related to PPP projects, which makes the governments find and deal with the defaulting behaviors as soon as possible, thereby minimizing the reputation lost caused by the defaulting behaviors. The new media make it more convenient for the governments to collect information and communicate with other parties and further improve the supervision efficiency.

(2) The punishments are proved to be valid for reducing the defaulting behaviors, so the governments should set the severe punishments and sanction clauses in contracts, laws and regulations on the defaulting behaviors [73]. The relevant news on the discovering defaulting behaviors and the punishment on them should also be released more often on the newspaper, television or other media. It will remind the private investors the risk that defaulting behaviors are discovered. The severer the punishments on the discovering defaulting behaviors are, the private investors' fear of punishment will be. Then the defaulting behaviors will be conducted less.

(3) The discovering probability of defaulting behaviors is very important for the supervision of PPP projects. When the private investors think it is difficult for the governments to discover the defaulting behaviors, the punishment cannot act as deterrence and the private investors are thereby

vulnerable to the temptation from the defaulting behaviors, so the governments should improve the supervision measures to increase the discovering probability of defaulting behaviors. Meanwhile, it is proved here that the supervision strategies are sensitive to the cost. The governments prefer supervision measures which can increase the discovering probability of defaulting behaviors without too much increase in the cost. In order to control the supervision cost, some advanced technologies can be applied in PPP projects in order to supervise the conduct behaviors of private investors and reduce the defaulting behaviors of private investors.

(4) The incentive mechanism affects defaulting behaviors of private investors. When the payments of private investors are related to the output of PPP projects, the defaulting behaviors will be conducted relatively less, so the governments can take it into consideration when designing incentive mechanism in PPP projects. The output sharing ratio makes the private investors to bear some risk of output. If the private investors know that the defaulting behaviors will impair their own benefit, they will take the conscious measures to reduce the defaulting behaviors.

(5) If the hard work arising from intensifying supervision could be encouraged adequately by material or spiritual measures, the governments would be more willing to choose strong supervision. The governmental authority should pay higher attentions to evaluation of government agencies and offer appropriate encouragement measures for the government agencies which works harder or creates more values. Apart from the material reward, the governments should pay attention to the spiritual encouragement as well. Regarding the spiritual encouragement, some honorary titles and awards is proposed to be offered to the government agencies and thereby the department can gain greater recognition by the public. The promotion in the governments should be related to the evaluation of the work, which motivates the governments to make greater effort in the PPP projects. More information related to the governmental affairs should be published online and then the performances of governmental agencies will be known by the public. In this way, the information transparency will be improved and all citizens will have more chance to supervise government agencies. The government agencies will strengthen the supervision so as to gain high reputation from the public.

7. Conclusions

The informational asymmetry between the governments and the private investors creates opportunities to perform the defaulting behavior successfully and causes various safety risks and environmental risks for the public. The development of new media creates a good environment for the public to engage in the supervision of PPP projects. This paper constructed an evolutionary game model which considers the new media and public engagement in order to analyze the behaviors of the both parties in supervision of PPP projects and different scenarios were obtained. Each scenario had different ESS displaying the change trends of the governments and the private investors. The findings in this paper shows that the public engagement through new media, government reputation, incentive mechanism, the discovering probability of defaulting behaviors and the punishment measures are the main factors for the private investors to make decision on the defaulting behaviors, so the governments should be more cautious with decisions related to such factors. It is worth noting that the discovering possibilities of defaulting behaviors, supervision cost and the encouragement measures for strong supervision are also important for the government to choose the supervision strategy. According to the conditions of different scenarios, the governments can judge which scenarios the states of projects belong to. When the PPP projects are under an unfavorable scenario, the change trend of defaulting behavior keeps growing in PPP projects. To control the important factors will help to change the behavior trend.

We put forward the following policy recommendations for the governments to guarantee the PPP projects go well for the public.

(1) Take various measures to encourage the public to participate in the supervision of PPP projects. If citizens are encouraged to express their opinions through new media, more defaulting behaviors will be exposed on the new media. The defaulting behaviors may be discovered timely and their

adverse influence on the society will be reduced. In the long run, the public will be more energized to participate in the supervision of PPP projects and governmental affairs.

(2) The governments should formulate regulation and laws to punish private investors which have conducted the defaulting behaviors. Some advanced technologies can be applied in the supervision of PPP projects so as to improve the discovering probability of defaulting behaviors. The governments should also pay high attention to the private investors who have conducted defaulting behaviors before.

(3) Enhance the evaluation and the encouragement in government agencies. The desire for promotion will stimulate the government workers to work hard and strengthen the supervision. If more news related to the performance of government agencies is released to the public online, the reputation effect will motive the government agencies to choose strong supervision.

In conclusion, this study presents contributions for PPP projects mainly from the following aspects: (1) identifying the factors affecting the behaviors of private investors and governments; (2) analyzing influence of the public participation through new media on the supervision of PPP projects, (3) providing a method to predict the defaulting behaviors of private investors and the supervision strategies of governments in PPP projects; (4) putting forward strategies for the governments to change unfavorable scenarios to other scenarios so as to change the behavior trends of private investors. This paper fills the literature gap from the above aspects. The findings in this paper can help the governments to discover the potential risks related to supervision and enhance the supervision efficiency of private investors conduct behaviors in PPP projects.

The model developed here is just a simplified scenario of PPP projects, so the model can just reduce the defaulting behaviors of private investors rather than eliminate them. It is the limitation of this paper. When dealing with complex cooperation between different parties in PPP projects, the characteristics of private investors should be analyzed comprehensively. Different type of private investors may have different values of parameters. Based on carefully analysis of the important parameters, the model built here can be applied in more complex projects. The relevant experience in the similar projects can also help the governments to supervise the private investors. Our future work will thereby focus on how to reduce the defaulting behaviors of private investors by using other methods, such as case studies and questionnaires. Supervision of defaulting behaviors is a tough but important issue for the governments and therefore the governments should apply various measures to improve the supervision efficiency according to their dynamic learning experience.

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Notations

All symbols in this paper are listed here:

R	the project output when the private investors do not conduct defaulting behaviors
F_0	fixed payment given by the governments
i	the output sharing ratio for private investors
s	the profit from conducting defaulting behaviors
h	the damage coefficient
R'	the output when conducting defaulting behaviors
k	the penalty coefficient of the defaulting behaviors
F_0'	is the fixed payments after discovering defaulting behaviors
C_g	the governmental supervision cost under weak supervision
C_g'	the cost under strong supervision
M	the sum of the encouragement for strong supervision

p_1 discovering probability of defaulting behaviors under weak governmental supervision
p_2 discovering probability of defaulting behaviors under strong governmental supervision
p_3 the probability of the defaulting behaviors discovered by some citizens
L the reputation lost value
x the proportion of strong governmental supervision
y the proportion that private investors do not carry out defaulting behaviors
$\overline{V}_1$ the expected income when the governments choose weak supervision
$\overline{V}_2$ the expected income of the governments under strong supervision
$\overline{V}$ the overall mean income of governments
$\overline{U}_1$ the expected income of private investors when not conducting defaulting behaviors
$\overline{U}_2$ the expected income of private investors when conducting defaulting behaviors
$\overline{U}$ the overall mean income of private investors

References

1. Xiong, W.; Zhang, X. Concession renegotiation models for projects developed through public-private partnerships. *J. Constr. Eng. Manag.* **2014**, *140*, 04014008. [CrossRef]
2. Gangwar, R.; Raghuram, G. Framework for structuring public private partnerships in railways. *Case Stud. Transp. Policy* **2015**, *3*, 295–303. [CrossRef]
3. Storto, C.L. Ownership structure and the technical, cost, and revenue efficiency of Italian airports. *Util. Policy* **2018**, *50*, 175–193. [CrossRef]
4. Panayides, P.M.; Parola, F.; Lam, J.S.L. The effect of institutional factors on public–private partnership success in ports. *Transp. Res. Part A Policy Pract.* **2015**, *71*, 110–127. [CrossRef]
5. Carpintero, S.; Siemiatycki, M. The politics of delivering light rail transit projects through public-private partnerships in Spain: A case study approach. *Transp. Policy* **2016**, *49*, 159–167. [CrossRef]
6. Storto, C.L. Benchmarking operational efficiency in the integrated water service provision. *Benchmarking Int. J.* **2014**, *21*, 917–943. [CrossRef]
7. Rui, C.M. Comparing private and public performance of portuguese water services. *Water Policy* **2008**, *10*, 25–42.
8. Yang, T.; Long, R.; Cui, X.; Zhu, D.; Chen, H. Application of the public–private partnership model to urban sewage treatment. *J. Clean. Prod.* **2016**, *142*, 1065–1074. [CrossRef]
9. Ma, G.; Du, Q.; Wang, K. A concession period and price determination model for PPP projects: Based on real options and risk allocation. *Sustainability* **2018**, *10*, 703.
10. Storto, C.L. Are public-private partnerships a source of greater efficiency in water supply? Results of a non-parametric performance analysis relating to the Italian industry. *Water* **2013**, *5*, 2058–2079. [CrossRef]
11. Gao, L.; Zhao, Z.Y. System dynamics analysis of evolutionary game strategies between the government and investors based on new energy power construction public-private-partnership (PPP) project. *Sustainability* **2018**, *10*, 2533. [CrossRef]
12. Soukopová, J.; Vaceková, G.; Klimovský, D. Local waste management in the czech republic: Limits and merits of public-private partnership and contracting out. *Util. Policy* **2017**, *48*, 201–209. [CrossRef]
13. Roehrich, J.K.; Lewis, M.A.; George, G. Are public-private partnerships a healthy option? A systematic literature review. *Soc. Sci. Med.* **2014**, *113*, 110–119. [CrossRef] [PubMed]
14. Brinkerhoff, D.W.; Brinkerhoff, J.M. Public–private partnerships: Perspectives on purposes, publicness, and good governance. *Public Adm. Dev.* **2011**, *31*, 2–14. [CrossRef]
15. Matos-Castaño, J.; Mahalingam, A.; Dewulf, G. Unpacking the path-dependent process of institutional change for PPPs. *Aust. J. Public Adm.* **2014**, *73*, 47–66. [CrossRef]
16. Qiu, L.D.; Wang, S. Bot projects: Incentives and efficiency. *J. Dev. Econ.* **2011**, *94*, 127–138. [CrossRef]
17. Zhang, S.; Gao, Y.; Feng, Z.; Sun, W. PPP application in infrastructure development in China: Institutional analysis and implications. *Int. J. Proj. Manag.* **2015**, *33*, 497–509. [CrossRef]
18. Button, K.; Daito, N. Sharing out the costs of a public–private partnership. *Appl. Econ. Lett.* **2014**, *21*, 383–386. [CrossRef]
19. Hodge, G.A.; Greve, C. Public–private partnerships: An international performance review. *Public Adm. Rev.* **2007**, *67*, 545–558. [CrossRef]

20. Liu, J.; Love, P.E.D.; Smith, J.; Matthews, J.; Sing, C.P. Praxis of performance measurement in public-private partnerships: Moving beyond the iron triangle. *J. Manag. Eng.* **2016**, *32*. [CrossRef]
21. Li, B.; Akintoye, A.; Hardcastle, C. Critical success factors for PPP/PFI projects in the UK construction industry. *Constr. Manag. Econ.* **2005**, *23*, 459–471. [CrossRef]
22. Qiao, L.; Wang, S.Q.; Tiong, R.L.K.; Chan, T.S. Framework for critical success factors of bot projects in China. *J. Struct. Finance* **2001**, *7*, 53–61. [CrossRef]
23. Friend, J. Partnership meets politics: Managing within the maze. *Int. J. Public Sect. Manag.* **2006**, *19*, 261–277. [CrossRef]
24. Liu, J.; Gao, R.; Cheah, C.Y.J.; Luo, J. Incentive mechanism for inhibiting investors' opportunistic behavior in PPP projects. *Int. J. Proj. Manag.* **2016**, *34*, 1102–1111. [CrossRef]
25. Bovaird, T. *Public-Private Partnerships in Western Europe and the USA: New Growths from Old Roots*; Palgrave Macmillan: Basingstoke, UK, 2004.
26. Shaoul, J.; Stafford, A.; Stapleton, P. Accountability and corporate governance of public private partnerships. *Crit. Perspect. Account.* **2012**, *23*, 213–229. [CrossRef]
27. Colverson, S.; Perera, O. *Harnessing the Power of Public–Private Partnerships: The Role of Hybrid Financing Strategies in Sustainable Development*; International Institute for Sustainable Development: Winnipeg, MB, USA, 2012.
28. Johnston, J.; Gudergan, S.P. Governance of public-private partnerships: Lessons learnt from an Australian case? *Int. Rev. Adm. Sci.* **2007**, *73*, 569–582. [CrossRef]
29. Manovich, L.; Murray, J.; Wiener, N.; Ascott, R.; Mcluhan, M.; Paik, N.J.; Baudrillard, J.; Negroponte, N.; Deleuze, G. *The New Media Reader*; MIT Press: Cambridge, MA, USA, 2003.
30. Dimmick, J.; Chen, Y.; Li, Z. Competition between the internet and traditional news media: The gratification-opportunities niche dimension. *J. Media Econ.* **2004**, *17*, 19–33. [CrossRef]
31. Peng, Y.; Li, J.; Xia, H.; Qi, S.; Li, J. The effects of food safety issues released by we media on consumers' awareness and purchasing behavior: A case study in China. *Food Policy* **2015**, *51*, 44–52. [CrossRef]
32. Lee, K. The role of media exposure, social exposure and biospheric value orientation in the environmental attitude-intention-behavior model in adolescents. *J. Environ. Psychol.* **2011**, *31*, 301–308. [CrossRef]
33. Bertot, J.C.; Jaeger, P.T.; Grimes, J.M. Using icts to create a culture of transparency: E-government and social media as openness and anti-corruption tools for societies. *Gov. Inf. Q.* **2010**, *27*, 264–271. [CrossRef]
34. Boyd, D. Social media: A phenomenon to be analyzed. *Soc. Media + Soc.* **2015**, *1*. [CrossRef]
35. Leung, M.Y.; Yu, J.; Liang, Q. Improving public engagement in construction development projects from a stakeholder's perspective. *J. Constr. Eng. Manag.* **2013**, *139*, 04013019. [CrossRef]
36. Dixon, T.; Pottinger, G.; Jordan, A. Lessons from the private finance initiative in the UK: Benefits, problems and critical success factors. *J. Prop. Investig. Finance* **2005**, *23*, 412–423. [CrossRef]
37. Liu, T.; Wilkinson, S. Can the pilot public-private partnerships project be applied in future urban rail development? *Built Environ. Proj. Asset Manag.* **2013**, *3*, 250–263. [CrossRef]
38. Liu, T.; Wang, Y.; Wilkinson, S. Identifying critical factors affecting the effectiveness and efficiency of tendering processes in public–private partnerships (PPPs): A comparative analysis of Australia and China. *Int. J. Proj. Manag.* **2016**, *34*, 701–716. [CrossRef]
39. Martins, A.C.; Rui, C.M.; Cruz, C.O. Public–private partnerships for wind power generation: The portuguese case. *Energy Policy* **2011**, *39*, 94–104. [CrossRef]
40. Decorla-Souza, P.; Mayer, J.; Jette, A.; Buxbaum, J. Key considerations for states seeking to implement public-private partnerships for new highway capacity. *Transp. Res. Rec. J. Transp. Res. Board* **2013**, *2346*, 23–31. [CrossRef]
41. Yun, S.; Jung, W.; Han, S.H.; Park, H. Critical organizational success factors for public private partnership projects—A comparison of solicited and unsolicited proposals. *J. Civ. Eng. Manag.* **2015**, *21*, 131–143. [CrossRef]
42. Petersen, O.H. Public-private partnerships as converging or diverging trends in public management? A comparative analysis of PPP policy and regulation in Denmark and Ireland. *Int. Public Manag. Rev.* **2011**, *12*, 1–37.
43. Lohmann, C.; Rötzel, P.G. Opportunistic behavior in renegotiations between public-private partnerships and government institutions: Data on public-private partnerships of the German armed forces. *Int. Public Manag. J.* **2014**, *17*, 1413–1422. [CrossRef]

44. Shash, A.A. Factors considered in tendering decisions by top UK contractors. *Constr. Manag. Econ.* **1993**, *11*, 111–118. [CrossRef]
45. Liu, J.; Gao, R.; Cheah, C.Y.J.; Luo, J. Evolutionary game of investors' opportunistic behaviour during the operational period in PPP projects. *Constr. Manag. Econ.* **2017**, *35*, 137–153. [CrossRef]
46. Hodge, G.A.; Coghill, K. Accountability in the privatized state. *Governance* **2007**, *20*, 675–702. [CrossRef]
47. Kumaraswamy, M.M.; Zhang, X.Q. Governmental role in bot-led infrastructure development. *Int. J. Proj. Manag.* **2001**, *19*, 195–205. [CrossRef]
48. Wu, J.; Liu, J.; Jin, X.; Sing, M.C.P. Government accountability within infrastructure public–private partnerships. *Int. J. Proj. Manag.* **2016**, *34*, 1471–1478. [CrossRef]
49. Hendricks, D. How Construction Companies Are Leveraging Social Media. Available online: http://socialnomics.net/2015/01/29/how-construction-companies-are-leveraging-social-media/i (accessed on 6 December 2018).
50. Russell, J.S.; Menassa, C.C.; Mccloskey, E. Lifelong learning to leverage project and career success: 21st-century imperative. *Pract. Period. Struct. Des. Constr.* **2014**, *19*, 137–141. [CrossRef]
51. Minsker, B.; Baldwin, L.; Crittenden, J.; Kabbes, K.; Karamouz, M.; Lansey, K.; Malinowski, P.; Nzewi, E.; Pandit, A.; Parker, J.; et al. Progress and recommendations for advancing performance-based sustainable and resilient infrastructure design. *Int. Rev. Adm. Sci.* **2015**, *141*, A4015006.
52. Jiang, H.; Lin, P.; Qiang, M. Public-opinion sentiment analysis for large hydro projects. *J. Constr. Eng. Manag.* **2016**, *142*, 05015013. [CrossRef]
53. Wang, Q.; Taylor, J.E. Process map for urban-human mobility and civil infrastructure data collection using geosocial networking platforms. *J. Comput. Civ. Eng.* **2016**, *30*, 04015004. [CrossRef]
54. Tang, L.; Zhang, Y.; Dai, F.; Yoon, Y.; Song, Y.; Sharma, R.S.; Tang, L.; Zhang, Y.; Dai, F.; Yoon, Y. Social media data analytics for the US Construction industry: Preliminary study on twitter. *J. Manag. Eng.* **2017**, *33*. [CrossRef]
55. Jiao, Y.; Wang, Y.; Zhang, S.; Li, Y.; Yang, B.; Yuan, L. A cloud approach to unified lifecycle data management in architecture, engineering, construction and facilities management: Integrating BIMs and SNS. *Adv. Eng. Inf.* **2013**, *27*, 173–188. [CrossRef]
56. Eid, M.S.; El-Adaway, I.H.; Coatney, K.T. Evolutionary stable strategy for postdisaster insurance: Game theory approach. *J. Manag. Eng.* **2015**, *31*, 04015005. [CrossRef]
57. Shi, Q.; Zhu, J.; Li, Q. Cooperative evolutionary game and applications in construction supplier tendency. *Complexity* **2018**, *2018*, 1–13. [CrossRef]
58. Guo, S.; Zhang, P.; Yang, J. System dynamics model based on evolutionary game theory for quality supervision among construction stakeholders. *J. Civ. Eng. Manag.* **2018**, *24*, 318–330. [CrossRef]
59. Li, L.; Li, Z.; Jiang, L.; Wu, G.; Cheng, D.; Rosen, M.A. Enhanced cooperation among stakeholders in PPP mega-infrastructure projects: A China study. *Sustainability* **2018**, *10*, 2791. [CrossRef]
60. Sun, J.; Wang, X.; Shen, L. Chinese construction workers' behaviour towards attending vocational skills trainings: Evolutionary game theory with government participation. *J. Differ. Equ. Appl.* **2017**, *23*, 468–485.
61. Feng, T.; Tai, S.; Sun, C.; Man, Q. Study on cooperative mechanism of prefabricated producers based on evolutionary game theory. *Math. Probl. Eng.* **2017**, *2017*, 1676045. [CrossRef]
62. Guo, B.; Li, J. Research on the evolution of participants collaboration mechanism in PPP model based on computer simulation: Based on the old community renovation project. *J. Supercomput.* **2018**, 1–18. [CrossRef]
63. Han, Z.; Niyato, D.; Saad, W.; Başar, T.; Hjørungnes, A. *Game Theory in Wireless and Communication Networks: Theory, Models, and Applications*; Cambridge University Press: Cambridge, UK, 2012.
64. Son, J.W.; Rojas, E.M. Evolution of collaboration in temporary project teams: An agent-based modeling and simulation approach. *J. Supercomput.* **2011**, *137*, 619–628. [CrossRef]
65. Weibull, J.W. *Evolutionary Game Theory*; Massachusetts Institute of Technology: Cambridge, MA, USA, 1995; Volume 78, pp. 850–853.
66. Turocy, T.; Stengel, B. *Game Theory*; London School of Economics and Political Science: London, UK, 2001.
67. Samuelson, L. *Evolutionary Games and Equilibrium Selection*; MIT Press: Cambridge, MA, USA, 1997.
68. Tserng, H.P.; Russell, J.S.; Hsu, C.-W.; Lin, C. Analyzing the role of national ppp units in promoting PPPs: Using new institutional economics and a case study. *J. Constr. Eng. Manag.* **2012**, *138*, 242–249. [CrossRef]
69. Robinson, H.S.; Scott, J. Service delivery and performance monitoring in PFI/PPP projects. *Constr. Manag. Econ.* **2009**, *27*, 181–197. [CrossRef]

70. Niesten, E.; Jolink, A. Incentives, opportunism and behavioral uncertainty in electricity industries. *J. Bus. Res.* **2012**, *65*, 1031–1039. [CrossRef]
71. Friedman, D. Evolutionary games in economics. *Econometrica* **1991**, *59*, 637–666. [CrossRef]
72. Ng, S.T.; Wong, J.M.W.; Wong, K.K.W. A public private people partnerships (P4) process framework for infrastructure development in Hong Kong. *Cities* **2013**, *31*, 370–381. [CrossRef]
73. Hofmeister, A.; Borchert, H. Public-private partnership in switzerland: Crossing the bridge with the aid of a new governance approach. *Int. Rev. Adm. Sci.* **2004**, *70*, 217–232. [CrossRef]