Evolutionary Game Research on PPP Scheme

The evolutionary game analysis of public-private partnership cooperation scheme under public supervision and application of BIM technology overlapping perspectives: a case study of Xiong'an New Area

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Master thesis

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Preface

It is my pleasure that you could spend time to glance at my research paper, it represents my final results of master graduate project at Eindhoven University of Technology (TU/e), from Construction Management and Engineering track of Built Environment department. Looking back to the unforgettable journey and experience in the Netherlands and Eindhoven, it is mixed and complex emotions that I want to express. The pandemic took apart my study and life into two sperate sections. It was a tough time to isolate us and stay at home to collaborate with others at the beginning. Later, we get used to the online study, discussion, and assignments. It was full of challenges that were faced and solved to enable us to grow, the study and research at TU/e are truly inspire us to think about the relations between technology and people, the connection between the human and society.

Standing from different perspectives to view how policy and technology can influence our behaviors mode and systematical change are my interest and motivation to conduct this research. "Butterfly Effect" can quantifiably describe that a small disturbance and change of a parameter in system can cause completely different ending and outcomes. The evolutionary game theory is the main methodology applied in this research, which combines system dynamics and game theory, as well as biological assumptions.

At this moment, I would like to express to sincere gratitude to the people who support me and help me all the time. First, I would like to express my special thanks to my supervisor Qi Han and Tao Feng for their patient guidance and timely feedback. Without their guidance and help, I could not complete this research and even improve it. It is started from the course R&D that Qi inspire me to study and research game theory and offered me a lot of help to continue the research by using evolutionary game theory in graduation project. Furthermore, I want to thank all my friends in Netherlands and in Eindhoven, as well as in my home country. Without their support on mentally, and encouragement, it would be more difficult for me the get through the isolating times. Lastly, I also hope to thank for my parents who provides me financial support and mental support to enable me to study abroad.

Anyway, at this special moment, after experiencing the unusual year and events, I still believe there is always hope for a better future. Hope you can enjoy and get some inspiration from this work.

Xingyu Fu
May 2021

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Summary

Public-Private Partnership (PPP) can effectively address the issues of shortage of funds in the government sector, as well as promote project execution efficiency and reduce total costs (Grimsey & Lewis, 2002). Globally, this scheme has become one of the most important modes for the construction of public projects in various countries. And in China, with the rapid development of urbanization, the demand for public infrastructure investment by government departments is increasing, and government are also facing growing financial pressures (Wang et al., 2019). However, from the practice cases of the PPP mode in recent years, the performance of PPP projects is not optimistic, and there is even a large amount of failure cases, causing significant losses to the economy and public interest (Jiang, 2016). The problems of PPP projects at present can be attributed to the lack of appropriate supervision mechanism and effective information management system and approach (Friend, 2006). In order to address the existing issues of PPP projects, public supervision and BIM technology are encouraged and applied in PPP projects, to alleviate the pressure failure in PPP projects and promote the cooperation efficiency. Therefore, the main research question is put forward as:

What are the strategies trends of government and private sector as stakeholders in the PPP project by cross-perspectives from public supervision and BIM technology?

In order to identify appropriate methodology to research the main question, as well as the components of construction the behavioral model of local governments. A comprehensive literature review on the contents of PPP scheme, public supervision, BIM technology, evolutionary game theory is conducted. Through the literature research, the main research gap is reflected in the following aspects: 1) Most of previous research apply traditional game theory in PPP scheme, which is based on the hypothesis of "rational players". However, due to the information asymmetry and limited decision-making time during the game, the players can merely perform limited rationality in real world. 2) Plenty of existing research only apply static analysis to find the equilibrium state of stakeholders in PPP scheme. However, PPP projects are influenced by various external factors and may change continuously with the change of environment; 3) There are few papers research and demonstrate the PPP scheme from different perspectives, and empirical analysis are usually applied, lack of simulation based on case study; 4) Xiong'an new area as a rapid developing region, lack of dynamic analysis according to current data of social and economic environment.

Hence, evolutionary game analysis is put forward and implemented as principle research methodology, to model and simulate the strategy trends of local government and private sector on the basis of detailed and true statistics of data. Evolutionary game theory is based on finite rationality hypothesis, which has a strong realistic character that the gamer cannot always precisely calculate the payoff from a decision, and would more rely on the imitating the high-return strategy. Furthermore, evolutionary game analysis and simulation provide a dynamic analysis of game process from the perspective of system. This research demonstrates and explore the PPP scheme from the perspectives of public supervision and

BIM technology. It is because that the public supervision in new media and BIM technology are increasingly popular and discussed in recent years. Last, the evolutionary game models from different perspectives are simulated on the basis of real statistical data by MATLAB.

The model from the perspective of public supervision includes three sub-models: 1) One-time cooperation PPP model; 2) One-time cooperation PPP model; 3) Long-term cooperation PPP model. It aims to cover complete range and types of PPP scheme and based on the classification of one-time game and repeated game scenario in traditional game theory. Moreover, a cross-perspective model from public supervision and BIM technology is constructed to illustrate how the BIM technology impact on PPP scheme under a general situation of public supervision. By constructing the evolutionary models, the duplication dynamic functions and scenario analysis are conducted to identify the critical attributes of PPP scheme. Regarding the datasets of this research, the first source of data is collected from the PPP information center "Annual Report of the Project Database of the National PPP Integrated Information Platform (2018)". The second main data source of target research area is collected from case by case statistical from the database of China PPP center, which covers more than 20 cases of Xiong'an new area.

The simulation results lead to the conclusions that 1) Initial strategy proportion of players can significantly influence the evolutionary stable strategy (ESS); 2) appropriate level of supervision with public supervision can improve the system gross benefits and improve the quality of projects in PPP projects; 3) The attributes of performance payment, Supervision cost rate, Rent-seeking cost are positively correlated with the possibility of ideal events, while the viability gap funding is negatively correlated with ideal events in PPP project; 4) The level of BIM technology applied in PPP project is decisive for strategy choice for players, while the lifecycle management of BIM can contribute to the ideal evolutionary stable strategy.

To sum up everything, in order to answer the research question and optimize the adoption of PPP scheme, the policy recommendation and management implications are put forward as: a) To investigate the initial proportion of strategy for the gamers when designing and formulating the policy related to PPP projects; b) Set priority for the influential parameters in the PPP project optimal, to seek out a feasible supervision mechanism combined with public supervision based on local environment; c) The proportion of performance payment and the coefficient of high-quality product should be raised, and advanced technology such as machine learning could be utilized to reduce the cost of encouraging public supervision and promote the efficiency of the supervision; d) BIM technology is supposed to be used in the entire lifecycle of PPP project, and phase out subsidies could be paid to private sector to reduce transition cost and productivity loss when spreading BIM Technology.

Abstract

This research discusses how to encourage public supervision and promote the efficiency of supervision in PPP project, as well as how to promote the utilization of BIM technology for both local governments and private sectors based on evolutionary game analysis and simulation. First, evolutionary game models on PPP projects from public supervision perspective and BIM technology perspective are constructed to explore the impact mechanism. The model from public supervision perspective contains three sub-models: 1) one-time cooperation model 2) long-term cooperation model, and 3) Nonprofitable model. The causation diagrams based on system dynamic are created to summary how the attributes of public supervision and BIM technology influence the payoff by gamers. Scenario analysis and duplicate function of the evolutionary game model are demonstrated to identify the sensitive parameters in the model. On this basis, the simulation results show that: 1) Initial strategy proportion of players can significantly influence the evolutionary stable strategy (ESS); 2) appropriate level of supervision with public supervision can improve the system gross benefits and improve the quality of projects in PPP projects; 3) The attributes of performance payment, Supervision cost rate, Rent-seeking cost are positively correlated with the possibility of ideal events, while the viability gap funding is negatively correlated with ideal events in PPP project; 4) The level of BIM technology applied in PPP project is decisive for strategy choice for players, while the lifecycle management of BIM can contribute to the ideal evolutionary stable strategy.

Key words: PPP projects, evolutionary game theory, Building information modelling (BIM) technology, public supervision

List of Abbreviations

PPP	Public-Private Partnership
ESS	Evolutionary Stable Strategy
BIM	Building Information Modelling
NGOs	Non-government Organizations
WOS	Web of Science
BOT	Build-Operate-Transfer
DBFM	Design – Build – Finance – Operate
CSFs	Critical Success Factors
VFM	Value for Money
PSC	Public Sector Comparator
VGF	Viability Gap Funding

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Chapter 1 Introduction

1.1 Background

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1 Introduction

1.1 Background

Public-Private Partnership (PPP) refers to the cooperation between government departments and the private sectors to provide public infrastructure facilities or public service by leveraging their respective advantages (Kang, 2013). Through this scheme, it can effectively address the issues of shortage of funds in the government sector, as well as promote project execution efficiency and reduce total costs (World Bank, 2011), which has become an important mode for the construction of public projects in various countries around the world. In order to satisfy the need for more infrastructures required for urbanization development and economic growth, great efforts have been made to promote the public-private partnership scheme (Ross, 2004). And in China, with the rapid development of urbanization, the demand for public infrastructure investment by government departments is increasing, and government are also facing growing financial pressures (Wang et al., 2019). To reduce the financial pressure on government departments and optimize resource allocation, the Chinese government has enacted a series of rules and regulations to gradually phase in private capital into the public infrastructure project. Against this backdrop, the PPP scheme has been widely used and developed in the construction of public projects in China and has become one of the main modes to provide public infrastructure facilities or services (Xu, 2010).

In fact, in the actual operation of PPP projects, the government pursues the maximization of public interest, i.e. providing public facilities or services to meet public demand of citizens and improve social welfare through PPP projects. While the private sector aims to maximize its commercial profit and margin rate, always focus on how to reduce costs, and increase revenue during the entire project operation process (Grimsey & Lewis, 2002). However, before the handover of a PPP project, the private sector is responsible for the execution and construction of the project, and the involvement of government is usually low level, which leads to the problem of deviation from the initial design(Liu et al., 2016). In this case, there is a risk of information asymmetry between the government and the private sector, and the private sector may act opportunistically to the detriment of the project during the long duration of the project in order to maximize its benefits (Friend, 2006).

In PPP projects, investors provide products or services to the public, and government departments represent the interests of the public and monitoring private investors. The public is a social group, including individuals, groups and other social organizations who are stakeholders in PPP scheme. As an indirect group of participants and ultimate beneficiaries in a PPP project, can supervise the execution and operation of the project, both to monitor the investors' business operation activities and to help the government to avoid possible regulatory vulnerability. Alchian & Demsetz (1972) argued that to solve the speculative and irresponsible behaviours of cooperative members in PPP projects, external supervision can be introduced. If the external supervisors could become the enjoyers of surplus-value, which can improve the motivation of supervisors. Wang et al., (2016) argue that by introducing third-party supervision, the content of government supervision is defined to delineate the government's role as both project implementor, project regulator and policymaker in PPP public infrastructure projects. Therefore, Ng et al. (2013) propose a P4 (public-private people partnerships) regulatory mechanism based on public participation from the perspective of government regulatory mechanism, which is used to reduce the cost of government supervision as well as to improve the efficiency of supervision in PPP projects. Thus, public participation plays an essential role in PPP projects (Siemiatycki, 2009; Goodfellow et al., 2013).

However, from the practice cases of the PPP mode in recent years, the performance of PPP projects is not optimistic, and there is even a large amount of failure cases, causing significant losses to the economy in China (Jiang, 2016). The reasons are, except the lack of government responsibility and constant monitor, the lack of effective information management of PPP projects is also an important reason for their failure, such as the absence of similar data on project cost information, progress information, price information, etc., resulting in the lack of practicality of the proposed project in the decision-making stage of the value for money quantitative evaluation; the smooth flow of information in the process of project implementation, information loss, duplication of work and other reasons caused by the project Rework and delays cause significant losses to social capital and lead to inefficient public services or products provided by private investors in PPP projects.

At present, there have been plenty of studies on the application of game theory to PPP projects (Medda, 2007; Javed et al., 2014), however the evolutionary game is the more cutting-edge approach which is yet rarely applied to the analysis of stakeholders in PPP project. Evolutionary game theory is based on finite rationality of participators, which breaks through the assumption of complete rationality of classical game theory and has strong realism, making it possible to carry out scientific explanation, analysis and prediction of various economic phenomena in society, and has played a significant role in promoting the development and application of game theory (Smith, 1974; Maynard, 1973). Evolutionary game theory holds that the participants are finite and rational, and in the game, the participants will learn and mutate from each other and eventually reach equilibrium (Levine et al., 2007). In the operation process of PPP projects, due to the asymmetry of information, the dynamic changes of the environment and the limitations of human thinking, the private sector and the government are finite rational individuals, and the game between them is a process of continuous learning and dynamic evolution.

1.2 Research Question

Xiong'an new area is located approximate 100 kilometers southwest of Beijing. In the near future, this area will house some of the institutions and organizations currently struggling to find space in the crowded capital of China. According to a 2017 study by Morgan Stanley, Xiong'an will draw in as much as ¥2.4 trillion (€300 billion) in investment, and the PPP scheme will be one of the most important project landing methods in this new area. In the next five years, the total annual addition of PPP projects in Xiong'an New Area will exceed ¥100 billion (€12.5 billion). However, there are many stakeholders in PPP projects, and the demands of all parties are not consistent, making it difficult to balance the interests of all parties and establishing a balanced interest distribution mechanism impossible, which makes PPP stakeholders prone to conflict of interest and undermines the enthusiasm of all parties in PPP projects. Therefore, in the process of PPP projects, in order to pursue the maximization of their own interests, all parties are unable to reach the unified goal of synergistic state and jointly promote the smooth promotion of PPP projects.

Meanwhile, there are problems existing in the PPP projects in current China. The failure of PPP projects in China is largely attributed to inadequate government supervision. There are few PPP-related regulations at the national level, mostly at the local level, and the legal effect is relatively low; meanwhile, there may be conflicts between local regulations and local rules. In addition, local government departments, as administrative organs, have special powers, such as government violation of the contract and government inaction. In PPP projects, the government is in a dominant position, and it is difficult for private sector to defend their corresponding rights.

Considering the rapid development and widely applied BIM technology in current engineering projects, as well as the importance of public supervision and participation, evolutionary game theory is applied to analyze the impact of BIM technology on stakeholders and public supervision in the design of the regulatory mechanism of PPP projects in this research. There are two main reasons for selecting the factors of public supervision and BIM technology. Firstly, public supervision is identified as a social influential factor, while the BIM technology is considered as a technical influential factor, they influence the implementation of PPP projects from two different perspectives. Another reason is that a large number of new construction projects in Xiong'an new area adopt PPP mode and BIM platform, which are critical to research the advantages and disadvantages.

At the same time, the structure system of PPP scheme is complex and relatively flexible, involving the participating stakeholders including government, private capital, financial institutions, material and equipment suppliers, contractors, design companies and consultants and relevant networks of stakeholders (Chung et al., 2010; Chowdhury et al., 2011). Among them, the government and the private sector are the two domain participants in the PPP model, and the project company jointly established by both parties is at the core of the PPP model. Figure 1-1 shows the interaction between local government and private sector in PPP scheme.

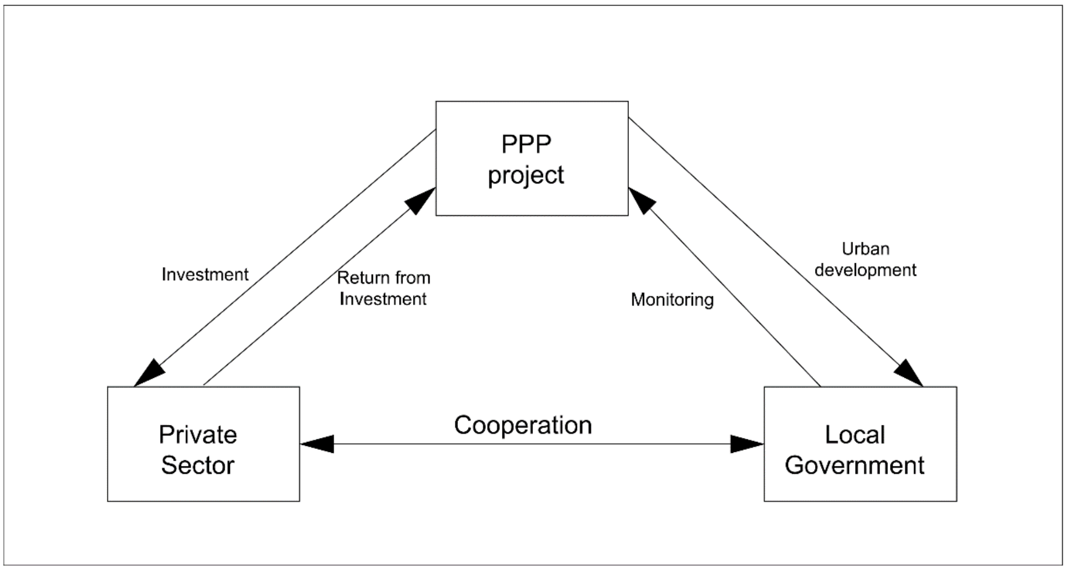

Figure 1- 1 Local government and private in PPP scheme

This study aims to explore whether BIM technology and public active supervision can effectively supervise the opportunism behavior of the private sector in PPP projects, and also provide a reference for the government to take regulatory measures. Moreover, it illustrates the insights of suppressing the speculative behavior of the private sector, promoting operation efficiency, and ensuring public interest in PPP scheme. Through the establishment of game theory model and MATLAB numerical simulation analysis, this study is expected to clarify and investigate the strategy choice and behavior pattern of government and private investors in PPP projects, predict and optimize the policy in PPP projects, thus improve the eventual product/service quality of PPP projects.

Therefore, the main research question is put forward as:

What are the strategies trends of government and private sector as stakeholders in the PPP project by cross-perspectives from public supervision and BIM technology?

The sub-questions are formulated as:

S1: What factors are determining the payoff value of the stakeholders in PPP project?

S2: What is the impact of the public actively supervising the implementation of PPP project in new media area?

S3: How the BIM technology influence the strategies of government and private capital, and will the BIM technology bring benefits for the stakeholders in PPP project? If so, how to promote the usage of BIM in the project?

S4: Is there universal optimal supervision mechanism to monitor and control the behavior of private sector in PPP project, while maximizing the profits and return of entire system?

1.3 Research Guide

Considering the research question and research objective, evolutionary game model and simulation will be utilized as the main approach to reach the research goal, and the research model is elaborated as in Figure 1-1 in next page:

In chapter 2, start from the literature review phase, the related stakeholders and influencing factors for the stakeholders' strategies in the PPP project will be identified and defined in the introduction background section. Moreover, the current research progress of PPP scheme by implementing the game theory analysis is discussed and summarized, as well as the increase in the number of failure PPP cases in recent years, which has led to the emergence of problems in the efficiency and quality of PPP projects that need to be improved. Since this research involves the case study of Xiong'an new area in China, the background, the research of PPP projects mode, and the regulatory policy in recent China are descript in detail. Therefore, the **Sub-Q1** is answered in this part.

Furthermore, Chapter 3 illustrates the general methodology and the methodological Justification of this research. The evolutionary game model and case simulation methods are explained, which explicitly describe the processes of modeling and solving the proposed questions in previous sections in detail. By combining the qualitative and quantitative analysis, the methodology is presented in a comprehensive way.

Additionally, the Chapter 4 and 5 as the main parts of this research, are modelling and solving phase. Based on the results of the previous analysis and assumptions, hypotheses are made to construct an evolutionary game model between the private sector and the government sector and to computationally replicate dynamic equations --By using the method of "analysis of the stability of local equilibrium point"--analysis of the stability of local equilibrium point-drawing the evolutionary path, we arrive at the evolutionary path of strategy choice between the private sector and government sector under different perspective conditions. The **Sub-Q2 and Sub-Q3** are discussed in these two Chapters

In Chapter 6, through data collection and processing, the game evolution paths of strategy choice between private enterprises and government departments in China's PPP projects are simulated by computer. According to the empirical results, the reasons for the decrease in the market share of private enterprises in PPP projects in China are explained. As well as the sensitivity analysis tests different input of the parameters, and also compares the eventually evolutionary stable state of the players in the game under different scenarios. The **Sub-Q4** is answered in this Chapter.

Finally, at the last stage of this research, the implication of the previous results and further research potential are discussed in Chapter 7, the policy suggestions and conclusion of improvement on the PPP projects of Xiong'an experience are popularized in the general level are put forward.

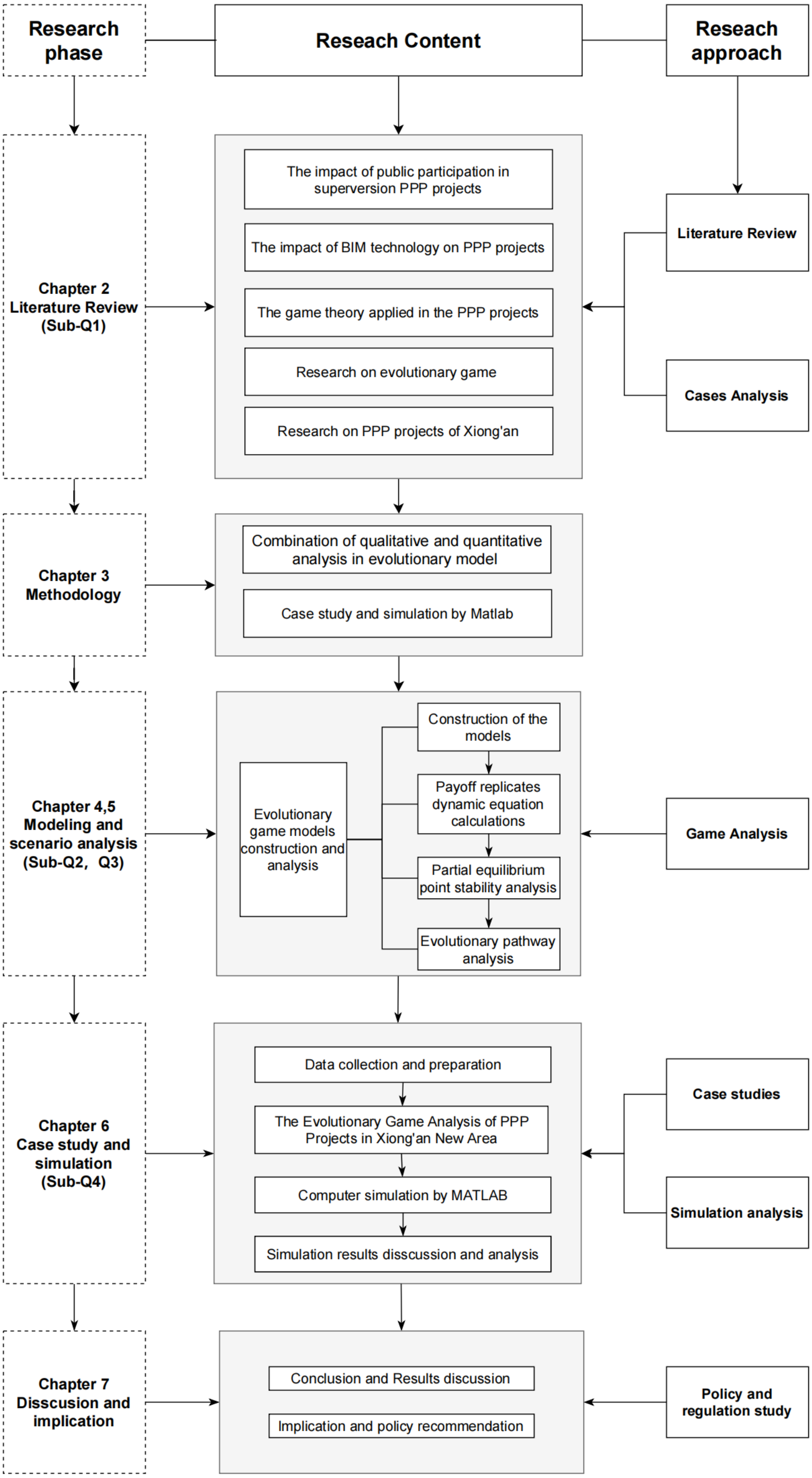

Figure 1- 2 Research process and mode

Chapter 2 Literature Review

2 literature Review

Structure of literature Review

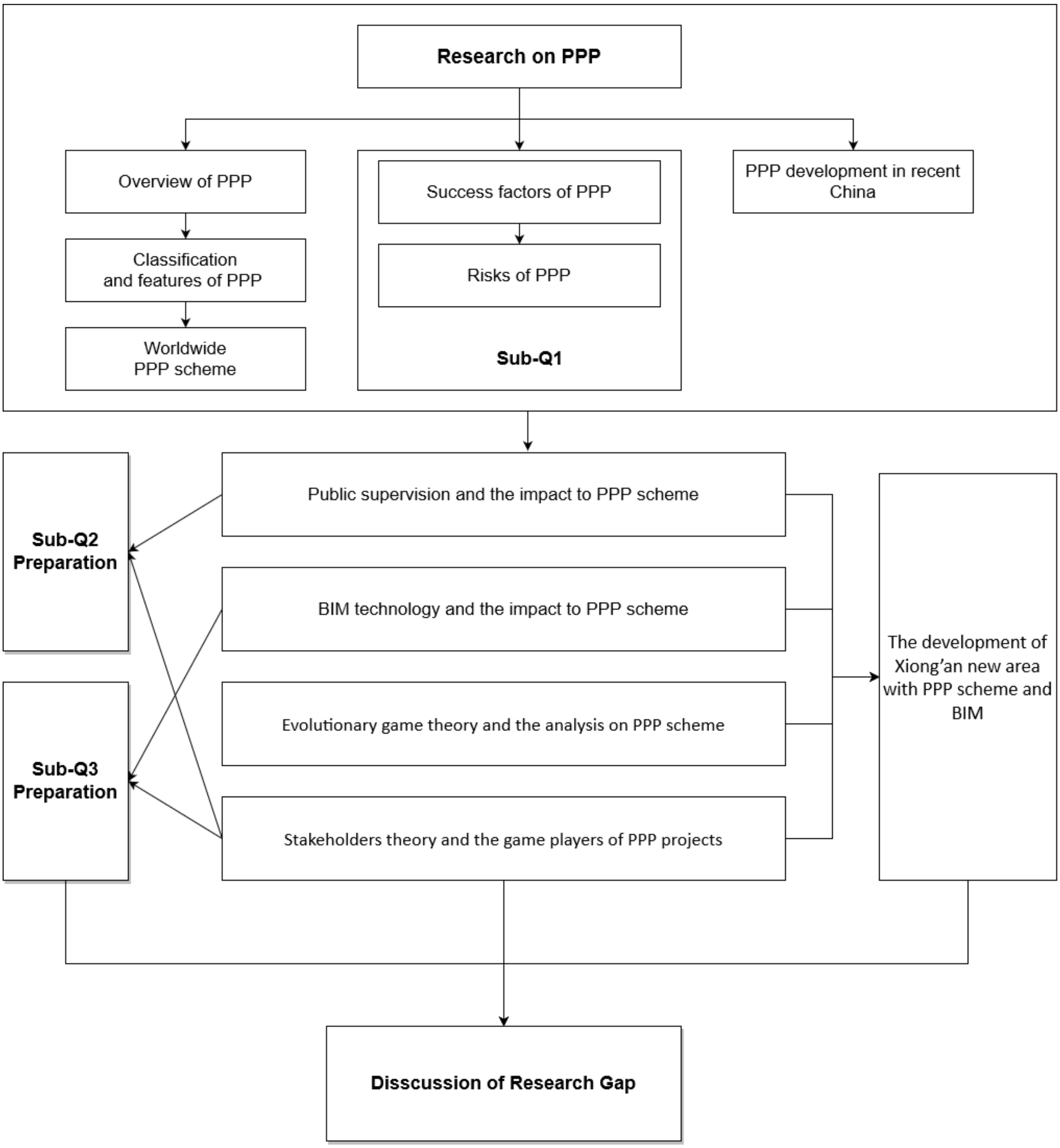

Figure 2- 1 Structure of literature review

The literature review section targets to clarify the current and previous research on the topics of PPP scheme, public supervision, BIM technology and the application of evolutionary game theory, and prepare for the modeling, simulation, and analysis phases. Moreover, literature review aims to identify the attributes of public supervision and BIM technology which can influence the PPP projects, as well as the influencing mechanism from both perspectives.

2.1 Research of PPP Scheme

2.1.1 Overview of fundamental and framework of PPP scheme

Public-private partnership (PPP) generally refers to a form of cooperation between the public sector, non-government organizations (NGOs) or business enterprises based on a certain project, which aims to share the risk and reward of the venture investment (Soumitra, 2007). PPP scheme was originally introduced into the infrastructure industry as a partnership between the governments and private sectors. To date, this partnership has been widely applied in urban infrastructure(Chattopadhyay, 2015), transportation(Verweij, 2015; Garvin, 2010), water treatment(Xu et al.,), waste-to-energy treatment and incineration(da Cruzet al., 2013), environmental protection(Environmental Protection Agency 2009), public housing(Ibem, 2013; Liu et al., 2012) and many other fields. The economic principle of the PPP model is that when faced with risks or the possibility of losses, the private sector is able to achieve a higher level of efficiency, thereby increasing the monetary value of the project （Cruz and Marques, 2014; Bennett and Iossa, 2006. And the classification of the articles related to the PPP theme is presented as Figure 2-2, the engineering sector attracts the most attention from the researchers in recent years.

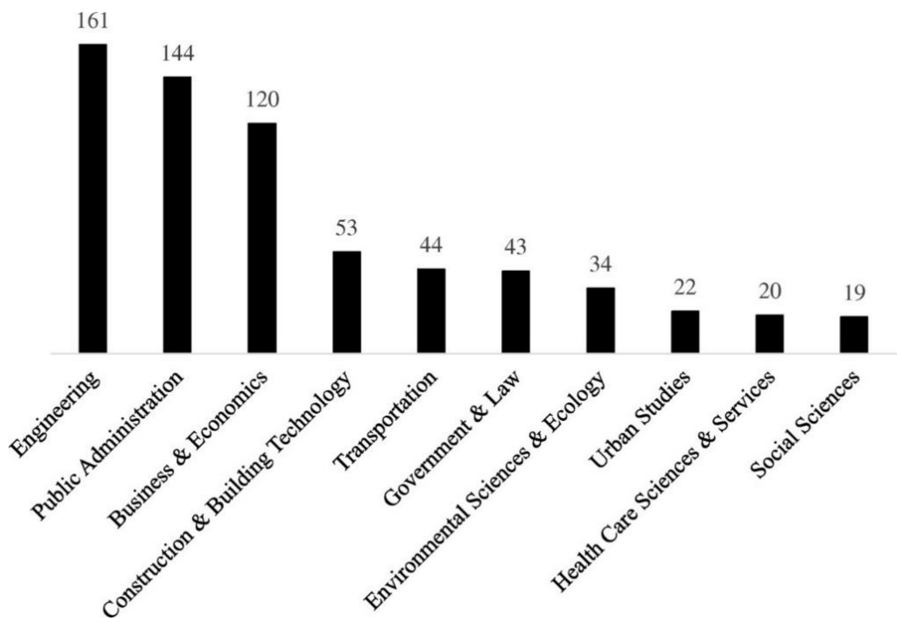

Figure 2- 2 Number of papers in the top 10 rankings by PPP research fields between 1990 and 2014 (castro, et al. 2016)

Mignon (1950) first put forward the concept of private finance initiative (PFI) in his publication, which was the very first term adopted by British governments and scholars. However, the most popular and widely used is PPP as the acronyms. From then on, until the early 1990s, the academia paid little attention to PPP. During this 40-year period, there were only fewer than 70 papers published concerning PPP scheme (Castro et al., 2016).

A review of the global emerging trend of PPP from Song et al. (2016) indicate that there was a remarkable increase on the publications from the WOS (Web of Science) core collection database since the year 2004. With a stable raise to the year 2010 and reached the peak of the annul amount of papers. Figure 2-3 illustrates the worldwide trend of the PPP publication.

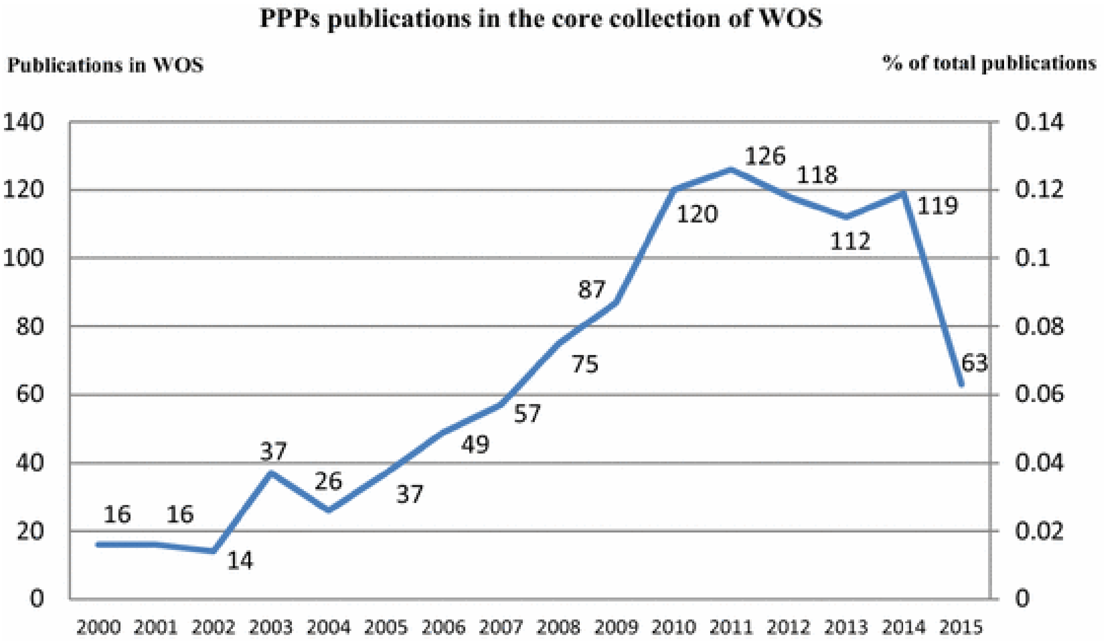

Figure 2- 3 Bibliographic records of PPP publication from 2000 to 2015 (Song et al. 2016)

2.1.2 Classification and features of PPP scheme

In general, the public-private partnership (PPP) shceme has a wide range of applications, ranging from simple, short-term (with or without investment requirement) management contracts to long-term contracts, including the aspects of capital and financing, planning, construction, operation, maintenance and asset divestiture(Engel et al., 2014; Daube et al., 2008). PPP arrangements are beneficial for large-scale projects that require highly-skilled engineers and heavy capital expenditures, which are useful for countries that legally require the state to develop infrastructure facilities to serve the public (Garvin, 2009). The partners in charge of owning and managing assets at various stages of the project decide the PPP funding model. Furthermore, the types of PPP mode are decided by the project kinds, the desired outcome, and the risk and investment structure (Bing et al., 2005). The operation modes of PPP in a broad sense include the following:

Build – Operate – Transfer (BOT)
For a certain period, private sector partners are allowed to finance, develop, build, and operate infrastructure components (as well as charge users), which upon expiration, is

transferred to public sector partners. Özdoganm et al. (2000) put forward a decision support framework (DSF) to illustrate the relationships and identify the critical ingredients of the BOT model, which is widely implemented worldwide with high efficiency. For instance, the critical ingredients in PPP scheme are demonstrated as cash flow, risk allocation, risk identification etc.

Build – Own – Operate – Transfer (BOOT)

The private sector is in charge of financing facility initiatives as well as their construction, ownership, and operation. The private sector turns over the facility and its ownership to the government at the end of the contract (Rebeiz, 2012). When the government has a substantial infrastructure financing gap, this arrangement is acceptable since the private sector bears equity and commercial risks throughout the contract time. This concept is commonly used for contracts between schools and hospitals (Kumari, 2016). (Chu, 1999).

Design – Build – Finance – Operate (DBFO)

Similar with BOOT, DBFO (and its variants, such as DBFM) pattern is originated in PFI projects in the UK. The private sector is responsible for developing, funding, and constructing a new infrastructure component in exchange for a long-term lease to run and maintain it. When the lease expires, the private sector transfers infrastructure components to the public sector (Villalba, 2016). And Acerete , (2019) compared the operation of DBFO mode in the UK and Spain through case analysis, and concluded that although DBFO can alleviate the debt pressure of government departments for the short-term period, however, the long-term rent payment may also lead to high financing costs.

In order to conclude the patterns of the PPP scheme, Tang (2018), referring to the classification methods of the PPP committees of the World Bank, the United States, Britain and Canada, etc., summarizes and classifies PPP scheme at the broad level into outsourcing, Concession and Divestiture (World Bank, 1997). This paper optimizes the current situation of China and obtains the classification as shown in Figure 2-4. Outsourcing initiatives are invested by the government, and social capital contracts one or multiple functions of the project, and the revenue is realized through government payment; the financing work of Concession projects is completed or partially completed by social capital, and under a certain cooperation mechanism, they share interests and risks with the public sector, such as BOT and BTO; and divestiture PPP project needs social capital to complete all the investment of the project, and obtain profit return through user payment. Finally, the ownership belongs to social capital, such as BOO.

However, countries over the world have not yet formed a unified understanding of the concept of PPP. According to the definition of the UNDP (United Nations Development Program) (Jomo et al. 2016), PPP refers to a form of cooperation formed by government departments, non-profit organizations, and for-profit enterprises to jointly complete a project. Although the definitions of are different among the worldwide countries, their essence is the same. They are based on the cooperation between the public sector and the private sector, with the provision of products and services as the goal, and emphasize the sharing of interests and risks. The core idea is to introduce market incentives, improve efficiency and disperse risks. According to the European Commission, the term "public-private partnership" refers to a partnership between the government and the private sector to offer public goods or services that were previously delivered by government departments (Decorla et al., 2013). Samii(2002) believes that PPP is an innovative form of partnership between government and private sectors to achieve output efficiency and sustainability. Spielman and von Grebmer(2004) conclude that PPP is a kind of cooperation institution formed by the public and private parties under a given goal by taking corresponding actions and providing their own resources, so as to achieve complementary advantages and cooperate to complete public goods or services of specific technologies.

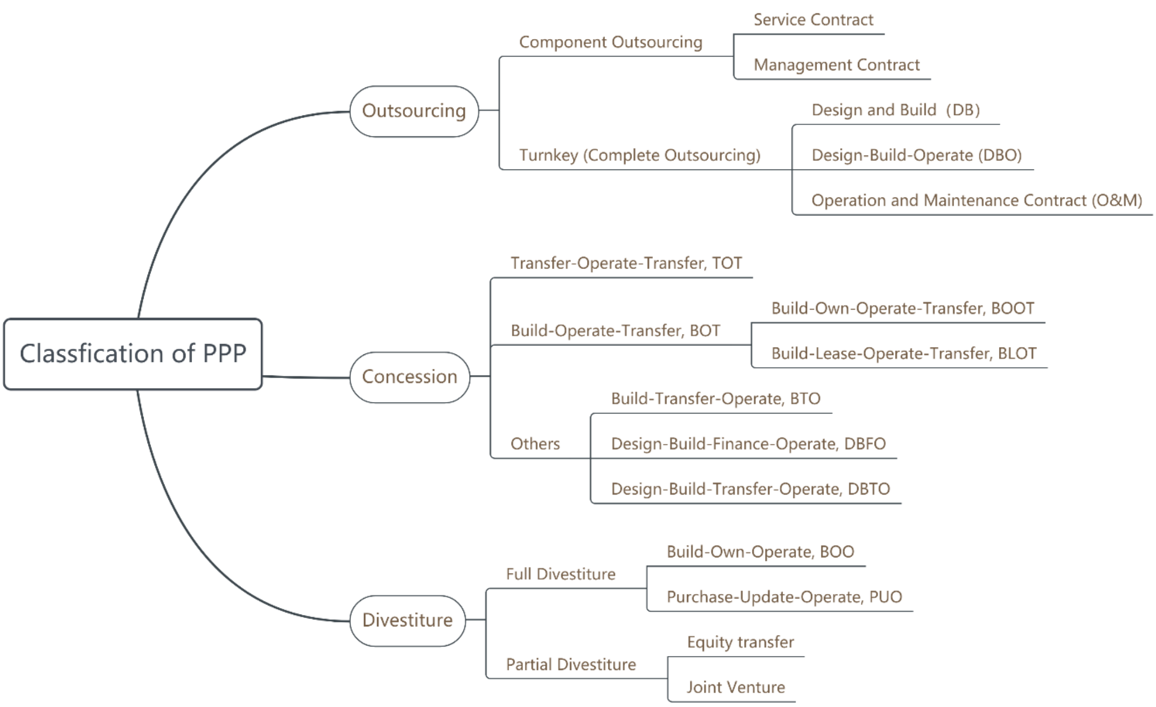

Figure 2- 4 Classifications of the PPP models

The essence of PPP scheme is not the government buy asset or receive financing from the private sector, rather than merely relieve the budget pressure, under the PPP specified terms and conditions, a stream of service is provided to increase the feasibility and reduce risk of the project (Grimsey & Lewis, 2004). And the elements and features of PPP including:

(1) Partnership relation

The primary feature of the PPP scheme is partnership, which means that all parties involved establish a mechanism and relationship of equal consultation, and it is the premise and foundation of the operation of the PPP project (Hodge & Greve, 2005). At the same time, partnership should embody the "spirit of contract" in the context of the rule of law, is a contractual partnership protected by law, that is, the government sector and the non-governmental private sector as equal civil subjects to jointly negotiate and sign a legal agreement, the rights and interests of the two sides as well as the responsibilities and obligations to be fulfilled are subject to the relevant laws and regulations(Grimsey & Lewis, 2004). Legal and regulatory safeguards. The alignment of project goals is the first step in forming a partnership. However, this is insufficient. To ensure the partnership's survival and growth, the partners must think about one other's difficulties and have two key distinguishing characteristics: shared rewards and shared risks.

(2) Sharing of Benefits

In the process of cooperation between the government and the private sector, the two sides achieve a win-win situation, which is benefit sharing (Carbonara, 2014). PPP projects generally provide public goods or services for the community and have a strong public interest and high monopoly. In order to avoid issues that may arise during the operation of the project, which may result in the private sector being unable to recover its investment return or the public interest being damaged, the public and private sectors should establish a reasonable profit distribution mechanism in the agreement, so that the social interest is guaranteed and the private sector is ensured to obtain a share of the profits and reasonable return on investment.

(3) Sharing of Risk

Risk-sharing, i.e. the risks involved in the operation of a project should be shared by both parties. In the PPP model, the two parties involved not only have their own advantages in terms of resources, but also their own characteristics in terms of risk sharing (Carbonara, 2014). Therefore, the principle of risk sharing is to allocate the risk to the party that is best able to deal with it, to achieve an optimal response and sharing of risk, and thus to minimise the overall risk of the project. In general, the private sector bears the design, construction and operation and maintenance risks of a project, while the government sector bears the legal and policy risks (Alkaf & Karim, 2011).

2.1.3 Worldwide PPP scheme research

In general, the institutional design of PPP project implementation and supervision systems in countries around the world is based on the PPP Unit, which includes all the institutions that help governments ensure the smooth implementation of PPP projects. Although the characteristics of PPP centers vary from country to country, it is theoretically possible to classify PPP implementation and supervision models according to the distribution of power between the central and local PPP supervisory bodies into three models (Ysa, 2007; van den Hurk, 2016):

(1) Local ownership model, represented by countries such as the USA and Australia;

(2) Central leadership model represented by countries such as South Korea, UK;

(3) Parallel and mixed the model is represented by countries such as Germany, France, and China.

The worldwide experience and mechanisms of PPP scheme is summarized as table 1.

Table 1 Public private partnerships in worldwide

Continent/Country	Experience with PPP scheme	Source/Reference
Europe		
Germany	The German PPP market is characterized by its small scale of investment in Europe and still has a high level of SME participation. However, recent PPP projects have been criticized for their lack of transparency. The construction company launched the "PPP Transparency Initiative" in 2011. In this initiative, companies are committed to disclosing PPP contracts. This must be achieved in cooperation with the contracting authority. Despite initial reluctance on the part of public authorities, the public response to the scheme is now mostly positive, especially in the municipal sector.	Jacob et al. (2014), W. McQuaid & Scherrer (2014)
France	In France, the supporting departments for PPP take direct responsibility for the actual PPP projects, with the MAPPP organization acting as the approving authority for national projects, which are then tendered by the French Ministry of Finance. This strong position enables MAPPP to play a decisive role in the implementation of projects: if a project is to be approved at central government level, it must first be approved by MAPPP.	van den Hurk (2016)
Netherlands	In the Netherlands there is an active PPP management sector, which was established in 1999 at the national level, but which has undergone some changes over time, both structurally and functionally. The Netherlands is constantly adapting its PPP policies and practices to the changing institutional context.	van den Hurk (2016)， Klijn et al. (2007)

Table 1 continued

Continent/Country	Experience with PPP scheme	Source/Reference
UK	The UK is one of the early countries in the world to introduce social capital to develop public projects and provide public services, and the standardization and operationalization of the PPP decision-making process, and the implementation of hierarchical management, hierarchical decision-making and multi-party participation in the project decision-making process, have greatly reduced the arbitrariness of PPP decisions. However, the biggest shortcoming of the UK's PPP decision-making system is probably the delay in the construction of its decision-making information system.	Coulson (2008)， Clark & Root (1999) Spackman (2002)
Spain	Although Spain is one of Europe's oldest, most active, and passionate PPP users, it also has one of the lowest levels of project notification, monitoring, supervision, and follow-up at the official level. PPP has received relatively little public attention in Spain at any level of government.	Allard & Trabant (2008).

Table 1 continued

Continent/Country	Experience with PPP scheme	Source/Reference
Asia		
China	Currently, the exit mechanism of PPP industrial investment funds from private sectors in China is still dominated by traditional exit methods, including Equity Repurchase, Asset Securitization, and financed by government bonds. The imperfection and lags of exit channels has affected the enthusiasm of social capital participation. At the same time, industrial investment funds applied to PPP projects in China show a development path of "local practice first, government ratification later", and many PPP laws lag behind or are parallel to the actual projects.	Zhang et al. (2015) Adams et al. (2006) Xu et al. (2010)
Japan	The formation of a PPP industrial investment fund in Japan was, on the one hand, due to the external causes caused by the Great Earthquake. At the same time, in order to optimize the composition of PPP projects and further attract private capital to participate in infrastructure and public services, the Japanese government legally established the PPP industrial investment fund system, showing a top-down development path of "legislation first, promotion later".	Hu et al. (2014) Choudhry, T. (2005).
India	In India, several state governments have taken the initiative to develop uniform policies to mitigate various risks. The state governments of Andhra Pradesh and Bihar have put in place a series of provisions to identify debt risks by assisting developers to review project assets and revenues in favor of lenders.	Kumar et al. (2018)

Table 1 continued

Continent/Country	Experience with PPP scheme	Source/Reference
Other Country		
America (USA)	At the federal level, there is no unified PPP center in the USA. Although a considerable number of states have set up PPP centers on their own initiative, due to the lack of a unified institutional design, they differ from state to state in terms of structure, funding and function. Some state PPP centres are semi-commercial organizations that are self-financing. For example, the Michigan PPP centre is funded by consultancy fees, while others are funded by the state budget.	Abdel & Nabavi (2014) Geddes & Reeves (2017)
Australia	In 2008, the Infrastructure Directorate and the National PPP Forum developed The National Public Private Partnership (NPP) policy guide, which requires all levels of government to consider the PPP model as an alternative for any project with an investment of more than $500,000. In addition, the federal Government has exercised its reserve power to amend the PPP policy steering authority.	Cuestas & Regis (2008).
Brazil	Similar to other countries' experiences with PPP projects, Brazil had an exceptionally high number of renegotiation events, including the first renegotiation event within a short time after the contract began. Furthermore, as the number of PPP projects grew, so did the frequency of renegotiation events, exacerbating the problem of PPP project inefficiency.	Neto et al. (2017).

2.1.4 The research of successful factors/positive profits of PPP project

Critical Success Factors (CSFs) refers to the critical influential factors or factors that are essential to the success of the project, which in term originated in the fields of data analysis, and business analysis. Previous research has identified PPP project failures as a lack of effective ways to improve project performance. It has been found that project teams that identification of critical success factors and taking appropriate corrective actions can improve the performance of PPP project (Williams, 2016). And Kagioglou et al. (2001) argue that critical success factors can be used to improve PPP project performance and ultimately project success; Yuan et al. (2012) further describe the importance of critical success factors for stakeholders who wish to improve PPP project performance; The use of the right critical success factors is advocated to improve PPP partnerships and thus make PPP projects the best value in economic(Zhang, 2005). Therefore, it is worth exploring the relationship between the impact of PPP project critical success factors and project performance as well as stakeholder benefits.

Rockart (1982) first introduced the concept of Critical Success Factors (CSFs): a few key activities that are necessary for a manager to achieve his/her goals. Several of these factors exist in any business or organization and if they are fulfilled, the organization will be well served; on the contrary, if they are not well attended to, the development of the organization will lag or suffer. Grant (1996) studied the key success factors of infrastructure PPP projects and concluded that 'appropriate risk allocation', 'risk sharing', 'risk management' and 'risk management' are the key success factors. "Jones et al. (1996) add to the critical success factors of the Grant by arguing that the critical success factors for PPP infrastructure projects should also include Two factors are a favorable legal framework and a well-organized public administration. Tiong (1996) identifies the key success factors for PPP projects as technical feasibility, a strong private consortium, a stable macroeconomic environment, and a well-established legal framework. Suitable project identification, stable political and economic condition, attractive financing choices, appropriate fee/tariff levels, adequate risk allocation, selection of suitable subcontractors, management control, and technology transfer are identified as eight independent important success criteria for BOT projects in China by Qiao et al. (2001).

Hardcastle et al., (2002) examine the relative importance of eighteen critical success factors for PPP/ PFI construction projects in the UK, including: transparency in the procurement process, competitive procurement process, good management, well-organized and reputable public bodies, social support, public and private sector shared power, thorough real cost and benefit assessment, a stable macroeconomic environment, sound economic policies, a favorable legal framework, technical feasibility of the project, appropriate risk allocation and risk sharing, responsibility and commitment of the public and private sectors, a strong private consortium, government guarantees, multi-benefit targets, political support, and adequate and sufficient financial markets.

Through a questionnaire survey and statistical analysis, Wang et al. (2007) identified 21 key success factors for infrastructure PPP projects in China, including: demand for project products or services, attractiveness to private capital, innovation in project technology, excellent international reputation, public interest, potential for economic prosperity, ability of leaders, efficient project team, and public interest. Reasonable project organizational structure, experience in PPP project development and management, reasonable risk sharing mechanism, PPP project financial system and policy, regulation and policy improvement, reasonable pricing mechanism, effective regulatory mechanism, political support from the government, meeting public safety and health standards, reasonable price, effective project control. By using a system engineering methodology and a structural model that explains things, it was found that

- Reasonable risk sharing mechanism
- Financial system and policies for PPP projects
- Improvement of regulations and policies
- Regulatory and policy improvement
- Reasonable pricing mechanism
- Effective regulatory mechanism
- Government political support
- Meeting public safety and health standards
- Reasonable price', 'effective project control
- Reasonable risk sharing, communication, and coordination

And five of the factors "reasonable pricing mechanisms", "effective monitoring mechanisms" and "effective monitoring mechanisms" that can influence the achievement of the other success factors are considered as the most crucial factors.

Wang et al., (2007) studied the essential elements impacting the performance of the PPP model, and offered appropriate recommendations based on the practical experience of developed countries and regions, based on China's national conditions and project practices. According to the study, the government's behavior must be consistent, all parties' responsibilities and rights must be clearly defined, and proper incentives and risk-sharing systems must be in place. The key factors include the following: prudent audit and commitment by the government, clear boundaries of government functions, clear payment mechanism, clear reward and punishment mechanism, reasonable capital structure, reasonable risk sharing mechanism, clear and complete policies and regulations, equality and integrity, and professional management body.

From the above-mentioned studies, it can be seen that most researchers believe that the CSFs of PPP projects include "favorable legal framework", "well-organized public administration", "multiple effect objectives", "public/private commitment", "sound regulatory mechanism", "strong private consortium", "stable external macro environment", "appropriate risk allocation", "government guarantees", "sound economic policy", "good legal system", "appropriate financial market" generally. Table 2 shows the overview of CSFs from literature review with descending order of frequency.

Critical Success Factors (CSFs)	Frequency
Appropriate risk allocation	8
Sound economic policy	7
Financial market	7
Favorable Legal system and framework	6
Stable external macro environment	6
Government guarantees	5
Well-organized public administration	3
Public commitment	3
Sound regulatory mechanism	2
Strong private consortium	1

Table 2 The CSFs with frequency in literatures

2.1.5 The research of risk/negative loss into PPP project

In the sphere of engineering and construction, risk is an objective phenomena., is defined in this thesis as a situation of uncertainty that, if it occurs, negatively affects duration, cost, scope, or quality, thus causing losses to the participants in the project. Compared to other types of projects, there are more complex risks in PPP projects, so the studies of project risks have been the focus on the research in PPP models (Bing et al., 2005).

Market risk, financial risk, political risk, legal risk, construction risk, and operational risk are the critical risk elements of BOT projects (particularly hydropower projects) in developing countries, according to Özdoganm & Talat (2000). Political risk, construction risk, operational risk, market and revenue risk, financial risk, and legal risk are among the 50 risk categories identified by Wang et al. (2000) for BOT projects. In their subsequent study, they re-categorized the BOT project risks, not only by the above-mentioned risk categories, but also by the stage of risk occurrence and project type, such as power plant, road, tunnel/bridge, railway/subway, airport/port, water/gas treatment plant, communication and risks common to all projects. There are macro-level risks due to external factors, meso-level risks due to project meat department factors, and micro-level risks due to various interests in the procurement process.

Risk sharing, as an optional measure for risk management, is generally defined in the contract (Lam et al, 2007). On the other hand, contract drafters are continually trying to shift more risk to the other side, resulting in lengthy negotiations and large costs before reaching an agreement (Rutgers & Haley, 1996). Therefore, project risk sharing has received more attention in risk management research than other risk management measures.

Tiong & Alum (1997) found that governments often transfer excessive risk to the private sector without considering their risk endurance, risks that the private sector lacks the ability to regulate and manage, such as interest rate and exchange rate risk, are examples. As a result, in actual PPP projects, risk sharing is often designed asymmetrically. Humpherys et al. (2003). According to the examination of air transportation projects, governments frequently give up their rights to the appropriate advantages in order to boost the project's financial feasibility. In this situation, the government will absorb the excess loss if the risk exceeds a pre-determined private sector tolerance range, but it will forfeit its share of the excess gain if the gain exceeds the corresponding range to encourage the private sector to operate the project more effectively. For example, the Citylink (Arndt, 1998) program in Melbourne provides that the government will be fully compensated if its actions result in a reduction in the project's benefits, but only shares 50% of the increased benefits if the government's actions result in an increase in the project's benefits, which is not symmetrical in terms of risk-taking and benefit sharing.

In summary, due to the diversity phases and aspects that risks exist in the PPP projects, different countries have different conditions, and risk sharing mechanism of a single country cannot simply be applied to another country or case.

2.1.6 PPP scheme research and development in recent China

In 1984, the first PPP project in China launched at Shenzhen, Shajiao B Power Plant BOT (Build-Operate-Transfer) project, was agreed upon and signed after cooperation between local government and private capital, marking the beginning of PPP practice and experience in China(Qiao et al, 2001). For almost 40 years, the Chinese government has been embarking on an ambitious programs of large-scale infrastructure investment to promote the urbanization. In order to facilitate China's urbanization development, it is estimated that between RMB 3.5 trillion and RMB 5 trillion had been spent for the infrastructure development in the first 20 years of the 21st century (Wu, 2007). Under the pressure of increasing demand for public goods and services, the PPP model, as one of the financing methods for introducing social capital to provide public goods and services, has become the subject of vigorous promotion by the government because of its advantages in easing the pressure on fiscal expenditure and stimulating economic development. By the end of March 2020, data from the Ministry of Finance's PPP China Project Database showed that a total of 9,820 projects had been initiated across the country over the past three years, with total investment estimated to reach a staggering RMB 15.2 trillion.

China has unique political, economic, and cultural characteristics (Mu et al., 2011; Buderi and Huang, 2006; Zhang et al, 2015). Prior to the 1980s, China had a highly centralized and purely planned socialist economy. Infrastructure investment and development was the sole responsibility of the government. With the reform and opening of China, PPP scheme is introduced in infrastructure construction, and considering the complexity of such economic transactional activities, the research of PPP in China has become the focusing topics by scholarly in recent years, especially in terms of PPP risks (Cheung and Chan, 2011; Wang et al, 2000; Sachs et al, 2007;), and also in field of critical success factors (Yuan et al., 2012; Cheung et al., 2012), failure cases and potential problems(Zhang et al., 2016) and PPP reform and policy aspect(Zhang et al., 2015; Yang et al., 2018).These studies provide us with a comprehensive overview of the current state of the art of PPP reform and policy in China. They also imply or suggest that sound institutions are essential to the success of PPP and that

China has a need for them. To create an institutional environment is conducive to PPP (Wang et al., 2012). However, according to the literature review on the previous studies, the lack of a systematical and evolutionary analysis on the dynamic perspective for the PPP projects, which means that numerical simulations can be carried out to quantitatively analyze the mechanisms of PPP from a system dynamics perspective in order to improve the efficiency and quality of PPP projects in China.

Regarding the differences between Chinese PPP scheme and the worldwide general PPP mode, there are therefore two main differences. The first is over-complexity of PPP system in China, the other is the issue of property rights (Adams, 2006). In addition to the 'direct' service and management contracts that governments may issue to the private sector, there are 14 different PPP models within the three 'general' PPP types. Three of the general types are: outsourcing, concession, and divesture, while the 14 specific models are not always clearly distinguishable from each other and some are actually a subset of others. Hence, an overly complex system arises from the similarities between the many PPP types. And there is still no well-developed system of recognizable (private) property rights, owing to a lack of clarity on ownership concerns (Yang, 2018). Even while the UK PPP system is as complicated as the Chinese PPP system, there are some important distinctions. The UK system, in instance, is dominated by long-term partnerships that may last up to 30 years (ACCA, 2004), and it was formed in a market-oriented economy. In China, the majority of the 'types' of PPP are short- or medium-term. This increases the risk that private participation in PPP projects would not result in long-term benefits such as lower tax burdens, fewer bureaucracy, and enhanced management efficiency. On the other hand, it is true that the use of relatively short-term PPP cooperation projects can "quickly" increase infrastructure development in the case of a shortage of state investment funds. Furthermore, the build-operate-transfer (BOT) model has dominated the use of PPP in China over the past two decades, mostly for big infrastructure projects. Despite the fact that there are 14 different models, they are rarely used in health, education, social care, or housing. In contrast, PPP contracts have long been employed in certain regions in the United Kingdom (Brown et al., 2006). As a result, in order to accomplish multiple goals in a very short partnership, including protecting current and future taxpayers, lowering total tax burdens, spreading risk, reducing "bureaucracy," and improving efficiency in the delivery of several public sector "duties,", China's The PPP model still has many problems to be studied and solved.

The more macroscopic objective of seeking local economic development is influenced by different circumstances at different times, and is a combination of several purpose sequences of varying importance (Xu et al., 2014). So that PPP scheme, as a tool for local governments to develop the local economy and urbanization, will inevitably be applied to different areas at different times and to different degrees as the purpose sequences change. Specific circumstances can be summarized as the overall economic situation of the country, the existing macro-policy context, and local financial resources.

In the development process of PPP, there are three different stages, depending on the specific circumstances faced by local governments (Mu et al, 2011, Chen et al, 2018). As the three stages of PPP development in China show in table 3, the development of the PPP model in China has not always been smooth and has undergone two downward adjustments (Chen, 2018; Zhang et al, 2015)). However, according to the data collected, the cooperation model as a whole represents an 'evolutionary' process of order, which is reflected in the following: an increase in the number of projects and the amount of investment, a gradual diversification of cooperation fields and methods, an increase in the number of explicitly constructed rules governing implicit behavior, an increase in the participation of social capital and the public, and an increase in the operation of the projects trends such as greater regulation and transparency.

Phase	Economic Background	Policy Background	Specific Purpose
Early Exploration Phase (1984-2000)	Start development, high fluctuations	Encourage foreign investment and tax system establishment	Developing local economy and promoting urban development
Preliminary Development Phase (2000-2010)	Continuously rapid development and Growth	Liberalizing access to non-public capital markets	Development of municipal utilities and rapid urbanization
Rapid Development Phase (2010-present)	Slowing economic growth rate	Market plays a decisive role in resource allocation	Safeguarding economic growth, alleviate local government debt

Table 3 Three stages of PPP development in China

2.2 Research of Public supervision and the impact to PPP projects

The public facilities or products provided by PPP projects are tightly related to the public interest of society, therefore, reasonable and efficient supervision are supposed to be carried out throughout the whole life cycle of the project from planning and design, construction, operation and handover phases (Mota & Moreira, 2015), in order to realize the Value for Money (VFM) of the projects. And the supervision mechanism protects the public interest by avoiding low levels of public service, operational inefficiencies, and market failures during the operational phase. (Decorla et al, 2013).

2.2.1 Research of PPP Project Performance supervision

In PPP scheme, there are discrepancies in the aims and objectives of the public and private sectors. Governments are able to promote social and public interest through low-risk activity, whereas the private sector seeks to maximize profit through opportunistic activity (Liu et al, 2016). Therefore, regulation of PPP projects is necessary for PPP projects. The success of PPP projects requires not only the selection of the right participants and the right timing of participation, but also the development of a reasonable cooperation contract and the development of a sound regulatory system (Lohmann & Rötzel, 2014).

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Shendy (2011) argues that the provision of financial support is only one aspect of the PPP model, and that it is more important to establish a reasonable institutional mechanism to carry out comprehensive supervision and control of PPP projects, so that financial funds can be properly managed and operated to maximise their impact. The key factors influencing the performance of PPP projects include not only the access mechanism, the level of market opening and the strength of contract enforcement, but also the level of regulation (Sanni, 2016; Liu et al, 2016; Yun et al, 2016). (Sanni, 2016; Liu et al, 2016; Yun et al, 2016) Through the empirical analysis of the leading factors for the smooth operation of PPP projects, it is concluded that the regulatory strength of the government is one of the important influencing factors. Sabry (2015) indicates that by improving government efficiency and regulatory standards, the performance of PPP projects can be improved, and the investment of private sector can also increase. According to Pusok (2016), whether the construction and operation of water utilities by private investors through the PPP model can improve the efficiency of services depends on the level of corruption in government. If there is a high level of government corruption, then private investors will increase their profits at the expense of the public interest and vice versa.

2.2.2 Research on supervisory mechanisms for PPP projects

Effective supervision can lead to promotion on the efficiency of PPP projects and the quality of products provided, as well as safeguard the public interest and promote social welfare, which completely based on a reasonable supervisory mechanism. Many scholars have conducted in-depth studies on the design of supervisory mechanisms for PPP projects. In terms of the construction of laws supervision systems, Robinson (2001) argues that taxation policy, income distribution schemes and social security systems for PPP projects should be determined by voting, while Alchian and Demsetz (1972) argue that it can be achieved through the introducing of external supervisors, who can also benefit from the PPP projects as end users. The motivation of the supervisors would be increased, and the irresponsible behavior of the participants will be effectively curbed. At the same time, government departments, as a special supervisor in PPP projects, represent the interests of the public and can control the residual revenue of the projects to a certain extent, and when evaluating the government's supervisory performance, the application of incentive mechanisms can compensate for the imperfection of the regulatory system to a certain extent. Ye (2014) believes that the complementarity and integration of government regulation and market mechanisms should be fully considered for the effective operation and rationality of supervisory mechanisms.

At the same time, public participation is an important factor in the supervision of PPP projects. When public opinions are ignored in the provision of public infrastructure and services through the PPP model, there is a risk of public opposition, delays and increased project costs (Creighton, 2005; Goodfellow et al, 2014; Rojanamon et al, 2012; Ng et al, 2012).). Osei-Kyei et al. (2017) argues that the public participation plays a crucial role in the operational performance of a project, therefore, PPP projects should have public participation from project initiation, planning and design, construction, operation and handover, so as to fully reflect the public will and ensure public interests. Antonson (2014) shows that citizens express their views on public transport projects by writing opinion letters, enhancing the public's sense of participation, and contributing to the improvement of public service levels. Bakht and Eldiraby (2016) argue that social networks such as Twitter allow the public to fully express their views and concerns on infrastructure projects, making the operation of projects more reflective of the public's wishes and making government decisions more rational. In the monitoring of PPP projects, the citizen can expose the illegal behaviours of the private sector through the new media, and such news always attracts strong attention from the government and the entire society. Public participation in the monitoring of PPP projects can help governments to better monitor private investors in a more transparent approach.

It is believed that the introducing of private capital under the PPP model can enhance competition in the public infrastructure sector and improve the efficiency of services, but the asymmetry of information and the profit-driven of the private sector might lead to opportunistic behaviour in the private sector. While effective government regulation is the key to improving the performance of PPP projects and realizing their smooth operation. In addition, by using empirical research, game theory and other methods, and from the perspective of the introduction of third-party regulation and emphasis on public participation, we explore how to strengthen government regulation in order to improve the efficiency and service level of public service projects, safeguard the public interest and improve the social welfare.

2.3 Research of BIM technology and the impact to PPP projects

Compared to traditional construction projects, there are more complex stakeholders and relationships in PPP projects. Due to the longer contract period and a higher density of information in PPP projects, how to achieve effective information sharing and communication across organizations in PPP projects has become one of the most important issues that influencing the performance and even the success of PPP projects (Castro et al., 2016; Song et al., 2016). At present, cross-organizational collaboration technology, with Building Information Modelling (BIM) as its core, is widely regarded as a powerful tool for solving the increasingly prominent problems in the construction industry globally, and is regarded by some scholars as causing an unprecedented revolution in the construction industry due to its huge potential impact on the performance of construction projects and the productivity of the industry (Ren, 2017; Arayici et al., 2011).

2.3.1 Definition and development of BIM

BIM technology is narrowly defined as a digital and visual representation process for establishing and managing the physical and functional characteristics of a construction project. In the implementation process, multiple forms of model information are used as a platform for sharing data and information resources to support and support, collaborate and manage decision making, design, construction, operation and maintenance throughout the entire lifecycle of a construction project (Watson, 2011; Redmond et al., 2012). As a project progresses through the construction phase, the information in the BIM model is deepened, refined and brought closer to reality, forming a tightly integrated information chain. Therefore, in a broad sense, BIM has developed into an information chain that includes a construction schedule as well as cost, resulting in 5D BIM (Wang, 2012; Cerovsek, 2011). The US National BIM Standard (NBIMS) defines BIM as a model that includes not only geometric information about a construction project, but also non-geometric information such as functionality.

According to the practice of the building industry and organizations' definitions, there is also a view that BIM is the integration of electronic design documents:
"BIM entails far more than 3D rendering and the transmission of electronic copies of paper documents. "Risk is decreased, design intent is retained, quality control is streamlined, communication is clearer, and higher analytic tools are more accessible" as a result of BIM implementation." (AIA, 2005, web site).**"**

A more recent opinion of BIM is explained as:
"A building information model (BIM) is a digital depiction of a facility's physical and functional attributes. As such, it acts as a shared knowledge repository for information about a facility, providing a solid foundation for decisions made throughout its life cycle. (BuildingSMART, 2008, web site). **"**

2.3.2 Features and benefits of BIM

The most significant feature of BIM is the highly integrating of data and information, where the model is the foundation, information is the core, software is the tool, collaboration is the focus and management is the key. BIM is a technology and method to support BLM (Building Lifecycle Management) project decision-making, design, construction, and operation throughout the life cycle of a building (Vanlande et al., 2008). BIM-based information of the construction realizes integrated management of project performance, quality, safety, schedule and cost at all stages of the building lifecycle (Li et al., 2008; Huang et al., 2007), improves work efficiency and quality, reduces errors and risks, and enhances the quality of work. Building industry efficiency and profit.

From the different descriptions of the BIM concept, it can be concluded that the following four characteristics are required.

First, BIM is an object-oriented information model (Kim et al., 2013). Parametric models are built by following certain technical modelling specifications. The basic building blocks in the model are component families, which build the entire project model by building rules between the various families. The model has the potential to be parametrically linked, i.e. if any point is changed in 3D or 2D drawing, the model information changes accordingly in the rest of the form. Each build includes not only geometric information, but also non-geometric information including functions, descriptions etc.
Secondly, BIM has the technical characteristic of inter-disciplinary coordination (Shafiq et al., 2013). Collision issues would be detected during the comprehensive review of drawings by various disciplines. The three-dimensional visualization by means of BIM technology allows for good detection and coordination. And thanks to the parametric characteristics of BIM, modifications to problem areas can be made more efficiently.

Furthermore, the simulating feature of BIM technology refers to the simulation of design and construction processes, and the simulation of wind, optical, thermal, noise and critical difficult construction sections, which can effectively avoid subsequent problems (Bazjanac, 2008). Finally, BIM technology is a diversified input and output platform for information (Li et al., 2018). The flow of information between different applications is achieved by using IFC-based information standards. It is saved in different file formats so that it can be easily viewed by different people and corresponding targets.

2.3.3 The application fields of BIM

BIM technology is widely applied in the fields and phases of AEC (architecture engineering & construction) projects, which has the potential to influence the entire processes of procurement and operation(Eastman et al., 2018). BIM technology is currently applied in the fields：

Model checking and maintenance: BIM model maintenance refers to the creation and maintenance of BIM models according to the progress of project construction, the use of the BIM platform to summaries all the construction information of each project team, eliminating information silos in the project, and combining the information obtained with the 3D model to collate and store it for ready sharing among all project stakeholders throughout the project (Liu & Issa, 2014). (Liu & Issa, 2014) The automatic checking of the model consists of two aspects: object-oriented checking and rule-based rule checking, which helps the project team to resolve conflicts before construction starts (Kim et al., 2013).

Site analysis: Inadequate quantitative analysis, excessive subjective aspects, and the difficulty to comprehend huge volumes of data and information are all disadvantages of traditional site analysis.By combining BIM and geographic information systems (GIS) to model the spatial data of the site and proposed buildings, more accurate analysis results can be obtained quickly, assisting the project in assessing the use conditions and characteristics of the site during the planning stage, allowing key decisions such as ideal site planning, traffic flow organizational relationships, and building layout for new projects (Azhar, & Brown, (2009; Zhang et al., 2011).

Collaborative design: Collaborative design is a new architectural design process that allows designers from various professions and around the globe to collaborate through a network. BIM technology provides the underlying support for collaborative design and significantly improves the technical content of collaborative design instead of simply referring to documents (Shafiq et al., 2013). With the benefits of BIM technology, the scope of collaborative design is expanded from the design phase to the entire building lifespan, which necessitates the involvement of all stakeholders, including planning, design, construction, and operation, and so has a broader meaning and results in a large rise in positive effects (Lu et al., 2013).

Cost estimation: For cost control, BIM incorporates a database rich in engineering data that offers accurate information about the volume of work necessary. (2008, Sabol) BIM-acquired accurate volume data may be used to estimate costs during the pre-design phase, to explore various design alternatives within the owner's budget, or to evaluate the construction costs of various design alternatives, as well as to estimate buildings before construction begins and to calculate the volume after construction is completed (Forgues, et al., 2012).

Building simulation: Construction is highly dynamic, and the management of the construction project is tremendously challenging as its breadth and complexity expand. By integrating BIM into the design, time and space can be fuse together into a visual 4D model which displays the entire building process visually and correctly (Boton et al., 2015). With the help of the BIM simulation of the construction organization the project management can understand the entire construction and installation time points and the installation process very intuitively. The contractor can further optimize the original installation scheme and enhance it. the project management can improve the contractor's compliance (Song et al., 2012).

2.3.4 The impact of BIM to PPP

While the PPP model is being promoted rapidly, there are still cases of PPP projects failing due to factors such as inappropriate decision-making at the early stage and failure of supervision during the operation phase (Soomro & Zhang, 2015). The reason for this is the lack of information management in PPP projects, which makes the project lack the necessary data support in the decision-making and early phases, resulting in 'distortion' of the value-for-money (VFM) arguments and asymmetric information in project operation and maintenance (Xiong et al., 2018; Ho et al., 2015). The key to solving this dilemma lies in the collection of data from previous similar projects, as well as in breaking down the information 'barrier' between government and social capital.
Based on the above problems, illegal behaviors provide a problem orientation for the introduction of BIM Technology. Ren et al. (2020) explores the establishment of a set of "VFM + BIM" regulatory system to give full play to the advantages of BIM Technology in engineering data storage and sharing and engineering simulation, and take the criteria and methods of

value for money evaluation as the breakthrough point to solve the issues of data distortion, false evaluation, operational failure in PPP projects. As an important part of PPP project identification, VFM (value for money) is a combination of qualitative analysis and quantitative analysis, which provide private sector a practical methodology and tool to capture more profiles in the process of PPP projects. At the same time, BIM can accurately integrate the information in the project scheme. Through the virtual simulation experiment of project design, construction and operation, the contents of public goods and services can be displayed in multiple dimensions. The present value (PPPs) of the government's net cost is compared with the Public Sector Comparator value (PSC) of the public sector, to increase the accuracy and consistency of quantitative evaluation of VFM. Figure 2-5 shows the components of structure for the quantitative assessment.

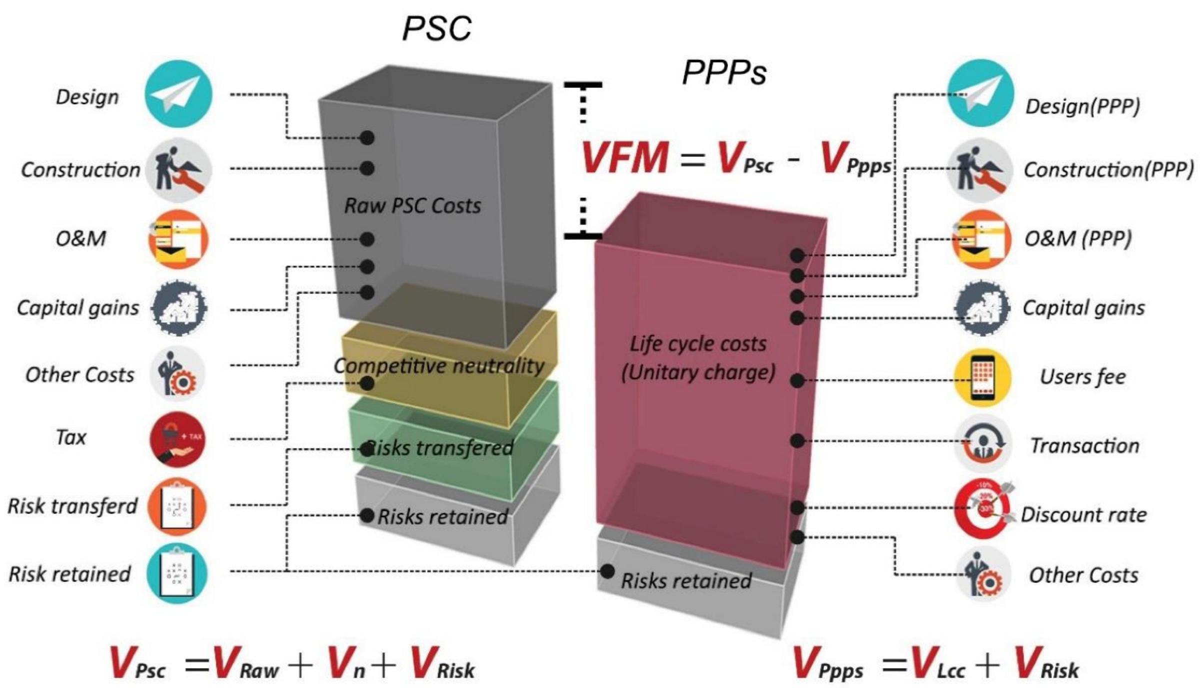


Figure 2- 5 Structure for the quantitative assessment in the VfM process.

PSC value structure model refers to the traditional procurement model which includes the separate cost of risk and other sources. However, the private would only apply PPP scheme as procurement mode when the calculated cost value must always be less than the possible cost of traditional public procurement model. And the simplified processes are illustrated in figure 2-6.

The role of BIM is not only limited to the construction and operation of PPP projects, but can also provide the private sector with the data necessary to focus on asset management, assist the private sector in making investment decisions and develop short- and long-term management plans, and improve management performance (Olawumi et al., 2019). Using operational model data, the costs of evaluating, renovating and renewing building assets can be assessed, and an asset database can be maintained and linked to the model. At the same time, BIM applications improve the accuracy of costing and enable owners to retain lower unforeseen costs than under traditional construction models (Ren et al., 2020).

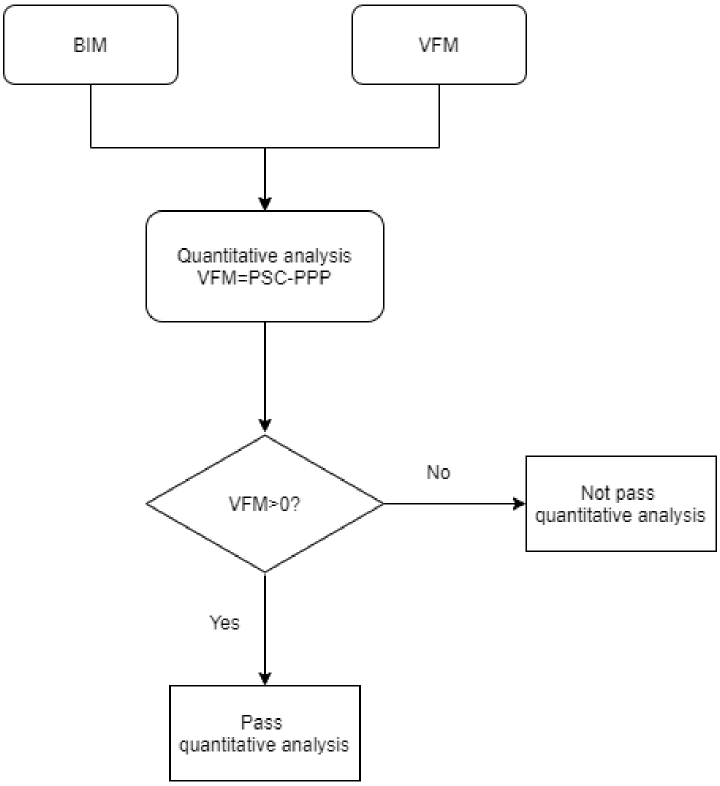


Figure 2- 6 Process of quantitative analysis on the BIM technology by VFM

BIM can also make municipal management convenient for the government. Data storage and exploitation of the BIM-based urban building information model can be built into urban geographic information systems to create a complete basic information basis and assist smart city building. At the same time, the transparency of data on the urban building information template can allow for real-time and convenient interaction between building suppliers, project managers and users, which helps create a colorful, healthy, safe urban environment and improve urban infrastructure public service levels. (Olawumi & Chan, 2018; DENG et al., 2017).

Through the study of relevant literature, it is found that current research mainly focuses on the specific application of BIM technology in PPP projects and the construction of a PPP project information management platform based on BIM technology, while there are few studies on the mechanism of the application of BIM technology by the government and private companies in PPP projects and the influencing factors of the payoff value in the game. As the two core stakeholders of PPP projects, government and private sector share the same vision of realizing project goals, but differ in the collaborative application of BIM technology. Private sector as the main investment agent of a PPP project, the application of BIM technology in the project is conducive to the improvement of project construction and operational efficiency and has a positive effect in a macro perspective; However, from an economic point of view, the application of BIM technology requires more initial investment in human resources and transaction cost, while the goal of the social capital party is to pursue the maximization of its own interests. This makes it easier to create problems such as prisoner's dilemmas. The private sector has an inherent need to apply BIM technology, but lacks sufficient driving force. Under the PPP model, although the government transfers infrastructure investment and construction work to the private sector, effectively reducing its own financial pressure, the nature of a PPP project is still to provide public facilities, so in the event of quality or other problems affecting the supply of products, or even causing losses to the public's personal property, the government is the most difficult to bear, because no matter what kind of supply is used, the government is the most vulnerable. The government side is the ultimate bearer of social responsibility. Therefore, in promoting the application of BIM technology, it is necessary and responsible for the government to take appropriate measures to supervise and guide the application of BIM technology by social capital parties in PPP projects, which not only helps to ensure the supply efficiency of PPP projects and safeguard public interests, but also promotes the development of information in the construction industry.

2.4 Evolutionary game theory and the dynamic analysis on PPP scheme

2.4.1 The development of evolutionary game theory

When John Nash (1951) first introduced the concept of “equilibrium”, he pointed out that there are two ways of interpreting equilibrium, i.e. “rationalist interpretation” and “interpretation of large-scale actions”. The former is an explanation of classical game theory, while the latter actually is an explanation of evolutionary games. Evolutionary games explore the process by which humans, with limited rationality, choose the optimal strategy by trial and adjustment to reach an equilibrium state in a group game. In an early stage of game theory research, biologist Lewontin (1961) took inspiration from this and used the idea of strategy interaction to construct an evolutionary model of biological competition to explain the evolutionary mechanisms of trait selection, sex allocation, growth and development in the evolutionary process.

2.4.2 Evolutionary stable strategy and duplicate function

Smith & Price (1973) first introduce and develop the basic concept of evolutionary gaming -- Evolutionary Stable Strategy (ESS). He argues that there is a widely accepted strategy, which under the forces of natural selection, would not be invaded by any different strategies, and this is the evolutionary stable strategy. An evolutionary stable strategy involves a process of survival of the fittest in a population. In the process of strategy selection, through learning and experience, the population prefers high-fitness, high-payoff strategies to those that pay less. The population would discard the strategies, which bringing them lower payoff when compared with others. To be more specific, if the behavioral pattern of a population (the original population) is not disturbed by any small mutant group, it must be able to obtain a higher payout than the mutant group, and over time the mutant group will eventually disappear from the original population:

The mathematical description is if the strategy S* satisfy the following conditions：

1) For any strategy S, when $U(S^*, S^*) \geq U(S^*, S)$;
2) If $S^* \neq S$, while $U(S^*, S^*) = U(S^*, S)$, and $U(S^*, S^*) > U(S^*, S)$ is true.

Then S^* is regarded as ESS. where U is the utility function, also known as the "expected payoff". Assuming that S^* is the populational strategy, S is the mutation strategy in the group. $U(S^*, S^*)$ indicates the expected payoff value that the player choosing strategy S^* would receive during the game, under the condition that the group chooses strategy S^*. Similarly, $U(S^*, S)$ represents the expected payoff that a player choosing mutation strategy S would receive during the game, given the group choice strategy S^*. The mutation strategy is discarded by the individual because the benefit received by the mutating individual for choosing the mutation strategy is less than the value of the payoff for choosing the group strategy. If the payoff from choosing a mutation strategy is higher than the gain from choosing a group strategy, the proportion of the group adopting a mutation strategy will increase, eventually breaking the steady state of the group strategy S^*, which does not meet the criteria for being an evolutionary stable strategy. Bach et al. (2006) discussed the problem of divergence in ESS and analyzed the formation of evolutionary stability strategies in the presence of multiple parties, arguing that multiparty evolutionary games differ from two-party evolutionary games, and negates the generality of the two-player conclusion.

Furthermore, Taylor & Jonker (1978) introduce a selection mechanism to construct a replication dynamic model. An important premise of evolutionary game theory assumes that the participants have limited rationality and that the key to game analysis is the strategy adjustment and learning and imitation behavior of the participants, but due to differences in learning ability and rationality issues between the participants, a different selection mechanism is needed to represent the process of adjusting the participants' strategy dynamics.

2.5 Stakeholders theory and the stakeholders of PPP projects

Organizations have traditionally been founded on the premise of shareholder primacy, with the belief that the primary goal of management is to increase the profits and wealth of the controlling shareholders. From this perspective, corporate behavior and decision making are driven by the need for economic income, but generally ignore public and macro interests, such as the optimal interests of society. It illustrates that private sector seek partial optimal state rather than whole optimal system of society. Stakeholder theory breaks away from this traditional view (Edward, 2002). Stakeholder theory is based on the premise that companies should balance the interests of all stakeholders rather than focusing primarily on shareholder wealth maximization. Companies should pay attention not just to their financial performance, but also to their social benefits. The management should understand and appreciate all those who have a stake in the conduct organization and its results, and their requests should be satisfied. The stakeholder theory says that the inclusion of the views of parties involved in organizational decision-making is both an ethical necessity and a strategic resource that both contribute to the competitive advantage of an organization (Cennamo et al., 2010; Plaza-Úbeda et al., 2010).

It is effective for decision maker to consider stakeholder theory in providing a normative and instrumental basis for the inclusion of stakeholders in management and business processes (Donaldson & Preston, 1995; Jones & Wicks, 1999). In the field of project management, Cleland (1986) was among the first scholars who put forward the theory for stakeholders, stressing the importance of stakeholder management as regards project success and creating a framework for the management of project stakeholders: identification, classification, analysis and training of management techniques. The management of stakeholders has now become a key competence for project managers (Crawford, 2005).

2.5.1 The development of Stakeholders theory

Stakeholders are individuals and groups of people who influence the behavior of an organization and the achievement of its objectives, or whom are affected by the achievement of organizational objectives in business processes (Freeman & Mcvea, 2008). Under a broad interpretative definition, any person or group can be referred to be a company stakeholder. This is why the theory of stakeholders frequently reduces the range of stakeholder definitions to major, lawful people and groups. The stakeholder theory largely eliminated and removed certain sections of the weak stakeholder population from the business's operations and aims (Hillman, & Keim, 2001; Walsh, 2005).

Sirgy (2002) divides stakeholders into three types: internal stakeholders, external stakeholders, and remote stakeholders. Employees, managers, corporate departments, and the board of directors are examples of internal stakeholders. Shareholders, suppliers, creditors, the local population, and the natural environment are all examples of external stakeholders. Competitors, consumers, the media, government agencies, voters, and labor unions are examples of remote stakeholders. The core notion of stakeholder theory is that a portion of the company's decision-making authority and interests, which are owned by shareholders, should be allocated to stakeholders (Stieb, 2009). And, as Freeman (2015) points out, any analogous theory relating to decision-making authority is likely to be misused by non-shareholders, as power flows from shareholders with greater wealth to stakeholders with less wealth. This transfer of wealth can be detrimental to stockholders benefiting from the company's profits.

Stakeholder theory can be categorized based on three perspectives: "descriptive accuracy, instrumental power, and normative validity" (Donaldson & Preston, 1995). The descriptive view merely indicates that the company has stakeholders. The organization's job is to serve the interests of a wide range of stakeholders, not just those of the firm's owners. When practicing shareholder management, several companies have been proven to adopt efforts to balance the demands of the company with the demands of the stakeholders (Clarkson, 1995). Recently, the discussion over stakeholder theory has recently centered on managers' moral and ethical responsibility to stakeholders. According to Greenwood (2007), stakeholder theory is ethically neutral since it is not necessary to include stakeholders and their requirements in order to act in the best interests of the firm's stakeholders.

2.5.2 The research of Stakeholders in PPP projects

The structure system of PPP scheme is complex and relatively flexible, involving the participating stakeholders including government, private capital, financial institutions, material and equipment suppliers, contractors, design companies and consultants and relevant networks of stakeholders (Chung et al., 2010; Chowdhury et al., 2011). Among them, the government and the private sector are the two domain participants in the PPP model, and the project company jointly established by both parties is at the core of the PPP model. The main responsibility of the public sector is to provide concession for the project company, provide policy support for the development of the project when necessary, and coordinate and supervise the construction and operation of the project company. Financial institution is a significant participant in PPP project, mainly referring to banks or consortia that provide financing loans for the projects. In addition, in order to ensure the correct implementation of the construction and operation phase of the project, the project company and the design company, contractors, material and equipment suppliers, and operation and management company reach a cooperative relationship through contracts to ensure the smooth implementation of the design, construction, material supply, and operation of the project and provide quality public services to the public. Meanwhile, the PPP project is supposed to be supervised by the supervisory department and the public in social media to continuously improve the quality of ultimate services and facilities (Chen et al., 2015). In the PPP model, different participating parties share different benefits and bear different risks, which together constitute the PPP model stakeholder relationship network, as shown in Figure 2-7.

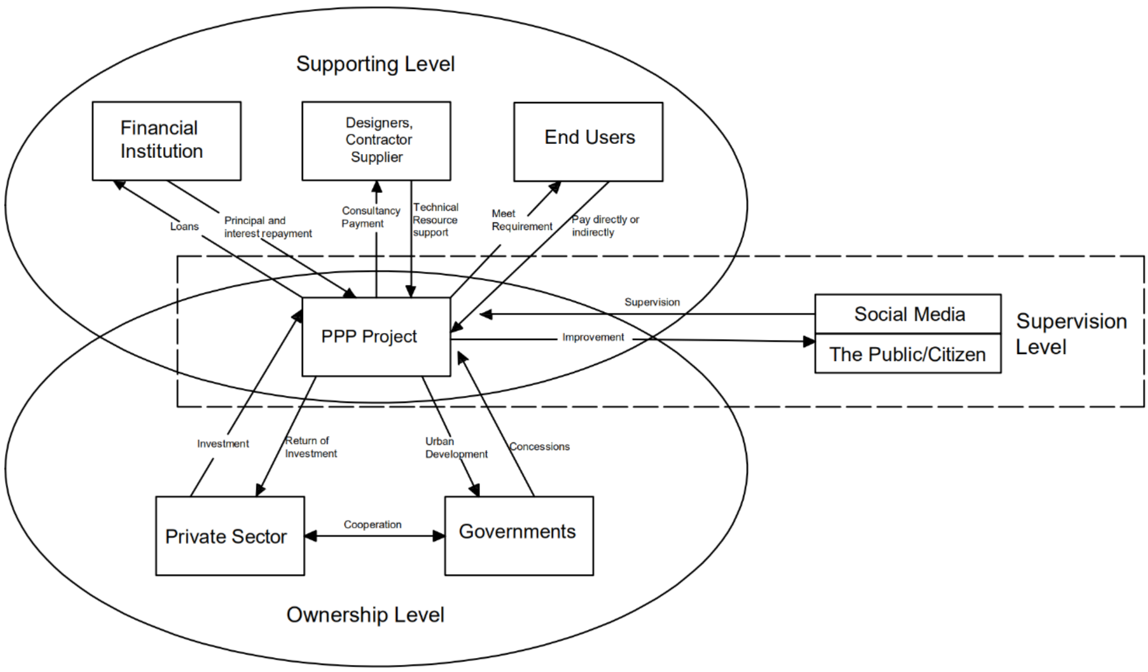


Figure 2- 7 The Relationships and level of stakeholders in PPP scheme

Based on the functions and roles of the stakeholders in PPP projects, the groups of stakeholders can be categorized into 4 types: (1) Public sector (2) Private sector (3) The general public refers to persons who are impacted by PPP projects or who are end customers of PPP scheme. (4) External research group. And the stakeholders also belong to the 3 main levels: The Ownership level, the supporting level, and the supervision level. The performance goals of stakeholder groups in PPP projects vary depending on expectations. However, despite the different preferences of stakeholders, the goal of a PPP is the successful implementation of a PPP project and should be achieved in a genuine PPP project. For example, the local government aims to make public facilities more efficient and will create significant profits from the PPP project for the private sector, and expects the public to benefit from the PPP project, which should depend on the successful conclusion of the PPP project in all areas.

Although, under the PPP model, public products or services are no longer directly produced or provided by government departments, the government still must assume the primary responsibility for public services. During the operation of PPP projects, there are at least three kinds of responsibilities that can only be assumed by government departments (Jovanic & Sredojevic, 2017; Wibowo & Alfen, 2015; Ke et al., 2009): (1) Since government departments are representing the interests of the public, they should ensure that the public goods or services If the public demand for the quantity and quality of public goods or services is not met, or if any problem occurs during the operation of the PPP project, the corresponding political responsibility must be borne by the government. (2) The government department, as the main participant, should also formulate and implement corresponding rules and procedures and regulations and policies, supervise the behavior of the private sector, and correct and punish its irregularities and violations, etc. (3) As the purchaser of public goods or services, the government department should also determine the subject matter of the procurement, select the appropriate private sector for the construction and operation of the project, and sign the contract agreement and implement it effectively.

The private sector, as another domain participant in PPP projects, sought to provide public products or services to government departments in accordance with the contract (Ismail, 2013; Ke et al., 2009). In the operation of PPP projects, the main responsibilities of the private sector are to participate in the bidding of the project according to the procurement agreement of the government department, and then to sign the cooperation agreement, and to fulfill the corresponding responsibilities and obligations according to the contract to achieve the normal construction and operation of the project. Although, it is still a commercial entity, and the basis and motivation for its survival and development is still to achieve commercial profits. Because the private sector produces or provides public products or services with public welfare nature, it also gives the private sector dual identities of private enterprise and public service provider. Therefore, dual identities determine that the private sector cannot increase its own profit by impairing the public interest.

2.6 The development of Xiong’an new area with PPP scheme and BIM

2.6.1 Overview of Xiong’an new area in China

In April 2017, China's national strategy to develop Xiong'an New Area was officially established. This is third national-level new area after the Shenzhen Special Economic Zone and Shanghai Pudong New Area in China. The central government also put forward the Planning Outline of Hebei Xiong'an New Area in April 2018, which is the basis plan for guiding the development and construction of Xiong'an New Area until 2050. It clarifies the urban and rural spatial layout, ecological and environmental construction, public services, industrial strategy, transportation system, and the main planning indicators in guiding ideology of Xiong'an. It clarifies the urban and rural spatial layout, ecological and environmental construction, public services, industrial strategy, transportation system, and the main indicators in guiding ideology of Xiong'an New Area.

Figure 2- 8 The location of Xiong’an new area and the three main City Clusters of China (Economist, 2017)

As shown in Figure 2-8, Xiong’an New Area locates in the hinterland of Beijing, Tianjin, 105 kilometers from Beijing and Tianjin, and 55 kilometers from Beijing's new airport. As a centralized bearer of the decentralization of Beijing's non-capital functions, Xiong’an New Area, together with Beijing's sub-center, will form two new wings of Beijing's development, and they will take on the historic responsibility of solving Beijing's "big city disease". Moreover, it is conducive to exploring a new model of optimal development of densely populated and economically dense areas, as well as to adjusting and optimizing the urban layout and spatial structure of Beijing-Tianjin-Xiong'an. The acceleration of creating a world-class city cluster and making Beijing-Tianjin- Xiong'an one of the three major city clusters in China.

2.6.2 Implement of PPP scheme in Xiong'an new area

Private sectors will serve a significant role in providing and infrastructure facilities and public services in Xiong'an New Area in Hebei Province. A recent report by international investment bank Morgan Stanley (Daniel, 2017) estimates that China's new Xiong'an New Area, which will take over Beijing's non-capital functions, will attract a large amount of investment and population, and is expected to absorb a total of RMB 1.2 trillion to 2.4 trillion(€ 300 Billion) in investment over the next 10 to 20 years. In order to promote the balanced development of Beijing, Tianjin, and Hebei (where Xiong'an area located), and it is estimated that 4.52 million people and workers in Beijing currently fall into the category of non-capital functional citizen.

However, the current Xiong'an New Area is composed of three small counties some surrounding areas, and at this stage, the financial revenue is weak, so the local financial support for regional infrastructure construction and public service development is limited. Although the central government will invest financial resources in the form of transfer payments to support the new area after it is upgraded to a national level, it is expected that the overall collaboration efficiency may not be able to catch up with the general market expectation of a GDP growth rate of 15% or more in the near future. PPP can help Xiong'an New Area to build infrastructure and public service-related projects quickly with limited financial resources, so that the competitiveness of the area can be improved in the shortest possible time and Xiong'an New Area can be developed more smoothly.

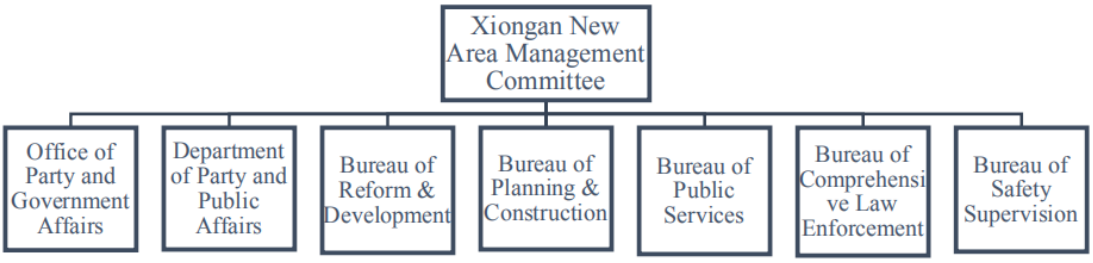


Figure 2- 9 The Administrative Departments and structure of Xiong'an New Area
(Recited from http://www.xiongan.gov.cn/)

" The PPP has become a complementary approach to raise financing for infrastructure projects, especially in municipal governments.," said by Yang, deputy director of the Center for Public-Private Partnership Studies at Tsinghua University (Zhang, 2017). He argues that the PPP scheme is an excellent way to alleviate the pressure on public sector financing. It is reasonable to reduce government debt for upcoming projects of such a great size and scale. In the private sector, the financial expenses are shared by means of risk management and competitive procurement methods. The Minister of the National Development and Reform Commission Lifeng He stated, "We will investigate a new regional management model, further administrative system reform and explore investments and finance." 'This will provide reliable investment for the long term and will attract social capital into building the new region.' PPP is the favored approach of dealing with the development of key infrastructure in China.'

"It is conservatively expected that the investment in infrastructure construction and public service facilities in Xiong’an New Area is expected to reach a scale of 500 billion yuan, and PPP will be an important project landing mode in this. Initially, it is predicted that the total annual addition of PPP projects in Xiong’an New Area will exceed 100 billion yuan in the next five years." Said by Tang, Research Director of PPP Research Center.

2.6.3 BIM technology application and development of Xiong’an new area

In August 2020, China's Xiong’an New Area Public Resources Transaction Service Platform released the "Xiong’an New Area Planning and Construction BIM Management Platform (Phase I) Project". At the same time, a winning bid announcement was published to the public, featuring Alibaba and China Academy of Urban Planning and Design teaming up to win the Xiong’an New Area Planning and Construction BIM Management Platform (Phase I) Project with a winning bid of 40.22 million RMB, beating other bidding rivals. It shows that the government aims to implement the BIM technology in the whole processes of development the new area.

As the focus of the national development strategy, there are no historical baggage and numerous potential problems of past urban planning of Xiong’an New Area, which and can completely take advantage of the BIM management platform. Using BIM technology, it can simulate the construction processes of key or difficult parts of the project, and comprehensively manage all kinds of information of the project from preparation, design, construction to operation stages. Through the interpretation of design data, BIM modeling of complex nodes, and analysis of complex nodes through the model. By quickly counting the workload of different professions, BIM technology can control on material planning and usage, and doing schedule simulation, construction simulation, and process design in advance, which can avoid the waste of materials. Meanwhile, the 3D visualization function of BIM can compare the construction plan with the actual project progress at any time, which greatly reduces the project rework and rectification.

In China's new generation of cities, Xiong'an will act as a model for the testing ground and application of innovative development ideas and technology. For instance, the building of the Xiong'an New Area Citizen Service Center already included more than 30 innovative development approaches, including Building Information Modelling (BIM) and Computer Integrated Processing (CIM). Wang, the vice-president of The China Academy of Urban Planning and Design, said Xiong'an will be a smart area for the future through widespread utilization of large-scale data and artificial intelligence.

2.7 Conclusion of Literatures and Research Gap

2.7.1 Summary of the Literatures Review

PPP scheme is regarded as an adaptive and practical financing mode, has played a significant role in infrastructure construction and public service delivery around the world. In the literature review sections, the critical success factors (CSF) and risk allocation in PPP projects are analyzed through the definition, characteristics, and stakeholder theory. It is found that in the evolutionary game, the payoff matrix of the game player affected by multiple influential factors in the PPP project, the analysis and summary of the influencing factors of the PPP project are helpful to the construction of the payoff matrix model. Similarly, this section analyzes the development of the PPP model in China and the similarities and differences with other countries around the world: the unique political system and the incomplete market economy in China often lead to an uneven distribution of risks in PPP projects, resulting in low willingness of the private sector to participate in PPP projects or low quality project outcomes. The research of promotion and optimization for the PPP scheme in China is valuable for the better development of urbanization.

Meanwhile, the literature review part summarizes the impact of BIM technology on PPP projects, and the stakeholders in PPP projects. With the rapid development of IOT technology and high-precision GIS technology to digital twin, 5D BIM (BIM model that considers process duration and cost). Although BIM technology and related digital management technologies have various advantages: including optimizing the duration and reducing design changes to reduce costs. However, since China is still in the early stage of BIM technology promotion and application, there is a gap in the usage rate and application area of BIM technology compared with the EU and the US. Therefore, in the transition process from traditional design and development methods to full-cycle application of BIM technology, which requires the investment in new design process and system. It may cause the design productivity loss in the transforming phase (Reizgevičius et al., 2018), which is the potential risk and can bring negative impact in the payoff matrix of the evolutionary model. The figure 2-10 illustrates the productivity loss during the transition process with the investment of BIM as new design methodology.

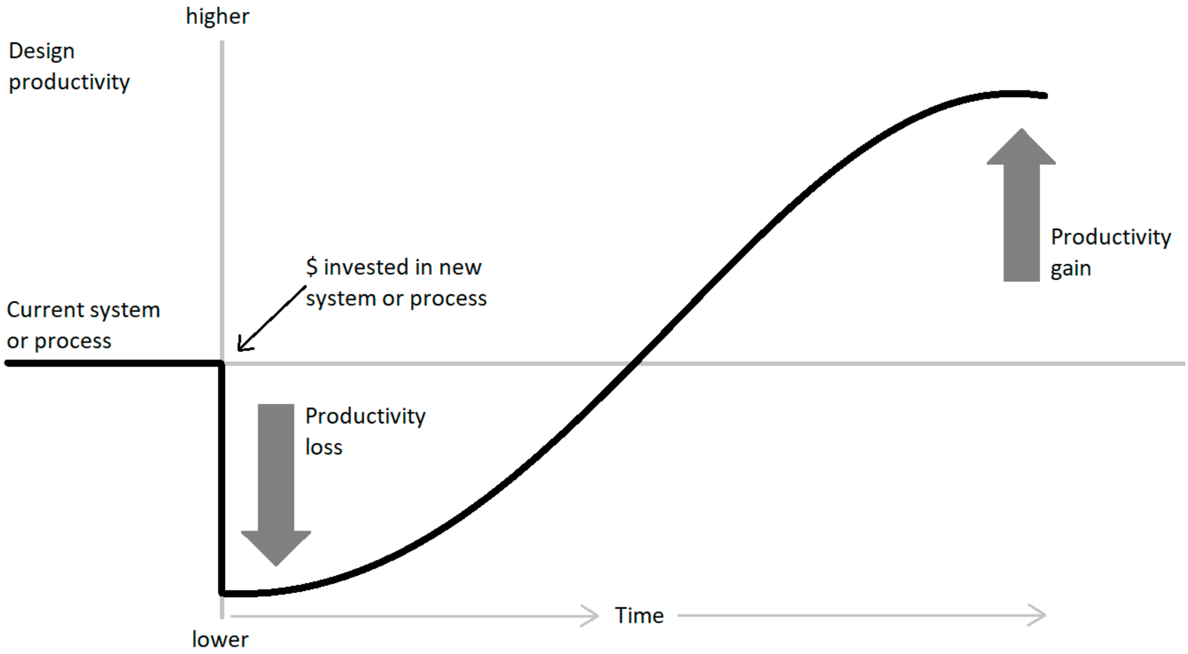


Figure 2- 10 The Administrative Departments and structure of Xiong’an New Area (Reizgevičius et al., 2018).

Furthermore, regarding the definition, channels, and mechanisms of public supervision are summarized and analyzed in the review section. In general, due to the numerous types of stakeholders and complex relationships in PPP projects often lead to inefficiencies and lack of information transparency in PPP projects. The public monitoring and media monitoring, as the external influencing factors of PPP organizations, play a crucial role in the quality of PPP project outcomes. Public supervision not only restrains the risky behavior of private sector, but also promotes the dissemination of project information to a certain extent and alleviates the information asymmetry problem faced by public sector and government in PPP projects. Meanwhile, the continuous development of mobile Internet social platforms in recent years has broadened the channels of public supervision and reduced the lag of information transmission in traditional methods. However, due to the existence of false information or news, how to identify the authenticity and validity of information on social platforms has also brought new challenges to the public monitoring system.

Finally, the literature review on evolutionary game theory and the current situation and planning of Xiong’an New Area, explain in detail the applicability and fitness of evolutionary game as a method based on ecology and game theory in social sciences and stakeholder analysis of PPP projects. The evolutionary game theory assumes of limited rational human beings, rather than hyperrationality, and the process by which individuals in a group behavior continuously imitate the superior strategies of other individuals, and then continuously adjust their strategies. The process of strategy replication is precisely described by using the replication dynamic equation. The correct model and the establishment of assumptions also play a decisive role in the subsequent simulation. Regarding the Xiong'an New Area in China, the establishment and development of this area as a national strategy aims to alleviate the congestion caused by the over-concentration of functions in Beijing and will be serve as the role of taking over the non-capital functions of Beijing. In order to promote the market economy and make it decisive in the future development, the PPP model will be used in the development of the Xiong'an New Area. PPP model will be the main financing method in the construction of this region. And the wide application of BIM technology，to optimize the behavior of the domain stakeholders is crucial for the success and efficiency in the PPP projects.

2.7.1 Research Gap

Based on the previous studies and research, the motivation of this paper and research gaps of include 3 aspects are identified as below:

First of all, game theory as a classical and effective approach has been wildly applied in the analysis of the stakeholders' behavior in the AEC (Architecture, Engineering and Construction) industry, especially in the PPP scheme (Li et al., 2017; Javed et al., 2014; Medda, 2007). However, traditional game theory is based on the hypothesis of rational man, which means all players possess complete information of the game and can calculate the payoff correctly. In evolutionary game theory, limited rationality means that players cannot find the best strategy from the beginning of the game, but can only learn and adjust their strategies by comparing with high-yielding individuals continuously to obtain higher payoff. Therefore, analyzing PPP organizations and stakeholders in the organizations from the perspective of evolutionary games is more in line with the real situation.

Second，In the previous studies have been mostly conducted to find the equilibrium and optimal strategies the game players in PPP projects mainly through theoretical static analysis or questionnaire method. However, PPP schemes and projects are affected by various external factors and may change continuously with the changing social environment conditions. As a dynamic system, the subsystems of the system are subject to change, resulting in changes in the behavior and strategies of the game players. In a population, changes in the factors affecting returns are often dynamic and it is difficult to accurately estimate the probability of an event occurring. Dynamic analysis can provide a changing relationship between time and strategy choice, and can provide a more intuitive response to the impact of different factors on the system.

Furthermore, the critical success factors (Williams, 2016; Kagioglou et al., 2001; Yuan et al., 2012), failure factors (Abdul & Jahn, 2011; Li & Wang, 2019) or risk allocation (Ke et al., 2010) of PPP projects are identified through empirical analysis of PPP project cases in previous research. However, the simulation is rarely applied in the previous research of PPP scheme, both in game theory model and real-time related model. Simulation can provide a testing methodology to compare what is the optimal value for a certain variable. Also, numerical simulations of game strategy choices can provide a more systematic and intuitive diagram of the critical factors that can influence the behavior of stakeholders. It is difficult to derive which variables will have a greater impact on the system just through the equation derivation analysis. Finding the key variables that affect the equilibrium of the system is an important step for further discussion and policy recommendations.

Meanwhile, the previous research focuses on single factor of PPP scheme, lack of dialectical studies that explore the PPP model from multiple perspectives. This study considers PPP model both from BIM technology and public supervision perspectives. It can be concluded that public supervision is a social influence factor, while the application of BIM can be regarded as a scientific and technological influence factor. It is found that there are few studies on PPP model under two different perspectives of BIM technology and public supervision under new media. At the same time, these two factors are also emerging macro environmental influences that have been developing rapidly in recent years, and exploring their influence on the traditional AEC industry and PPP scheme has a crucial role in optimizing and improving the PPP model.

Finally, there are still many unsolved issues regarding the PPP model for the Xiong'an New Area and the urban development plan. The national strategy to develop the Xiong'an New Area and make it part of the future capital city cluster of China was only officially proposed and announced in 2017. And Beijing-Tianjin-Xiong'an city cluster would become one of the biggest city clusters in future China. Therefore, there are many research gaps in both theoretical and practical work on the urban development and long-term planning of Xiong'an New Area. At the same time, it also provides research space for the promotion of PPP scheme under the evolving and changing environment. At present, we human is confronting the third industrial revolution: the information revolution. And the digitalization of the construction industry still needs to be improved. The development of Xiong'an New Area provides the basis for experimentation, not only as an attempt to use new technology to improve the efficiency of PPP projects in China, but also as a vision to bring more in-depth thinking and imagination about the PPP model to countries around the world.

To sum everything up, based on the comprehensive analysis above, this research considers the behavioral strategies and evolutionary process of the government and social capital parties in applying BIM technology in PPP projects as the background, applies evolutionary game theory to build a game model based on BIM application for both parties, analyzes the stable equilibrium strategies and conditions for both parties, and MATLAB as tool is used to simulate different scenarios to visually reflect the evolutionary driving forces and trends of the government and social capital parties, so as to provide help for applying and promoting cross-organizational collaborative technologies such as BIM in PPP projects.

Chapter 3 Methodology: Theory, Tool, and Justification

3.1 Evolutionary Game theory

3.2 Evolutionary game model construction and payoff matrix

3.3 Evolutionary game analysis

3.4 Data collection and simulation by MATLAB

3.5 Methodology Justification: Reasons of evolutionary game theory in PPP projects analysis

3 Methodology: Theory, Tool, and Justification

To select an appropriate methodology is of importance to achieve the research goal and address the research questions. In this section, the theory and tool of the main methodology are introduced to justify the applicability of evolutionary game analysis for the PPP projects. Furthermore, the evolutionary game analysis including the payoff matrix construction, data collection and evolutionary simulation by MATLAB are explained in this part.

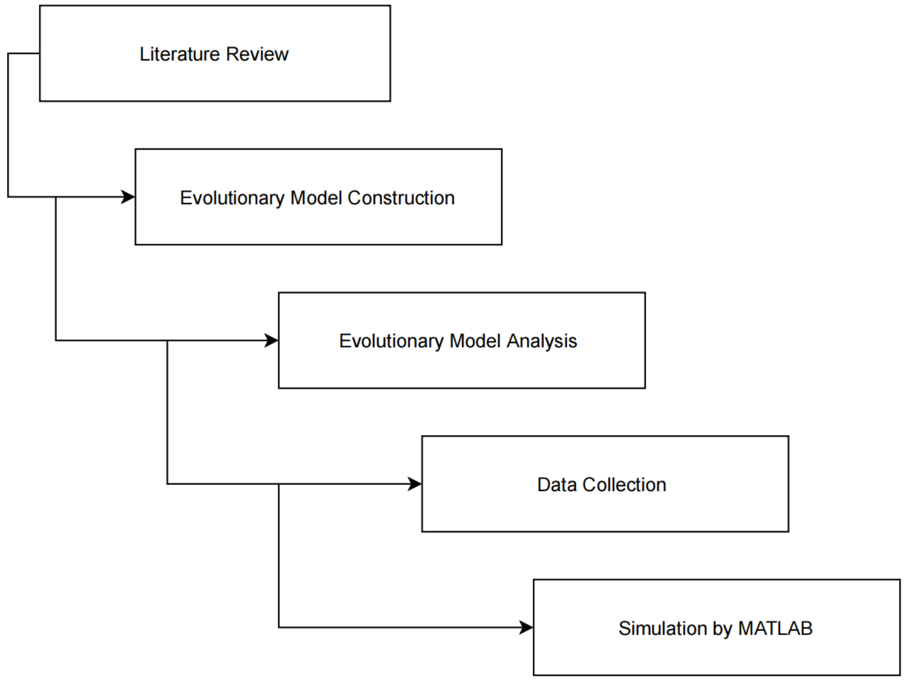


Figure3- 1 Methodology and process of evolutionary game analysis and simulation

As shown in Figure 3-1, the main methodology that applied in this research is evolutionary game analysis, which assisted with the literature review, data collection and simulation by MATLAB. Among them, evolutionary game analysis mainly includes the construction of evolutionary game model and game path analysis. At the same time, in order to intuitively demonstrate the impact of public supervision and BIM technology on the behavior of the players, MATLAB is used to simulate the replication dynamic equation in the game model. Literature review and data collection are auxiliary research methods. The former provides a theoretical basis for the construction of evolutionary model, while the latter improves the reliability and authenticity of simulation results through a variety of different data sources.

This study uses an evolutionary game approach to model and analyze behaviors of local government and private sectors in PPP project. The participators under the evolutionary game theory can learn and compete with each other and adapt optimized strategy in the game process. Compared with the traditional game theory, evolutionary game theory mainly contains the following characteristics. The research object is a group that changes with time, the purpose of theoretical exploration is to understand the dynamic process of group evolution, and explain why the group would reach a certain equilibrium state and how to reach it. At the same time, compared with the rational human hypothesis in traditional game theory, evolutionary game regards agents in the model as bounded rationality, which is more in line with the situation that players can not accurately calculate the decision-making benefits in real projects due to asymmetric information or random events.

3.1 Evolutionary Game theory

When John Nash first put forward the concept of "equilibrium", he pointed out that there are two means to explain "equilibrium", namely "the explanation under rationalism" and "the explanation of large-scale action" (John Nash, 1951). The former is the explanation of classical game theory, while the latter is actually the explanation of evolutionary game theory. The content of evolutionary game is the process that human beings choose the optimal strategy through trial and error under the premise of bounded rationality to achieve the equilibrium of group game.

In the early stage of research, biologists got inspiration from it, and used the idea of strategic interaction to build a biological competitive evolution model to explain the evolutionary mechanism of traits selection, gender distribution, growth and development in the process of evolution (Lewontin, 1961). Smith & price (1973) first proposed the basic concept of evolutionary game evolutionary stable strategy Their computer simulation analysis shows that the "limited war" strategy between the same species is beneficial to both individuals and species. On this basis, Taylor & Jonker (1978) introduced the selection mechanism to construct a replication dynamic model, and studied the stability and asymptotic behavior of the players' strategy selection behavior through the first-order nonlinear differential equations. At the same time, it is proved that under certain conditions, the game player's strategy combination should approach the optimal state or equilibrium state

This study uses an evolutionary game approach to model and analyze the stakeholders in a PPP project. Evolutionary game theory, which views participator as limited rational agents. The participators under the evolutionary game theory can learn and compete with each other and adapt optimized strategy in the game process.

In evolutionary game theory, a finite rational individual has limited decision-making ability, is unable to correctly calculate their own gains and make the best decisions, often through trial and error and on imitation to learn the strategy with higher returns, and then form an equilibrium steady state (Levine et al., 2007). At the same time, evolutionary game theory is based on finite rationality, breaking through the assumption of complete rationality of classical game theory, with strong realism, making it possible for people to carry out scientific explanation, analysis and prediction of various economic phenomena in society, which has played a great role in promoting the development and application of game theory.

Because of the practical implication of the evolutionary game model, it has been widely applied to answer the a variety of research questions that related to these topics: the subsidy policy of new energy vehicles (Ji, 2019), investment plan of infrastructure (Dimitriou et al.,), and the cases that the stakeholders have the issues of information absence, and dynamic competition and adjustment in the project. Furthermore, the methodology justification and reasons of applying evolutionary game theory in PPP scheme domain are explain in section 3.4 of this chapter.

3.2 Evolutionary game model construction and payoff matrix

Based on evolutionary game theory, the impact of public supervision and BIM technology on the payoff matrix is quantified into specific parameter variables, an evolutionary game model is constructed, and the model would be solved according to the theory. In order to analyze and simulate the game behavior of local governments and private sectors under the public supervision and the implementation of BIM technology. First of all, this evolutionary game model requires the assumptions of the model construction. The completeness and correctness of these assumptions will have a significant impact on the model and the subsequent simulations. These assumptions are supposed to be as realistic as possible, or the model should be simplified as necessary to make the results of the analysis consistent with the expected and actual situation.

Furthermore, after establishing the model assumptions, it is important to establish the payoff matrix of game participants and the definition and calculation of payoff value. According to the literature review, the abstract policy and environmental effects are transformed into concrete and quantified parameter variables, which are brought into the payoff matrix. Also, because the problem can be explained and viewed from a system perspective, the system dynamics model will be used in this section to explain the parameters and variables in the model that are used to explain the negative feedback adjustment mechanism. Due to the specialty of public supervision, which can cause favorable or unfavorable effects on both players of the game, it is difficult to illustrate the actual impact through examples or empirical evidence.

3.3 Evolutionary game analysis

Under the condition of limited rationality, the strategy choice of the players is a gradual process, that is, through learning, adjusting their own strategy choice, and finally reaching the stable state of group equilibrium. Due to individual differences, the change of strategy choice is fast and slow, not all players adjust at the same time, and the speed of strategy adjustment can be expressed by the dynamic equation of biological evolution - replication dynamic equation. Replicator dynamics is essentially a dynamic differential equation describing the frequency or frequency of a particular strategy in a population:

$$\frac{dx_i(t)}{dt} = [U(S_i, x) - U(x, x)]x_i \quad (3\text{-}1)$$

In the equation x_i is the proportion of the group that chooses strategy S_i, and t is time, which represents the derivative of x_i over time t, i.e. the growth rate of x_i. $U(S_i, x)$ represents the expected payment to the individuals in the group who choose strategy S_i, given random anonymous matching, and $U(x, x)$ represents the average expected payment to the group. The replicator dynamics specifies that the proportion of the group using the strategy rises when it is possible to generate a higher return than the average expectation of the group, falls when the return is lower than the average expectation, and remains unchanged when the return is equal to the average expectation.

Lastly, the analysis and calculation part of the model, scenario analysis would be conducted to illustrate the potential situations which caused by different parameters value and their numerical features. The features values of the payoff matrix would be transferred into a Jacobian matrix, and the determinant and the trace value of Jacobian matrix would be calculated to clarify the end scenario of the evolutionary game behaviors under certain values. A series of diagrams would be depicted to demonstrate the evolutionary path of the behaviors and strategies of the local governments and private sectors. The path figures also illustrate the stable points or the ESS points of the evolutionary process, which is helpful to identify the appropriate supervision mechanism and encouraging mechanism for optimizing the resource allocation and promoting the quality of final products in PPP scheme.

3.4 Data collection and simulation by MATLAB

The methods of data collection mainly include literature research and case statistics. In order to improve the reliability of the simulation results, the source and processing method of the receipt data play a vital role in the subsequent simulation. Literature research as the main data source, the 2018 annual report of PPP center of the Ministry of finance of China, the academic journal papers of quantitative research on public supervision and BIM Technology all provide data sources for variables in payoff matrix. At the same time, the cases which located in the target research area would be retrieved are used to supplement the data that are not included in the literature or annual report. At the same time, the accuracy of the data of the first method can be verified.

Finally, the model is simulated numerically, and this study intends to use MATLAB software to simulate the evolutionary game path of the two parties in the perspective of private sectors. After the execution of the ode45 function is completed, the function plot (t, x) can be called to draw a two-dimensional graph of variables x1 and x2, and the results can be analyzed by combining the graphs.

3.5 Methodology Justification: Reasons of evolutionary game theory in PPP projects analysis

As a research method proposed by ecology and biology fields, evolutionary game theory can accurately describe the dynamic behavior of groups in process of game, and is widely used in various social and economic studies. In order to study the game process between local government and private sectors in PPP projects, optimize the supervision of PPP projects and the use of emerging technologies, and ultimately improve the quality of PPP projects and the cooperation and communication efficiency of multiple project participants. The main reasons and advantages of PPP projects are as follows.

Firstly, evolutionary game theory is based on finite rationality, which breaks through the assumption of complete rationality of classical game theory and has a strong realistic character. It enables players to carry out scientific interpretation, analysis, and prediction of various economic phenomena in society and business. Evolutionary game analysis has played a significant role in promoting the development and application of game theory. In the practical process of PPP projects, due to the asymmetry of information, the dynamic changes in the environment and the limitations of human thinking, the private sector and government departments are all finite and rational agents, and the game between them is a process of continuous learning and dynamic evolution.

Furthermore, evolutionary game theory is a dynamic analysis of game process from the perspective of system. Dynamic analysis is mainly reflected in the path analysis of evolutionary game theory and the irreversibility of time. In the traditional game theory, the behavior subject is completely rational. Usually, under the assumption of complete rationality, if Nash equilibrium exists, then both sides of the game can directly reach Nash equilibrium in one game. This result does not depend on the initial state of the market, so it does not need any dynamic adjustment process. According to evolutionary game theory, the Nash equilibrium can only be achieved after multiple games, which requires a dynamic adjustment process. The equilibrium depends on the initial state, which is path dependent, that is, the initial state may have an impact on the final stable equilibrium state. Game theory pays attention to the study of equilibrium state and ignores the process of reaching equilibrium. In the game theory, the actor can immediately make a perfect judgment of the external environment to achieve equilibrium. The game theory ignores the problem of time, emphasizes the equilibrium of the actor's instant question, and even considers the problem of time as symmetric or reversible. In evolutionary game theory, time plays a very important role. In the process of evolution, actors constantly modify and improve their own behavior, imitate successful strategies for higher pay off in evolutionary game.

Additionally, the hypothesis of evolutionary game theory is more realistic and can better predict the behavior of players in the real world. When there are multiple Nash equilibria in the game, it is difficult to predict the outcome of the game even if the players are completely rational. If the players have only limited rationality, it is even more difficult to predict the outcome of the game. Of course, in game theory, when there are multiple Nash equilibria, backward induction can be used to refine the Nash equilibrium, but the premise of this method is that the participants need to satisfy a more rational assumption than complete rationality - sequential rationality. This is impossible in reality. In evolutionary game theory, the refining of equilibrium is realized by forward induction, that is, participants choose their future behavior strategies according to the history of the game, which is a dynamic selection and adjustment process. Therefore, although the participants are bounded rational, the dynamic selection mechanism will make it possible to reach one of the Nash equilibria when there are multiple Nash equilibria, and realize the refinement of Nash equilibrium.

Last, the application of evolutionary games at the level of PPP is mainly focused on the discussion of cooperation mechanisms, incentive mechanisms and regulatory mechanisms of the PPP model. Liu et al. (2017) explore reasonable risk sharing by constructing utility functions between the public and private sectors, introducing long-term cooperation mechanisms, and analyzing the evolutionary game model of risk sharing under private sector opportunism. Li et al. (2016) Consider the impact of reputation on the regulation of PPP projects, construct an evolutionary game model, and find that when the impact of reputation on returns reaches a certain level, it can effectively promote the public and private sectors to provide quality public services. Li et al. (2018) conclude the public-private partnership in large-scale infrastructure projects has revealed that in PPP projects, the evolution of the partners alone cannot lead to an optimal strategy, and that regulatory and incentive systems need to be introduced to modify the direction of the evolutionary path.

Chapter 4 Model construction by Public supervision

4 Evolutionary game model construction by Public supervision

In this section, the evolutionary game models from the public supervision perspective are formed and analyzed by with payoff matrix and scenario exploration. The variety of PPP schemes and norms of partnership in current China and the uniqueness of each PPP projects, to categorize and cluster different PPP modes and projects based on their similarity can significantly reduce the redundancy of this research. Hence, three sub-models under the public supervision are constructed and analyzed in this section, which is aimed to cover all the forms and modes of PPP projects. Figure 4-1 shows the structure of evolutionary game models under public supervision, which are composed of one-time cooperation PPP project, long-term cooperation and nonprofitable projects as three sub-models of this section. The first level is to distinguish profitable PPP projects and nonprofitable PPP projects, all PPP projects can be categorized into the binary types. To be more specifically, profitable PPP projects refer to the projects which applying user-pay mode in the operation phase, such as regional power station and toll expressway are typical profitable PPP projects. On the other hand, the PPP projects that involved government payment mode and Viability Gap Funding (VGF) payment mechanism fall into the nonprofitable projects. For instance, urban greening and ecological engineering projects are typical nonprofitable projects which means the end-user would gain benefits from these projects without direct payment.

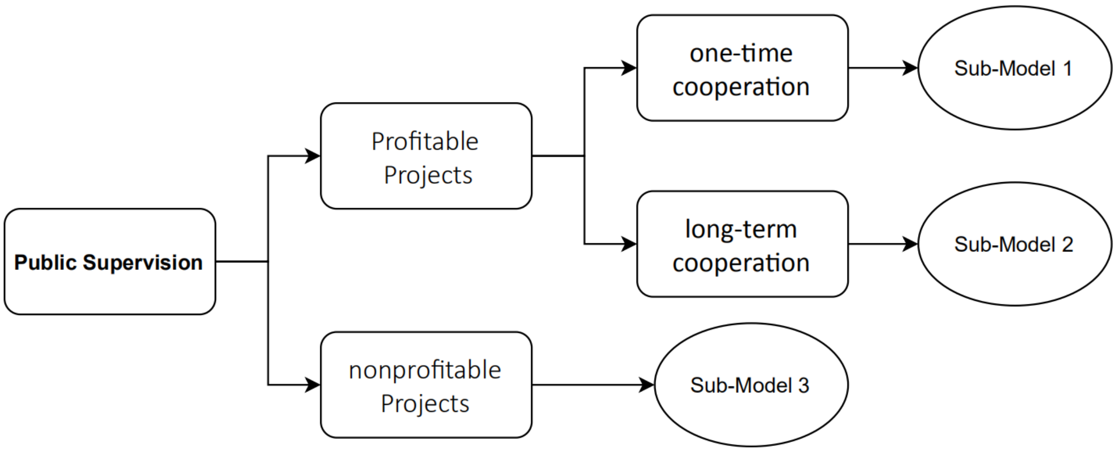


Figure 4- 1 Classification of PPP modes under public supervision

Moreover, the profitable projects can be further divided into two categories, the one-time cooperation and long-term cooperation. The behavior and strategical choice of the game players can be distinct due to the optimism and long-term trust benefits are different in the two categories.

These section aims to model the behavior and identified critical influential factors of the players in the payoff matrix, and analyze the numerical relation of the variables in the case by case analysis. The scenario analysis provides a comprehensive and systematical approach to explore the equilibrium states of the evolutionary game process. Also, the numerical relation of the variables under different equilibrium states serve as the preparation for further simulation, and critical and sensitive variables can be identified in this section.

4.1 Evolutionary model of one-time cooperation under public supervision

4.1.1 Assumptions and hypothesis for one-time cooperation model

1. The players in the model are local governments and private sectors, both of them are finite rationality and not overlap.
2. The players can make decisions based on the comparison and imitate the strategy choice of the individual who has the maximum payoff in group.
3. There are two strategical choices for local governments. The government's behavior strategies are: {Encourage public supervision, Not encourage public supervision}, the strategy of governments can be summarized as whether to encourage the public to participate in the supervision of PPP projects and provide a platform or channel for public supervision.
4. Private sectors have two choices of strategy: {Opportunism, Compliance Contract}. Compliance contract refers to complete the engineering project with high quality in accordance with the specification requirements of the contract, while opportunism may choose complete project with insufficient quality.
5. Assume that the probability of local governments choosing to encourage public supervision is x ($0 < x < 1$), and the probability of choosing not encourage is 1-x; The strategy of private sectors to choose to opportunism is defined as y ($0 < y < 1$), while the probability of choosing to compliance contract strategy is 1-y.
6. The payment of PPP project contains fix payment and performance payment, and the performance payment depends on assessed quality and performance of projects, so i0 and i1 refer to coefficients of performance payment under the Opportunism and Compliance Contract strategies respectively.
7. There is cost of providing channels to the public and identification cost of the authenticity in reports on social media for local governments.
8. When the private sector chooses Opportunism strategy, the probability when local governments encourage public supervision and being found by public supervision the low quality of projects is P1, and when local governments do not encourage public supervision is P2, and assume that P1> P2.
9. The bonus from encouraging the public to supervise include the benefits from upper department and benefits from KPI of public reputation.
10. There is potential loss for local governments when the private sector do not comply the contract and finish projects in low quality.
11. The cost of providing high quality projects and chose opportunism are C_2 and C_1 respectively, and $C_1 < C_2$.

4.1.2 Parameters Statement and model demonstration

Game Player	Game strategy	Symbol	Description
Local Government	Encourage	x	Proportion of local governments who encourage the public supervision($0<x<1$)
		F	Fixed Payment to private sector
		F_P	Performance payment to private sector
		S	Default Supervision cost
		C_0	The cost of providing channels to the public and identification cost of the authenticity in reports on social media
		B	The benefits from encouraging the public to supervise
		P_1	The Probability of finding the private sector do not complete projects as contract When the private sector chooses Opportunism strategy and government encourage public supervision($P_1> P_2$)
	Not Encourage	$1-x$	Proportion of local governments who do not encourage the public supervision
		P_2	The Probability of finding the private sector do not complete projects as contract when government do not encourage public supervision
Private Sector	Opportunism (Low-quality project)	y	Proportion of private sectors who perform Opportunism in PPP project($0<y<1$)
		C_1	Cost of providing low-quality project ($C_1< C_2$)
		L	The loss from the low-quality projects by punishment from upper-level departments for local governments when not finding issues in projects
		i_0	Coefficient of Performance payment in low-quality project ($i_0< i_1$)
	Compliance Contract (High-quality project)	$1-y$	Proportion of private sectors who do not perform Opportunism in PPP project($0<y<1$)
		C_2	Cost of providing High-quality project
		i_1	Coefficient of Performance payment in high-quality project

Table 4 Description of game model parameters of one-time cooperation PPP model

	Strategies	Local Government: Encourage (x)	Local Government: Not Encourage (1-x)
Private Sector	Opportunism (y)	($F+ i_0 F_P- C_1- P_1 i_0 F_P$; $-F-i_0 F_P-S+B- C_0+ P_1 i_0 F_P- P_1 L$)	($F+ i_0 F_P- C_1- P_2 i_0 F_P$; $-F-i_0 F_P-S - C_0+ P_2 i_0 F_P- P_2 L$)
	Compliance (1-y)	($F+ i_1 F_P- C_2$; $-F-i_1 F_P-S+B- C_0$)	($F+ i_1 F_P- C_2$; $-F-i_1 F_P-S$)

Table 5 One-time cooperation PPP model by pay off matrix

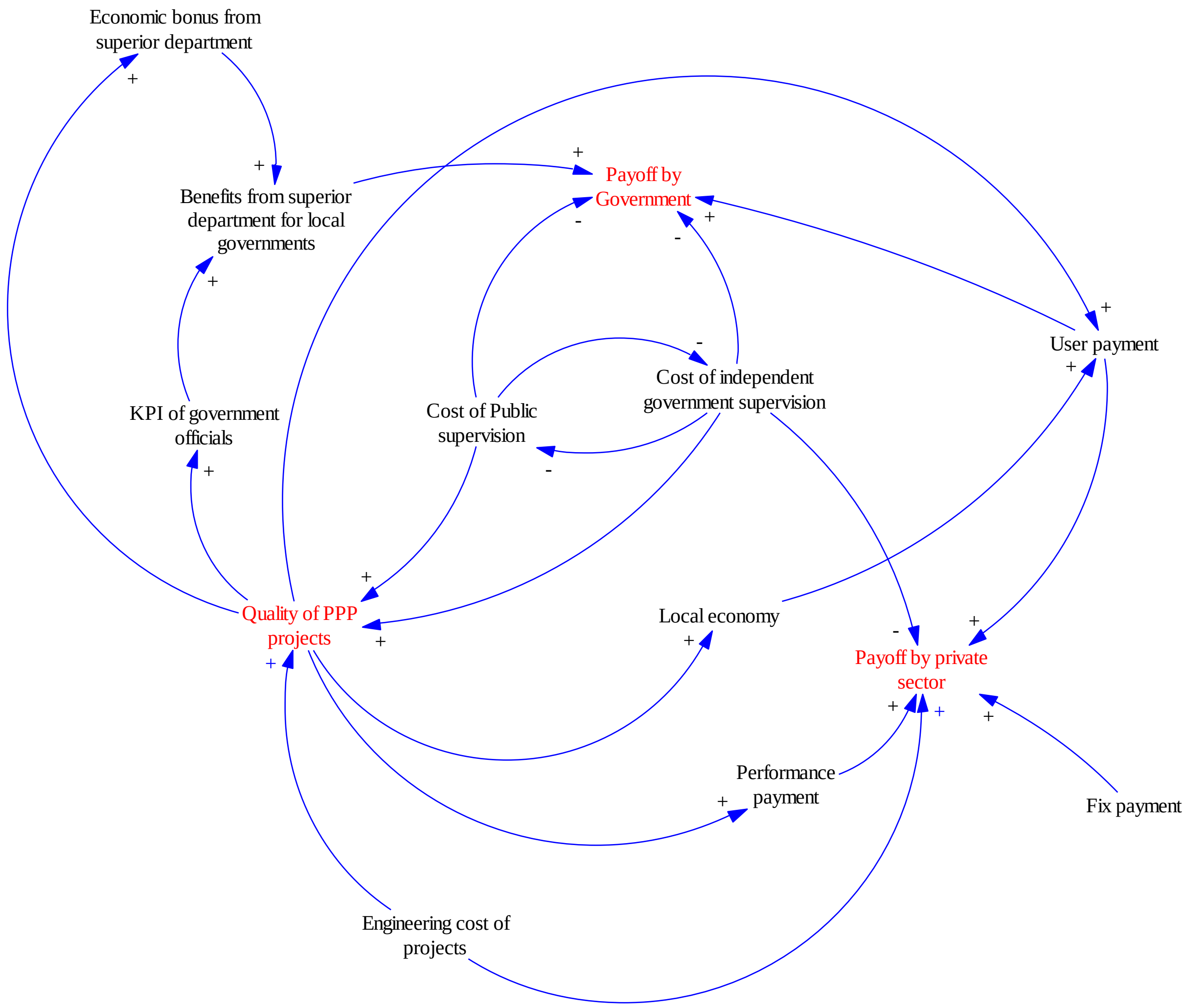


Figure 4- 2 The system dynamic interpretation for the evolutionary model under public supervision

The expected payoff of local governments when they choose strategy A (Encourage) and strategy B (Not encourage) are U_{1A} and U_{1B}, and the average payoff of the population is $\overline{U_1}$.

$$U_{1A} = y(-F - i_0 F_P - S + B - C_0 + P_1 i_0 F_P - P_1 L) + (1-y)(-F - i_1 F_P - S + B - C_0) \quad (4\text{-}1)$$

$$U_{1B} = y(-F - i_0 F_P - S - C_0 + P_1 i_0 F_P - P_2 L) + (1-y)(-F - i_1 F_P - S) \quad (4\text{-}2)$$

$$\overline{U_1} = x \cdot U_{1A} + (1-x) \cdot U_{1B}$$
$$= xy(-\mathrm{F} - i_0F_P - \mathrm{S} + \mathrm{B} - C_0 + P_1\, i_0F_P - P_1\mathrm{L}) + x(1-y)(-\mathrm{F} - i_1F_P - \mathrm{S} + \mathrm{B} - C_0) + (1-x)y(-\mathrm{F} - i_0F_P - \mathrm{S} - C_0 + P_1\, i_0F_P - P_2\mathrm{L}) + (1-x)(1-y)(-\mathrm{F} - i_1F_P - \mathrm{S}) \quad (4\text{-}3)$$

The expected payoff of private sector when they choose strategy A (Opportunism) and strategy B (Compliance) are U_{2A} and U_{2B}, and the average payoff of the population is $\overline{U_2}$

$$U_{2A} = x(\mathrm{F} + i_0F_P - C_1 - P_1\, i_0F_P) + (1-x)(\mathrm{F} + i_0F_P - C_1 - P_2\, i_0F_P) \quad (4\text{-}4)$$

$$U_{2B} = x(\mathrm{F} + i_1F_P - C_2) + (1-x)(\mathrm{F} + i_1F_P - C_2) \quad (4\text{-}5)$$

$$\overline{U_2} = y \cdot U_{2A} + (1-y) \cdot U_{2B}$$
$$= xy(\mathrm{F} + i_0F_P - C_1 - P_1\, i_0F_P) + y(1-x)(\mathrm{F} + i_0F_P - C_1 - P_2\, i_0F_P) + y(1-x)(\mathrm{F} + i_1F_P - C_2) + (1-x)(1-y)(\mathrm{F} + i_1F_P - C_2) \quad (4\text{-}6)$$

From this, we can get the replication dynamic equation of the local governments is

$$\frac{dx}{dt} = x(U_{1A} - \overline{U_1})$$
$$= x(1-x)[U_{1A} - U_{1B}]$$
$$= x(1-x)[y(-\mathrm{F} - i_0F_P - \mathrm{S} + \mathrm{B} - C_0 + P_1\, i_0F_P - P_1\mathrm{L}) + (1-y)(-\mathrm{F} - i_1F_P - \mathrm{S} + \mathrm{B} - C_0) - y(-\mathrm{F} - i_0F_P - \mathrm{S} - C_0 + P_1\, i_0F_P - P_2\mathrm{L}) + (1-y)(-\mathrm{F} - i_1F_P - \mathrm{S})]$$
$$= x(1-x)[y(C_0 - P_1\mathrm{L} + P_2\mathrm{L}) + (\mathrm{B} - C_0)] \quad (4\text{-}7)$$

The replication dynamic equation of the private sectors is

$$\frac{dy}{dt} = y(U_{2A} - \overline{U_2})$$
$$= y(1-y)[U_{2A} - U_{2B}]$$
$$= y(1-y)[x(\mathrm{F} + i_0F_P - C_1 - P_1\, i_0F_P) + (1-x)(\mathrm{F} + i_0F_P - C_1 - P_2\, i_0F_P) - x(\mathrm{F} + i_1F_P - C_2) + (1-x)(\mathrm{F} + i_1F_P - C_2)]$$
$$= y(1-y)[xi_0F_P(P_2 - P_1) + (i_1F_P - i_0F_P + P_2\, i_0F_P + C_1 - C_2)] \quad (4\text{-}8)$$

4.1.3 Model solution and analysis for one-time cooperation model

1) Strategy stability analysis of local governments

Based on the stability theorem, Solving the equation $\frac{dx}{dt} = x(1-x)[y(C_0 - P_1\mathrm{L} + P_2\mathrm{L}) + (\mathrm{B} - C_0)]$, the x=0, x=1 and $y = \frac{C_0 - B}{C_0 - L(P_1 - P_{2)}}$ are the roots of

$$F(x) = \frac{dx}{dt} = 0,\ F'(x) = \frac{dF(x)}{dx} = (1-2x)[y(C_0 - P_1\mathrm{L} + P_2\mathrm{L}) + (\mathrm{B} - C_0)] \quad (4\text{-}9)$$

When $F(x) = 0$, and $F'(x) \le 0$, x is the evolutionary stable strategy.

If $y = \frac{C_0 - B}{C_0 - L(P_1 - P_{2)}}$, then for any x, $F(x) = 0$, and $F'(x) = 0$, any strategy of local governments is stable while axis x is in a stable state;

If $y \neq \frac{C_0-B}{C_0-L(P_1-P_2)}$, then the different cases would be conducted to analysis to demonstrate the stability of the equation roots

Due to $0 < y < 1$, we have $0 < \frac{C_0-B}{C_0-L(P_1-P_2)} < 1$. And $P_1 > P_2$, hence $P_1 - P_2 > 0$, the numerical relation between $L(P_2 - P_1)$ and B would determine the stability of the strategy.

(1) Case 1: when $C_0 < B$ and $C_0 > L(P_1 - P_2)$, it leads to $\frac{C_0-B}{C_0-L(P_1-P_2)} < 0$ *and* $0 < y < 1$, then $y > \frac{C_0-B}{C_0-L(P_1-P_2)}$. So, the two other roots and solutions are stable solutions. Moreover, because of the $F'(x)|_{x=0} > 0$, $F'(x)|_{x=1} < 0$, so that the root $x = 1$ is the only evolutionary stable strategy.

Case 1 illustrates that when the cost of providing channels to the public and monitoring (C_0) them is higher than its benefits to local government (B). While the loss of being found that low quality of project for private sector is so limited that it cannot prevent private sector to choose opportunism strategy. It may cause the local government to perform encourage public supervision strategy, even the direct benefits cannot cover the cost of providing channel for the public. It is caused when the governments decide to encourage the public to supervise the PPP project, it will improve the possibility of finding the opportunism behavior of private sector and cause higher expected loss for private sector. The evolutionary process is presented as figure 4-3.

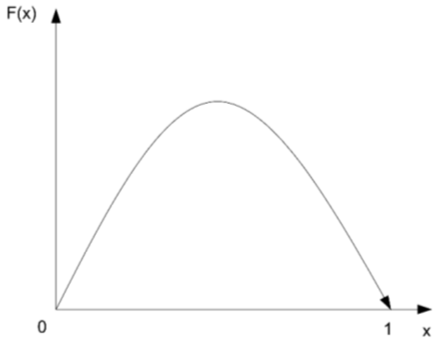


Figure 4- 3 The strategical process of case 1 for local governments

(2) Case 2: when $0 < C_0 - B < C_0 - L(P_1 - P_2)$, simplify the inequality, which is equal to $0 < L(P_1 - P_2) < B$. Hence, the value range of $\frac{C_0-B}{C_0-L(P_1-P_2)}$ would be $0 < \frac{C_0-B}{C_0-L(P_1-P_2)} < 1$, and due to the $0 < y < 1$, so two scenarios are existing in this case.

Scenario 1: When $1 > y > \frac{C_0-B}{C_0-L(P_1-P_2)} > 0$, $y(C_0 - P_1\mathrm{L} + P_2\mathrm{L}) > C_0 - B$, $F'(x)|_{x=0} > 0$, $F'(x)|_{x=1} < 0$, $x = 1$ is the only evolutionary stable strategy in this scenario;

Scenario 2: When $0 < y < \frac{C_0-B}{C_0-L(P_1-P_2)} < 1$, $y(C_0 - P_1\mathrm{L} + P_2\mathrm{L}) < C_0 - B$, $F'(x)|_{x=0} < 0$, $F'(x)|_{x=1} > 0$, $x = 0$ is the only evolutionary stable strategy in this scenario;

The inequality $L(P_1 - P_2) < B$ as the condition of this case. $L(P_1 - P_2)$ is regarded as the expected loss and punishment under the possibility of finding the opportunism behavior of private sector, and B is defined as the benefits from encouraging public supervision. Hence, case 2 shows that the local governments could gain more benefits from encouraging public supervision, when the expected loss of low-quality project is less than the benefits of encourage public supervision.

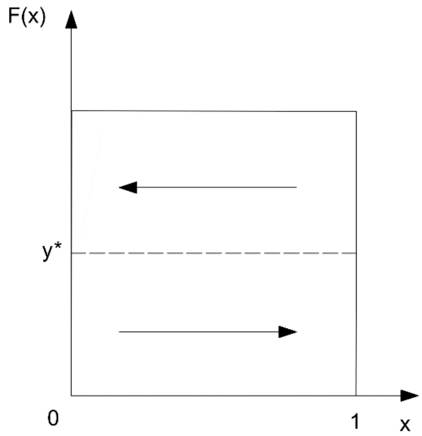


Figure 4- 4 The strategical process of case 2 for local governments

(3) Case 3: If $\frac{C_0-B}{C_0-L(P_1-P_2)} > 1$ which is equal to the form of inequality as $B < L(P_1 - P_2)$,

Then the $y < 1 < \frac{C_0-B}{C_0-L(P_1-P_2)}$, $y(C_0 - P_1\mathrm{L} + P_2\mathrm{L}) < C_0 - B$ for the solutions of $F'(x)|_{x=0} < 0$, $F'(x)|_{x=1} > 0, x = 0$ is the only evolutionary stable strategy.

Case 3 shows the situation that when the expected loss $L(P_1 - P_2)$ is higher than the benefits of encouraging public supervision for local government. This describe the phenomenon that when the punishment for the local government from the upper-level department is so serious that the local government may perform less motivation in supervising the behavior of private sectors.

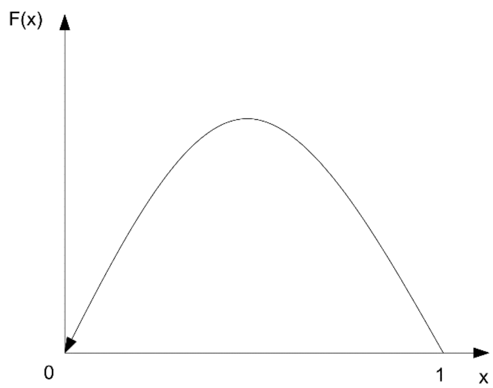


Figure 4- 5 The strategical process of case 3 for local governments

2) Strategy stability analysis of the private sectors

The replication dynamic equation of the private sectors was established in the previous section,

$$F(y) = \frac{dy}{dt} = y(1-y)[xi_0F_P(P_2 - P_1) + (i_1F_P - i_0F_P + P_2\, i_0F_P + C_1 - C_2)] \quad \text{(4-10)}$$

Hence

$$F'(y) = \frac{dF(y)}{dy} = (1-2y)[xi_0F_P(P_2 - P_1) + (i_1F_P - i_0F_P + P_2\, i_0F_P + C_1 - C_2)] \quad \text{(4-11)}$$

Solve the equation of $F(y) = 0$, it is easy to see the roots of the is y=0, y=1 and $x = x^* = \frac{F_P(i_1 - i_0) + P_2\, i_0F_P + (C_1 - C_2)}{i_0F_P(P_1 - P_2)}$ $(P_2 < P_1,\ i_0 < i_1, C_1 < C_2)$

Similar to the analysis of previous cases, when $x = x^*$, and $F(y) = 0$, then for any y, $F'(y) = 0$, any strategy of private sector is stable while axis y is in a stable state;

When $x \neq x^*$, cases in different conditions are discussed separately as follow:

(4) Case 4: when $\frac{F_P(i_1 - i_0) + P_2\, i_0F_P + (C_1 - C_2)}{i_0F_P(P_1 - P_2)} < 0$, due to the assumptions are defined as $P_2 < P_1,\ i_0 < i_1, C_1 < C_2$, Hence

$$\frac{F_P(i_1 - i_0) + P_2\, i_0F_P + (C_1 - C_2)}{i_0F_P(P_1 - P_2)} < 0 \leftrightarrow F_P(i_1 - i_0) + P_2\, i_0F_P + (C_1 - C_2) < 0 \leftrightarrow F_P(i_1 - i_0) + P_2\, i_0F_P < C_2 - C_1 \ (\leftrightarrow: means\ equal\ to) \quad \text{(4-12)}$$

$F'(y)|_{\,y=0} < 0$, $F'(y)|_{\,y=1} > 0$, so that the root $y = 0$ is the only evolutionary stable strategy, which refers to private sectors would choose the comply contract strategy, and complete project in high quality.

$F_P(i_1 - i_0) + P_2\, i_0F_P$ is defined as the expected loss of being found by the public supervision, and $C_2 - C_1$ could be explained as the difference between the cost of providing high quality and low-quality PPP products. Case 4 demonstrates the private sector would comply the contract and finish project in high quality, when the loss of being found the low quality of project is less than the difference between the cost of providing high quality and low-quality PPP products.

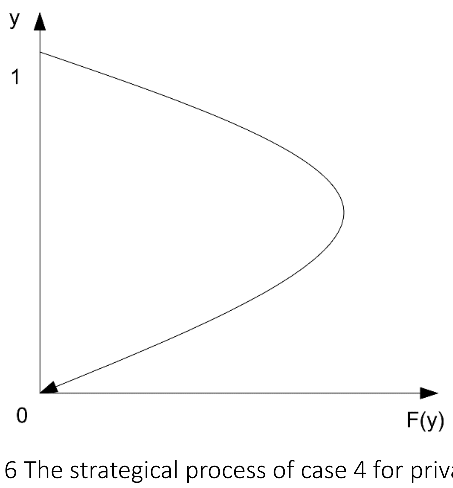


Figure 4- 6 The strategical process of case 4 for private sector

(5) Case 5: when $0 < \frac{F_P(i_1 - i_0) + P_2\, i_0 F_P + (C_1 - C_2)}{i_0 F_P (P_1 - P_2)} < 1$, due to the range of $0 < x < 1$, two scenarios are existing in this case:

Scenario 1: When $1 > x > \frac{F_P(i_1 - i_0) + P_2\, i_0 F_P + (C_1 - C_2)}{i_0 F_P (P_1 - P_2)} > 0$, $x i_0 F_P (P_1 - P_2) > F_P(i_1 - i_0) + P_2\, i_0 F_P + (C_1 - C_2)$, $F'(y)|_{y=0} < 0$, $F'(y)|_{y=1} > 0$ $y = 0$ is the only evolutionary stable strategy in this scenario.

Scenario 2: When $0 < x < \frac{F_P(i_1 - i_0) + P_2\, i_0 F_P + (C_1 - C_2)}{i_0 F_P (P_1 - P_2)} < 1$, $x i_0 F_P (P_1 - P_2) < F_P(i_1 - i_0) + P_2\, i_0 F_P + (C_1 - C_2)$, $F'(y)|_{y=0} > 0$, $F'(y)|_{y=1} < 0$, $y = 1$ is the only evolutionary stable strategy in this scenario.

Case 5 shows the possibility of and the efficiency of the public supervision as well as the cost difference between low-quality product and high-quality project are sensitive variables for private sector. The value of $i_0 F_P (P_1 - P_2)$ could be defined as the expected punishment of being found that private sector completing project in low quality with and without the public supervision. The higher punishment of being found the product in low quality is, the more likely for private sectors to comply contract and finish project in high quality.

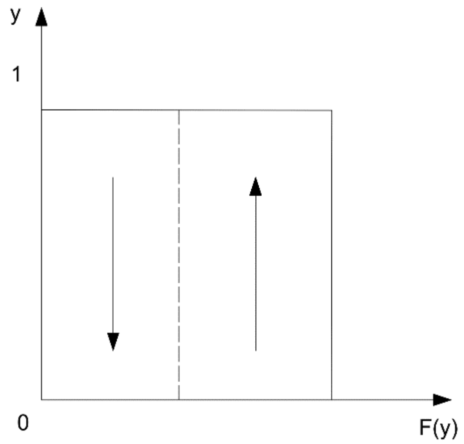


Figure 4- 7 The strategical process of case 5 for private sector

(6) Case 6: when $\frac{F_P(i_1 - i_0) + P_2\, i_0 F_P + (C_1 - C_2)}{i_0 F_P (P_1 - P_2)} > 1$, hence, we have the $\frac{F_P(i_1 - i_0) + P_2\, i_0 F_P + (C_1 - C_2)}{i_0 F_P (P_1 - P_2)} > x$ which is equal to

$x i_0 F_P (P_1 - P_2) < F_P(i_1 - i_0) + P_2\, i_0 F_P + (C_1 - C_2)$, for the roots of $y = 0$ and $y = 1$, the $F'(y)|_{y=0} > 0$, $F'(y)|_{y=1} < 0$,

Then $y = 1$ is the only evolutionary stable strategy, which means the private would choose comply contract strategy anyway.

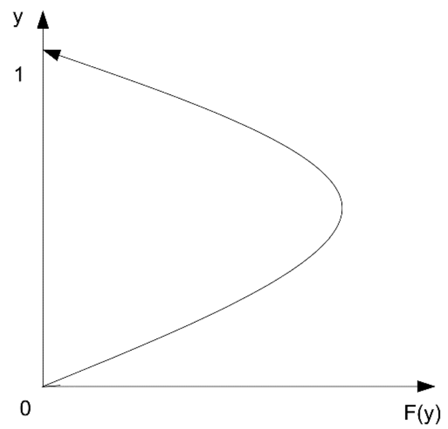


Figure 4- 8 The strategical process of case 6 for private sector

3) ESS analysis between local governments and private sectors

Based on the Evolutionary stable strategy theory of Freidman, the ESS could be analyzed from the local stability, and the dynamic evolution of population is defined by the differential equations. According to the replication dynamic equations in the previous sections, the Jacobian matrix J is computed as below:

$$J = \begin{bmatrix} \frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} \\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y} \end{bmatrix}$$

(4-13)

Hence $J =$

$$\begin{bmatrix} (1-2x)[y(C_0 - P_1\mathrm{L} + P_2\mathrm{L}) + (\mathrm{B} - C_0)] & x(1-x)(C_0 - P_1\mathrm{L} + P_2\mathrm{L}) \\ y(1-y)[i_0 F_P(P_2 - P_1)] & (1-2y)[x i_0 F_P(P_2 - P_1) + (i_1 F_P - i_0 F_P + P_2\, i_0 F_P + C_1 - C_2)] \end{bmatrix}$$

(4-14)

Then the determinant of the Jacobian matrix is

$\det(J) = \frac{\partial F(x)}{\partial x} \cdot \frac{\partial F(y)}{\partial y} - \frac{\partial F(y)}{\partial x} \cdot \frac{\partial F(x)}{\partial y} = (1-2x)[y(C_0 - P_1\mathrm{L} + P_2\mathrm{L}) + (\mathrm{B} - C_0)] \cdot (1 - 2y)[x i_0 F_P(P_2 - P_1) + (i_1 F_P - i_0 F_P + P_2\, i_0 F_P + C_1 - C_2)]$ - $y(1-y)[i_0 F_P(P_2 - P_1)] \cdot x(1-x)(C_0 - P_1\mathrm{L} + P_2\mathrm{L})$

(4-15)

And the trace of the Jacobian matrix is

$\mathrm{Tr}(J) = \frac{\partial F(x)}{\partial x} + \frac{\partial F(y)}{\partial y} = (1-2x)[y(C_0 - P_1\mathrm{L} + P_2\mathrm{L}) + (\mathrm{B} - C_0)] + (1-2y)[x i_0 F_P(P_2 - P_1) + (i_1 F_P - i_0 F_P + P_2\, i_0 F_P + C_1 - C_2)]$

(4-16)

The 5 equilibrium points $P_1(0,0)$, $P_2(1,0)$, $P_3(0,1)$, $P_4(1,1)$, $P_5(x^*, y^*)$, when $x^* = \frac{F_P(i_1 - i_0) + P_2\, i_0 F_P + (C_1 - C_2)}{i_0 F_P(P_1 - P_2)}$ and $y^* = \frac{C_0 - B}{C_0 - L(P_1 - P_2)}$, are put into the formulations of $\det(J)$ and $\mathrm{Tr}(J)$, then the determinant and trace of the 5 equilibrium points could be summarized as Table 6.

Equilibrium point	$\det(J)$	$\mathrm{Tr}(J)$
$(0,0)$	$(\mathrm{B}- C_0)\cdot(i_1F_P - i_0F_P + P_2\, i_0F_P + C_1 - C_2)$	$(\mathrm{B}- C_0) + (i_1F_P - i_0F_P + P_2\, i_0F_P + C_1 - C_2)$
$(1,0)$	$-(\mathrm{B}- C_0)\cdot(i_0F_PP_1 + i_1F_P - i_0F_P + 2P_2\, i_0F_P + C_1 - C_2)$	$-(\mathrm{B}- C_0) + (i_0F_PP_1 + i_1F_P - i_0F_P + 2P_2\, i_0F_P + C_1 - C_2)$
$(0,1)$	$-(\mathrm{B} - P_1\mathrm{L} + P_2\mathrm{L})\cdot(i_1F_P - i_0F_P + P_2\, i_0F_P + C_1 - C_2)$	$(\mathrm{B} - P_1\mathrm{L} + P_2\mathrm{L}) - (i_1F_P - i_0F_P + P_2\, i_0F_P + C_1 - C_2)$
$(1,1)$	$(\mathrm{B} - P_1\mathrm{L} + P_2\mathrm{L})\cdot (i_0F_PP_1 + i_1F_P - i_0F_P + 2P_2\, i_0F_P + C_1 - C_2)$	$-(\mathrm{B} - P_1\mathrm{L} + P_2\mathrm{L}) - (i_0F_PP_1 + i_1F_P - i_0F_P + 2P_2\, i_0F_P + C_1 - C_2)$
(x^*, y^*)	$\pm$	0

Table 6 ESS local stability analysis of one-time cooperation model

4) **Evolutionary game path analysis**

According to the evolutionary game theory, equilibrium point is defined as: when $\det(J) > 0$ and $\mathrm{Tr}(J) < 0$ as conditions are satisfied. Due to the equilibrium point $P_5(x^*, y^*)$ does not meet the condition of $\mathrm{Tr}(J) < 0$, while in this case, the $\mathrm{Tr}(J) = 0$. Hence, (x^*, y^*) is not ESS point. Then the other equilibrium points have the potential to be the local stable equilibrium strategy, then 6 scenarios are discussed and analysis as below:

Scenario 1: When $\mathrm{B}- C_0 < 0$, $\mathrm{B} - P_1\mathrm{L} + P_2\mathrm{L} < 0$ and $i_0F_PP_1 + i_1F_P - i_0F_P + 2P_2\, i_0F_P + C_1 - C_2 < 0$

Due to the value of $i_0F_PP_1$ is defined $i_0F_PP_1 > 0$ in the assumption, so under this condition, $i_1F_P - i_0F_P + P_2\, i_0F_P + C_1 - C_2 < 0$ is true

Equilibrium point	$\det(J)$	$\mathrm{Tr}(J)$	Results of stability
$(0,0)$	$+$	$-$	ESS
$(1,0)$	$-$	$Uncertain$	Saddle point
$(0,1)$	$+$	$Uncertain$	Saddle point
$(1,1)$	$+$	$+$	Unstable point

Table 7 ESS analysis based on Scenario 1 of one-time cooperation model

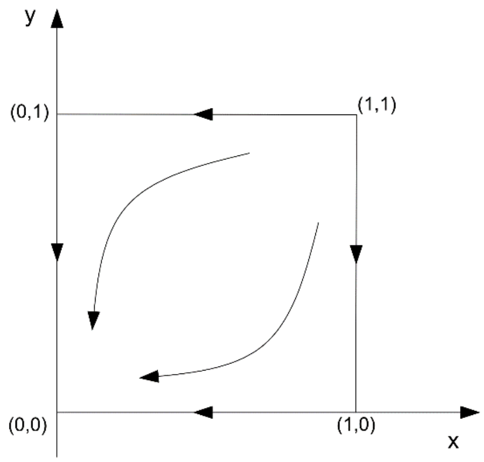


Figure 4- 9 The path analysis results for both gamers by scenario 1

Scenario 2: When $\mathrm{B}-C_0>0$, $\mathrm{B}-P_1\mathrm{L}+P_2\mathrm{L}<0$ and $i_0F_PP_1+i_1F_P-i_0F_P+2P_2\,i_0F_P+C_1-C_2<0$, $i_1F_P-i_0F_P+P_2\,i_0F_P+C_1-C_2<0$

Equilibrium point	$\det(J)$	$\mathrm{Tr}(J)$	Results of stability
$(0,0)$	$-$	$-$	Saddle point
$(1,0)$	$+$	$-$	ESS
$(0,1)$	$+$	$Uncertain$	Saddle point
$(1,1)$	$+$	$+$	Unstable point

Table 8 ESS analysis based on Scenario 2 of One-time cooperation model

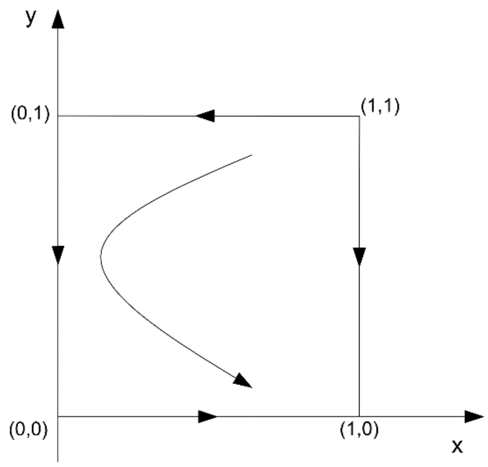


Figure 4- 10 The path analysis results for both gamers by scenario 2

Scenario 3: When $\mathrm{B} - C_0 < 0$, $\mathrm{B} - P_1\mathrm{L} + P_2\mathrm{L} > 0$ and $i_0F_PP_1 + i_1F_P - i_0F_P + 2P_2\, i_0F_P + C_1 - C_2 < 0$, $i_1F_P - i_0F_P + P_2\, i_0F_P + C_1 - C_2 < 0$

Equilibrium point	$\det(J)$	$\mathrm{Tr}(J)$	Results of stability
$(0,0)$	$+$	$-$	ESS
$(1,0)$	$-$	$Uncertain$	Saddle point
$(0,1)$	$+$	$Uncertain$	Saddle point
$(1,1)$	$-$	$Uncertain$	Saddle point

Table 9 ESS analysis based on Scenario 3 of One-time cooperation model

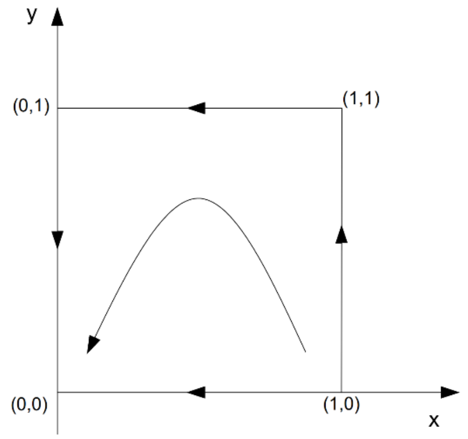


Figure 4- 11 The path analysis results for both gamers by scenario 3

Scenario 4: When $\mathrm{B} - C_0 < 0$, $\mathrm{B} - P_1\mathrm{L} + P_2\mathrm{L} < 0$ and $i_0F_PP_1 + i_1F_P - i_0F_P + 2P_2\, i_0F_P + C_1 - C_2 > 0$, $i_1F_P - i_0F_P + P_2\, i_0F_P + C_1 - C_2 < 0$

Equilibrium point	$\det(J)$	$\mathrm{Tr}(J)$	Results of stability
$(0,0)$	$+$	$-$	ESS
$(1,0)$	$+$	$+$	Unstable point
$(0,1)$	$+$	$Uncertain$	Saddle point
$(1,1)$	$-$	$Uncertain$	Saddle point

Table 10 ESS analysis based on Scenario 4 of One-time cooperation model

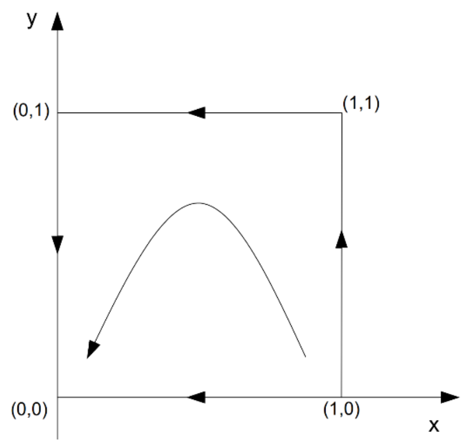


Figure 4- 12 The path analysis results for both gamers by scenario 4

Scenario 5: When $\mathrm{B}-C_0<0$, $\mathrm{B}-P_1\mathrm{L}+P_2\mathrm{L}<0$ and $i_0F_PP_1+i_1F_P-i_0F_P+2P_2\,i_0F_P+C_1-C_2>0$, $i_1F_P-i_0F_P+P_2\,i_0F_P+C_1-C_2>0$

Equilibrium point	$\det(J)$	$\mathrm{Tr}(J)$	Results of stability
(0,0)	$-$	$Uncertain$	Saddle point
(1,0)	$+$	$+$	Unstable point
(0,1)	$+$	$-$	ESS
(1,1)	$-$	$Uncertain$	Saddle point

Table 11 ESS analysis based on Scenario 5 of One-time cooperation model

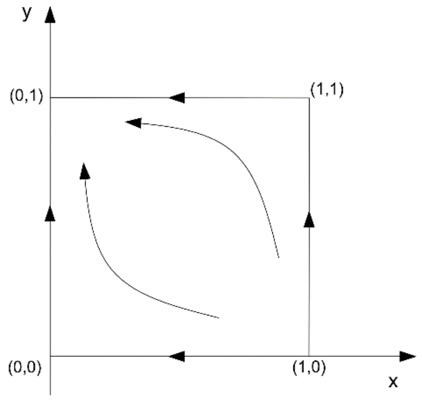


Figure 4- 13 The path analysis results for both gamers by scenario 5

Scenario 6: When $\mathrm{B}-C_0<0$, $\mathrm{B}-P_1\mathrm{L}+P_2\mathrm{L}>0$ and $i_0F_PP_1+i_1F_P-i_0F_P+2P_2\,i_0F_P+C_1-C_2>0$, $i_1F_P-i_0F_P+P_2\,i_0F_P+C_1-C_2>0$

Equilibrium point	$\det(J)$	$\mathrm{Tr}(J)$	Results of stability
(0,0)	$-$	$Uncertain$	Saddle point
(1,0)	$+$	$+$	Unstable point
(0,1)	$-$	$Uncertain$	Saddle point
(1,1)	$+$	$-$	ESS

Table 12 ESS analysis based on Scenario 6 of One-time cooperation model

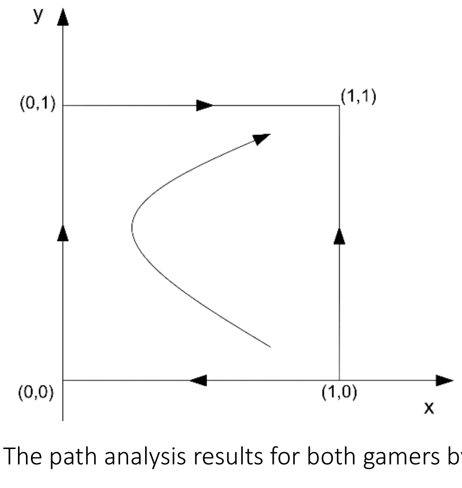


Figure 4- 14 The path analysis results for both gamers by scenario 6

4.2 Evolutionary model of multi-time (Long-term) cooperation under public supervision

4.2.1 Assumptions and hypothesis for Long-term cooperation model

The long-term cooperation model is based on one-time scenario, and most of assumptions are similar with hypothesis of one-time cooperation model. However, repeated game mechanism leads to a change in strategical preference players by introducing reputational benefits, especially when the project is completed with high quality.

1. Due to the long-term mechanism, both the local governments and private sectors will consider the impact of strategy choice on the further game and cooperation. When private sectors comply the contract, the local governments would have higher possibility of being satisfied with the performance of private sector. Trust and potential reputation between the players for further cooperation can be quantified as benefits of Q, and coefficient ε are defined the reputational benefits in the payoff matrix.
2. Long-term cooperation mechanism, when being found the project is complete with low quality, the private sector may perform rent seeking behavior in the game, which refer to the corruption and give direct benefits for the local governments. In this case, the cost of rent-seeking activities is defined as R_S, and the Probability of rent-seeking is P'.
3. The cost of rent-seeking activities is paid to the local government from the private sector, consequently the local government would reduce supervision level, which leads to lower investment on encouraging public supervision and lower possibility in discovering the low-quality PPP projects.

4.2.2 Parameters Statement and model demonstration

		Local Government	
	Strategies	Encourage (x)	Not Encourage (1-x)
Private Sector	Opportunism (y)	($F- C_1- P_1 P' (i_0 F_P- R_s) - (1- P') i_0 F_P$); $R_s - F-i_0 F_P-S+B- C_0+ P_1 i_0 F_P- P_1 L$)	($F+ - C_1- P_2 P' (i_0 F_P- R_s) -(1- P') i_0 F_P$); $R_s - F-i_0 F_P-S - C_0+ P_2 i_0 F_P- P_2 L$)
	Compliance (1-y)	($F+ i_1 F_P- C_2+\varepsilon Q$; $- F-i_1 F_P-S+B- C_0$)	($F+ i_1 F_P- C_2+\varepsilon Q$; $- F-i_1 F_P-S$)

Table 13 The payoff matrix of the gamers in long-term cooperation

Game Player	Game strategy	Symbol	Description
Local Government	Encourage	x	Proportion of local governments who encourage the public supervision(0<x<1)
		F	Fixed Payment to private sector
		F_P	Performance payment to private sector
		S	Default Supervision cost
		C_0	The cost of providing channels to the public and identification cost of the authenticity in reports on social media
		B	The benefits from encouraging the public to supervise
	Not Encourage	1-x	Proportion of local governments who do not encourage the public supervision
		P_1	The Probability of finding the private sector do not complete projects as contract (When the private sector chooses Opportunism strategy)
		L	The loss from the low-quality projects by Punishment from Upper departments when do not encourage
Private Sector	Opportunism (Low-quality project)	y	Proportion of private sectors who perform Opportunism in PPP project(0<y<1)
		C_1	Cost of providing low-quality project ($C_1< C_2$)
		i_0	Coefficient of Performance payment in low-quality project ($i_0< i_1$)
		R_s	The cost of rent-seeking
		P’	The Probability of rent-seeking
	Compliance Contract (High-quality project)	1-y	Proportion of private sectors who do not perform Opportunism in PPP project(0<y<1)
		C_2	Cost of providing High-quality project
		i_1	Coefficient of Performance payment in low-quality project
		ε	The Coefficient of High-quality strategy in further cooperation
		Q	The reputational benefits of finish project in high-quality in further cooperation

Table 14 Description of game model parameters in long-term cooperation

In the long-term cooperation payoff matrix model, the payoff values of the local governments stay the same with the one-time cooperation model, while private sectors changed due to the potential further cooperation mechanism and rent seeking behavior. Hence, the evolutionary process of the private sectors is discussed in this scenario to explore the influence of long-term cooperation for their behavior and strategical choice.

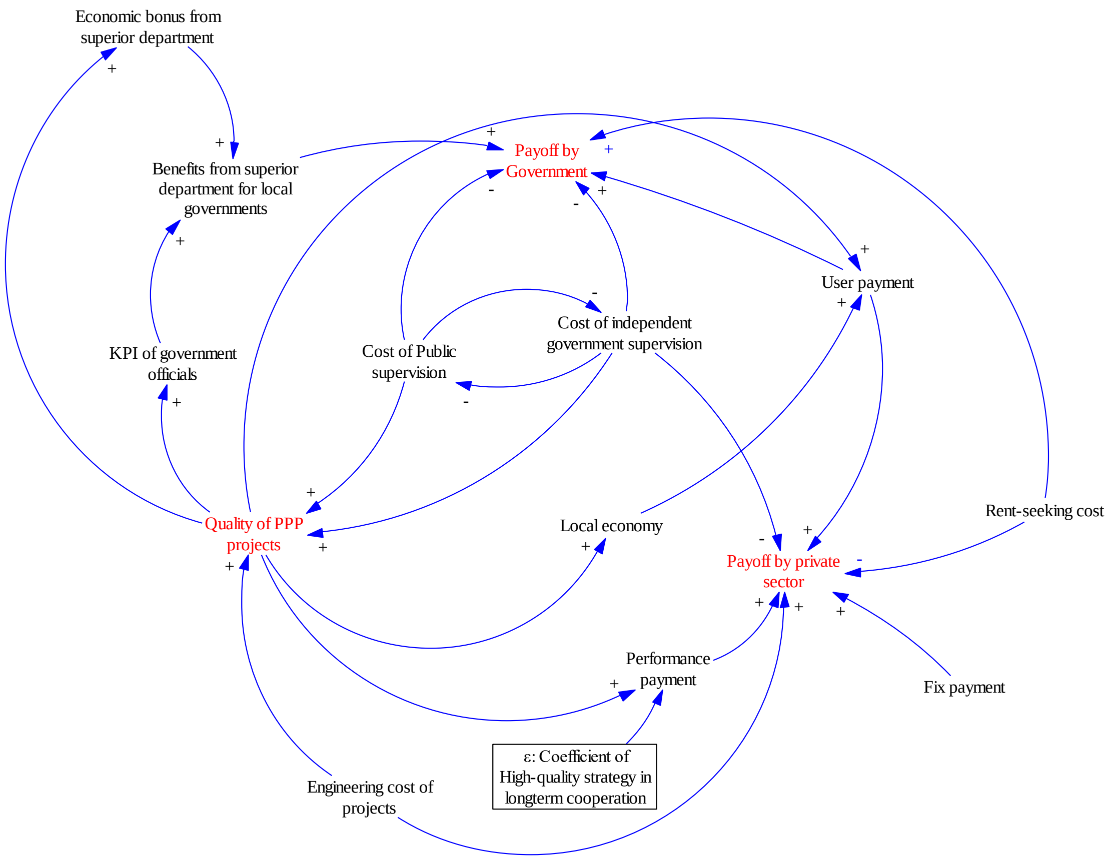


Figure 4- 15 The system dynamic interpretation for the long-term cooperation model under public supervision

For the local governments, the strategy A (Encourage) and strategy B (Not Encourage) are U_{1A} and U_{1B}, and the average payoff of the population is $\overline{U_1}$

$$U_{1A} = y(R_s - \mathrm{F} - i_0 F_P - \mathrm{S} + \mathrm{B} - C_0 + P_1 i_0 F_P - P_1 \mathrm{L}) + (1-y)(R_s - \mathrm{F} - i_1 F_P - \mathrm{S} + \mathrm{B} - C_0) \quad (4\text{-}17)$$

$$U_{1B} = y(-\mathrm{F} - i_1 F_P - \mathrm{S} - C_0) + (1-y)(-\mathrm{F} - i_1 F_P - \mathrm{S}) \quad (4\text{-}18)$$

$$\overline{U_1} = x \cdot U_{1A} + (1-x) \cdot U_{1B}$$
$$= xy(R_s - \mathrm{F} - i_0 F_P - \mathrm{S} + \mathrm{B} - C_0 + P_1 i_0 F_P - P_1 \mathrm{L}) + x(1-y)(R_s - \mathrm{F} - i_1 F_P - \mathrm{S} + \mathrm{B} - C_0) + (1-x)y(-\mathrm{F} - i_1 F_P - \mathrm{S} - C_0) + (1-x)(1-y)(-\mathrm{F} - i_1 F_P - \mathrm{S})$$
(4-19)

$\frac{dx}{dt} = x(U_{1A} - \overline{U_1})$
$= x(1-x)[U_{1A} - U_{1B}]$
$= x(1-x)[y(R_s - \mathrm{F} - i_0F_P - \mathrm{S} + \mathrm{B} - C_0 + P_1\, i_0F_P - P_1\mathrm{L}) + (1-y)(R_s - \mathrm{F} - i_1F_P - \mathrm{S} + \mathrm{B} - C_0) - y(-\mathrm{F} - i_0F_P - \mathrm{S} - C_0) - (1-y)(-\mathrm{F} - i_1F_P - \mathrm{S})]$
$= x(1-x)[y(\mathrm{B} + P_1\, i_0F_P - C_0) + R_s + B - C_0]$

(4-20)

The expected payoff of private sector when they choose strategy A (Opportunism) and strategy B (Compliance) are U_{2A} and U_{2B}, and the average payoff of the population is $\overline{U_2}$

$$U_{2A} = x(\mathrm{F} + i_0F_P - C_1 - P_1\, i_0F_P) + (1-x)(\mathrm{F} + i_0F_P - C_1 - P_2\, i_0F_P) \quad (4\text{-}21)$$

$$U_{2B} = x(\mathrm{F} + i_1F_P - C_2) + (1-x)(\mathrm{F} + i_1F_P - C_2) \quad (4\text{-}22)$$

$\overline{U_2} = y \cdot U_{2A} + (1-y) \cdot U_{2B}$
$= xy(\mathrm{F} + i_0F_P - C_1 - P_1\, i_0F_P) + y(1-x)(\mathrm{F} + i_0F_P - C_1 - P_2\, i_0F_P) + y(1-x)(\mathrm{F} + i_1F_P - C_2) + (1-x)(1-y)(\mathrm{F} + i_1F_P - C_2)$ (4-23)

From this, we can get the replication dynamic equation of the local governments is

$\frac{dx}{dt} = x(U_{2A} - \overline{U_2})$
$= x(1-x)[U_{2A} - U_{2B}]$
$= x(1-x)[y(-\mathrm{F} - i_0F_P - \mathrm{S} + \mathrm{B} - C_0 + P_1\, i_0F_P - P_1\mathrm{L}) + (1-y)(-\mathrm{F} - i_1F_P - \mathrm{S} + \mathrm{B} - C_0) - y(-\mathrm{F} - i_0F_P - \mathrm{S} - C_0 + P_1\, i_0F_P - P_2\mathrm{L}) + (1-y)(-\mathrm{F} - i_1F_P - \mathrm{S})]$
$= x(1-x)[y(C_0 - P_1\mathrm{L} + P_2\mathrm{L}) + (\mathrm{B} - C_0)]$

(4-24)

The expected payoff of private sector when they choose strategy A (Opportunism) and strategy B (Compliance) are U_{2A} and U_{2B}, and the average payoff of the population is $\overline{U_2}$

$U_{2A} = x[\mathrm{F} - C_1 + P_1\, P'\,(i_0F_P - R_s) + (1 - P_1)\, i_0F_P] + (1-x)(\mathrm{F} - C_1 + P_2\, P'\,(i_0F_P - R_s) + (1 - P_2)i_0F_P)$ (4-25)

In order to simplify the equations, let $P'\,(i_0F_P - R_s) = a$, $i_0F_P = b$

$$U_{2A} = x[\mathrm{F} - C_1 + P_1\, a + (1 - P_1)b] + (1-x)(\mathrm{F} - C_1 + P_2\, a - (1 - P_2)b) \quad (4\text{-}26)$$

$$U_{2B} = x(\mathrm{F} + i_1F_P - C_2 + \varepsilon\mathrm{Q}) + (1-x)(\mathrm{F} + i_1F_P - C_2 + \varepsilon\mathrm{Q}) \quad (4\text{-}27)$$

$$\overline{U_2} = y \cdot U_{2A} + (1-y) \cdot U_{2B} \quad (4\text{-}28)$$

The replication dynamic equation of the private sectors is in long-term cooperation is

$\frac{dy}{dt} = y(U_{2A} - \overline{U_2})$
$= y(1-y)[U_{2A} - U_{2B}]$
$= y(1-y)[x[\mathrm{F} - C_1 + P_1\, a + (1 - P_1)b] + (1-x)(\mathrm{F} - C_1 + P_2\, a + (1 - P_2)b) - (\mathrm{F} + i_1F_P - C_2 + \varepsilon\mathrm{Q})]$

$= y(1-y)\{x[(P_1 - P_2)\, a + (P_2 - P_1)\,)b] + (C_2 - C_1 + P_2\, a + P_2 i_0 F_P) + (i_0 - i_1)F_P - \varepsilon Q\}$

(4-29)

4.2.3 Model solution and analysis for long-term cooperation model

Hence $F'(y) = \frac{dF(y)}{dy} = (1-2y)\{x[(P_1 - P_2)\,(a - b)\,] + (C_2 - C_1 + P_2\, a + P_2 i_0 F_P) + (i_0 - i_1)F_P - \varepsilon Q\}$ (4-30)

Solve the equation of $F'(y) = 0$, it is easy to find the roots of the is y=0, y=1 and $x = x^* = \frac{(C_2 - C_1 + P_2\, a + P_2 i_0 F_P) + (i_0 - i_1)F_P - \varepsilon Q}{(P_2 - P_1)(a - b)}$ $(P_2 < P_1,\ i_0 < i_1, C_1 < C_2, b > a)$

Similar to the analysis of previous cases, when $x = x^*$, and $F(y) = 0$, then for any y, $F'(y) = 0$, any strategy of private sectors is stable while axis y is in a stable state;

When $x \neq x^*$, cases in different conditions are discussed separately as follow:

(7) Case 1: when $\frac{(C_2 - C_1 + P_2\, a + P_2 i_0 F_P) + (i_0 - i_1)F_P - \varepsilon Q}{(P_2 - P_1)(a - b)} < 0$, due to the assumptions are defined as $P_2 < P_1,\ i_0 < i_1, C_1 < C_2$, Hence $(P_2 - P_1)(a - b) > 0$ is true.

$\frac{(C_2 - C_1 + P_2\, a + P_2 i_0 F_P) + (i_0 - i_1)F_P - \varepsilon Q}{(P_2 - P_1)(a - b)} < 0 \leftrightarrow (C_2 - C_1) + P_2\,(a + i_0 F_P) + (i_0 - i_1)F_P - \varepsilon Q < 0 \leftrightarrow P_2\,(a + i_0 F_P) + (i_0 - i_1)F_P + \varepsilon Q < C_1 - C_2$ ($\leftrightarrow$: *means equal to*) (4-31)

$F'(y)|_{\,y=0} < 0,\ F'(y)|_{\,y=1} > 0$, so that the root $y = 0$ is the only evolutionary stable strategy, which refers to private sectors would choose the comply contract strategy, and complete project in high quality.

$P_2\,(a + i_0 F_P) + (i_0 - i_1)F_P + \varepsilon Q$ is explained as the expected payoff value from the long-term cooperation with the local governments under the public supervision in PPP projects. Because $a = P'\,(i_0 F_P - R_s\,)$ which consider the rent seeking behavior as well as the benefits εQ from the long-term mechanism. When the total expected payoff value of performing rent-seeking behavior is less than the difference between providing high-quality project and low-quality projects, the private sectors would choose to comply the contract and not perform rent-seeking behavior.

(8) Case 2: when $0 < \frac{(C_2 - C_1 + P_2\, a + P_2 i_0 F_P) + (i_0 - i_1)F_P - \varepsilon Q}{(P_2 - P_1)(a - b)} < 1$, due to the range of $0 < x < 1$, two scenarios are existing in this case:

Scenario 1: When $1 > x > \frac{(C_2 - C_1 + P_2\, a + P_2 i_0 F_P) + (i_0 - i_1)F_P - \varepsilon Q}{(P_2 - P_1)(a - b)} > 0$, $x(P_2 - P_1)(a - b) > (C_2 - C_1 + P_2\, a + P_2 i_0 F_P) + (i_0 - i_1)F_P - \varepsilon Q$, $F'(y)|_{\,y=0} < 0$, $F'(y)|_{\,y=1} > 0$ $y = 0$ is the only evolutionary stable strategy in this scenario.

Scenario 2: When $0 < x < \frac{(C_2 - C_1 + P_2\, a + P_2 i_0 F_P) + (i_0 - i_1)F_P - \varepsilon Q}{(P_2 - P_1)(a - b)} < 1$, $x(P_2 - P_1)(a - b) < (C_2 - C_1 + P_2\, a + P_2 i_0 F_P) + (i_0 - i_1)F_P - \varepsilon Q$,, $F'(y)|_{\,y=0} > 0$, $F'(y)|_{\,y=1} < 0$, $y = 1$

is the only evolutionary stable strategy in this scenario.
Case 2 illustrates the fact that the benefits from complying the contract, and expected revenue of choosing opportunism strategy are decisive for the behavior trend of private sector. When the benefits from complying-contract strategy is higher than the expected revenue of opportunism strategy, the private sector would choose to finish the project with high quality. It actively demonstrates that designing the parameter ε, which refer to the bonus coefficient for ideal long-term cooperation, is of importance to restrain and supervise the behavior and strategy of private sector.

(9) Case 3: when $\frac{(C_2 - C_1 + P_2\,a + P_2 i_0 F_P) + (i_0 - i_1)F_P - \varepsilon Q}{(P_2 - P_1)(a - b)} > 1$, hence, we have the $\frac{(C_2 - C_1 + P_2\,a + P_2 i_0 F_P) + (i_0 - i_1)F_P - \varepsilon Q}{(P_2 - P_1)(a - b)} > x$ which is equal to $x(P_2 - P_1)(a - b) < (C_2 - C_1 + P_2\,a + P_2 i_0 F_P) + (i_0 - i_1)F_P - \varepsilon Q$, for the roots of $y = 0$ and $y = 1$, the $F'(y)|_{y=0} > 0$, $F'(y)|_{y=1} < 0$,
Then $y = 1$ is the only evolutionary stable strategy, which means the private would choose not comply contract strategy anyway. It indicates that when the supervision and punishment are insufficient, the private sector would choose opportunism strategy in PPP projects.

4.3 Evolutionary model of nonprofitable PPP project under public supervision

4.3.1 Assumptions and hypothesis of nonprofitable PPP project

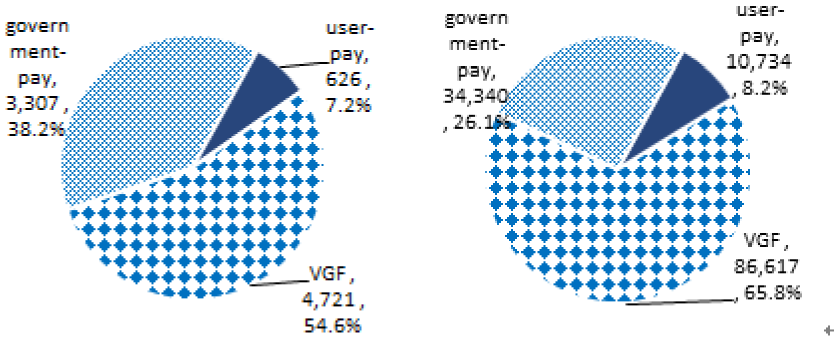


Figure 4- 16 Break down of project in PPP centre database by return mechanism in number of cases and amount of money (100 million RMB) in annual report of 2018 (http://www.cpppc.org/en/djyw/997940.jhtml)

According to the annual report of China public private partnership center in 2018, there is merely 7.2% of projects are user-pay return mechanism in current China, which takes up around 8% of amount of money. The rest and majority of PPP projects are VGF (Viability Gap Funding) and government pay mechanism, which can be included as non-profitable PPP projects mode. Nonprofitable projects refers to non-profit investment projects that provide products or services to the public in order to achieve social and environmental goals, including social welfare projects (education, medical and health care projects, etc.), environmental pollution control projects, public infrastructure projects. The distinctive feature of these projects economically is that the services and usage functions provided to the society do not charge fees or the charge fees are so minimal that cannot cover the cost of projects. It is meaningful to discuss nonprofitable project not only they are the domain mode of PPP in current China, but also because nonprofitable mode lacks revenue-oriented background, the local government would take more consideration of the quality of products and service of project. Hence, the interaction mechanism and strategy choice for both game players could be explored to guide the further cooperation and optimize the operation and investment on nonprofitable projects.

Based on previous models, the parameters and payoff matrix are constructed in table 15 and 16. The main differences between nonprofitable game model with user-pay PPP model reflect on the payment mechanism and the weight of project quality. Because there is no direct payer in the operation phase, the private sector can only receive payment by VGF and government payment. And the government can merely receive the benefits from nonprofitable PPP project from an indirect means (such as benefits for local economy and urbanization) or the benefits on their KPIs on the basis of PPP-project performance. It actively demonstrates that for both game players in PPP mode, the higher quality of the project is, the higher benefits and profits can be gained from the performance payment. However, for the private sectors in the nonprofitable PPP projects, the income and revenue are barely gained from government payment. At the same time, the local government would give more weight on the quality of product and service which provided by private sectors. The lack of monetary motivation for the private sectors and local government, a magnification coefficient of reputational benefits of government μ is introduced in the system, and $\mu > 1$ is set to describe more attention is paid to the quality of projects.

4.3.2 Parameters Statement and model demonstration

		Local Government	
	Strategies	Encourage (x)	Not Encourage (1-x)
Private Sector	Opportunism (y)	$(F - C_1+P_1V; - F - S+\mu B- C_0+ P_1 (V-L))$	$(F - C_1+P_2V; - F -S+\mu B- C_0+ P_2 (V-L))$
	Compliance (1-y)	$(F - C_2 + V; - F-S+B- C_0)$	$(F - C_2 + V; -F-S)$

Table 15 Description of game model parameters of nonprofitable model

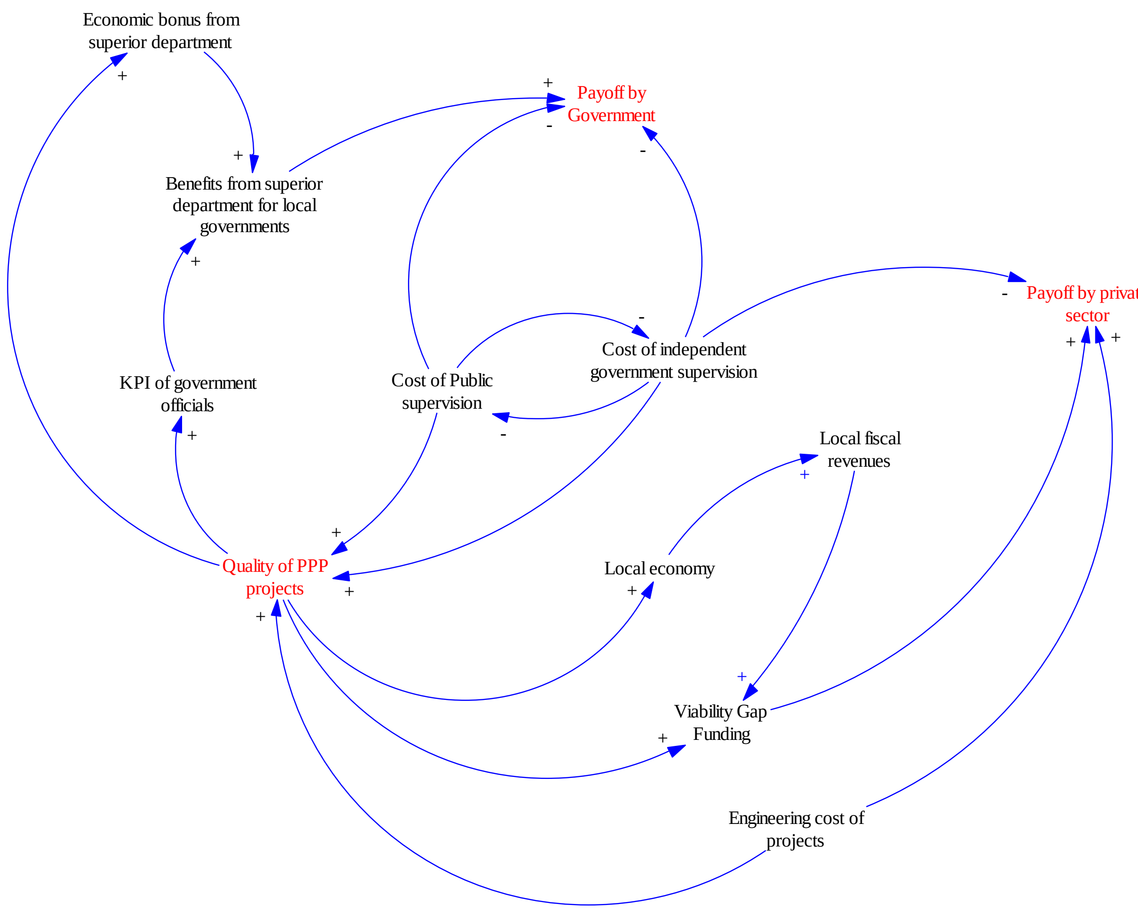


Figure 4- 17 The system dynamic interpretation for the nonprofitable model under public supervision

Game Player	Game strategy	Symbol	Description
Local Government	Encourage	x	Proportion of local governments who encourage the public supervision(0<x<1)
		F	Fixed Payment to private sector
		V	Viability gap funding
		S	Default supervision cost for local governments
		C_0	The cost of providing channels to the public and identification cost of the authenticity in reports on social media
		B	The benefits from encouraging the public to supervise
		P_1	The Probability of finding the private sector do not complete projects as contract (When the private sector chooses Opportunism strategy)
	Not Encourage	1-x	Proportion of local governments who do not encourage the public supervision
		P_1	The Probability of finding the private sector do not complete projects as contract (When the private sector chooses Opportunism strategy)
		L	The loss from the low-quality projects by Punishment from Upper departments when do not encourage
Private Sector	Opportunism (Low-quality project)	y	Proportion of private sectors who perform Opportunism in PPP project(0<y<1)
		C_1	Cost of providing low-quality project ($C_1 < C_2$)
		μ	The magnification coefficient of reputational benefits of government ($\mu > 1$)
	Compliance Contract (High-quality project)	1-y	Proportion of private sectors who do not perform Opportunism in PPP project(0<y<1)
		C_2	Cost of providing High-quality project

Table 16 Description of game model parameters in nonprofitable model

The expected payoff of local governments when they choose strategy A (Encourage) and strategy B (Not encourage) are U_{1A} and U_{1B}, and the average payoff of the population is $\overline{U_1}$.

$$U_{1A} = y(-\mathrm{F} - \mathrm{S} + \mu\mathrm{B} - C_0 + P_1(\mathrm{V} - \mathrm{L})) + (1-y)(-\mathrm{F} - \mathrm{S} + \mathrm{B} - C_0) \tag{4-32}$$

$$U_{1B} = y(-\mathrm{F} - \mathrm{S} + \mu\mathrm{B} - C_0 + P_2(\mathrm{V} - \mathrm{L})) + (1-y)(-\mathrm{F} - \mathrm{S}) \tag{4-33}$$

$$\begin{aligned}\overline{U_1} &= x \cdot U_{1A} + (1-x) \cdot U_{1B} \\ &= xy(-\mathrm{F} - \mathrm{S} + \mu\mathrm{B} - C_0 + P_1(\mathrm{V} - \mathrm{L})) + x(1-y)(-\mathrm{F} - \mathrm{S} + \mathrm{B} - C_0) + (1-x)y(-\mathrm{F} - \\ &\mathrm{S} + \mu\mathrm{B} - C_0 + P_2(\mathrm{V} - \mathrm{L})) + (1-x)(1-y)(-\mathrm{F} - \mathrm{S})\end{aligned} \tag{4-34}$$

The expected payoff of private sector when they choose strategy A (Opportunism) and strategy B (Compliance) are U_{2A} and U_{2B}, and the average payoff of the population is $\overline{U_2}$

$$U_{2A} = x(\mathrm{F} - C_1 + P_1\mathrm{V}) + (1-x)(\mathrm{F} - C_1 + P_2\mathrm{V}) \tag{4-35}$$

$$U_{2B} = x(\mathrm{F} - C_2 + \mathrm{V}) + (1-x)(\mathrm{F} - C_2 + \mathrm{V}) \tag{4-36}$$

$$\begin{aligned}\overline{U_2} &= y \cdot U_{2A} + (1-y) \cdot U_{2B} \\ &= xy(\mathrm{F} - C_1 + P_1\mathrm{V}) + y(1-x)(\mathrm{F} - C_1 + P_2\mathrm{V}) + y(1-x)(\mathrm{F} - C_2 + \mathrm{V}) + (1 - \\ &x)(1-y)(\mathrm{F} - C_2 + \mathrm{V})\end{aligned} \tag{4-37}$$

From this, we can get the replication dynamic equation of the local governments is

$$\begin{aligned}\frac{dx}{dt} &= x(U_{1A} - \overline{U_1}) \\ &= x(1-x)[U_{1A} - U_{1B}] \\ &= x(1-x)[y(-\mathrm{F} - \mathrm{S} + \mu\mathrm{B} - C_0 + P_1(\mathrm{V} - \mathrm{L})) + (1-y)(-\mathrm{F} - \mathrm{S} + \mathrm{B} - C_0) - y(-\mathrm{F} - \\ &\mathrm{S} + \mu\mathrm{B} - C_0 + P_1(\mathrm{V} - \mathrm{L})) - (1-y)(-\mathrm{F} - \mathrm{S})] \\ &= x(1-x)\{y[(P_1 - P_2)(\mathrm{V} - \mathrm{L}) - \mathrm{B} + C_0] + (\mathrm{B} - C_0)\}\end{aligned} \tag{4-38}$$

The replication dynamic equation of the private sectors is

$$\begin{aligned}\frac{dy}{dt} &= x(U_{2A} - \overline{U_2}) \\ &= y(1-y)[U_{2A} - U_{2B}] \\ &= y(1-y)[x(\mathrm{F} - C_1 + P_1\mathrm{V}) + (1-x)(\mathrm{F} - C_1 + P_2\mathrm{V}) - x(\mathrm{F} - C_2 + \mathrm{V}) + (1 - \\ &x)(\mathrm{F} - C_2 + \mathrm{V})] \\ &= y(1-y)[x\mathrm{V}(P_1 - P_2) + (C_2 - C_1 + P_2V - V)]\end{aligned} \tag{4-39}$$

4.3.3 Model solution and analysis for nonprofitable PPP model

1) Strategy stability analysis of local governments

Based on the stability theorem, Solving the equation, the x=0, x=1 and $y = \frac{C_0 - B}{(P_1 - P_2)(\mathrm{V}-\mathrm{L}) - \mathrm{B} + C_0}$ are the roots of

$$F(x) = \frac{dx}{dt} = 0,\ F'(x) = \frac{dF(x)}{dx} = (1-2x)\{y[(P_1 - P_2)(\mathrm{V}-\mathrm{L}) - \mathrm{B} + C_0] + (\mathrm{B} - C_0)\} \tag{4-40}$$

When $F(x) = 0$, and $F'(x) \leq 0$, x is the evolutionary stable strategy.

If $y = \frac{C_0 - B}{(P_1 - P_2)(\mathrm{V}-\mathrm{L}) - \mathrm{B} + C_0}$, then for any x, $F(x) = 0$, and $F'(x) = 0$, any strategy of local governments is stable while axis x is in a stable state;

If $y \neq \frac{C_0 - B}{(P_1 - P_2)(\mathrm{V}-\mathrm{L}) - \mathrm{B} + C_0}$, then the different cases would be conducted to analysis to demonstrate the stability of the equation roots

Due to $0 < y < 1$, we have $0 < \frac{C_0 - B}{(P_1 - P_2)(\mathrm{V}-\mathrm{L}) + C_0 - B} < 1$. And $P_1 > P_2$, hence $P_1 - P_2 > 0$, the numerical relation between the combination of variables $(P_1 - P_2)(\mathrm{V}-\mathrm{L})$ and $C_0 - B$ would determine the stability of the strategy. In order to simplify the solving process, $\frac{C_0 - B}{(P_1 - P_2)(\mathrm{V}-\mathrm{L}) + C_0 - B}$ can be equal to $\frac{1}{\frac{(P_1 - P_2)(\mathrm{V}-\mathrm{L})}{C_0 - B} + 1}$.

Case 1: when $\frac{C_0 - B}{(P_1 - P_2)(\mathrm{V}-\mathrm{L}) + C_0 - B} < 0\ and\ 0 < y < 1$, which is equal to $\frac{1}{\frac{(P_1 - P_2)(\mathrm{V}-\mathrm{L})}{C_0 - B} + 1} < 0$, which leads to $\frac{(P_1 - P_2)(\mathrm{V}-\mathrm{L})}{C_0 - B} < -1$, due to the undetermined value of $C_0 - B$ and $\mathrm{V}-\mathrm{L}$, therefore 2 scenarios existing in this case and discussed as below:

Under to condition of $\frac{(P_1 - P_2)(\mathrm{V}-\mathrm{L})}{C_0 - B} < -1$, the two scenarios are

Scenario 1: When $C_0 - B > 0, (P_1 - P_2)(\mathrm{V}-\mathrm{L}) < 0$, and $(P_1 - P_2)(\mathrm{V}-\mathrm{L}) < B - C_0$ hence, $(P_1 - P_2)(\mathrm{V}-\mathrm{L}) + C_0 - B < 0$, and $F'(x)|_{x=0} < 0,\ F'(x)|_{x=1} > 0,\ x = 0$ is the only evolutionary stable strategy in this scenario;

Scenario 2: When $C_0 - B < 0, (P_1 - P_2)(\mathrm{V}-\mathrm{L}) > 0$, and $(P_1 - P_2)(\mathrm{V}-\mathrm{L}) > B - C_0$ hence, $(P_1 - P_2)(\mathrm{V}-\mathrm{L}) + C_0 - B > 0$, and $F'(x)|_{x=0} > 0,\ F'(x)|_{x=1} < 0,\ x = 1$ is the only evolutionary stable strategy in this scenario;

Case 1 shows the net benefits of providing channels to the public to supervise PPP project $C_0 - B$ and subjective expected utility(SEU) $(P_1 - P_2)(\mathrm{V}-\mathrm{L})$ are crucial for the local governments to consider. When the net benefits are negative, the local governments tend to choose not to encourage the public supervision. While the net benefits are positive value, the encouraging strategy would be the evolutionary stale strategy. Due to the unprofitability in this case, the viability gap funding from financing sources and platform would be the critical variable for the local government to consider. And the viability gap funding is based on the construction cost, reasonable profit rate and the operation duration of PPP projects.

Case 2: when $0 < \frac{C_0 - B}{(P_1 - P_2)(\mathrm{V}-\mathrm{L}) + C_0 - B} < 1$, simplify the inequality, which is equal to $0 < \frac{1}{\frac{(P_1 - P_2)(\mathrm{V}-\mathrm{L})}{C_0 - B} + 1} < 1$. We let $\frac{(P_1 - P_2)(\mathrm{V}-\mathrm{L})}{C_0 - B} = a$, then the inequality is simplified as

$\frac{1}{\frac{(P_1 - P_2)(\mathrm{V-L})}{C_0 - B} + 1} = \frac{1}{\mathrm{a} + 1}$, the value range of a would determine the ESS.

This leads to $a > 0, \frac{(P_1 - P_2)(\mathrm{V-L})}{C_0 - B} > 0$. There are two scenarios existing in this case.

Scenario 1: $C_0 - B > 0\ and\ (P_1 - P_2)(\mathrm{V-L}) > 0$, hence $F'(x)|_{x=0} > 0$, $F'(x)|_{x=1} < 0$, $x = 1$ is the only evolutionary stable strategy in this scenario;
Scenario 2: $C_0 - B < 0\ and\ (P_1 - P_2)(\mathrm{V-L}) < 0, F'(x)|_{x=0} < 0$, $F'(x)|_{x=1} > 0$, $x = 0$ is the only evolutionary stable strategy in this scenario;
Case 2 demonstrates when the expected net benefits of encouraging the public to supervise PPP project and subjective expected utility (SEU) are relatively close with each other, but in different directions of numerical values, the results can be remarkably different. When they are both positive values, which indicates there are economical and subjective incentive motivation for the local governments to take measures to encourage public supervision. While when they are both negative, the local governments would be less motivated to provide channels for the public to supervise due to the negative expected feedback of this behavior.

Case 3: When $-1 < a < 0$, hence, we have $\frac{1}{\mathrm{a}+1} > 1$ which is equal to $\frac{C_0 - B}{(P_1 - P_2)(\mathrm{V-L}) + C_0 - B} > 1$, and leads to the results of $C_0 - B > 0\ and\ (P_1 - P_2)(\mathrm{V-L}) < 0$. hence $F'(x)|_{x=0} < 0$, $F'(x)|_{x=1} > 0$, $x = 0$ is the only evolutionary stable strategy in this case;
Case 3 shows the local government would choose not to encourage the public supervision when the conditions above are satisfied. Because the loss of low-quality of project is relatively small in this case, the local governments is less motivated to encourage the public to supervise the non-profitable PPP projects.

2) Strategy stability analysis of the private sectors
The replication dynamic equation of the private sectors was established in the previous section,

$$F(y) = \frac{dy}{dt} = y(1-y)[x\mathrm{V}(P_1 - P_2) + (C_2 - C_1 + P_2 V - V)] \quad (4\text{-}41)$$

Hence

$$F'(y) = \frac{dF(y)}{dy} = (1-2y)[x\mathrm{V}(P_1 - P_2) + (C_2 - C_1 + P_2 V - V)] \quad (4\text{-}42)$$

Solve the equation of $F(y) = 0$, it is easy to see the roots of the is y=0, y=1 and $x = x^* = \frac{C_1 - C_2 + V(1 - P_2)}{\mathrm{V}(P_1 - P_2)}$ $(P_2 < P_1,\ C_1 < C_2)$
Similar to the analysis of previous cases, when $x = x^*$, and $F(y) = 0$, then for any y, $F'(y) = 0$, any strategy of private sectors is stable while axis y is in a stable state;
When $x \neq x^*$, cases in different conditions are discussed separately as follow:

(10) Case 4: when $\frac{C_1 - C_2 + V(1 - P_2)}{\mathrm{V}(P_1 - P_2)} < 0$, due to the assumptions are defined as

$P_2 < P_1, C_1 < C_2 \leftrightarrow P_1 - P_2 > 0, C_1 - C_2 < 0$ Hence $\frac{C_1 - C_2 + V(1 - P_2)}{\mathrm{V}(P_1 - P_2)} < 0 \leftrightarrow$

$$C_1 - C_2 + V(1 - P_2) < 0 \leftrightarrow V(1 - P_2) < C_2 - C_1 \ (\leftrightarrow: means\ equal\ to) \quad (4\text{-}43)$$

$F'(y)|_{y=0} > 0$, $F'(y)|_{y=1} < 0$, so that the root $y = 1$ is the only evolutionary stable strategy, which refers to private sectors would choose the opportunism strategy, and not fully complete project in high quality.

In this case, $(1 - P_2)$ is defined as the possibility that local governments do not encourage the public to supervise PPP projects and the low-quality product are not found. When the cost of providing high-quality project is overwhelmingly exceed expected Viability gap funding payment, then the private sector would choose not to comply the contract and provide low-quality of products.

(11) Case 5: when $0 < \frac{C_1 - C_2 + V(1 - P_2)}{V(P_1 - P_2)} < 1$, due to the range of $0 < x < 1$, two scenarios are existing in this case:

Scenario 1: When $1 > x > \frac{C_1 - C_2 + V(1 - P_2)}{V(P_1 - P_2)} > 0$, $xV(P_1 - P_2) + V(P_2 - 1) > C_1 - C_2$, $F'(y)|_{y=0} > 0$, $F'(y)|_{y=1} < 0, y = 1$ is the only evolutionary stable strategy in this scenario.

Scenario 2: When $0 < x < \frac{C_1 - C_2 + V(1 - P_2)}{V(P_1 - P_2)} < 1$, $xV(P_1 - P_2) + V(P_2 - 1) < C_1 - C_2$, $F'(y)|_{y=0} < 0$, $F'(y)|_{y=1} > 0$, $y = 0$ is the only evolutionary stable strategy in this scenario.

Case 5 illustrates when the value of the root is between 0 and 1, the numerical change during the evolutionary process can significantly cause different equilibrium states. $xV(P_1 - P_2) + V(P_2 - 1)$ could be understood as the expected payoff from Viability gap funding (VGF), when the value of VGF is higher than the cost difference of providing high-quality products and low-quality products $C_1 - C_2$, the private sector would perform opportunism strategy in this scenario.

(12) Case 6: when $\frac{C_1 - C_2 + V(1 - P_2)}{V(P_1 - P_2)} > 1$, hence, we have the $\frac{C_1 - C_2 + V(1 - P_2)}{V(P_1 - P_2)} > x$ which is equal to $xV(P_1 - P_2) < C_1 - C_2 + V(1 - P_2)$, for the roots of $y = 0$ and $y = 1$, the $F'(y)|_{y=0} < 0$, $F'(y)|_{y=1} > 0$,

Then $y = 0$ is the only evolutionary stable strategy, which means the private would choose to finish the project in high quality regardless other irrelevant variables.

Chapter 5 Model construction by BIM Technology

5.1 Assumptions and hypothesis

5.2 Parameters Statement

5.3 Model solution and analysis

5 Evolutionary model construction by BIM Technology

BIM technology and methodology have increasing impact on AEC industry as well as the rapid developing PPP scheme in China and worldwide recent years. It plays increasingly significant role in the processes and development in automation and information of Engineering projects. In this section, the evolutionary model of PPP project under perspective of BIM technology is based on the domain scheme of public supervision model in previous part. Firstly, the assumptions of this model are formulated to solidate the foundation of this model and some of less important variables are simplified, which is aimed to focus on modeling the influence of BIM technology. Similar with public supervision perspective, the payoff matrix is constructed to illustrate the influencing mechanism from BIM technology to the evolutionary process of game players. Furthermore, the case demonstration and scenario analysis are conducted to explore the potential evolutionary stable strategies (ESS) of game players. The scenarios analysis is discussed to identify the significant variables, which influence significantly on the behaviors of the game players. Besides, it also provides foundation and directions for the later processes of data collection and simulation, which can virtually present the evolutionary processes and interaction for both players.

To organically integrate the perspectives from public supervision and BIM technology, the model from BIM technology is based on a general situation of public supervision. The integrated structure from BIM technology is formulated as below:

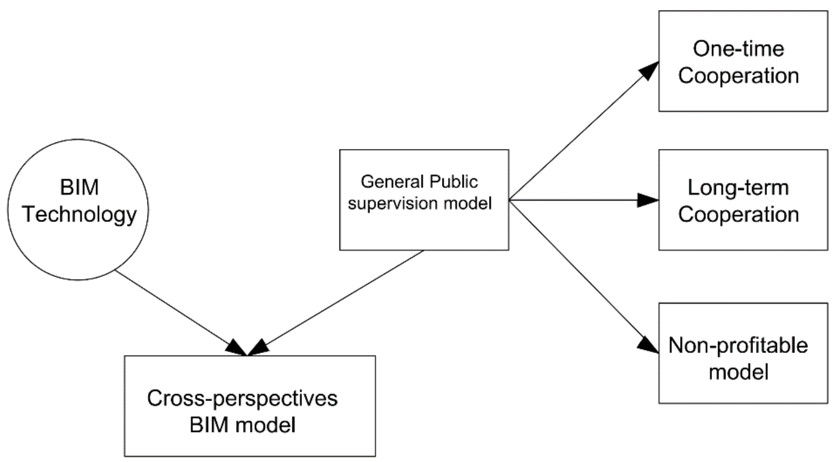


Figure 5- 1 Cross-perspective on the PPP model influence by BIM technology and public supervision

5.1 Assumptions and hypothesis of PPP project under BIM technology

1. The evolutionary model of PPP projects under BIM technology is based on the domain and general scenario of PPP project under public supervision. It is the most common scenario in current practice of PPP projects in China, some of the variables and mechanism will be simplified to demonstrate the prominent features and issues from BIM technology perspective.
2. There are two strategical choices for local governments and private sectors. The government's behavior strategies are: {Encourage BIM, Not encourage BIM}; While there are two strategies for private sector: {Traditional Construction Method, BIM Method}.
3. Assumed that all the PPP projects in this model is supervised by the public and third independent organizations. And according to previous scenarios analysis, the local governments tend to choose to encourage public supervision strategy, while the private sector would comply the contract in the game.
4. The payment from government and performance are simplified as well as the variables related to the public supervision.
5. There is cost for local governments and private sector to transfer traditional design and built methods into BIM approach. For the local governments, providing unified BIM platform and implementing BIM check according to regulations and standards are the main initial cost; For the private sectors, the transition cost, and the cost due to design productivity loss are taken into consideration in BIM perspective model.
6. The loss of using traditional method due to design changes or clashes and benefits from using BIM technology are also considered and defined as L_T and R_2 respectively.
7. When the projects are completed with satisfactory quality when the private sectors using BIM approach, the local government will provide incentive bonus for the private sectors as B.

5.2 Parameters Statement and model demonstration for BIM

Game Player	Game strategy	Symbol	Description
Local Government	Encourage	x	Proportion of local governments who encourage the BIM technology in PPP projects ($0<x<1$)
		C_E	The cost of providing unified BIM platform for private sector to encourage the application of BIM
		R_1	The benefits of implementing BIM technology to government
		B	The bonus of using BIM technology in PPP project for private sector
	Not Encourage	$1-x$	Proportion of local governments who do not encourage the BIM technology in PPP projects
Private Sector	Traditional Construction Method	y	Proportion of private sectors who perform Opportunism in PPP project($0<y<1$)
		C_D	Default cost of PPP project for private sector
		L_T	The loss of using traditional method due to design changes or clashes
		P	Default and simplified payment from government to private sector
	BIM Method	$1-y$	Proportion of private sectors who do not perform Opportunism in PPP project($0<y<1$)
		R_2	The benefits of implementing BIM technology to private sector
		C_B	The cost of implementing BIM technology in project for private sector
		C_P	Cost due to design productivity loss

Table 17 Description of game model parameters in BIM technology perspective model

		Local Government	
	Strategies	Encourage (x)	Not Encourage (1-x)
Private Sector	Traditional Construction Method (y)	$P-C_D-L_T$; $-P-C_E-L_T$	$P-C_D-L_T$; $-P-L_T$
	BIM Method (1-y)	$P-C_D-C_B-C_P+R_2+B$; $-P-C_E+R_1-B$	$P-C_P-C_D-C_B+R_2$; $-P$

Table 18 Description of game model parameters of BIM perspective

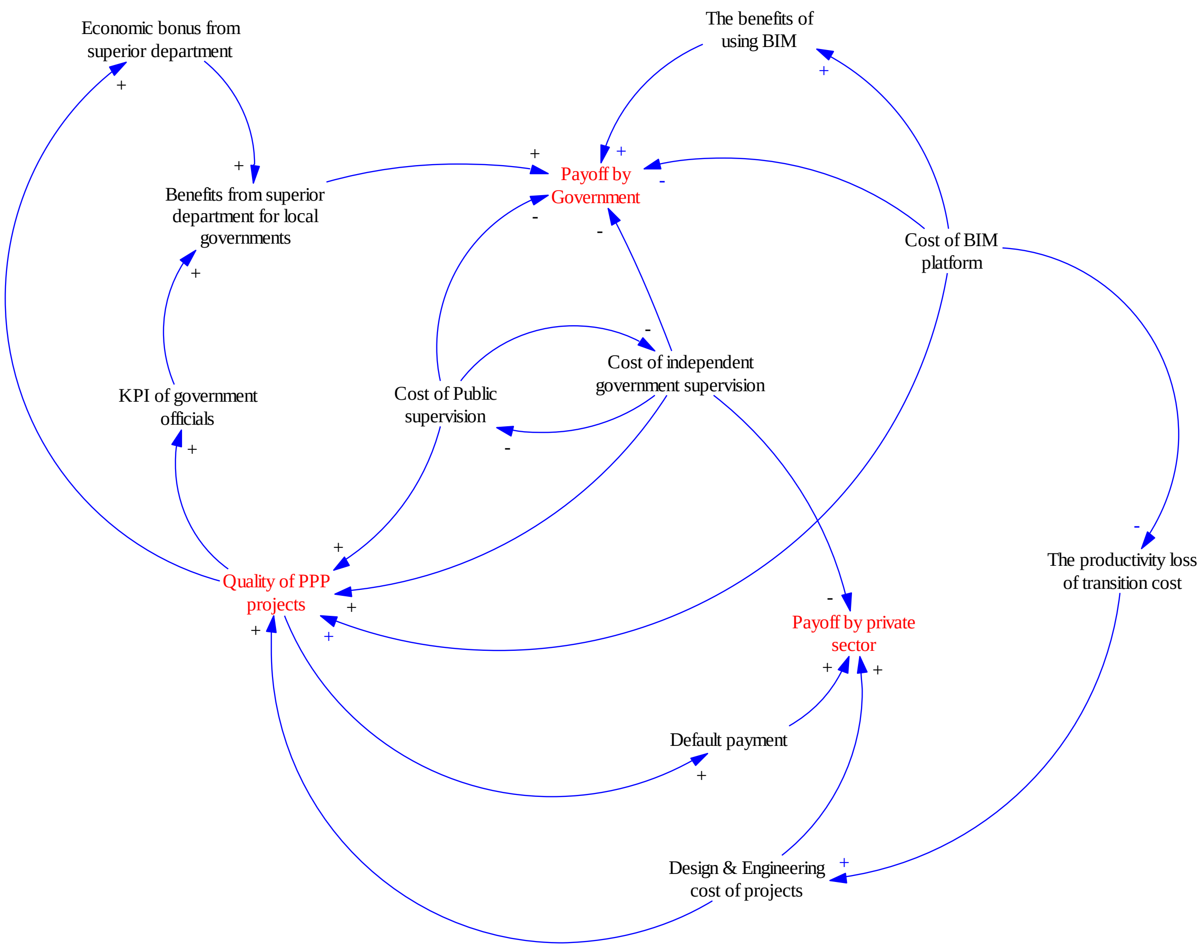


Figure 5- 2 The system dynamic interpretation for the BIM model under public supervision overlapping perspective

Assume that expected payoff of local governments when they choose strategy A (Encourage BIM technology) and strategy B (Not encourage BIM technology) are U_{1A} and U_{1B}, and the average payoff of the population is $\overline{U_1}$.

$$U_{1A} = y(-\mathrm{P} - C_E - L_T) + (1-y)(-\mathrm{P} - C_E + R_1 - \mathrm{B}) \quad (5\text{-}1)$$

$$U_{1B} = y(-\mathrm{P} - L_T) + (1-y)(-\mathrm{P}) \quad (5\text{-}2)$$

$$\overline{U_1} = x \cdot U_{1A} + (1-x) \cdot U_{1B}$$
$$= xy(-\mathrm{P} - C_E - L_T) + x(1-y)(-\mathrm{P} - C_E + R_1 - \mathrm{B}) + (1-x)y(-\mathrm{P} - L_T) + (1-x)(1-y)(-\mathrm{P}) \quad (5\text{-}3)$$

The expected payoff of private sector when they choose strategy A (Opportunism) and strategy B (Compliance) are U_{2A} and U_{2B}, and the average payoff of the population is $\overline{U_2}$

$$U_{2A} = x(\mathrm{P} - C_D - L_T) + (1-x)(\mathrm{P} - C_D - L_T) \quad (5\text{-}4)$$

$$U_{2B} = x(\mathrm{P} - C_D - C_B - C_P + R_2 + \mathrm{B}) + (1-x)(\mathrm{P} - C_D - C_B - C_P + R_2) \quad (5\text{-}5)$$

$$\overline{U_2} = y \cdot U_{2A} + (1-y) \cdot U_{2B}$$
$$= xy(\mathrm{P} - C_D - L_T) + y(1-x)(\mathrm{P} - C_E - L_T) + y(1-x)(\mathrm{P} - C_D - C_B - C_P + R_2 + \mathrm{B}) + (1-x)(1-y)(\mathrm{P} - C_D - C_B - C_P + R_2) \quad (5\text{-}6)$$

From this, we can get the replication dynamic equation of the local governments is

$$\frac{dx}{dt} = x(U_{1A} - \overline{U_1})$$
$$= x(1-x)[U_{1A} - U_{1B}]$$
$$= x(1-x)[y(-\mathrm{P} - C_E - L_T) + (1-y)(-\mathrm{P} - C_E + R_1 - \mathrm{B}) - y(-\mathrm{P} - L_T) - (1-y)(-\mathrm{P})]$$
$$= x(1-x)[y(\mathrm{B} - R_1) + (R_1 - \mathrm{B} - C_E)] \quad (5\text{-}7)$$

The replication dynamic equation of the private sectors is

$$\frac{dy}{dt} = y(U_{2A} - \overline{U_2}) +$$
$$= y(1-y)[U_{2A} - U_{2B}]$$
$$= y(1-y)[x(\mathrm{P} - C_D - L_T) + (1-x)(\mathrm{P} - C_D - L_T) - x(\mathrm{P} - C_D - C_B - C_P + R_2 + \mathrm{B}) - (1-x)(\mathrm{P} - C_D - C_B - C_P + R_2)]$$
$$= y(1-y)[xB + (C_B + C_P - L_T - R_2)] \quad (5\text{-}8)$$

5.3 Model **solution and analysis for** nonprofitable PPP **model**

5.3.1 **Strategy stability analysis of local governments**

Based on the stability theorem, solving the equation $\frac{dF(x)}{dx} = x(1-x)[y(\mathrm{B} - R_1) + (R_1 - \mathrm{B} - C_E)]$, the x=0, x=1 and $y = \frac{R_1 - \mathrm{B} - C_E}{\mathrm{B} - R_1}$ are the roots of

$$F(x) = \frac{dx}{dt} = 0,\ F'(x) = \frac{dF(x)}{dx} = (1-2x)[y(C_0 - P_1\mathrm{L} + P_2\mathrm{L}) + (\mathrm{B} - C_0)] \quad (5\text{-}9)$$

When $F(x) = 0$, and $F'(x) \leq 0$, x is the evolutionary stable strategy.

If $y = \frac{R_1 - \mathrm{B} - C_E}{\mathrm{B} - R_1}$, then for any x, $F(x) = 0$, and $F'(x) = 0$, any strategy of local governments is stable while axis x is in a equilibrium state;

If $y \neq \frac{R_1 - \mathrm{B} - C_E}{\mathrm{B} - R_1}$, then the different cases as follows would be conducted to analysis the stability of the equation roots.

Case 1: when $\frac{R_1 - \mathrm{B} - C_E}{\mathrm{B} - R_1} < 0$ and $0 < y < 1$, then $y > \frac{R_1 - \mathrm{B} - C_E}{\mathrm{B} - R_1}$. Then two scenarios existing in this case: scenario 1 $\begin{cases} \mathrm{B} - R_1 < 0 \\ R_1 - \mathrm{B} - C_E > 0 \end{cases}$ and scenario 2 $\begin{cases} \mathrm{B} - R_1 > 0 \\ R_1 - \mathrm{B} - C_E < 0 \end{cases}$.

Scenario 1: When $\begin{cases} \mathrm{B} - R_1 < 0 \\ R_1 - \mathrm{B} - C_E > 0 \end{cases}$, $y(\mathrm{B} - R_1) < R_1 - \mathrm{B} - C_E$, $F'(x)|_{x=0} < 0$, $F'(x)|_{x=1} > 0$, $x = 0$ is the only evolutionary stable strategy in this scenario;

Scenario 2: When $\begin{cases} \mathrm{B} - R_1 > 0 \\ R_1 - \mathrm{B} - C_E < 0 \end{cases}$, $y(\mathrm{B} - R_1) > R_1 - \mathrm{B} - C_E$, $F'(x)|_{x=0} > 0$, $F'(x)|_{x=1} < 0$, $x = 1$ is the only evolutionary stable strategy in this scenario;

Case 1 shows the local government would choose strategy based on the net benefits from implementing BIM technology. When the net benefits $\mathrm{B} - R_1$ is positive and meet the numerical requirement $-C_E > \mathrm{B} - R_1$, the cost of providing platform and support for private sector is defined as C_E, then the local governments would prefer encouraging BIM strategy.

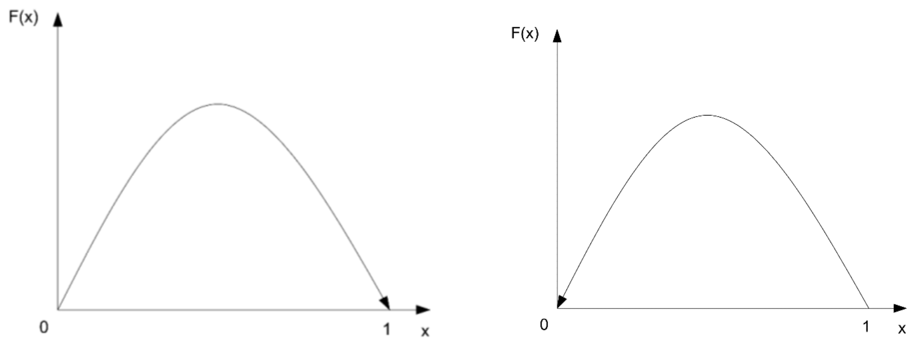


Figure 5- 3 Two scenarios in case 1 for local governments under BIM perspective

Case 2: when $0 < \frac{R_1 - \mathrm{B} - C_E}{\mathrm{B} - R_1} < 1$, simplify the inequality, $R_1 - \frac{C_E}{2} < \mathrm{B}$,

and due to the $0 < y < 1$, so two scenarios are existing in this case.

Scenario 1: When $1 > y > \frac{R_1 - \mathrm{B} - C_E}{\mathrm{B} - R_1} > 0$, $y(\mathrm{B} - R_1) > R_1 - \mathrm{B} - C_E$, $F'(x)|_{x=0} > 0$, $F'(x)|_{x=1} < 0$, $x = 1$ is the only evolutionary stable strategy in this scenario;

Scenario 2: When $0 < y < \frac{R_1 - \mathrm{B} - C_E}{\mathrm{B} - R_1} < 1$, $y(\mathrm{B} - R_1) < R_1 - \mathrm{B} - C_E$, $F'(x)|_{x=0} < 0$, $F'(x)|_{x=1} > 0$, $x = 0$ is the only evolutionary stable strategy in this scenario;

Case 2 means the local governments will adopt the strategy of encouraging private sector to use BIM technology with extra bonus benefits from superior administrative department.

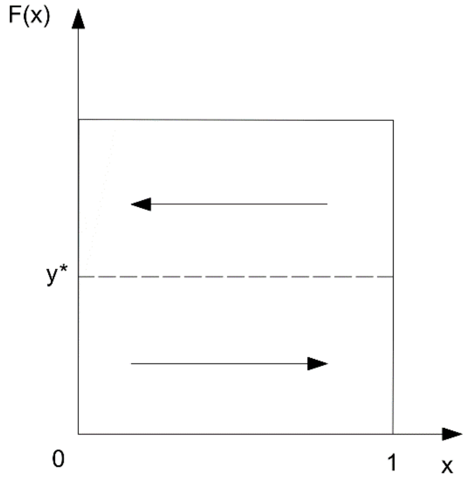


Figure 5- 4 Scenarios in case 2 for local governments under BIM perspective

(13) Case 3: If $\frac{R_1 - \mathrm{B} - C_E}{\mathrm{B} - R_1} > 1$ which is equal to the form of inequality as $R_1 > \mathrm{B} + \frac{C_E}{2}$,

Then the $y < 1 < \frac{R_1 - \mathrm{B} - C_E}{\mathrm{B} - R_1}$, $y(\mathrm{B} - R_1) < R_1 - \mathrm{B} - C_E$ for the solutions of $F'(x)|_{x=0} < 0$, $F'(x)|_{x=1} > 0$, $x = 0$ is the only evolutionary stable strategy.

Case 3 means when the BIM payment to the private sector is overwhelmingly higher than the benefits from using BIM platform, the local governments tend to adopt not encouraging strategy.

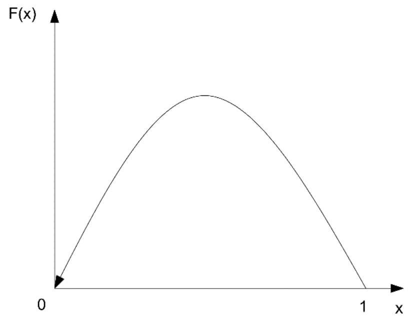


Figure 5- 5 Scenarios in case 3 for local governments under BIM perspective

5.3.2 Strategy stability analysis of the private sectors

The replication dynamic equation of the private sectors was established in the previous section,

$$F(y) = \frac{dy}{dt} = y(1 - y)[xB + (C_B + C_P - L_T - R_2)] \quad (5\text{-}10)$$

Hence

$$F'(y) = \frac{dF(y)}{dy} = (1 - 2y)[xB + (C_B + C_P - L_T - R_2)] \quad (5\text{-}11)$$

Solve the equation of $F(y) = 0$, it is easy to find out the roots of this equation is y=0, y=1 and $x = x^* = \frac{L_T+R_2-C_B-C_P}{B}$

Similar with the analysis of previous cases, when $x = x^*$, and $F(y) = 0$, then for any y, $F'(y) = 0$, any strategy of private is stable while axis y is in a stable state;
When $x \neq x^*$, cases in different conditions are discussed separately as follow:

Case 4: when $\frac{L_T+R_2-C_B-C_P}{B} < 0$, due to the assumptions define that all the variables are non-negative values, Hence $\frac{L_T+R_2-C_B-C_P}{B} < 0 \leftrightarrow L_T + R_2 - C_B - C_P < 0 \leftrightarrow L_T + R_2 < C_B + C_P$ ($\leftrightarrow$: $means\ equal\ to$)

$F'(y)|_{y=0} > 0$, $F'(y)|_{y=1} < 0$, so that the root $y = 1$ is the only evolutionary stable strategy.
Case 4 shows for private sectors, more benefits gained from traditional design and construction methodology when the switching cost and productivity loss are higher than the benefits from implementing BIM technology in whole phases of PPP project.

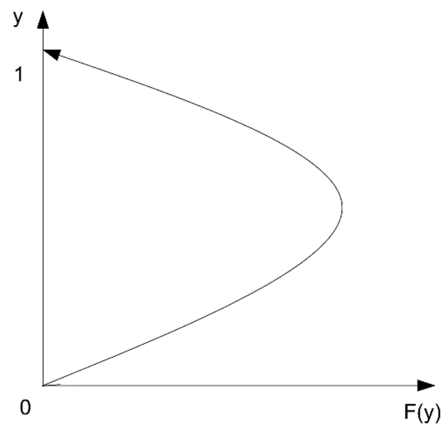


Figure 5- 6 Scenario in case 4 for private sector under BIM perspective

(14) Case 5: when $0 < \frac{L_T+R_2-C_B-C_P}{B} < 1$, due to the range of $0 < x < 1$, two scenarios are existing in this case:

Scenario 1: When $1 > x > \frac{L_T+R_2-C_B-C_P}{B} > 0$, $xB > L_T + R_2 - C_B - C_P$, $F'(y)|_{y=0} > 0$, $F'(y)|_{y=1} < 0$, $y = 1$ is the only evolutionary stable strategy in this scenario.

Scenario 2: When $0 < x < \frac{L_T+R_2-C_B-C_P}{B} < 1$, $xB < L_T + R_2 - C_B - C_P$, $F'(y)|_{y=0} < 0$, $F'(y)|_{y=1} > 0$, $y = 0$ is the only evolutionary stable strategy in this scenario.

Case 5 illustrates the private sector would adopt using BIM technology strategy when the direct benefits and bonus from local government is higher than the expected benefits of implementing BIM technology for themselves.

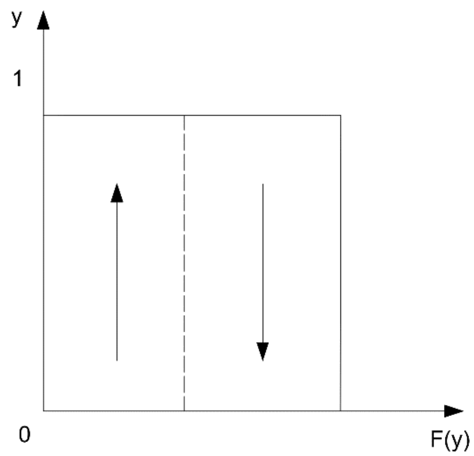


Figure 5- 7 Scenario in case 5 for private sector under BIM perspective

(15) Case 6: when $\frac{L_T+R_2-C_B-C_P}{B} > 1$, hence, we have the $\frac{L_T+R_2-C_B-C_P}{B} > x$ which is equal to $xB < L_T + R_2 - C_B - C_P$, and $B < L_T + R_2 - C_B - C_P$. for the roots of $y = 0$ and $y = 1$, the $F'(y)|_{y=0} < 0$, $F'(y)|_{y=1} > 0$

Then $y = 0$ is the only evolutionary stable strategy, which means the private sectors would adopt using BIM technology strategy anyway.

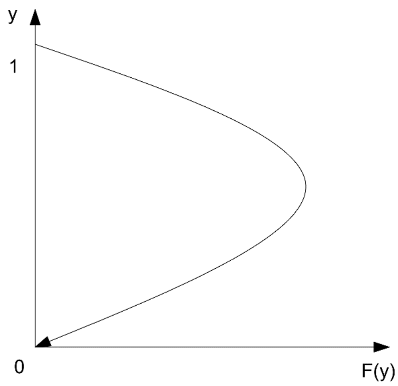


Figure 5- 8 Scenario in case 6 for private sector under BIM perspective

5.4 ESS analysis between local governments and private sectors

Based on the Evolutionary stable strategy theory of Freidman, the ESS could be analyzed from the local stability, and the dynamic evolution of population is defined by the differential equations. According to the replication dynamic equations in the previous sections, the Jacobian matrix J is computed as below:

$$J = \begin{bmatrix} \frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} \\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y} \end{bmatrix} \tag{5-12}$$

Hence $J =$

$$\begin{bmatrix} (1-2x)[y(\mathrm{B}-R_1)+(R_1-\mathrm{B}-C_E)] & x(1-x)(\mathrm{B}-R_1) \\ y(1-y)B & (1-2y)[xB+(C_B+\ C_P-L_T-R_2)] \end{bmatrix} \tag{5-13}$$

Then the determinant of the Jacobian matrix is

$$\det(J) = \frac{\partial F(x)}{\partial x} \cdot \frac{\partial F(y)}{\partial y} - \frac{\partial F(y)}{\partial x} \cdot \frac{\partial F(x)}{\partial y} = (1-2x)[y(\mathrm{B}-R_1)+(R_1-\mathrm{B}-C_E)] \cdot (1-2y)[xB+(C_B+\ C_P-L_T-R_2)] - xy(1-y)(1-x)(\mathrm{B}-R_1)B \tag{5-14}$$

And the trace of the Jacobian matrix is

$$\mathrm{Tr}(J) = \frac{\partial F(x)}{\partial x} + \frac{\partial F(y)}{\partial y} = (1-2x)[y(\mathrm{B}-R_1)+(R_1-\mathrm{B}-C_E)] + (1-2y)[xB+(C_B+C_P-L_T-R_2)] \tag{5-15}$$

The 5 equilibrium points $P_1(0,0)$, $P_2(1,0)$, $P_3(0,1)$, $P_4(1,1)$, $P_5(x^*,y^*)$, when $x^* = \frac{L_T+R_2-C_B-C_P}{B}$ and $y^* = \frac{R_1-\mathrm{B}-C_E}{\mathrm{B}-R_1}$, are put into the formulations of $\det(J)$ and $\mathrm{Tr}(J)$, then the determinants and traces of the 5 equilibrium points are calculated in Table 19

Equilibrium point	$\det(J)$	$\mathrm{Tr}(J)$
(0,0)	$(R_1-\mathrm{B}-C_E)\cdot(C_B+\ C_P-L_T-R_2)$	$(R_1-\mathrm{B}-C_E)+(C_B+\ C_P-L_T-R_2)$
(1,0)	$-(R_1-\mathrm{B}-C_E)\cdot(B+C_B+\ C_P-L_T-R_2)$	$-(R_1-\mathrm{B}-C_E)+(B+C_B+C_P-L_T-R_2)$
(0,1)	$C_E\cdot(C_B+\ C_P-L_T-R_2)$	$-C_E-\ (C_B+\ C_P-L_T-R_2)$
(1,1)	$-C_E\cdot\ (B+C_B+\ C_P-L_T-R_2)$	$C_E-\ (B+C_B+\ C_P-L_T-R_2)$
(x^*,y^*)	$\pm$	0

Table 19 ESS local stability analysis of BIM

5.5 Evolutionary game path analysis

The path analysis under BIM technology perspective are conducted to demonstrate evolutionary directions and potential scenarios of local governments and private sectors. According to the evolutionary game theory, equilibrium point is defined as: when $\det(J) > 0$ and $\mathrm{Tr}(J) < 0$ as conditions are satisfied. Due to the equilibrium point $P_5(x^*, y^*)$ does not meet the condition of $\mathrm{Tr}(J) < 0$, while in this case, the $\mathrm{Tr}(J) = 0$. Hence, (x^*, y^*) is not ESS point. Then the other equilibrium points have the potential to be the local stable equilibrium strategy, then 4 scenarios are discussed and analysis as below:

Scenario 1: When $R_1 - \mathrm{B} - C_E < 0$, $C_B + C_P - L_T - R_2 < 0$
Due to the values of C_E and B are defined positive in the assumption, so under this condition, the value of $B + C_B + C_P - L_T - R_2$ is undetermined.

Equilibrium point	$\det(J)$	$\mathrm{Tr}(J)$	Results of stability
$(0,0)$	$+$	$-$	ESS
$(1,0)$	$Uncertain$	$Uncertain$	Saddle point
$(0,1)$	$-$	$-$	Unstable point
$(1,1)$	$Uncertain$	$Uncertain$	Saddle point

Table 20 ESS analysis based on Scenario 1 of BIM

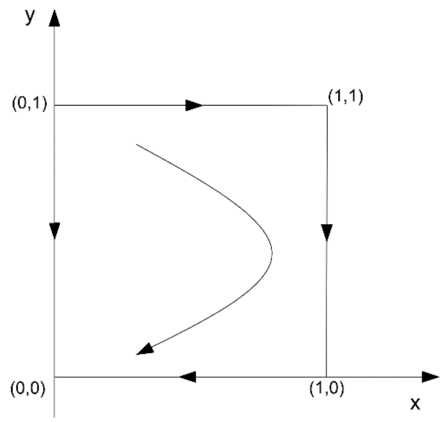


Figure 5- 9 The path analysis results for both gamers by scenario 1 of BIM

Scenario 2: When $R_1 - \mathrm{B} - C_E > 0$, $C_B + C_P - L_T - R_2 < 0$
Due to the values of C_E and B are defined positive in the assumption, so under this condition, the value of $B + C_B + C_P - L_T - R_2$ is still undetermined.

Equilibrium point	$\det(J)$	$\mathrm{Tr}(J)$	Results of stability
$(0,0)$	$-$	$Uncertain$	Saddle point
$(1,0)$	$+$	$-$	ESS
$(0,1)$	$-$	$Uncertain$	Saddle point
$(1,1)$	$Uncertain$	$Uncertain$	Unstable point

Table 21 ESS analysis based on Scenario 2 of BIM

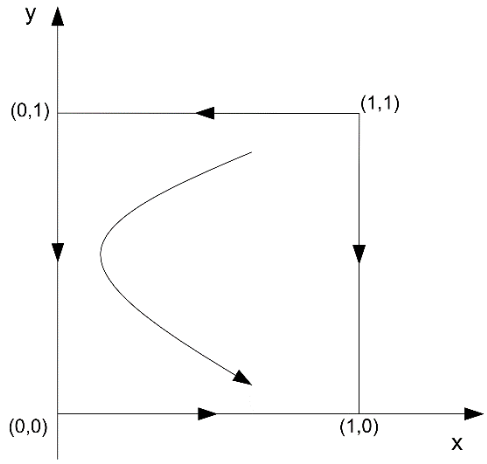


Figure 5- 10 The path analysis results for both gamers by scenario 2 of BIM

Scenario 3: When $R_1 - \mathrm{B} - C_E < 0$, $C_B + C_P - L_T - R_2 > 0$
Due to the values of C_E and B are defined positive in the assumption, so under this condition, the value of $B + C_B + C_P - L_T - R_2 > 0$ is still true.

Equilibrium point	$\det(J)$	$\mathrm{Tr}(J)$	Results of stability
$(0,0)$	$-$	$Uncertain$	Saddle point
$(1,0)$	$+$	$+$	Unstable point
$(0,1)$	$+$	$-$	ESS
$(1,1)$	$-$	$Uncertain$	Saddle point

Table 22 ESS analysis based on Scenario 3 of BIM

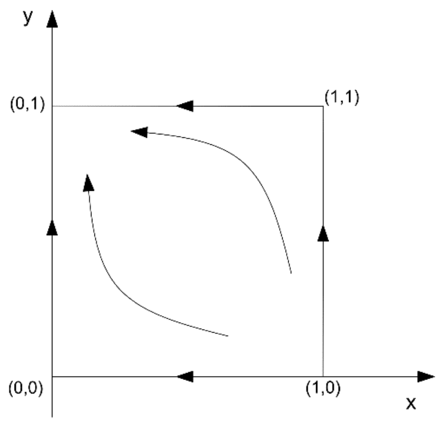


Figure 5- 11 The path analysis results for both gamers by scenario 3 of BIM

Scenario 4: When $R_1 - \mathrm{B} - C_E < 0$, $C_B + C_P - L_T - R_2 > 0$
Due to the values of C_E and B are defined positive in the assumption, so under this condition, the value of $B + C_B + C_P - L_T - R_2 > 0$ is still true.

Equilibrium point	$\det(J)$	$\mathrm{Tr}(J)$	Results of stability
(0,0)	−	*Uncertain*	Saddle point
(1,0)	+	+	Unstable point
(0,1)	+	−	ESS
(1,1)	−	*Uncertain*	Saddle point

Table 23 ESS analysis based on Scenario 4 of BIM

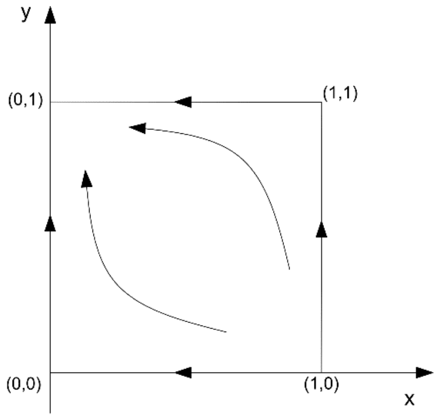


Figure 5- 12 The path analysis results for both gamers by scenario 4 of BIM

Scenario 5: When $R_1 - \mathrm{B} - C_E > 0$, $C_B + C_P - L_T - R_2 > 0$
Due to the values of C_E and B are defined positive in the assumption, so under this condition, the value of $B + C_B + C_P - L_T - R_2 > 0$ is still true.

Equilibrium point	$\det(J)$	$\mathrm{Tr}(J)$	Results of stability
(0,0)	−	−	Unstable point
(1,0)	−	*Uncertain*	Saddle point
(0,1)	+	−	ESS
(1,1)	−	*Uncertain*	Saddle point

Table 24 ESS analysis based on Scenario 5 of BIM

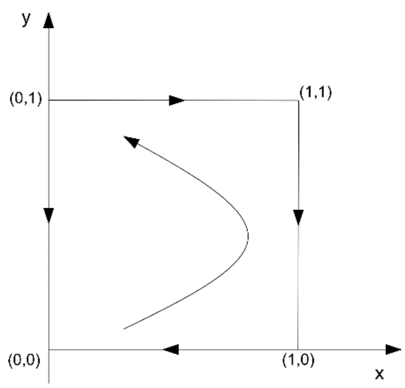


Figure 5- 13 The path analysis results for both gamers by scenario 5 of BIM

Chapter 6 Data collection and Preparation

6 Data collection and Preparation

Data of variables in payoff matrix as well as in replication dynamic equations are collected and sourced by two means, which promote the reliability of data and prepare for the simulation in later sections. In first approach to collect data, the annual report from China Public Private Partnership Center is utilized to extract data that are contributed in the payoff matrix and partial replicational functions. As shown in Figure 6-1, more than 10 thousand PPP projects are included in this database, and almost all required data can be found in the annual report which based on this dataset.

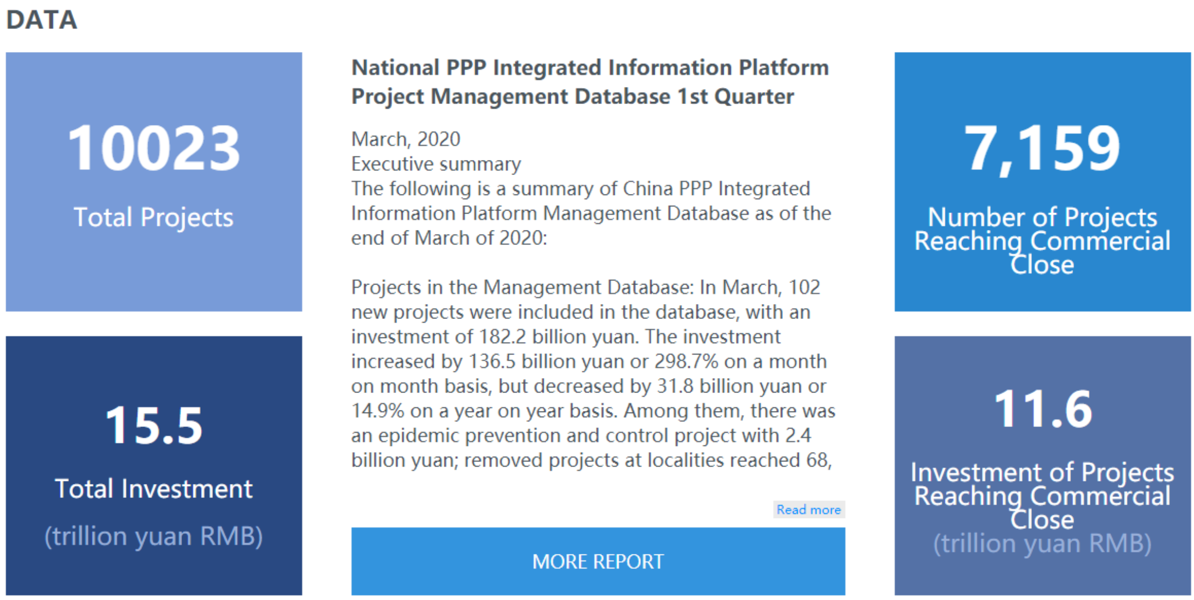


Figure 6- 1 Overview of included project and data in China PPP database

Moreover, the data that related to financial performance and bidding information of PPP projects are retrieved from BRIdata, which is an widely applied database as sources to analyze PPP projects in current China. In order to verify and enable the data more reliable, a cross check is applied when there are duplicated variables. And some unique variables, such as profit rate of PPP project within the research area, which are not presented in the annual report, are clarified in this database.

The annual report in China PPP center along with BRIdata provide almost complete and comprehensive data of this research. Moreover, case by case statistics methodology is implemented in second mean of collecting data. This study focuses on modelling PPP projects and the strategy process of local governments and private sectors in Xiong'an new area. In order to collect the projects data within the research area, some data of variables are calculated based on the case by case statistics mean, which are designated in certain area. Furthermore, this method can not only verify the existing data from previous method, but also provides needed data that do not presented or merely in national wide in first mean.

The detailed collecting processes and the data results are presented in this section below. It indicates and traces which variables are retrieved from which database and means specifically.

6.1 Data source I: Annual Report from PPP Center and BRIdata

The newest and most recent annual report "Annual Report of the Project Database of the National PPP Integrated Information Platform (2018)", which include 8.654 projects cases with total investment of RMB 13.2 trillion yuan (1.3 trillion euros). It is applied in the first mean of collecting data, which provides an overview for the nationwide PPP projects. The average investment of PPP project in the research and target areas can be retrieved from Figure 6-2.

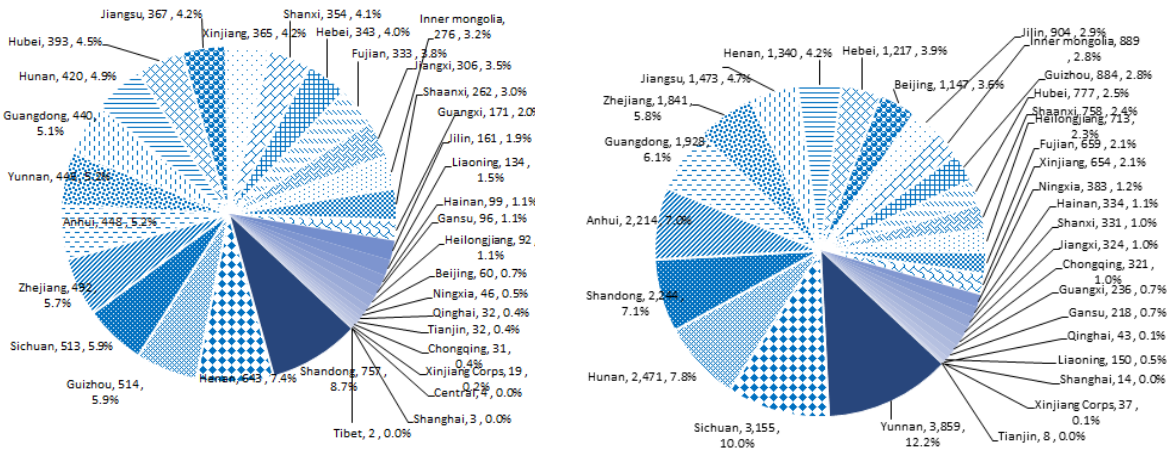


Figure 6- 2 Number and investment of PPP projects by province and regions (in 100 billion RMB)

It demonstrates the total investment and number of cases by different province and province-level municipalities. As shown in the bar diagrams, the research area which located in Beijing, Tianjin, and Hebei province, process 14, 1, and 125 PPP projects in the database respectively. And the responding investment are 1.147, 8, and 1.217 (100 billion RMB). The average investment of PPP projects within the target area can be easily as 18.24 (100 billion RMB).

Some of data can be directly and explicitly retrieved from the report, and some of the target values are processed and calculated based on the existing data as above. And the BRIdata as an open source database, which provides basic financial performance, distributed regions, and bidding information. Figure 6-3 shows PPP projects return rate on investment by time, the average return rate in recent years is 6.7%.

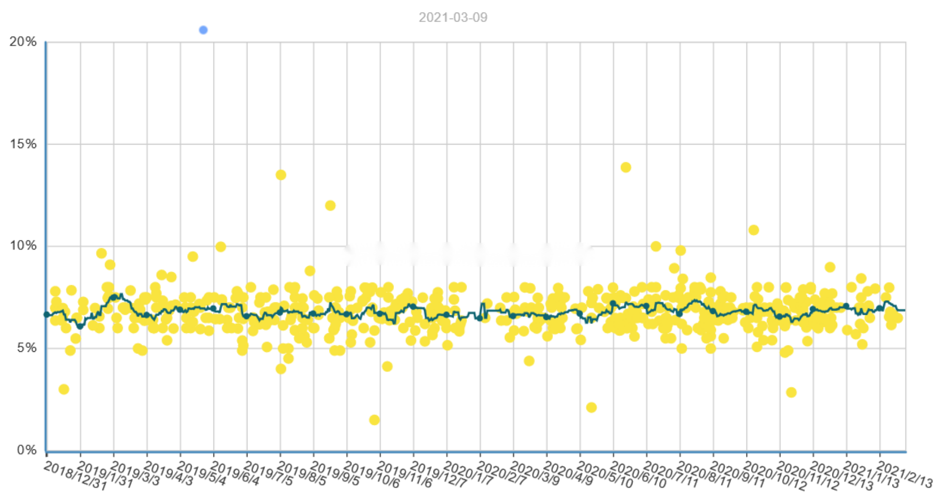


Figure 6- 3 Investment return rate trend of PPP projects concluded

6.2 Data source II: Case by Case Statistics

In order to verify and crosscheck the reliability and accuracy of the data and values of variables, case by case statistics methodology is used as the second approach of collecting data. The samples of case are selected based on location and types of PPP contract, which cover the information related project phase, payment mechanism, duration, project cost, fix and performance payment over 20 PPP projects in research area. On the one hand, case by case collection approach verifies the data in the first mean, and promote validity of data in previous mean. From another perspective, this approach also provides the data under different payment mechanism of sub-models. The information cases are retrieved from the database, which has been encrypted through blockchain technology. As shown in Figure 6-4, the interface of the project database illustrate the PPP project can be categorized and retrieved according to conditions. And these constraints can be set by setting the conditions of region and payment methods to target the cases that meet the research objectives.

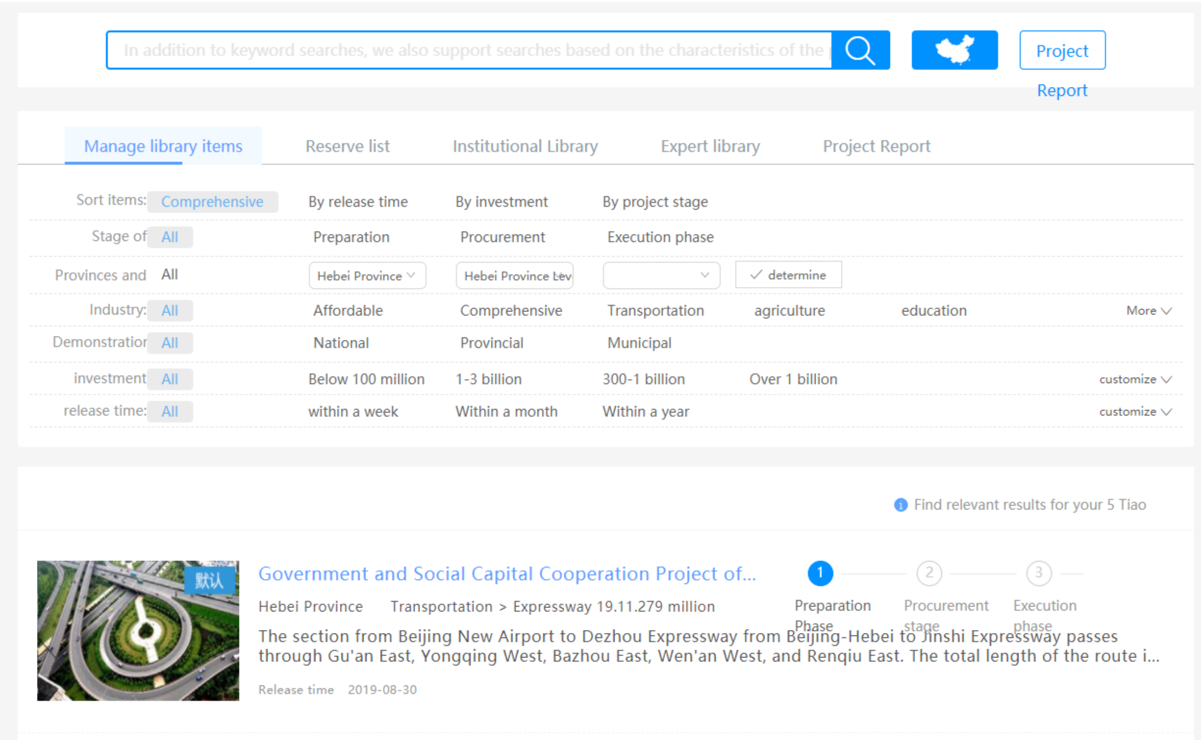


Figure 6- 4 The interface of PPP projects cases in database

https://www.cpppc.org:8082/inforpublic/homepage.html#/projectList

Finally, the PPP projects that meet the requirements are recorded into the data table of this study, as shown in Appendix 1. These cases record the key indicators of PPP projects in the target area in detail. Through these existing data, the final data used for simulation is as following sections.

6.3 The Results of Data collection

6.3.1 The data results of PPP project under public supervision

Sub-Model 1: One-time cooperation

Symbol	Value	Description	Data Source (I /II)
F	4.2	Fixed Payment to private sector	II
F_P	16.7	Performance payment to private sector	II
S	0.18%	Default Supervision cost rate	I /II
C_0	0.37%	The cost rate of providing channels to the public and identification cost of the authenticity in reports on social media	Gao & Liu, 2019
B	1.3%(Initial)	The benefits from encouraging the public to supervise (In Political KPI and monetary benefits)	II
L	2.6%(Initial)	The loss from the low-quality projects by Punishment from Upper departments	II
C_1	18.6	Cost of providing low-quality project ($C_1 < C_2$)	I /II
i_0	0.84 (Initial)	Coefficient of Performance payment in low-quality project ($i_0 < i_1$)	N/A
C_2	20.1	Cost of providing High-quality project	I /II
i_1	1.06 (Initial)	Coefficient of Performance payment in high-quality project	N/A

Table 25 The specification of data sources by parameters of one-time cooperation
Unit: 100 Million CNY

The formulations of target variables based on assumptions and existing data are shown below:

$$\text{Total investment} \times \text{Return rate} = \text{Profits}$$

6- 1 The profit based on return rate

$$\text{Project Cost} = \frac{Total\ investment}{(1 + Return\ rate)} = \frac{Fix\ payment + Performance\ payment}{(1 + Return\ rate)} = \frac{4.2 + 16.7}{1 + 6.7\%} = 19.6 \tag{6-1}$$

6- 2 The project cost is defined to include the cost of construction and design, financial cost, and consulting cost of PPP projects.

$$C_2 = \frac{Total\ investment}{(1 + Excess\ return\ rate)} = \frac{20.9}{(1 + 12\%)} = 18.6 \tag{6-2}$$

6- 3 The cost of providing low-quality project

$$C_1 = \frac{Total\ investment}{(1 + Low\ return\ rate)} = \frac{20.9}{(1 + 3.9\%)} = 20.1$$

(6-3)

Sub-model 2: Multi-time (Long-term) cooperation

Symbol	Value	Description	Source
F	3.1	Fixed Payment to private sector	II
F_P	12.5	Performance payment to private sector	II
S	0.18%	Default Supervision cost	I /II
C_0	0.37%	The cost of providing channels to the public and identification cost of the authenticity in reports on social media	Gao & Liu, 2019
B	0.65%	The benefits from encouraging the public to supervise	II
L	2.6%(Initial)	The loss from the low-quality projects by Punishment from Upper departments when do not encourage	II
C_1	18.6	Cost of providing low-quality project ($C_1 < C_2$)	I /II
i_0	0.84 (Initial)	Coefficient of Performance payment in low-quality project ($i_0 < i_1$)	N/A
R_s	2.4%(Initial)	The cost of rent-seeking	Krueger, 2008
C_2	20.1	Cost of providing High-quality project	I /II
i_1	1.06 (Initial)	Coefficient of Performance payment in low-quality project	N/A
ε	1.1(Initial)	The Coefficient of High-quality strategy in further cooperation	N/A
Q	3.2%	The reputational benefits of finish project in high-quality in further cooperation	I /II

Table 26 The specification of data sources by parameters of long-term cooperation

Unit: 100 Million CNY

The components of rent-seeking costs are complicated and affected by multiple factors. Bellante & Long (1981) and Krueger (2008) hold view that the cost of rent-seeking behavior is composed of three parts: 1) The costs incurred in seeking monopoly status; 2) Benefits loss caused by monopoly itself; 3) Opportunities for technological innovation lost to rent-seeking and its benefits.

For the rent-seeker, among these three costs, the cost of seeking monopoly status is considered as the main cost. While the latter two costs are not directly related to the rent-seeker, but these costs are externalized into a macro social loss, which will be undertook by the whole society. The prominent differences between rent-seeking behavior and profit-seeking behavior is that the same pursuit of value maximization results in social surplus, while rent-seeking behaviors are a waste of social resources. The cost of seeking monopoly statue mainly includes the information cost, the cost of lobbying government officials, and the cost of maintaining monopoly rent. Moreover, the cost of seeking monopoly statue is often related to the expectation of rent seeker. It means that the larger the rent-seeking person's expectation of monopoly rent in the future, the higher the cost of seeking monopoly rent in the early stage. In addition, in a short period, the cost of seeking monopoly rents may be greater than the monopoly rents they obtain. But in the long period, the benefits of rent-seeking outweigh its rent-seeking costs. After an inextricable link is established between the rent-seeker and the person in power (usually presented government), the game process between them has a significant impact on the cost expended in seeking monopoly rent. For the rent-seeker, all the payment is the cost of seeking monopoly. As for the welfare loss caused by the monopoly itself, the opportunity for technological innovation and its welfare lost by rent-seeking may not be directly related to the rent-seeker.

Sub-model 3: Nonprofitable PPP projects

Symbol	Value	Description	Source
F	3.1	Fixed Payment to private sector	II
V	25.79	Viability gap funding	II
C_0	0.37%	The cost of providing channels to the public and identification cost of the authenticity in reports on social media	Gao & Liu, 2019
B	0.65%	The benefits from encouraging the public to supervise	N/A
L	2.6%(Initial)	The loss from the low-quality projects by Punishment from Upper departments when do not encourage	II
C_1	18.6	Cost of providing low-quality project (C1< C2)	I /II
μ	1.30(Initial)	The Magnification Coefficient of reputational benefits of government ($\mu > 1$)	N/A
C_2	20.1	Cost of providing High-quality project	I /II

Table 27 The specification of data sources by parameters of nonprofitable model

Unit: 100 Million CNY

Based on case by case statistics method, which is presented in Appendix 1, the average Viability gap funding of samples in target area is 25.79. And some of the value are marked as initial value, which means different values would be tested in the simulation phase of research.

6.3.2 The data results of PPP project under BIM technology

Model: PPP projects under BIM perspective

Symbol	Value	Description	Data Source (I /II)
C_E	0.4	The cost of providing unified BIM platform for private sector to encourage the application of BIM	I /II, ①
R_1	2% (initial)	The benefits of implementing BIM technology to government	Barlish& Sullivan, 2012
B	3% (initial)	The bonus of using BIM technology in PPP project for private sector	N/A
C_D	19.6	Default cost of PPP project for private sector	I /II
L_T	27%	The loss of using traditional method due to design changes or clashes	Barlish& Sullivan, 2012
P	20.9	Default and simplified payment from government to private sector (The total investment)	I /II
R_2	-12%(saving)	The benefits of implementing BIM technology to private sector	Barlish& Sullivan, 2012
C_B	9.8%	The cost of implementing BIM technology in project for private sector	Bryde et al. (2013)
C_P	0.71	Cost due to design productivity loss	Bryde et al. (2013)

Table 28 The specification of data sources by parameters of BIM perspective

Unit: 100 Million CNY

①

According to the Bidding announcement of Xiong'an New District Planning and construction BIM management platform (phase I) project, the first successful candidate is Alibaba cloud computing Co., Ltd. and China urban planning and Design Institute as collaborative organization to win the bid as 40.2 million CNY

([online] Available at: https://www.sohu.com/a/341804371_465914)

The average additional design cost of using BIM methodology for the designers is 34%, when compared with the traditional design approach (Bryde et al.,2013; Barlish & Sullivan, 2012) Hence, the cost due to design productivity loss can be calculated as

$$C_P = Total\ investment \times average\ design\ cost \times productivity\ loss$$
$$= 20.9 \times 10\% \times 34\% = 0.71 \quad (6\text{-}4)$$

Metric	Unit	Non-BIM	BIM	Δ (Non-BIM vs. BIM)
RFIs	Quantity/tool	6	3	3
Change orders	% of standard project costs	12%	7%	42%
Schedule	% behind standard schedule	15%	5%	67%

Figure 6- 5 The comparison of BIM and Non-BIM for projects (Barlish& Sullivan, 2012)

The previous research quantitatively compares the projects with or without BIM technology, it shows trough implementing BIM in engineering project can significantly reduce the design change and project duration for the entire project. This research assumes that the benefits of BIM is equal to both private sector and governments. Hence, the related values of variables are calculated as following.

The loss of using traditional method due to design changes or clashes can be summarized as

$$L_T = Cost\ of\ design\ change + Cost\ of\ schedule = 12\% + 15\% = 27\% \tag{6-5}$$

The benefits of implementing BIM technology to private sector

$$R_2 = -(Cost\ of\ design\ change\ of\ BIM + Cost\ of\ schedule\ of\ BIM) = -12\%(Savings) \tag{6-6}$$

Chapter 7 Simulation and Results Discussion

7 Simulation and Results Discussion

7.1 Summary on processes of evolutionary game simulation

In this section, the values of attributes that collected in previous part are put into the replication dynamic functions. By implementing the functions in MATLAB, as well as examining the different combination of values, the evolutionary processes and sensitive analysis are plotted and provides more comprehensive insights to justify model analysis. **Figure 7-1** shows the processes of inputting the present initial values, which are inserted to corresponding attributes and simulated by MATLAB. The essence of replication dynamic functions for gamers are essentially partial differential functions, by implementing function “Ode45” in MATLAB, the partial differential equations can be solved, and the roots of equations are plotted in diagrams.

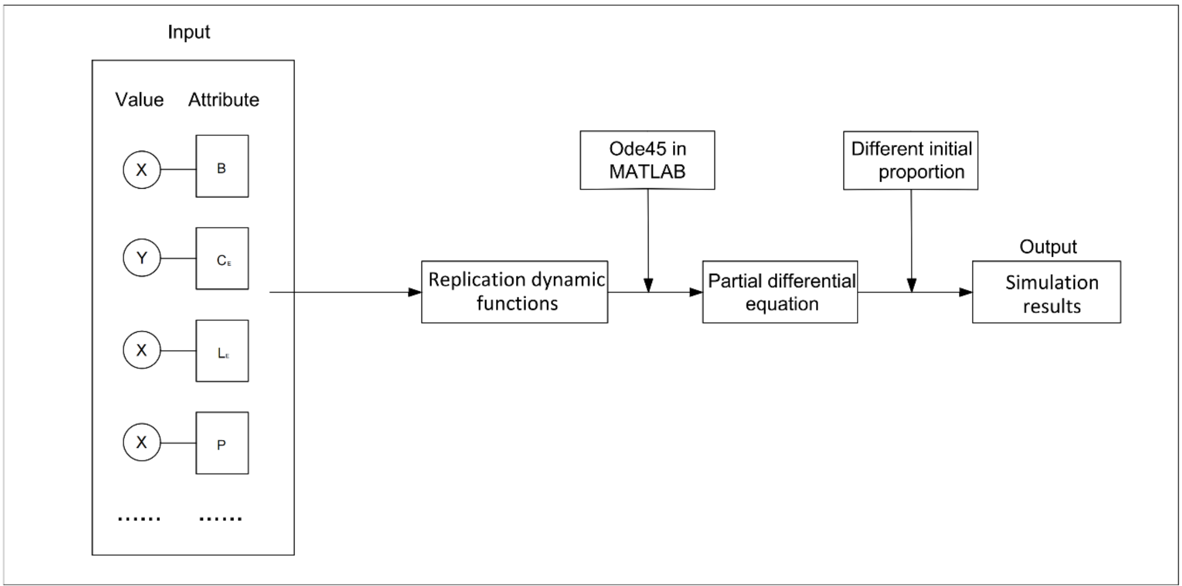


Figure 7- 1 Simulation processes for overview of evolutionary game with initial values

Figure 7-2 demonstrates the processes of conducting sensitive analysis in simulation phase, which is targeted to clarify what attributes and parameters can be more significantly influence the system. Compared with the merely inputting the initial values into the system, the sensitive analysis tests, and inputs different values for one attribute. The output can be completely changed when testing the sensitive attributes, it means the slight variation of sensitive attributes can alter the strategy choice and lead to different evolutionary stable strategy for gamers.

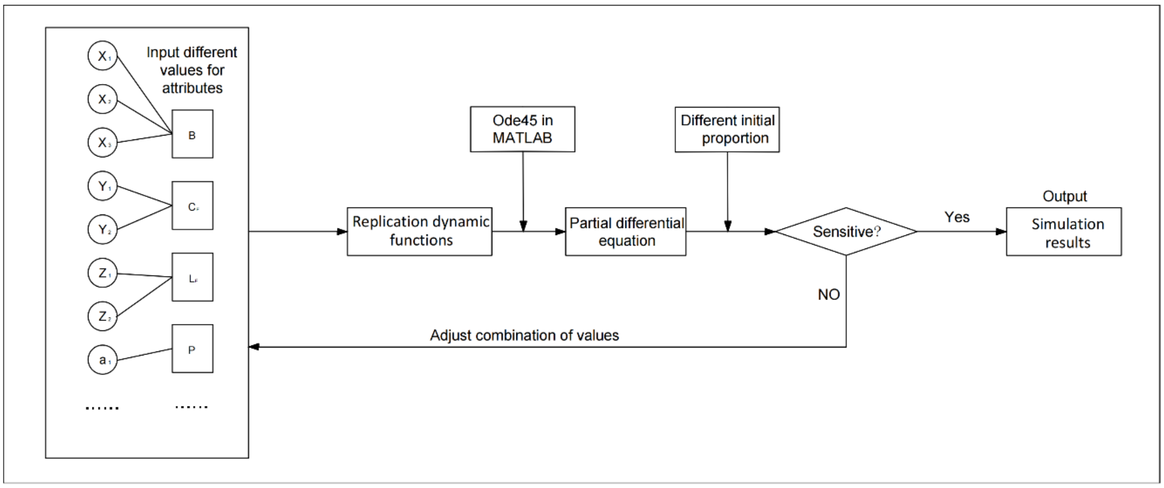


Figure 7- 2 Simulation processes for sensitive analysis of attributes

7.2 Simulation Results of PPP projects by public supervision

7.2.1 Overview of interaction and strategical choice between private sectors and governments and evolutionary path diagrams

a. PPP projects under one-time cooperation by public supervision

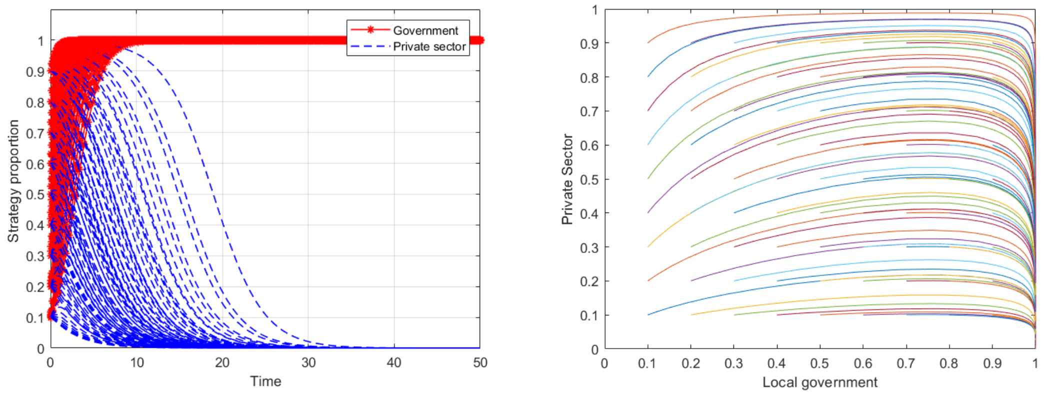


Figure 7- 3 Evolutionary game diagrams under the different initial ratio of strategies of one-time cooperation

As shown in **Figure 7-3**, under current values of variables in the model, regardless of the initial strategy proportion, local government will choose to encourage public supervision to participate in the supervision process of PPP projects; While the private sector would apply complete projects with high-quality strategy. It caused by the overwhelmingly higher performance payment that can be obtained when the private sector complies with the contract. Moreover, the punishment and loss of user payment in the operation phase of PPP projects also contribute to these results.

b. PPP projects under long-term cooperation by public supervision

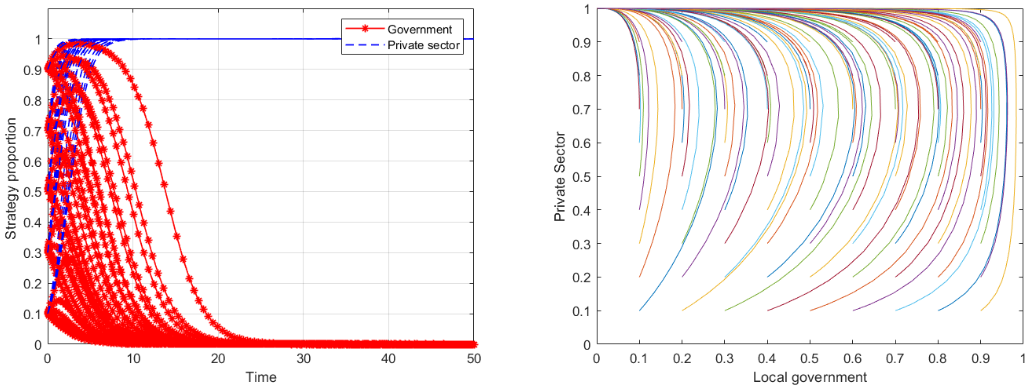


Figure 7- 4 Evolutionary game diagrams under the different initial ratio of strategies of long-term cooperation

As illustrated in the **Figure 7-4**, under current values of variables in the model, regardless of the initial strategy proportion, local government will choose to not encourage public supervision to participate in the supervision process of PPP projects; While the private sector would apply opportunism strategy in PPP projects with low-quality products. In the long-term cooperation, due to the non-public and transparent bidding process, private sector will have a greater chance of long-term illegal cooperation with local government through rent seeking behavior, and choose the strategy of opportunism. At the same time, in the model of long-term cooperation, reputation benefits are mainly generated by reducing the bidding process and communication costs in early phase of PPP projects, while the cost of long-term high-quality PPP project is lower than reputation benefits, which leads to rent-seeking activities existing between the government and private sector.

c. Nonprofitable PPP project by public supervision

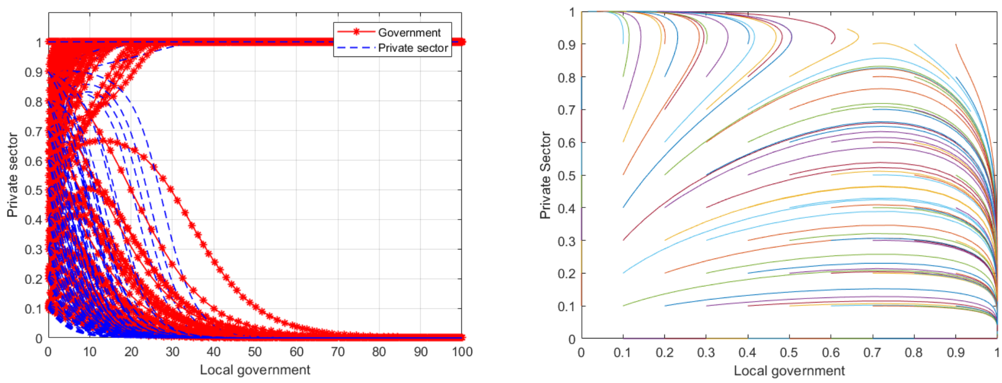


Figure 7- 5 Evolutionary game diagrams under the different initial ratio of strategies of non-profitable PPP project

Figure 7-5 demonstrates the simulation results of evolutionary game and path analysis of nonprofitable PPP project under the current values and conditions. As shown in the diagrams of simulation results, the final evolutionary stable state is depended on the initial strategy proportion of gamers. It indicates that the initial values of strategy have significantly impact on the strategical choice in nonprofitable PPP projects. This phenomenon is mainly caused by the benefits of the government to encourage public supervision and the uncertainty of the stable state caused by similar costs. At the same time, because there is no user payment in the income of the project, the main income of the private sector comes from the government's viability gap financing, so it is difficult to predict how the private sector will adjust its strategy in the game process. In order to improve the proportion of non-profit PPP projects completed by the private sector with high quality, we can appropriately increase the proportion of performance payment in the viability gap financing to restrict the behavior of the private sector.

7.2.2 Sensitive analysis and scenarios analysis for PPP project

In this part, the exploration and scenario analysis are implemented to identify and evaluate the sensitive attributes and parameters, test what degree can the sensitive attributes impact on the system output, and optimize them in this dynamic system. Table 29 shows scenarios list to provide an overview for the tested attributes.

Sensitive Attributes	Initial Value	Test input 1	Test input 2	Test input 3
Public supervision view				
Degree of supervision	N/A	Moderate	Insufficient	Excessive
Performance payment	70%	25%	50%	80%
Default supervision cost	1.8%	0.9%	1.2%	2.5%
Loss of low-quality product	L=2.6%	L=3.0%	L=3.0%	L=1.5%
	i_0=0.84	i_0=0.84	i_0=0.75	i_0=0.9
Rent-seeking cost	Rs=2.4%	Rs=1.0%	Rs=5.0%	Rs=2.4%
	Q=3.2%	Q=3.2%	Q=3.2%	Q=1.6%
Viability Gap funding	V=25.79	V=25.79	V=20	V=25.79
	L=2.6%	L=1.0 %	L=2.6%	L=5.0%
BIM view				
BIM level	N/A	1	2	3
Benefits of BIM	R_1+R_2=14%	R_1+R_2=20%	R_1+R_2=10%	
Cost and productivity loss	C_B+C_P=13.2%	C_B+C_P=30%		

Table 29 Scenarios list with tested sensitive values

Unit: 100 Million RMB

a. The optimal degree of supervision

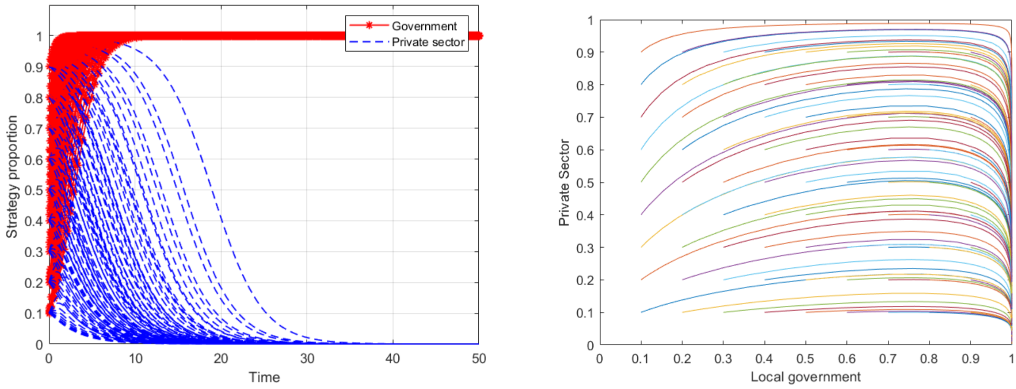


Figure 7- 6 Ideal evolutionary game process with moderate supervision

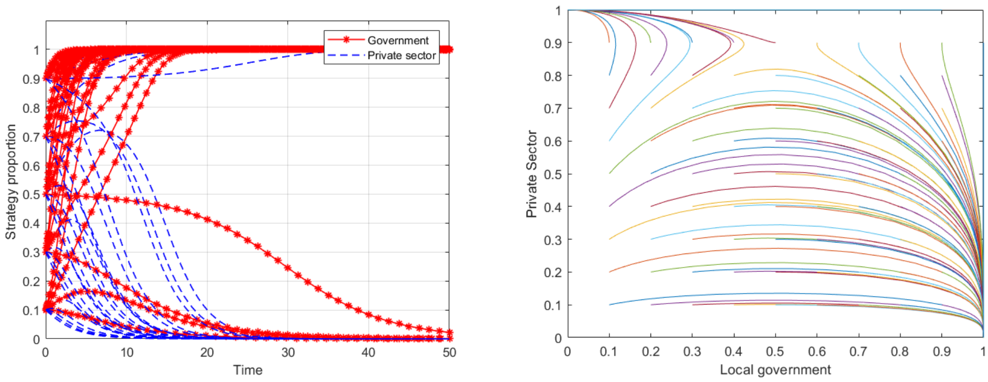


Figure 7- 7 Evolutionary game process with Insufficient supervision

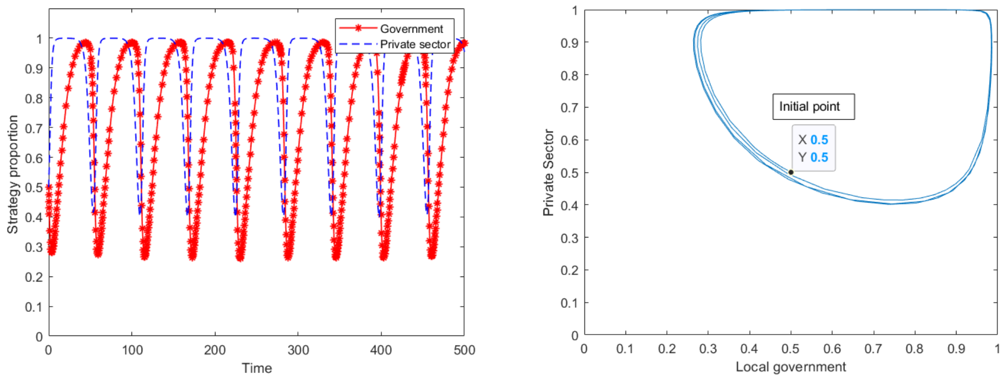


Figure 7- 8 evolutionary game process with excessive supervision

By inputting different values of parameters in duplicated functions, it proves that the existence of optimal level of supervision in this system. As shown in Figure 7-6, under the current parameter values, regardless of the initial state of the strategies of both parties, the final private sector will adopt the strategy of completing the project with high quality according to the contract; and the government will encourage public supervision to improve the quality of

PPP projects. The supervision of PPP projects mainly comes from two aspects, one is the independent third-party government supervision agency, the other is the public supervision in the new media era. By adjusting the cost of providing channels to the public supervision C0, the benefits of outsourcing public to participation supervision B, And the loss of low-quality PPP projects for both players in the model. Similarly, the change of these parameters will lead to a higher probability of finding engineering defects and quality problems in the project, which will lead to the change of game behavior and strategy.

The evolutionary game process with Insufficient supervision is demonstrated in figure 7-7, which depict the fact that the evolutionary stable strategy is affected by the initial proportion of strategy in this situation. Due to the reduction of the intensity of public supervision and the benefits of public supervision, under certain initial condition, private sector will eventually choose the strategy of opportunism, while the government may choose not to encourage public supervision. In contrast, figure 7-8 illustrate the results that when the supervision is excessive, the strategies of the government and private institutions are constantly adjusting and changing, and there is no evolutionary stable strategy. The simulation results show that when the supervision is too strong, the system does not have a stable state, but may cause fluctuations in the system.

By testing different supervision levels, it is proved that there is optimal supervision for PPP projects. Therefore, a good PPP project supervision should find the most suitable supervision mechanism and supervision strength according to the social environment and local economic environment, and there is no universally applicable supervision mode.

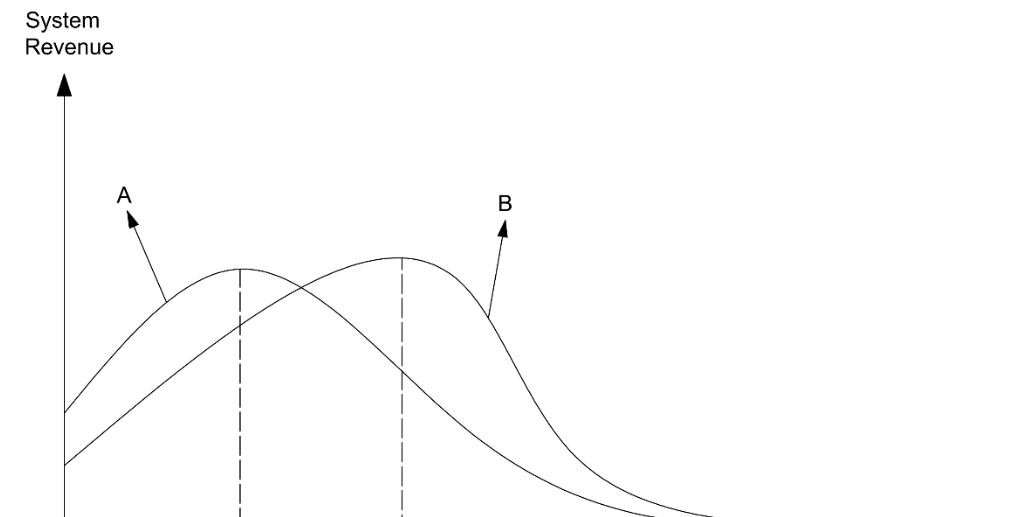


Figure 7- 9 Optimal supervision with the overall system revenue

Figure 7-9 shows the relationship between the supervision of PPP projects and the total revenue of the system. Curve A and curve B respectively describe the revenue supervision relationship of different systems, and different systems have different optimal supervision strength. At the same time, Insufficient supervision, or excessive supervision both have negative impact on the total system revenue. Therefore, finding the optimal supervision of the current environment can make the system in evolutionary equilibrium and maximize the benefits of both sides.

b. Different performance payment F_P values

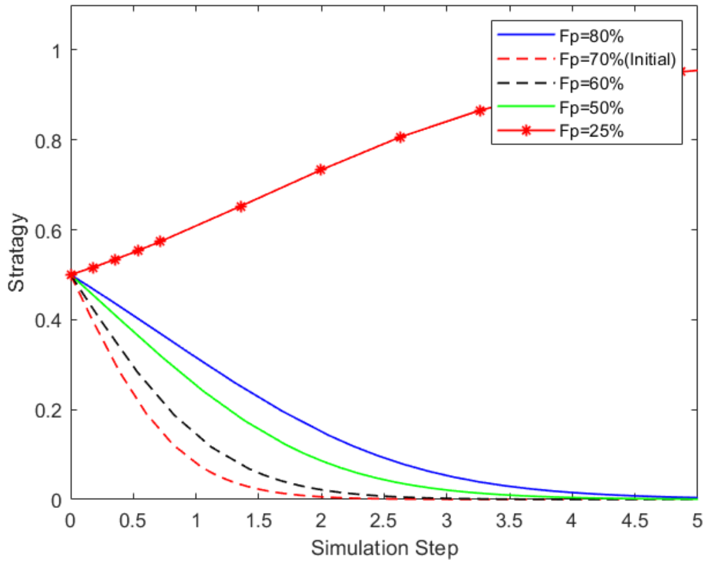


Figure 7- 10 The relationship between the proportion of private sector participating in PPP projects and time under different performance payment Fp values

Figure 7-10 shows the evolutionary process under different percentages of performance payment in PPP projects. During the operation period, the private sector's revenue is mostly derived from fixed payment, performance payment, and user payment. The government is primarily responsible for fix and performance payments. By changing the proportion of performance payment, the strategy choice shift from complying the contract to opportunism in the PPP project. Therefore, when private sector completes the project with high quality, it can get higher performance score and more performance payment. The higher the proportion of performance payment, the faster the strategy choice of private sector tends to complete the project with high quality.

c. Default Supervision cost rate

Figure 7-11 illustrates the evolutionary game process under different value of default supervision cost which based on the total project investment. With the increase of default supervision cost, the local governments are more likely tend to choose the strategy of encouraging public supervision. It can be explained by the total supervision cost is reduced when the governments encourage the public to supervise PPP project. Public supervision can be used as a supplement to the third-party independent organization of the supervision (usually from the higher authorities). At the same time, the information dissemination in the new-media era also significantly reduces the cost of traditional supervision and improves the supervision efficiency of the system.

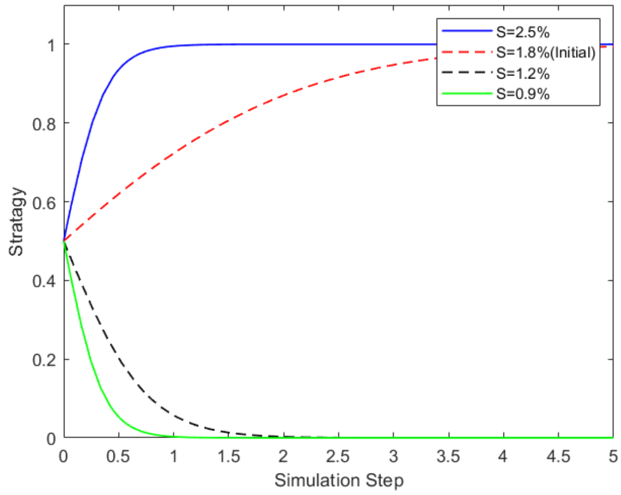


Figure 7- 11 The relationship between the proportion of local government participating in PPP projects and time under different default supervision cost S values

d. Different loss values of and coefficients of performance payment of low-quality projects

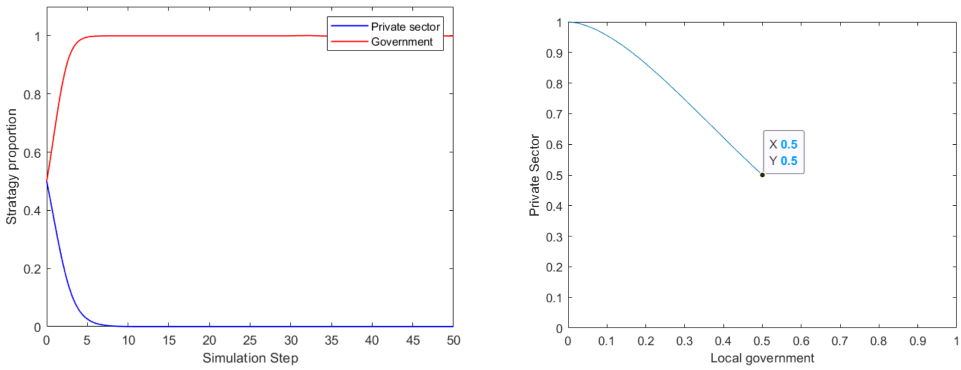


Figure 7- 12 The evolutionary simulation under conditions L=2.6%, i_0=0.84 (Initial value)

Figure 7-12 show the evolutionary game process under initial values between local governments and private sectors. The local government would choose the strategy of encouraging public supervision, while the private sector would choose finish PPP projects with high quality.

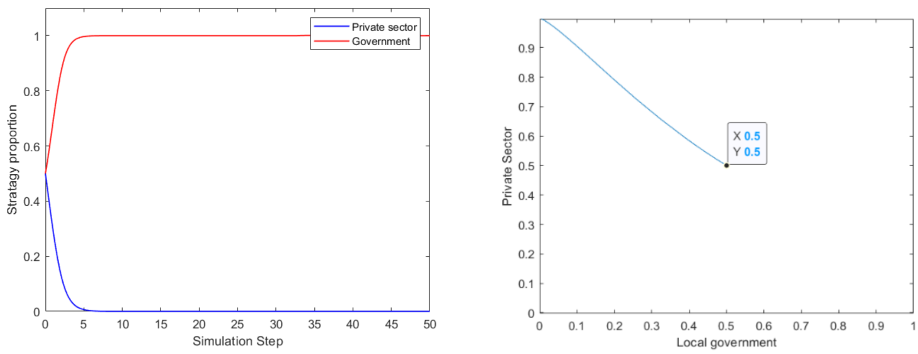


Figure 7- 13 The evolutionary simulation under conditions L=3.0%, i_0=0.84

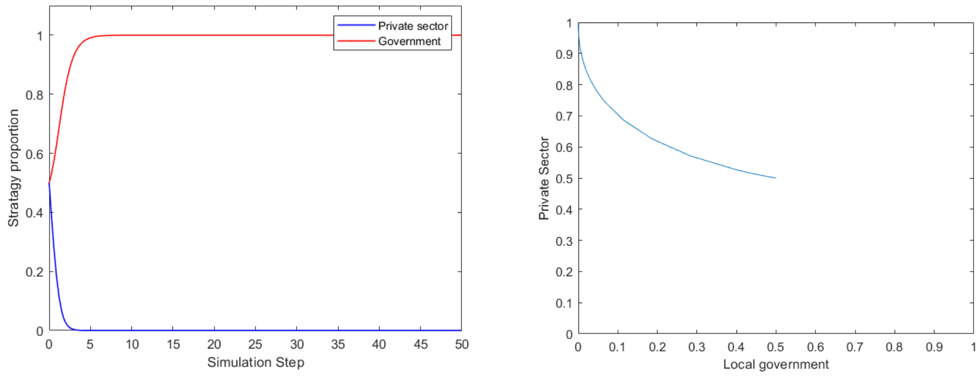


Figure 7- 14 The evolutionary simulation under conditions L=3.0%, i_0=0.75

Figure 7-13 and 7-14 demonstrate the fact that when the loss of low-quality projects increases, or the coefficients of performance payment when the project being found in low quality reduces, the private sector would be more likelihood to perform the strategy of complying the contract. Compared with the initial value, under these two numerical conditions private sector strategy choices converge more rapidly to contract compliance.

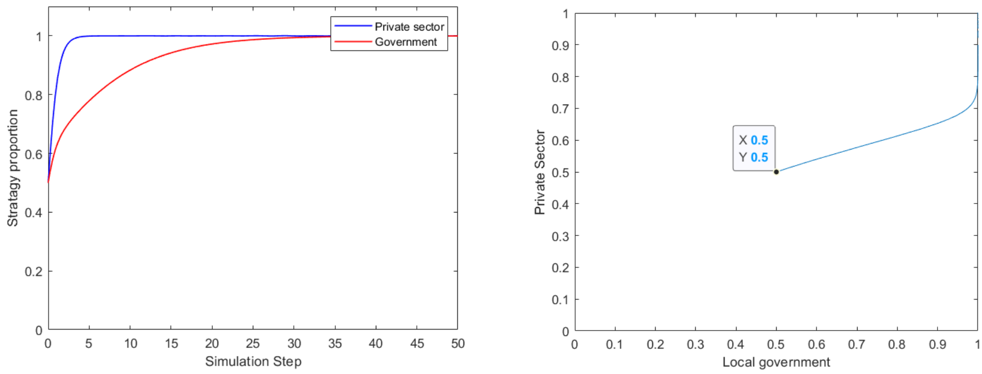


Figure 7- 15 The evolutionary simulation under conditions L=1.5%, i_0=0.9

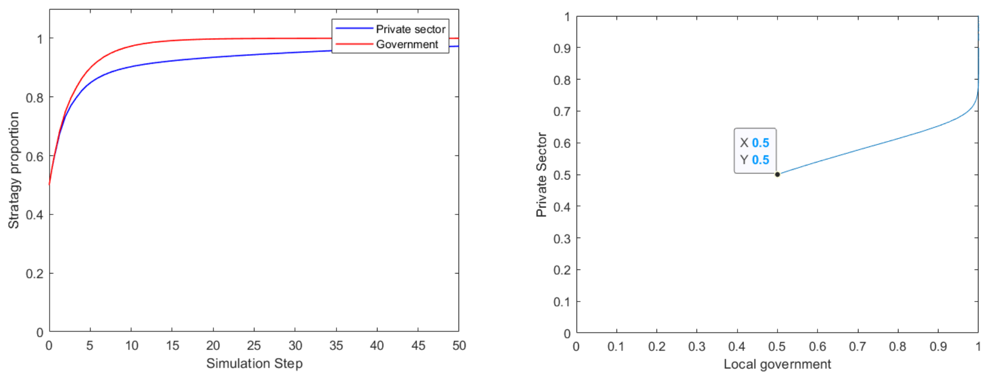


Figure 7- 16 The evolutionary simulation under conditions L=1.5%, i_0=0.84

On the contrary, Figure 7-15 and 7-16 show the phenomenon that when the loss of low-quality projects reduce, or the coefficients of performance payment when the project being found in low quality increases, the private sector would be more likelihood to perform the strategy of complying the contract. It means that if the private sectors receive more negative return from opportunism strategy, they are more likely to choose the strategy of complying the contract.

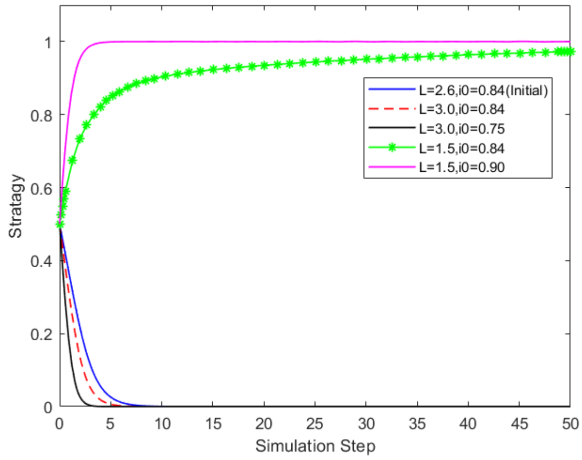
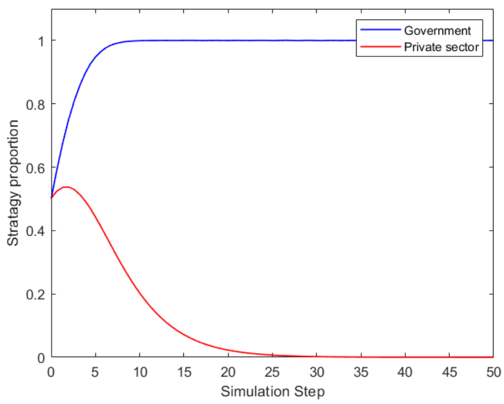


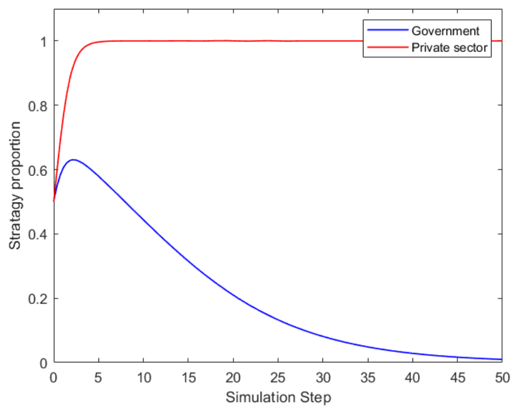
Figure 7- 17 Overview for different testing values in evolutionary game diagram

Figure 7-17 presents the overview for the numerical conditions and scenarios analysis above, and integrate them into a diagram, which is more Intuitively present the comparison among the scenarios. The measures of preventing the private sector from opportunism strategy could be implemented by improving the loss of low-quality projects, and giving lower performance payment when the PPP projects are found in low-quality. In order to reach the goal of optimize the supervision and regulation mechanism, the public supervision is ought to be encouraged to promote the possibility of finding the clashes and issues of PPP projects. It is effective approach to restrain the opportunism behaviors for private sectors.

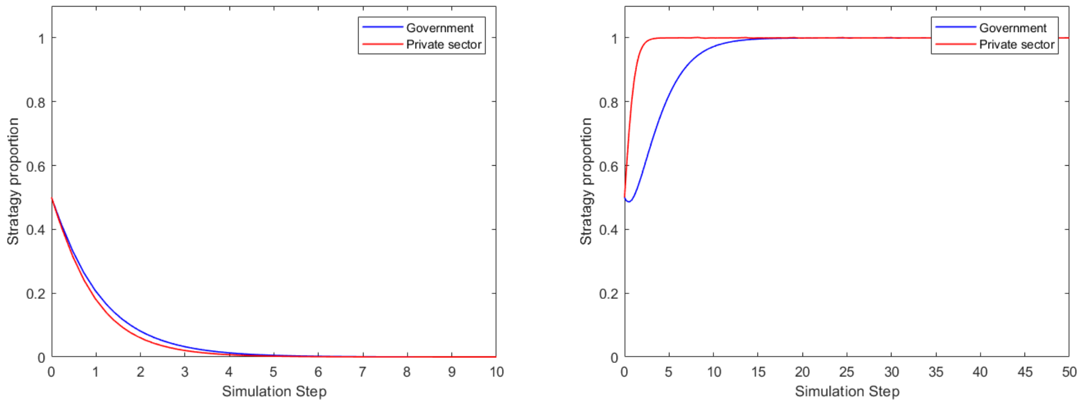
e. Long-term cooperation and Rent-seeking activities in PPP projects



a. Rs=1.0%, Q=3.2%



b. Rs=2.4%, Q=3.2%(Initial)



c. Rs=5.0%, Q=3.2% d. Rs=2.4%, Q=1.6%

Figure 7- 18 The evolutionary simulation results by different rent-seeking cost Rs and Q

For the analysis and simulation of long-term cooperation model, **Figure 7-18** shows the evolutionary game simulation results which test the different rent-seeking cost Rs and the reputational benefits of long-term cooperation for both local governments and private sectors. The results indicate that when the private sector choose to perform rent seeking activities, the cost can significantly influence the strategy in the game. At the initial values of Rs and Q, the private sector would choose opportunism strategy, while the local government would perform not to encourage strategy in this scenario. When increase the cost of rent-seeking, the private sectors would shift their strategy to comply the contract in the game. While when reducing the cost of rent-seeking in the model, the private sectors would be more rapidly approach the strategy of opportunism. At the same time, the behavior and strategical choice of local governments receive impact by the changes in the cost of rent-seeking Rs.

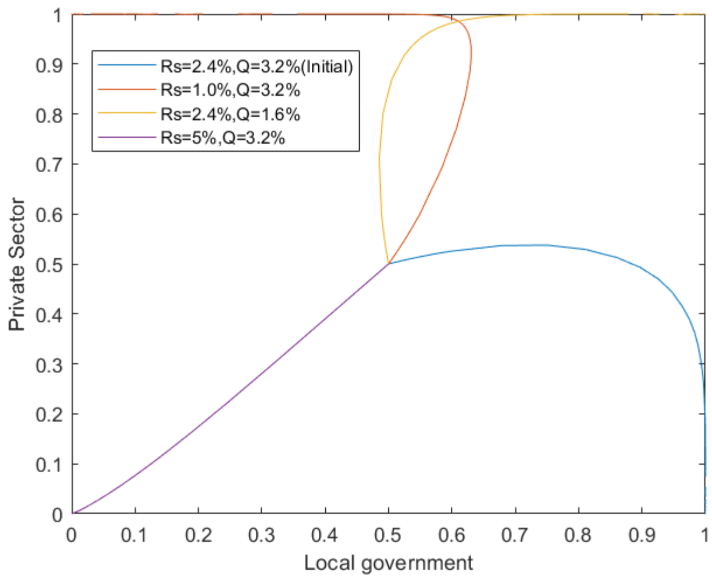
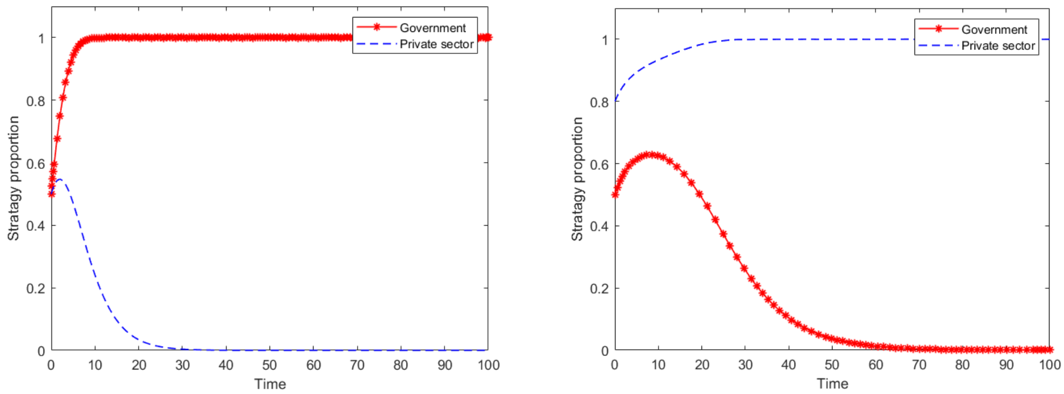


Figure 7- 19 Path analysis of evolutionary simulation results by different rent-seeking cost Rs and Q

Figure 7-19 presents an overview for the scenario analysis of rent-seeking cost and long-term benefits through the strategical path analysis. As shown in the diagram, the interaction and behaviors of the gamers are remarkably influenced by the different values. In order to suppress the rent seeking behaviors, which is proven to be harmful for public benefits of entire society, measures could be taken based on increasing the cost of rent seeking activities. And when the private sectors choose to comply contract in the game, reward and economic benefits on the positive strategy choice is supposed to be given from the regulation organizations or governments.

f. Nonprofitable PPP projects



a. Ideal evolutionary game process b. Non-ideal evolutionary game process

Figure 7- 20 Different initial values of proportion lead to different final state

Figure 7-20a shows the ideal evolutionary game process which starts on the initial point of 0.5, which indicates that at the starting point, 50 percent of local governments would choose the strategy "1", while the rest are performing strategy "0" in the game. It is the same proportion for the strategical choices for the private sectors. Under this situation, the final equilibrium state, which is so-called ESS in the simulation phase, would reach a satisfactory state: the local governments would choose to encourage public supervision, and the private would perform high-quality projects strategy. However, Figure 7-20b illustrates the fact that when the initial proportion of private sector starts at the point of 0.8, the evolutionary stable strategies of gamers switch into completely opposite direction: the local governments would not encourage the public supervision, while the private sector would choose opportunism strategy in the end state. This comparison indicates that the importance of investigation the initial proportion of the gamers when design the regulatory values, as well as the reward and punishment mechanism for the entire system.

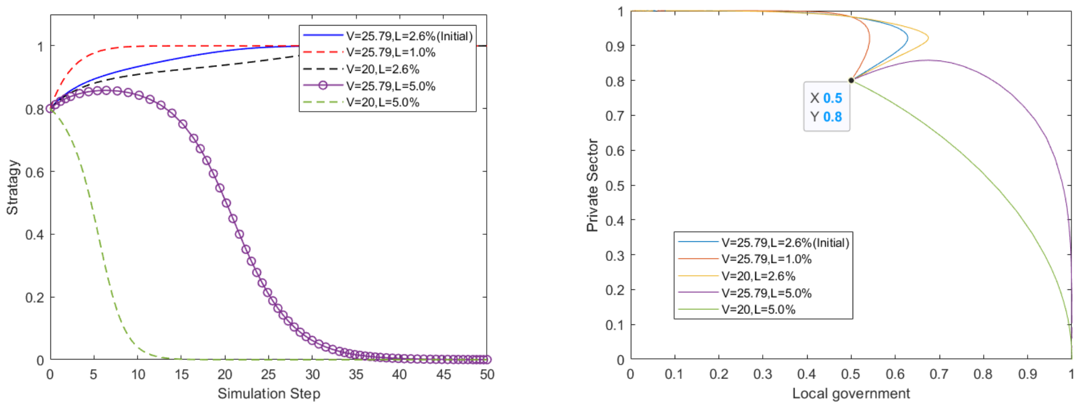


Figure 7- 21 Different initial Viability Gap funding and Loss value due to low-quality projects for private sectors

Furthermore, in order to research the measures that can optimize the unfavorable situation in Figure 7-21b, the tests of critical influential factors VGF and the loss value V are discussed. The scenarios analysis by different viability gap funding and the loss values of low-quality projects are depicted in Figure 7-21. As can be seen in the diagrams, at the initial proportion that 80 percent of private sectors choose the opportunism strategy, which is represented by “1” in the evolutionary game diagram. The increase of the loss value due to low-quality projects or reduce the viability gap funding can significantly address the issue. The particular reasons for circumstance that the private sector change their strategy are when reducing the VGF payment, the income and profits of the PPP projects mainly comes from the performance payment or user payment, which is largely depends on the quality of end products.

7.3 Simulation Results of PPP projects from BIM technological Perspective

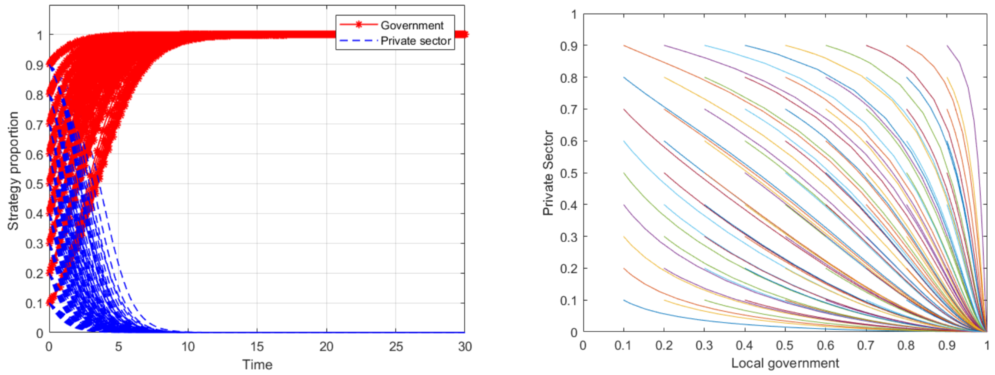


Figure 7- 22 Evolutionary game diagrams under the different initial ratio of strategies of BIM technology

The evolutionary game simulation from implementing BIM technology perspective for PPP projects is shown in Figure 7-22. The simulation results actively demonstrate that regardless the initial proportion, the local governments would choose to encourage the usage of BIM technology in the PPP projects, while the private sector would apply BIM methodology rather than traditional approach. The current data proves that the implementing BIM technology is win-win strategy in PPP projects, which can reduce the clashes and cost, as well as the construction duration in the whole phases of PPP projects.

However, the partly application or using BIM method in the entire stages of projects can significantly impact on the evolutionary game process. If the BIM technology is merely applied in certain phase of PPP project, it might cause negative impact for the benefits of whole system. Hence, to research how the levels of BIM technology influence PPP project is of important. Figure 7-23 shows the different levels of using BIM technology. This is a widely accepted model that clarifies the usage of BIM technology into four levels, from the lowest level to the highest level: building lifecycle management (BLM). The further simulation provides the strategy preference for and evolutionary stable state for the local governments and private sectors by different level of BIM in PPP projects.

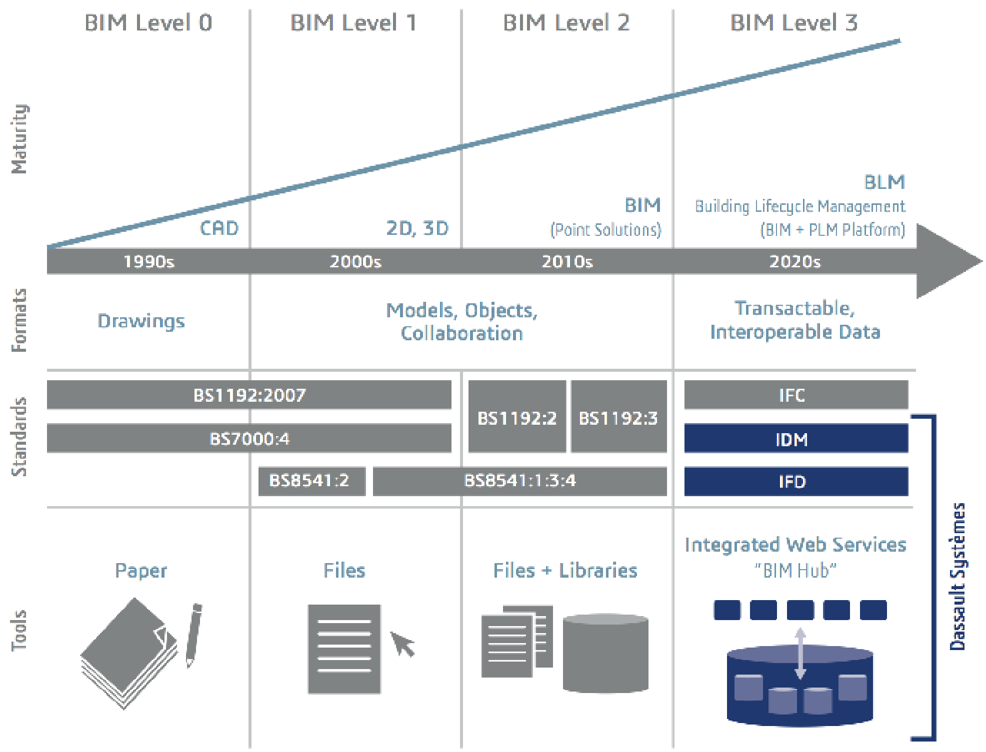
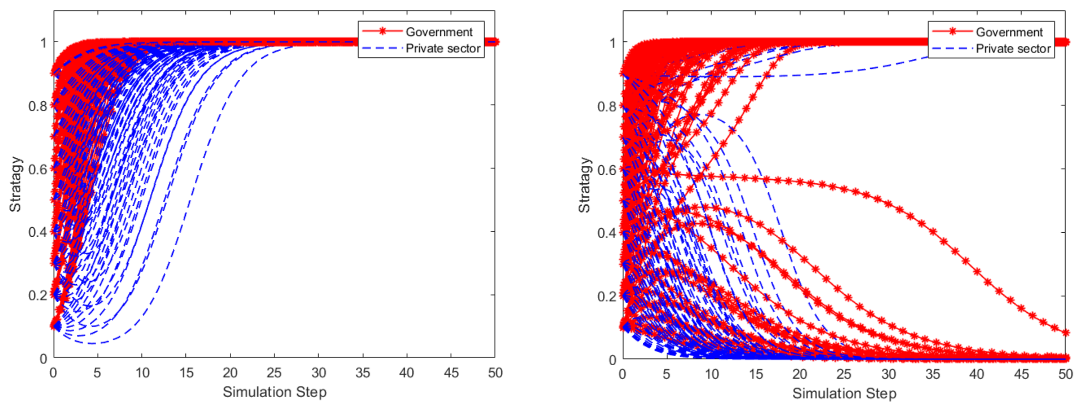


Figure 7- 23 The BIM maturity model levels of BIM technology (Eynon, 2016)

a. The impact of different Level of BIM in PPP projects



a. L=1 b. L=2

Figure 7- 24 The evolutionary simulation results by different levels of BIM technology L=1 and L=2

In order to model the BIM levels in the evolutionary game simulation, different parameters in the duplicate functions, which decide the evolutionary process, are influenced by different levels of BIM technology. The duplicate functions are shown below:

$$F(x) = x(1-x)[y(\mathrm{B} - R_1) + (R_1 - \mathrm{B} - C_E)]$$

$$F(y) = y(1-y)[xB + (C_B + C_P - L_T - R_2)]$$

As shown in the functions, several different parameters determine the behavior of both players in evolutionary game. And different levels of BIM are assumed to have impact on the cost of providing BIM platform C_E for governments, the cost of implementing BIM technology in project for private sector C_B, and the benefits of implementing BIM technology for both local government and private sector. The particular reasons for circumstance that the higher levels of BIM technology require more initial investment on the platform for lifecycle management, and also it would lead to higher transition cost for both players. The productivity loss at the transition phase is larger due to more implements and schemes, as well as the working processes can be greatly changed in the BIM methodology. Hence, Figure 7-24a shows at the first level of BIM technology, the private sectors tend to choose using traditional design and construction methods, while the local governments would choose encourage BIM technology in the PPP project, regardless the initial proportion of strategy is. The main reason is that the government usually spends less on providing BIM information platform, while the private sector has a higher cost of switching from traditional mode to BIM mode.

Figure 7-24b shows the evolutionary game process under BIM level 2, and evolutionary stable strategy depends on the initial proportion of strategy. It indicates that when improving the level of BIM technology that applied in PPP projects, more proportion of private sector would adopt BIM technology in their working process. BIM technology is implemented as point solution to promote the efficiency and reduce the communication cots for private sector, which enable them to have more motivation to utilize BIM in PPP project.

Moreover, the partial BIM technology may cause the issue of remodeling among different stakeholders and professional processes. The cost of communication increases between different agents in PPP projects because the BIM technology is only applied in part of stages.

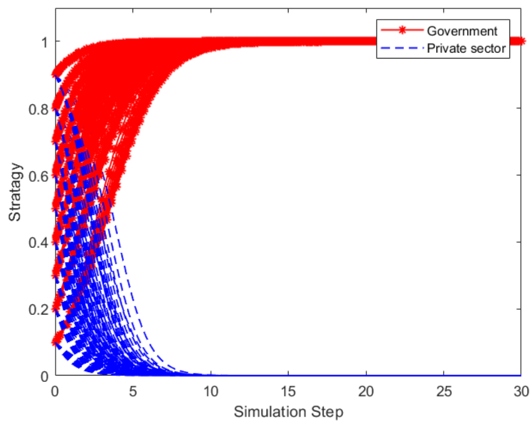
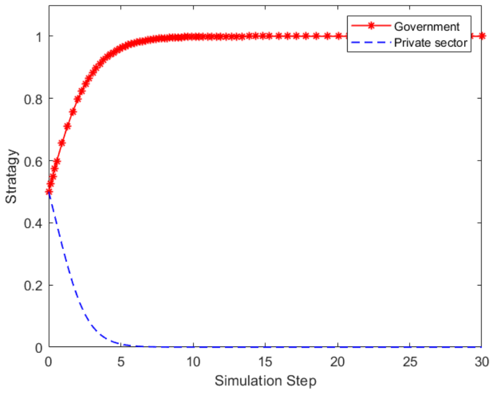


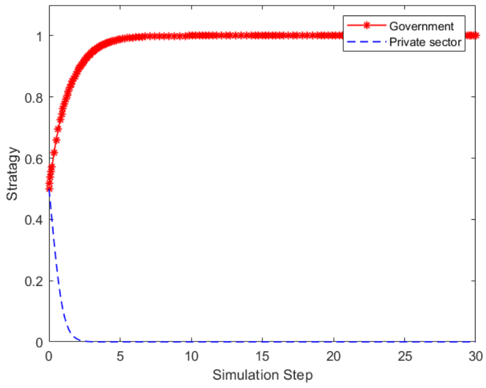
Figure 7- 25 The evolutionary simulation results by different levels of BIM technology L=3

The evolutionary game process under building lifecycle management L=3 is demonstrated in figure e7-25, which shows the ideal phenomenon that all the private sector choose to adopt BIM technology, and the private encourage the usage of BIM technology in the PPP project.

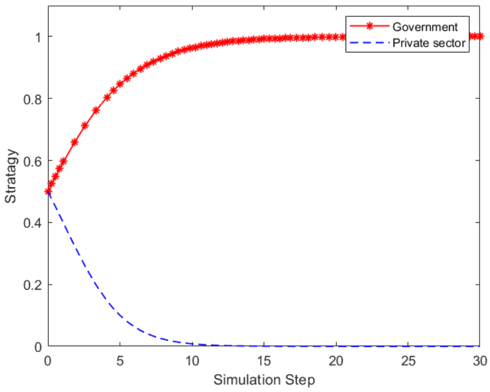
b. Benefits and Loss of implementing BIM technology in PPP projects



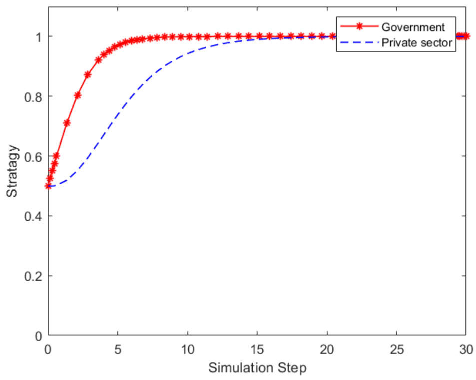
a. R_1+R_2=14%， C_B+C_P=13.2% (Initial)



b. R_1+R_2=20%， C_B+C_P=13.2%



c. R_1+R_2=10%， C_B+C_P=13.2%



d. L_T=14%， C_B+C_P=30%

Figure 7- 26 Evolutionary simulation results by different Benefits and Loss of implementing BIM

Lastly, the evolutionary game simulation for different values of benefits and loss in PPP projects is illustrated in Figure 7-26. The four diagrams compare the interaction behavior and evolutionary game processes between private sectors and governments. At the initial values, R_1+R_2=14%， which represents the benefits of implementing BIM technology for both gamers is average 14% of the total investment. While C_B+C_P=13.2% defines the total cost of using BIM technology is 13.2% at the average level. The results show that at the initial value of parameters, the private sector would choose adopt BIM technology in PPP project, and the local governments tend to choose provide BIM platform for private sector. When increasing the benefits values of BIM, both the gamers will be more rapidly reach the evolutionary stable strategy. Moreover, if the cost of adopting BIM technology in PPP project rises, the private sectors, which is more sensitive for the change of BIM cost, would rather choose to switch to apply traditional working process in PPP projects.

Chapter 8 Conclusion and Policy Recommendation

8 Conclusion and Policy Recommendation

8.1 Conclusion

The impact of public supervision and supervision mechanism on PPP projects in the new media era, as well as whether local governments should provide financial incentives for public supervision and BIM technology application are controversial issue. They are often discussed and focused by the stakeholders and agents in PPP project, such as the local governments, private sector, and the regulatory departments. This research implements evolutionary game analysis, sensitive analysis, and case review as tools, to model and analyze the PPP projects under public supervision and influence of BIM technology. Compared with traditional game theory, the evolutionary game analysis provides dynamic processes of gamers with time, the equilibrium state of evolutionary, and the present issues in PPP projects. The main policy implications and conclusion are as follows:

First, in different types of PPP projects, the final evolutionary stable strategies of local governments and private sectors may be completely different. In the model of one-time cooperation between local governments and private sectors, public supervision plays the role of optimizing supervision in PPP projects, reducing the cost of supervision, and restraining the behavior and strategical choice of private sectors. However, in the model of long-term cooperation, the existence of rent-seeking behavior is not conducive to the stable state of encouraging public supervision, and private sector also tends to choose the strategy of opportunism in PPP project. In the non-profit PPP project, the evolutionary stable strategies of both gamers depend on the initial strategy proportion. Hence, the investigation and determining the present initial proportion gamers' strategy are of importance when introducing and encouraging the public supervision mechanism.

Second, in the model of PPP projects under the impact of BIM technology, by using the present data and values of parameters, the evolutionary stable strategy of local governments is encourage the application of BIM; while the private sector would adopt BIM technology in PPP project without consideration of initial proportion of strategy.

Furthermore, this research proves that the existence of optimal degree of supervision in a PPP project theoretically. When the supervision is inadequate, the evolutionary game process and ESS of players are influenced by the initial proportion of strategy; While the supervision is excessive, the behavior of the players shows periodicity characteristics, and there is no systematic ESS. Therefore, moderate regulation can restrain the behavior of both sides of the game, and at the same time make the system achieve maximum benefits. In practice of public supervision, it is crucial to implement the supervisory mechanism and policy on the basis of environmental parameters and local economic circumstances.

Additionally, in the model of PPP projects under the public supervision, the ideal events of gamers are defined as the local government encouraging the public to supervise PPP projects in new media era, while the private sector would comply the contract to complete PPP projects with high quality. This research indicates that the attributes of performance payment, default supervision cost, loss values of low-quality products, cost of rent-seeking, and Viability Gap funding are positively correlated with the occurrence of ideal events, while the coefficients of performance payment of low-quality projects are correlated with the ideal events negatively. Hence, the public supervision can promote the supervisory efficiency and promote the quality of PPP project, when the values of parameters are designed and adjusted precisely and dynamically.

In the evolutionary game mode of PPP projects from BIM technology perspective, the simulation results prove that the higher level of BIM technology can be incentive for the private sector to adopt BIM technology. The partial application of BIM technology might lead to private sector to discard BIM technology in PPP project. At the same time, to provide guidance and platform for the usage of BIM technology can significantly reduce the transition cost for both local governments and private sectors, and stimulate the ideal event happening in the evolutionary game process.

To sum up everything, this study constructs and analyzes evolutionary model and simulates it model by MATLAB for the public-private partnership scheme from the cross perspectives of BIM Technology and public supervision for Xiong'an new area. The impact as well as the influencing mechanism are explored in this study, which is targeted to create some general conclusion and implication for the PPP modes all over the world. Hence, the policy recommendation and management implications are in line with the findings in previous sections as follows.

8.2 Policy recommendation and management implication

According to the simulation results and discussion of the reasons, some general policy recommendation and management implication are put forward as six points as following:
1) To investigate the initial proportion of strategy for the gamers when designing and formulating the policy related to PPP projects. In certain types of PPP mode, the initial strategical proportion can be decisive for the evolutionary stable strategy.

2) To optimize the strategical parameters, and to set priority for the influential factors in the PPP project are of important measures to encourage public supervision and application of BIM technology. In order to set priority of the important factors, the key factors for local governments in PPP scheme are identified as: performance payment, loss value due to low-quality project, default supervision cost, initial investment on BIM platform. Meanwhile the key factors for private sector are recognized as degree supervision, performance payment, the bonus from high-quality products, and the benefits from applying BIM technology

3) Seeking out the optimal and feasible supervision mechanism combined with public

supervision, avoiding insufficient supervision or over supervision can promote the payoff of the entire system.

4) In order to motivate the private sector to comply the contract and achieve the goal of PPP projects in high quality, the proportion of performance payment and the coefficient of high-quality product should be raised.

5) When providing the channel and encouraging the public to participate the supervision process of PPP project in new media era, machine learning technology could be applied to help with identifying and detecting the authenticity of the public report (Ahmed et al., 2017). This advance and recent technology can reduce the cost of encouraging public supervision and promote the efficiency of the supervision.

6) To avoid reverse modeling, BIM technology is supposed to be used in the entire lifecycle of PPP projects; at the same time, in the process of promoting the use of BIM, government departments should give private sector phase out subsidies to reduce transition cost and productivity loss when spreading BIM Technology.

8.3 Limitation and Further Research

In this research, several limitations are identified in different aspects as follow:

Firstly, the assumption of either-or pure strategy is applied in this research, which is similar with most of publication and previous research. It actively demonstrates that the individual can merely adopt pure strategy in evolutionary game process. For instance, in the BIM perspective model, the individual of private sectors can only apply either strategy “Adopt BIM technology” or “Complete traditional design & construction method”. Because the individual of the private sector can adopt partial BIM technology in PPP project of reality. Hence, there is a gap between this assumption and the real world.

Additionally, in simulation part of this research, the evolutionary strategy processes are illustrated by strategy proportion-time diagrams and strategy path diagrams. However, from system dynamic view, the univariate revenue diagram is not modelled and presented in this paper. This research only proves that there is optimal degree of supervision, rather than finding the optimal value. The further research can explore how can factors influence the entire revenue of local government and private sectors. Consequently, combined with the evolutionary game analysis, the optimal values of attributes can be achieved and found from a system dynamic perspective.

Lastly, this research investigates and models the strategy trend of two-gamer evolutionary analysis, which is on the basis of stakeholder theory to identify the domaining stakeholders in PPP scheme. However, the end-users play significant role in PPP project, who are directly interact with the product or service produced in PPP projects. Hence, further research can explore PPP scheme by applying three-gamer evolutionary game analysis from different standpoints, to conduct more comprehensive analysis.

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Appendix 1

Project name	Project phase	Payment mechanism	Duration (year)	Investment	Fix payment	Performance Payment	Specific mode
1. PPP Project of Water Environment Treatment Project in Changziying Town, Daxing District, Beijing	Execution Phase	Government Payment	30	150.8	53.4	234.4	BOT
2. Tianjin Beichen District Landscaping and Supporting Facilities PPP Project	Procurement phase	Viability gap funding	20	404.5 (Excluding operating fee)	80.9	2320	TOT
3. Tianjin Dongli District Forestry Ecological Construction PPP Project	Execution Phase	Viability gap funding	15	981.5	320	1832	BOT
4. Tianjin Ninghe District 2018 Ninghe Town and other 7 towns of rural living sewage treatment project	Execution Phase	Viability gap funding	16	573	56.5	680	BOT
5. Tianjin Ninghe District surface water plant and supporting pipe network project concession project	Execution Phase	Viability gap funding	30	371.3	90.4	420.6	BOT+TOT +O&M
6. Tianjin Yuqiao Reservoir TOT Project	Procurement phase	Viability gap funding	25	1259	94.4	2250	TOT
7. Tianjin Metro Line 1 (including the East Extension) Stock PPP Project	Preparation Stage	User-pay	30	1931	120.6	3630	BOT+O&M
8. Beichen East Road, comprehensive pipeline corridor and ancillary projects in Beichen District, Tianjin	Procurement phase	Viability gap funding	20	2571	246.1	4733.8	BOT
9. National Highway 109 New Line Expressway (West Sixth Ring Road - City Boundary Section) PPP Project	Execution Phase	Viability gap funding	29	2238.7	330.6	2768.4	BOT
10. Beijing Fangshan District Rural Sewage Treatment Project (Treatment Station Area)	Execution Phase	Government Payment	25	322.6	63.2	792.6	BOT
12. PPP project of national speed skating Hall of Beijing 2022 Winter Olympic Games	Execution Phase	Viability gap funding	30	1529.6	364.8	1264.6	BOT

Project name	Project phase	Payment mechanism	Duration (year)	Project cost	Fix payment	Performance Payment	Specific mode
13. Beijing Xiong'An Expressway (Beijing section) government social capital cooperation (PPP) project	Procurement phase	Viability gap funding	28	12259	2819	10064	BOT
14. "Coal to gas" PPP project of Binhe and Xinggu heating plants in Pinggu District of Beijing	Execution Phase	User-pay	25	956	286	1280	ROT
15. Beijing New Airport North Line Expressway (Beijing section) PPP project	Execution Phase	Viability gap funding	27	11000	2806	9826	BOT
16. Construction and operation of citizen activity center in Gu'an County, Langfang City, Hebei Province	Procurement phase	Viability gap funding	14	208	39	151	TOT
17. PPP project of rural domestic sewage treatment project in Ninghe District of Tianjin in 2019 (33 villages in 6 towns)	Execution Phase	Government Payment	15.5	975	970	5	BOT
18. PPP project of Wurenqiao town sewage treatment plant in Anguo City, Hebei Province	Procurement phase	Viability gap funding	30	408	125	432	BOT
19. PPP project of Anguo citizen Cultural Expo Center in Baoding City, Hebei Province	Procurement phase	Viability gap funding	13	360	12	550	BOT
20. PPP project of Baoding National Health Information Platform in Hebei Province	Procurement phase	Viability gap funding	15	310	420	0	BOT
21. "South to North Water Diversion" surface water plant and its emergency water supply project in Gaobeidian, Baoding City, Hebei Province	Execution Phase	Government Payment	30	1420	139	1256	BOT
22. Urban education complex project of Gaobeidian City, Baoding City, Hebei Province	Execution Phase	Viability gap funding	14	1370	240	1280	BOT
23. Heating pipe network project of cogeneration in Zhuozhou City, Baoding City, Hebei Province	Execution Phase	Viability gap funding	30	3192	460	2980	BOT