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Incentives for green retrofits: An evolutionary game analysis on Public-Private-Partnership reconstruction of buildings

Abstract

To solve the problems of existing buildings with high energy consumption, the government has organized for private sectors to implement green retrofits for the Public-Private-Partnership reconstruction of buildings (PPP-BR). However, most private sectors are reluctant to implement green retrofits because of high costs, low benefits and long payback periods. The existing literature analyzed PPP-BR projects, barriers and incentives of green retrofits. However, it does not provide any quantitative method to illustrate the effectiveness of incentives and the strategy changes of investment groups. To fill this gap, this paper reveals the game strategy change of encouraging green retrofits and implementing green retrofits in government groups and investment groups through an evolutionary game analysis. On this basis, the case simulation method is used to change the parameters to analyze the incentive effectiveness and the strategy change of green retrofitting by investment groups. It can be found that the final evolutionary game results will take on two forms: first, the government groups encourage green retrofits, and the investment groups implement green retrofits; second, the government groups do not encourage green retrofits, and the investment groups do not implement green retrofits, respectively. When the government groups highly encourage green retrofits, the investment groups will also increase its willingness to implement green retrofits. The simulation results show that reducing costs and increasing benefits will promote green retrofits; however, this incentive measure will be limited by objective conditions. Comparatively speaking, the policy incentive measures are less affected by an objective environment, but positive policy incentive measures will get negative effects. In contrast, negative policy incentive measures that may cause problems will be most effective. Therefore, the combination of positive and negative policy incentive measures will be the better and more moderate way to promote green retrofits for PPP-BR.

1. Introduction

To coordinate rapid and sustainable urban development and environmental sustainability, many countries have proposed the renovation of the existing buildings with high-energy consumption and imperfect function (La Rosa et al., 2017). However, since the lack of funds has affected the implementation of reconstruction, the United States, the United Kingdom, the Netherlands and other countries have introduced Public-Private Partnerships (PPPs) into reconstruction (Heurkens and Hobma, 2014; Calabro and Spina, 2014). Referring to the Nijkamp et al. (2002) and Heurkens (2012), Public-Private-Partnership reconstruction of buildings (PPP-BR) is an institutionalized form of cooperation between public and private actors who, on the basis of their own indigenous objectives, work together towards the reconstruction of an existing building in which both parties accept investment risks on the basis of a predefined distribution of revenues and costs. That means the government and the private sectors sign long-term contracts to introduce social capital; that is, the private sectors replace the government to carry out the reconstruction of existing buildings. In

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addition to financial difficulties, the high-energy consumption and waste of resources of existing buildings are also urgent problems to be solved (Thiers and Peuportier, 2012). Buildings in developed countries consume approximately 30% of the total energy requirement, while the data of Europe and the USA far exceed that figure (Kashif et al., 2013).In recent years, with the economic progress of developing countries, building energy consumption is also gradually increasing (Kurekci, 2016; Carolina et al., 2017; Yu et al., 2017). The building energy consumption in China increases by 10% per year, while the annual growth rate in India is approximately 8% (Yu et al., 2017).Therefore, policy incentives include green retrofits into PPP-BR are the key to achieving energy saving and emission reduction in the end-user behavior and operational phase of buildings, and achieve green and sustainable urban development. “Green retrofits for PPP-BR" can be defined as a kind of retrofit that can optimize the building function, achieve green quality and meet the green building standards by signing PPP contracts between the government and the private sectors to renovate, repair, rehabilitate and renew existing buildings, which include public buildings, residential buildings, etc. (Hewitt, 2012; Guarini et al., 2017; China Academy of Building Research (CABR), 2017). The objectives of “green retrofits for PPP-BR" include improving and saving energy efficiency, reducing energy consumption and operating costs, reducing waste emissions and environmental pollution, and improving life quality and work efficiency. (Hewitt, 2012; Guarini et al., 2017; China Academy of Building Research (CABR), 2017).

PPP-BR in various countries is strongly advocated for green retrofits, while many private sectors are not concerned about it. For example, by 2015, less than one percent of the 2538 green retrofits for PPP-BR projects could meet the green standard in China (MOHURD, 2015). This means many private sectors promised to achieve the standards of green retrofits according to PPP contracts, but the assessment results of some projects were disappointing. The possible reasons for this phenomenon are as follows: high cost and long payback periods of PPPs, lack of experiments and technology for green retrofits, and insufficient government subsidies or incentives for green retrofits (Menassa, 2011; Akman et al., 2013). Relevant green retrofit researches are focused on the reasons for non-green retrofits from the technical, financial, political, economic and environmental aspects (Siller et al., 2007; Bu et al., 2015; Menassa, 2011; Fan and Xia, 2018; Ardente et al., 2011; Mcarthur and Jofeh, 2016); and related PPP studies are focused on model exploration, financial management, risk management and benefit distribution (Foley et al., 2011; Li, 2012; Guarini et al., 2017; Fan and Xia, 2018). There is little research on how to promote and encourage the private sectors to implement green retrofits with higher cost and longer payback periods for PPP-BR projects which are conducive to the sustainable green development of the city.

This study aims to reveal the game strategy change of encouraging green retrofits and implementing green retrofits in the public sectors (government-user consortium) and private sectors (investment group) through the evolutionary game analysis in the PPP-BR projects. This study also analyzes the changes in green retrofit decision-making of the investment groups with different incentives through a case simulation which changes the parameters to simulate different incentive measures. In that context, this paper demonstrates the ways to incentivize green retrofitting of investment groups in PPP projects, rather than how to promote PPP in building reconstruction. Although financing is an important driving force to promote reconstruction, the results of building reconstruction are crucial to the future development of the city. This paper is focused on how to promote the healthy and sustainable development of urban reconstruction.

The rest of the paper is divided into 6 sections. Section 2 reviews the literature on PPP-BR projects, barriers and incentives of green retrofits. Section 3 describes the method of the paper. Section 4 gives the game results of the initial parameters and different incentives (changing parameters). Section 5 discusses the results and analyzes the reasons for different results. Section 6 concludes the study, describes the limitations and presents the future study.

2. Literature review

2.1. PPP-BR projects

Since PPPs began in Britain in the 1990s, the model has been widely advocated and has increasingly become a financing measure for governments to achieve their economic goals and raise the level of public services (Heurkens and Hobma, 2014). PPP-BR is one of the most important types of PPP urban reconstruction projects (Guarini et al., 2017; Zhan and Jong, 2018). For PPP-BR, the main stakeholders include the government, investment groups and building users. Public participation departments, financial institutions, expert teams, and other participants also play important roles in promoting the implementation of PPP-BR. (Jung et al., 2015).

PPP-BR projects consist of many participants involving different interests, therefore the proportion of private investment and effectiveness of financing have the important impact on the implementation of PPP-BR (Liao and Liu, 2015). In addition, the quality of PPP, the trust of partners, excellent financial incentives and the reduction of political uncertainty are important factors for reducing the risk and promoting the successful operation of PPP-BR (Wibowo and Alfen, 2015; Carbonara and Pellegrino, 2018; Roshchanka and Evans, 2016). However, some scholars point out that the specific organizations (such as government) involved in PPP-BR have no significant impact on success, and the orderly network relationship is more important (Kort, 2011).

PPP-BR projects focus more on optimizing the function of buildings (e.g. improving building insulation performance, enhancing electricity safety and efficiency, and reducing water waste etc.) and protecting the environment (Copiello et al., 2016; Kurekci, 2016; China Academy of Building Research (CABR), 2017), which is called “green retrofits for PPP-BR". The varied partnerships of PPP are not without risks in achieving the government's sustainable development policies, but it can help to achieve a balance between optimizing low-carbon and function in reconstruction and easing the financial pressure (Xin et al., 2015). Energy Services Companies (ESCO) combined with PPP can make the building reconstruction more energy-efficient (Jensen et al., 2013). Some companies encourage employees to support low-carbon management, conduct environmental training and use “green teams” through green human resources plans, which will help to achieve sustainable environmental development, ecological innovation and environmental protection of PPP-BR (Charbel et al., 2019). For companies where employees receive high levels of advanced green HR training, the linkage of green innovation practices with the economic and environmental performance is stronger (Singh and El-Kassar, 2018). The application of big data can effectively help to realize environmental protection and sustainable development in PPP-BR (De et al., 2018), therefore some companies try to combine big data with cloud-based enterprise resource plan to promote the effective integration of company resources and sustainable development of PPP-BR (Gupta et al., 2018).

2.2. Barriers of green retrofits

Some barriers exist and adversely affect decision-making in green retrofits. Although the willingness of investors is an important factor affecting the green reconstruction decision-making process of private sectors, it is mainly constrained by other factors (Trianni et al., 2017). Lack of opportunity to recover costs is one of the main reasons why the green reconstruction for PPP-BR fails, and the cost of green retrofits is much higher than that of the traditional reconstruction (Liang et al., 2016). Therefore, a lack of additional revenue and higher costs can lead to longer payback periods making the private sectors abandon the project (Kasivisvanathan et al., 2012; Zuo and Zhao, 2014). To achieve lowcarbon environmental protection in green retrofits, private sectors need to develop green technology and run additional investments in green technology, which will bring economic pressure to private sectors (Shaharudin et al., 2019). The private sectors often lack the knowledge of and experience in green reconstruction (Bertone et al., 2018). More resources are needed to acquire knowledge and experience, while the construction industries lack innovation, which also increase the difficulties of green reconstruction (Ryghaug and Sørensen, 2009).

In addition, these insufficient policies have negative impacts (Akman et al., 2013). Some countries have issued policies to promote green retrofits in the private sectors, while the lack of a comprehensive implementation strategy leads to the negligible effect (Ryghaug and Sørensen, 2009). No dedicated funding, a lack of financial feasibility (Sentman et al., 2008), and insufficient information (Marino et al., 2011) also seriously restrict green retrofits. 2.3. Incentives of green retrofits

To solve the barriers encountered in the green retrofits for PPPBR, many scholars have proposed different incentive measures, which include policy incentives, financial incentives and nonfinancial incentives (Olubunmi et al., 2016).

Policy incentives include promulgating relevant laws, regulations and documents which support green retrofits. The government provides the subsidies of green technological innovation to promote the development of green technology industries by reducing the costs. Green technological innovation is in fact an important strategic catalyst to obtain sustainable development of PPP-BR (El-Kassar and Singh, 2018). It will not only promote the development of green technological industry and help private sectors gain competitive advantages, but encourage the private sectors to adopt low-cost green retrofits (Koppenjan, 2015; Oliva et al., 2018). In the short term, policy incentives are advantageous to private sectors willing to make green retrofits, and others who resist green retrofits will face the negative effects (Gou et al., 2013).

Financial incentives include economic subsidies (Ma et al., 2012), tax incentives (Fuerst and McAllister, 2011), and credit incentives (Koppenjan, 2015). Economic subsidies are the most common financial incentives (Amabile, 1993). Direct subsidies and rewards for green retrofits can be seen as an additional benefits, subsidizing the excessive costs and compensating for the insufficient revenues (Ma et al., 2012). Many governments are also keen to use tax incentives and believe that the current tax incentives, including tax reliefs or duty-free, are far from enough. (Kubba, 2010). It is noteworthy that the imposition of high additional taxes can also be used as a penalty for non-green retrofits, which means that tax incentives have positive or negative advantages (Koppenjan, 2015). Credit incentives mainly include the provision of low interest loans (Xin et al., 2015). Interestingly, some scholars suggest that policy incentives are more effective than financial incentives, and even financial incentives may be ineffective in promoting green retrofits (Harrison and Seiler, 2011).

In addition, there are many non-financial incentives, such as improving corporate image by assessing the reconstructed buildings as star green buildings or providing more PPP cooperation opportunities (Gucyeter and Gunaydin, 2012). These measures have not been reflected economically, but they are also attractive to some private sectors (Davies and Osmani, 2011).

The previous studies focus on the reconstruction mode, the functions of participants, the relationships between main stakeholders and participants, and the barriers and incentives of green retrofits. However, at first, the implementation strategies of the main stakeholders in green retrofits for PPP-BR have not been illustrated clearly. Second, these studies mainly prompt the incentive measures from a qualitative point, not from the perspective of a quantitative point. It is impossible to directly determine the effectiveness of incentive measures and the combined promotion of different incentives in the merely qualitative studies. The effective usages of these incentive measures will be affected. Therefore, this paper, based on establishing the evolutionary game optimization model of green retrofits for PPP-BR, mainly aims to reveal the implementation strategies of public sectors and private sectors. Then, the study will reveal the game strategy change through case simulation and the evolutionary game analysis, and analyze the changes in green retrofit decisionmaking of investment groups under different incentives in the quantitative point. The most suitable and effective incentive measures for green retrofits in the PPP-BR projects will be explained intuitively. Combined with those results, the paper will propose some suggestions on how to promote green retrofits in the PPP-BR project to remedy the insufficiencies of the previous studies.

3. Method

3.1. Evolutionary game theory and hypothesis

PPP-BR project involves many stakeholders, but from the perspective of the objectives and responsibilities of the participants, the main stakeholders include government,[1] investment groups and users (Jung et al., 2015). In PPPs, the government has many responsibilities, such as formulating relevant policies, introducing participants and designing PPP contracts to form a PPP project company. Investment groups provide social capital and sign the contracts with other participants. Users can supervise the PPP project company by joining the public participation agencies, or pay a certain fee to promote PPP-BR. Cooperation between the partners can be promoted, and the objective

[1] From the investigation of experts and the review of laws and regulations, for green retrofits of PPP-BR, there are some differences in policy design and incentive measures in different regions, but the main contents of the objectives originate from the laws and regulations of the central government. The main differences include the different degree of pursuing the objectives, the difference in the amount of subsidies in different regions, etc., however, the main objective is similar to that of the central government. In this study, the government is defined as the local government, referring to the central government's objectives, policies and incentive measures for green retrofits.

differences of various stakeholders can be blurred through PPPs. However, there are, in fact, some differences in the objectives and goals pursued by main stakeholders (Fig. 1).

According to the definition of “green retrofits for PPP-BR", the building type includes public buildings and residential buildings. There are some differences in green retrofit objectives between the users of public buildings and those of residential buildings, but the objectives of the government cover the objectives of different building users (Fig. 1).Therefore, the government and the users can be united as the government-user consortium. In Fig. 1, the objectives of the government-user consortium and investment groups are different. The consortium pursues the maximization of social benefits, while the investment groups pursue the maximization of economic benefits. However, PPPs can urge them to adjust and optimize their own benefits to realize the win-win cooperation in the process of pursuing their own benefits maximization. It means “green retrofits for PPP-BR" can be treated as a game between the government-user consortium and the investment groups attempting to maximize their payoffs (Tserng et al., 2012). Whether to encourage green retrofits and whether to implement green retrofits can be considered as an equilibrium outcome of the game (Xin et al., 2015; Wu et al., 2019). This paper will analyze the strategies of green retrofits of the government-user consortium and the investment groups by evolutionary game theory.

Evolutionary game theory takes groups as the subjects, emphasizing the dynamic equilibrium among different kinds of groups. Any group has the right to choose their strategy, but the final choice may depend on the other groups in the game. In the process of evolutionary game, each group can evolve into the best decision-making results through continuous learning and evolution (Hilbe, 2011). In the green retrofits for PPP-BR projects, the demands of the government-user consortium and the investment groups are constantly adjusted and improved; that is, many games are carried out. They will also imitate and learn from the correct experience of other governments and investment groups to build their own knowledge system, similar to the biological evolution process (Roca et al., 2009). Therefore, evolutionary game theory can effectively achieve a certain balance between the government-user consortium and the investment groups.

It assumes that the users in the green retrofits have no extra payment, and the government needs to pay a certain amount. In this study, the government acts on behalf of the agent of the consortium to participate in the game. The two sides of the game decision makers are the government groups (government-user consortium) and the investment groups. The investment groups could be a single institute or a joint investment by several institutes. According to the analysis of evolutionary game theory and the objectives, the two sides have their own decision-making strategies for green retrofits

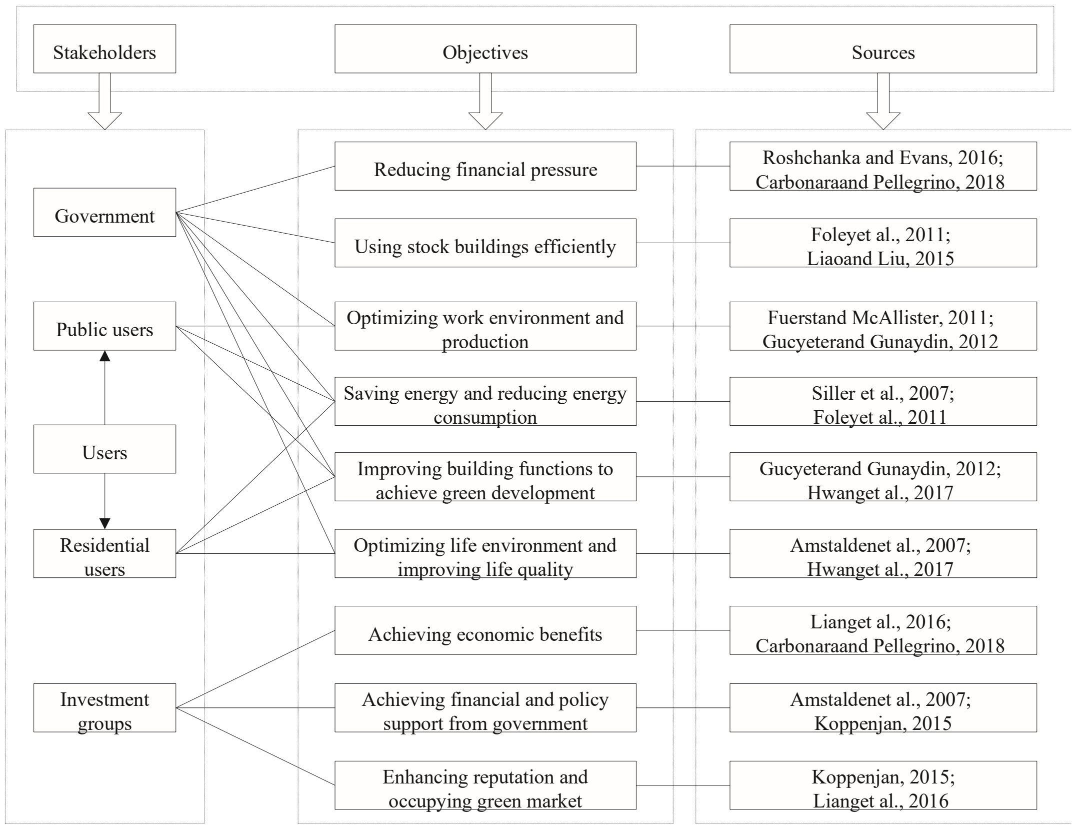

Fig. 1. The objectives of the main stakeholders.

in the PPP-BR project. As proposed by Xin et al. (2015) and Wu et al. (2019), the hypotheses are following:

H1. The strategies of the government groups are “Encouraging green retrofits” (G_1) and “Non-encouraging green retrofits” (G_2).

H2. The strategies of the investment groups are “Implementing green retrofits” (I_1) and “Non-implementing green retrofits” (I_2).

3.2. Incentive measures and variables

If income of social capital is greater than the cost, the green retrofits for PPP-BR will be implemented. To make sure of that implementation, it is necessary to balance the potential benefits of green retrofits and to ensure the “Pareto” optimum between two sides. For the investment groups, the benefits of green retrofits for PPP-BR have the characteristics of green retrofits and PPPs, which include basic benefits and additional benefits. The policy benefits include rewards, subsides and special funds for green retrofits.

According to the barriers for green retrofits, the investment groups will not implement green retrofits because of high cost, lack of additional benefits, absence of green retrofit technology and insufficient policy incentives. To solve these barriers and promote the green retrofit of investment groups, this paper will put forward many incentive measures, which must be scarce and exclusive and needed by the recipient. The incentives also need to arise the desire of the recipient.

The recipient of this paper is the investment groups, and the desire is to actively implement green retrofits. First, the investment groups pursue the maximization of economic benefits. This paper will simulate reducing the cost and expanding additional benefits as two incentives from the perspective of investment group cost and benefit. Additionally, the government needs to provide policy incentives. The government groups pursue the maximization of social benefits, therefore, the government will propose the incentives of green retrofits for PPP-BR considering the social and economic development. These incentives may not all be positive incentives, such as a high surtax (Koppenjan, 2015). The government groups encourage the investment groups with both positive and negative incentive measures, which coincides with the reinforcement theory (Skinner, 1948). According to this theory, behaviors can be reinforced from the stimuli. It means, to gain the certain consequences, human would take certain behaviors to the stimuli from the environment (Scharff, 1999). From the logic of economics, the effectiveness of stimulus depends on the following premises: first, the stimulus must be needed to the recipient; second, the stimulus must be scarce and exclusive to make the recipient enjoy the stimulus exclusively; third, the marginal utility of stimulus is diminishing. (Aronowitz and Weinberg, 1966). It means excessive stimulus will lead to the lack of the stimulus scarcity, the effectiveness of stimulus will fail; to gain the certain consequences, more and more people take certain behaviors under the stimulus that will lead to the lack of the stimulus exclusiveness, the effectiveness of stimulus will also fail. (Skinner, 1948). Based on the premises, the stimulus can be either positive or negative, which is called positive reinforcement or negative reinforcement (Hambly et al., 2017). Positive reinforcement strengthens a behavior by providing a consequence an individual finds rewarding. Negative reinforcement strengthens a behavior by removing the unpleasant experience. But the degree of negative reinforcement need to be paid attention, it will cause some problems such as reducing the satisfaction, causing social unrest or negative emotions. (McLeod, 2018). In this paper, the positive policy incentives which include increasing green retrofit subsidies and increasing special funds for green retrofit technology can be regarded as positive reinforcement. It means if the investment groups implement green retrofits, they might acquire subsidies or special funds from the government for this behavior. The negative policy incentives which include increasing taxes for non-green retrofits can be regarded as negative reinforcement. It means if the investment groups do not implement green retrofits, they might pay high taxes for this behavior, unless they are willing to implement green retrofits. To simulate positive incentives or negative incentives, this paper realizes the simulation by changing the value of variables. The description of the variables and corresponding incentives are shown in Table 1.
shown below:

$$E_{11} = y(m_1 + m_2 \; m_4 \; m_5) + (1 \; y)(m_1 \; m_5 \; m_3 + n_5)$$

(1)

E12 ¼ym1 þ ð1 yÞðm1 m3Þ (2)

E_1 ¼xE_{11} þ ð1 xÞE_{12} (3)

In the process of the game, the replicator dynamic equation of the government groups is shown as follows:

FðxÞ¼xðE11 E1Þ ¼ xð1 xÞ½yðm2 m4 m5Þ ðm5 n5Þ

(4)

When F(x) ¼ [1] and F0(x) < 0, the evolutionary stability strategy (ESS) of the government groups will be got. When FðxÞ ¼ 0, x_1¼ 0; x_2 ¼ 1 and y* ¼ ðm5n5Þ=ðm2m4n5Þ will be attained.

The strategy choice of government groups is shown in Table 3.

The expected benefit of I_1 is E_{21}, and that of I_2 is E_{22}. The average benefit of the investment groups is E_2. The equations are shown below:

E21 ¼xðn2 þ n3 þ n4 n1Þ þ ð1 xÞðn2 þ n3 n1Þ (5)

E22 ¼xðn2 n5Þ þ ð1 xÞn2 (6)

E_2 ¼yE_{21} þ ð1 yÞE_{22} (7)

In the process of the game, the replicator dynamic equation of the investment groups is shown as follows:

FðyÞ¼yðE21 E2Þ ¼ yð1 yÞ½xðm4 þ n5Þ n1 þ n3(8)

Similarly, when F(y) ¼ 0 and F0(y) < 0, the ESS of government groups *

willn₁ben₃Þ=attained.ðm₄þn₅Þ will be attained.When FðyÞ ¼ 0, y_1 ¼ 0; y_2 ¼

1 and x ¼ ð

It is worth noting that there are two conditions for investment groups. The strategy choice of the investment groups is shown in Table 4.

The local stability of the Jacobian matrix analysis is shown as follows:

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[1] vFðxÞ vFðxÞ1

;

J BB vx vy CC 2ð1 2xÞ½yðm2 m4 n5Þ ðm5 n5Þ;

xð1 xÞðm2 m4 n5Þ 3 (9)

¼BBBvFvðxyÞ;vFvðyyÞCCCA ¼ 4 yð1 yÞðm4 þ n5Þ; ð1 2yÞ½ðm4 þ n5Þx n1 þ n3Þ5

Table 1

3.3. Evolutionary game optimization model

Based on the hypothesis and variable analysis, in order to quantitatively analyze the change to investment group strategy due to different incentives, this paper established the evolutionary game optimization model of green retrofits for PPP-BR to determine the game strategies of government groups and investment groups. The payoff matrix of green retrofits for PPP-BR is shown in Table 2.

The expected benefit of G_1 is E_{11}, and that of G_2 is E_{12}. The average benefit of the government groups is E_1. The equations are

The determinant and trace of the Jacobian matrix are shown below: det j ðxÞ,vFðyÞ

vFðxÞ,vFðyÞ

vF

¼ vx vy vy vx

tr¼ vðxxÞ þ vFvðyyÞ (10) vF

According to the Jacobian matrix analysis, the local equilibrium points O (0, 0) and B (1,1) are ESS. A (0,1) and C (1, 0) are unstable. D

Variables and corresponding incentives.

Variable	Name	Meaning	Incentives	Sources
m_1	rnment s Basic benefits	Government benefits from PPP-BR, such as tax.	e	Amstalden et al. (2007) Shazmin et al. (2017)
m_2	Additional benefits	Government benefits when choosing G_1 and I_1, such as the benefits from an environmental improvement, promotion of upgrading traditional industries, new industries related to green retrofits and soft benefits.	e	Wibowo and Alfen (2015) Hwang et al. (2017)
m_3	Governance costs	Government costs when choosing I_2, such as the money paid by the government for resolving the high energy consumption and pollution.	e	Liao and Liu (2015) Ladhad and

				Parrish (2013)
m_4	Financial incentive costs	Government costs when choosing G_1 and I_1, such as government financial subsidy. It is the positive incentive measure for the government.	Direct financial incentives of green retrofit for PPP-BR Positive policy incentives	Ma et al., 2012 Kubba (2010)
m_5	Technological innovation costs	Government costs when choosing G_1, such as the special funds for technological upgrading of green retrofits.	Financial incentives of green retrofit technological development Positive policy incentives	Pisello and Asdrubali (2014) Koppenjan (2015) Liang et al. (2016)
Investment groups n_1	Incremental costs	Investment group additional costs when choosing I_1, such as costs of energy conservation, photovoltaic and geothermal.	Cost optimization incentives Introducing new green retrofit technology or materials	Hwang et al. (2017) Ladhad and Parrish (2013)
n_2	Basic benefits	Investment group benefits from PPP-BR.	e	Liao and Liu (2015) Amstalden et al. (2007)
n_3	Additional benefits	Investment group benefits when choosing I_1, such as the income from new operating facilities.	Benefit optimization incentives Expanding the channel of additional income acquisition	Kasivisvanathan et al. (2012); Zuo and Zhao (2014)
n_4	Incentive benefits	Investment group benefits when choosing G_1 and I_1. The benefits are obtained from the government, and n_4 is the same as m_4.	Same as m_4	Ma et al., 2012 Kubba (2010)

n_5	Incremental tax	Investment group costs when choosing G_1 and I_2, such as the additional taxes for non-green retrofits.	Tax punishment incentives of non-green retrofits for PPP-BR Amstalden et al. (2007) Negative policy incentives Koppenjan (2015)

Table 2
yoff matrix of government groups and investment groups.

Investment groups	Government groups	
	Encouraging green retrofits G_1 (x)	Non-Encouraging green retrofits G_2 (1-x)
Implementing green retrofits I_1 (y) Non-implementing green retrofits I_2 (1 y)	m1 þ m2 m4 m5; n2 þ n3þ n4 n1 m1 m5 m3þ n5; n2 n5	m1; n2 þ n3 n1 m1 m3; n2

Table 3
The ESS choice of government groups.

y	Steady state point	F0(x)	ESS
y ¼ y*	all x values	F0(x) ¼ 0 (discarded)	e
y < y* y > y*	x_1 ¼ 0; x_2 ¼ 1 x_1 ¼ 0; x_2 ¼ 1	F^0 ð0Þ< 0; F^0 ð1Þ> 0 (discarded$_0$ $_1$Þ< $_0$) ^{F0} ð0Þ> 0 (discarded); F ð	Non-encouraging green retrofits G_2 Encouraging green retrofits G_1

Table 4
The ESS choice of investment groups.

Condition	x	Steady state point	F0(x)	ESS
n_1 n_3< 0	Incremental cost is always less than the incremental income. (profitable)			Implementing green retrofits I_1
n_1 n_3> 0	x ¼ x* x < x* x > x*	all y values y_1 ¼ 0; y_2 ¼ 1 y_1 ¼ 0; y_2 ¼ 1	F^0 ð0Þ< 0; F ð F0^0 (y0)Þ¼> $_0$ $_($0 (discarded); Fdiscarded$_0$ $_1$Þ> 0 (discarded) ^{0} ð1Þ< $_0$) F ð	e Non-implementing green retrofits I_2 Implementing green retrofits I_1

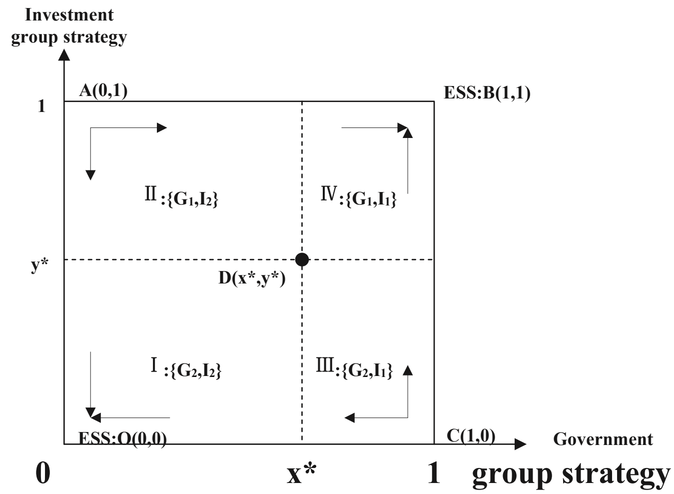


Fig. 2. The evolutionary game strategy of green retrofits for PPP-BR.

(x*, y*) is the saddle point. The evolutionary game strategy is represented in Fig. 2.

It can be found that when x < x and y < y , the game strategy is “Non-encouraging green retrofits $G_2$00 and “Non-implementing green retrofits $I_2$00, and the acreage of I (S_I ¼ x^* y^* 100%) represents the probability of this game strategy. Similarly, the acreage of II, III and IV (S_{IV} ¼ ð1 x^*Þ ð1 y^*Þ 100%) represent the probability of {G_1, I_2} strategy, {G_2, I_1} strategy and {G_1, I_1} strategy respectively. Because O (0, 0) and B (1, 1) are two ESS points, the government groups and the investment groups will eventually evolve into the final strategies of {Encouraging green retrofits G_1, Implementing green retrofits I_1} and {Non-encouraging green retrofits G_2, Non-implementing green retrofits I_2}. D (x*, y*) is the saddle point affecting the changes in game evolution. The values of x* and y* (representing the incentive change) will vary because of the variable parameter change, resulting in the changes of government group strategy and investment group strategy.

3.4. Case study and simulation

As a research method, the case study is used in many situations. The more that the scientific questions seek to explain some present circumstances, the more that case study research will be relevant (Robert, 2014). To promote the healthy and sustainable development of urban reconstruction, this paper mainly explores the incentives for investment groups to implement green retrofits for PPP-BR; therefore, a case study is the better method. In Table 2, the variables have been linked to different incentive measures. Changing the values of these variables can effectively simulate the different incentive measures.

(1) Case choice and description

According to the case study, there is no formula for choosing the case. However, the selected cases need to meet the requirements of their own research (William, 2018). This paper will to study the green retrofits for PPP-BR, so the case needs to be in accord with the PPP-BR building standard, which include public buildings and residential buildings. The selected case needs to be demonstrative, and the standards and expected objectives are basically consistent with the research hypothesis.In this paper, the selected case is from the open demonstrative projects in the exchange regarding key technology research and demonstrative projects of green retrofits in China - Tang Long primary school green retrofits project in Nanshan District, Shenzhen.

The area of the project is 18,100 m^2, and the area of the school buildings is approximately 7400 m^2. The old teaching buildings and staff dormitories were built in the 1990s. As it has been a long time since construction, renovation and repair, the dilapidated building facades have affected the urban landscape. The drainage and power supply facilities were severely aging, leading to low energy efficiency and high energy consumption. The protection facilities were damaged and they were not suitable for protecting students and teachers. To beautify the campus environment, improve energy efficiency, reduce operating costs and optimize learning and working efficiency, the green retrofits for the campus were decided upon. After the green retrofits, the project needs to meet the twostar claim of the "Green Campus Evaluation Standard" (CGBC, 2013).

The total duration of the project is two years. The government submitted the implementation units through public bidding and established the PPP project company. The sources of funds is shown in Table 5.

To avoid high operating pressure, the bank loan repayment period and the franchise period should be consistent. During the construction period, only the interest was paid. After the construction period, the project should repay the money in the form of average capital. The project company obtains franchise rights for 15 years, the first two years of which are the preparation period and green retrofit period. The remaining 13 years make up the operation period. After the franchise rights period, it will be taken over by the government.

(2) Parameter change and simulation

The simulation is divided into four steps (shown in Fig. 3).

STEP 1. According to the principle of case choice, the appropriate PPP-BR is selected. The initial parameters of each variable are determined according to project introduction, relevant laws and regulations.

STEP 2. The evolutionary game optimization model is used to obtain the game strategy results of the government groups and the investment groups under the initial parameters, which is a comparison basis.

STEP 3. The evolutionary game optimization model is used to obtain the game strategy results of the government groups and the investment groups under the parameter changes (simulating an incentive measure or a group of measures).

STEP 4. The effectiveness and efficiency of incentives are illustrated by comparing the initial results with the results under the parameter change.

When the results under the parameter change are better than the initial results, the incentives play a role in this paper. It is worth noting that there are many incentives of green retrofits for PPP-BR; therefore, STEP 3 and STEP 4 need to be repeated until all the incentive measures are analyzed, and then, the final conclusion is reached.

This paper has completed the case choice, and the initial parameters have been decided by the project introduction (Table 6). According to the local regulations and investigation, the reasonable value of incentive simulation is shown in Table 6. The results will be shown in Section 4.

Notes: Some values do not need to be calculated in the Formula (1)-(10), and the numerical values are not collected. The Chinese government intends to promote the environmental protection tax, although the tax rate is unclear. Therefore, the value of n_5

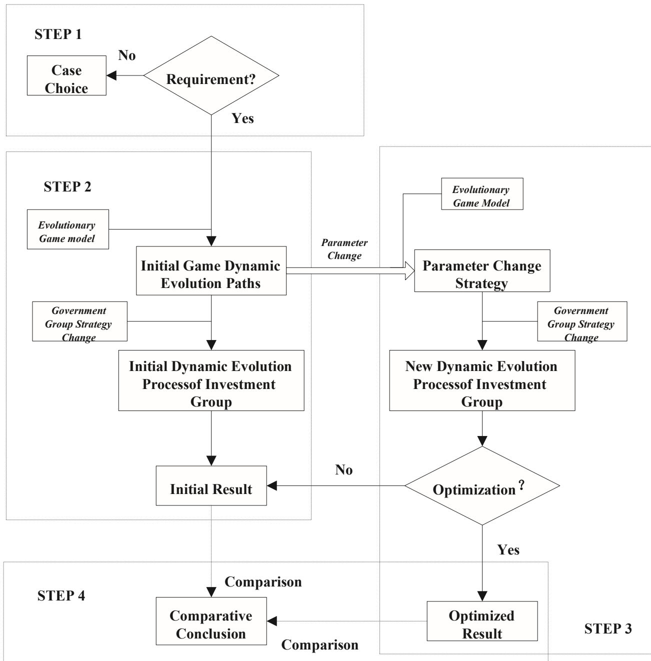


Fig. 3. Steps of simulation.

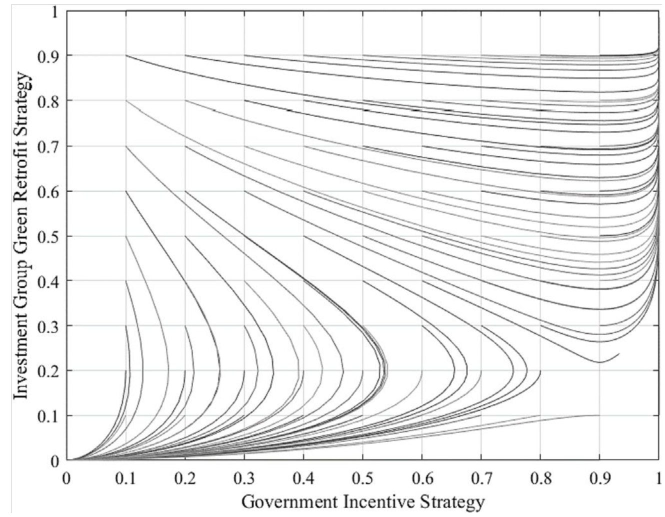


Fig. 4. Game dynamic evolution path under the initial parameters.

probability that the government groups do not encourage green retrofits and the investment groups do not implement green retrofits is 0:9 0:2 100% ¼ 18%. The figures in the upper-right region (IV) of the saddle point (0.90, 0.20) gather to (1, 1), which means the strategies of the government groups and the investment groups evolve into {G1, I1}. This means the probability that the

simulation is the sum of increments of m4 and. m5: government groups encourage green retrofits and the investment groups implement green retrofits is ð1 0:9Þ ð1 0:2Þ 100% ¼

4. Results

8%. By comparison, the probability of {G_2, I_2} is higher than that of {G1, I1}. The incentives for green retrofits for PPP-BR are necessary.

4.1. Initial game strategy

To observe the evolution trend of the investment groups with the strategy change of the government groups under the initial

Table 5
Fund source and composition.

Source	Form	Meaning	Amount of Money($)
Government	Subsidy	The economic assistance to green retrofits for PPP-BR from government	60,584.94
Social capital	Currency	The money from investment group directly	91,952.66
Financial institution	Bank loans	The loans applied by investment group due to the insufficient of subsidies and currency	49,387.48
Sum			201,925.08

Government group m_2 Additional benefits	140	e	140
m_4 Financial incentive costs	40	Increasing direct subsidies of green retrofit for PPP-BR (Positive)	45
m_5 Technological innovation costs	20	Increasing special funds for technological upgrading of green retrofits (Positive)	30

Investment group	n_1			
	Incremental costs	193	Reducing cost caused by technological upgrading of green retrofits	184
n_3	Additional benefits	157	Increasing benefit caused by expanding the idle use of playgrounds and 164 parking lots	
n_5	Incremental tax	0	Increasing tax of non-green retrofit (Negative)15	

According to x ¼ ðn1n3Þ=ðm4þn5Þ and y ¼ ðm5 n5Þ= parameters. The strategy of the government groups x is taken as 0.4 ðm2 m4 n5Þ, x ¼ 0:90 and y ¼ 0:20 are achieved under the (low-encouraging), 0.6 (moderate-encouraging) or 0.8 (highinitial parameters. Using MATLAB R2015b to simulate, the game encouraging) to view the change in the investment group strategy dynamic evolution paths of the government groups and the in-

y: (Fig. 5).

vestment groups are shown in Fig. 4.

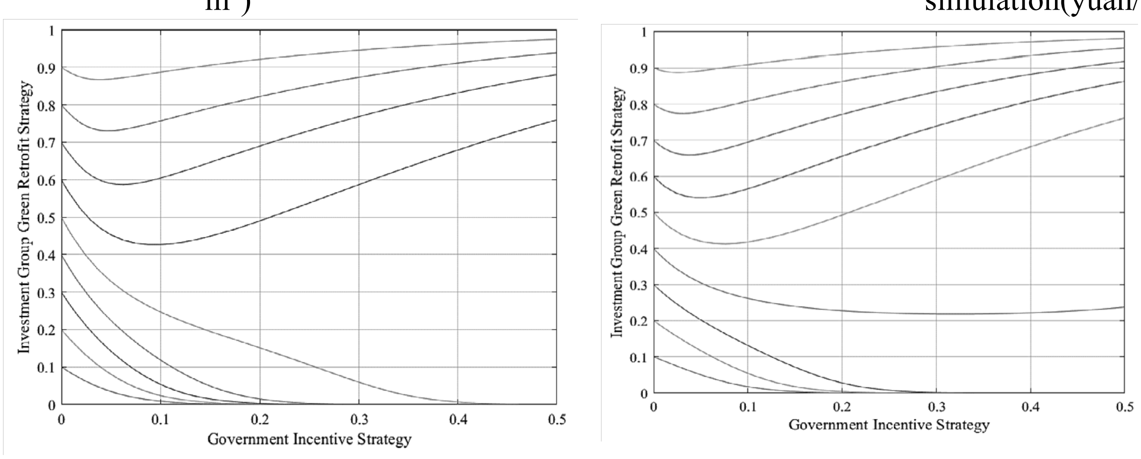
From Fig. 5, when the other conditions remain unchanged, the

The figures in the lower-left region (I) of the saddle point (0.90, more active the government groups are in encouraging green ret0.20) gather to (0, 0), and the strategies of the government groups rofits, the more active the investment groups tend to be in and the investment groups evolve into {G_2, I_2}. This means the

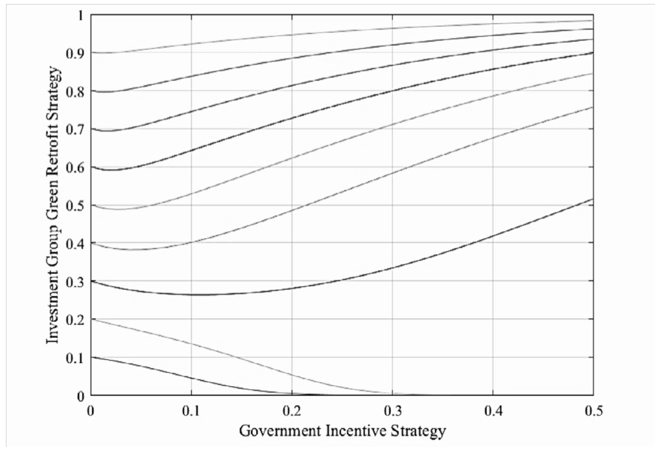
Table 6

Initial parameter and value of incentive simulation.

Variable Name	Initial parameter (yuan/ m^2)	Incentives	Value of incentive simulation(yuan/m^2)



(a) (b)



(c)

Fig. 5. Dynamic evolution process of investment group strategy change under initial parameters: (a) x ¼ 0.4 (b) x ¼ 0.6 (c) x ¼ 0.8.

implementing green retrofits. However, under the initial parameters, when the government groups highly encourage the green retrofit (x ¼ 0.8), there are still some investment groups that do not implement green retrofits for PPP-BR. This situation needs to change with incentives. This paper simulates different incentive strategies by referring to the changing parameters in Table 5.

4.2. Parameter change game strategy

4.2.1. Simulated incentive measures from the perspective of benefit and cost

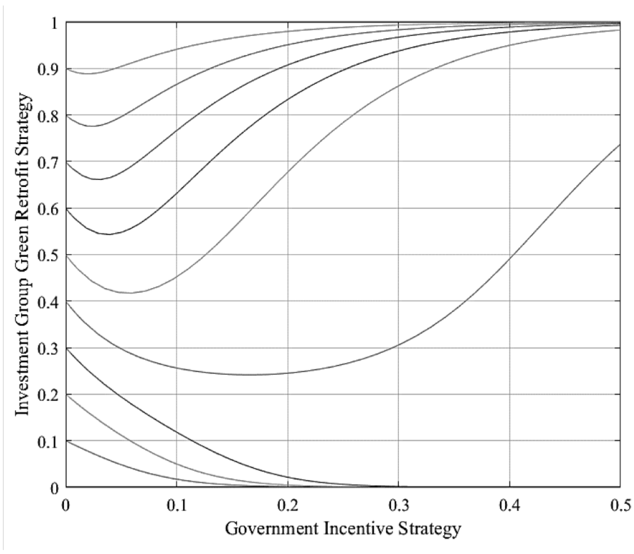
(1) Increasing additional benefits (n_3)

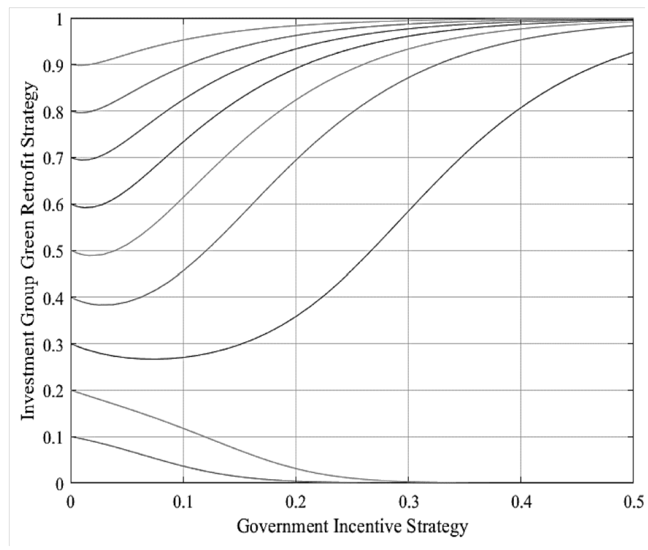
For the investment groups, the most direct way to stimulate a PPP-BR project to implement green retrofits is to increase its additional benefits. Although increasing the additional benefits of public non-profit campus project is a little difficult, the additional benefits can be increased by renting parking space or playgrounds in the free time. According to Table 5, the saddle point is changed to (0.725, 0.20) by changing the value of additional benefits (n_3). The probability that the government groups do not encourage green retrofits and the investment groups do not implement green retrofits is reduced to 14.5%. The probability that the government groups encourage green retrofits and the investment groups implement green retrofits is increased to 22%. Similarly, the strategy of the government groups x is taken as 0.4, 0.6 or 0.8 to view the change in the investment group strategy y (Fig. 6).

Compared with the initial parameters, increasing additional benefits can promote the green retrofit strategy of the investment groups. However, when the government groups highly encourage the green retrofit (x ¼ 0.8), there are still some investment groups that do not implement green retrofits for PPP-BR. Despite this, the amount of investment groups who are non-implementing green retrofit has been gradually decreasing. Under this kind of incentive measure, it is still not possible to urge all the investment groups to implement green retrofits.

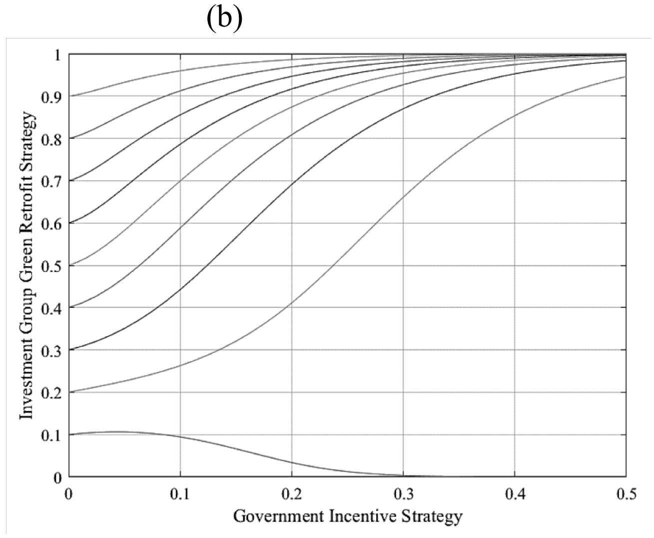
(2) Reducing incremental costs (n_1)

With the upgrade of key technology, the improvement of management and the perfection of the financing mechanism, reducing incremental costs may also encourage the investment groups to implement green retrofits for PPP-BR. The saddle point is changed to (0.675, 0.20) by changing the value of incremental costs (n_1).The probability that the government groups do not encourage green retrofits and the investment groups do not implement green retrofits is reduced to 12.5%. The probability that the government groups encourage green retrofits and the investment groups





(a) (b)



(c)

Fig. 6. Dynamic evolution process of investment group strategy change under increasing additional benefits: (a) x ¼ 0.4 (b) x ¼ 0.6 (c) x ¼ 0.8.

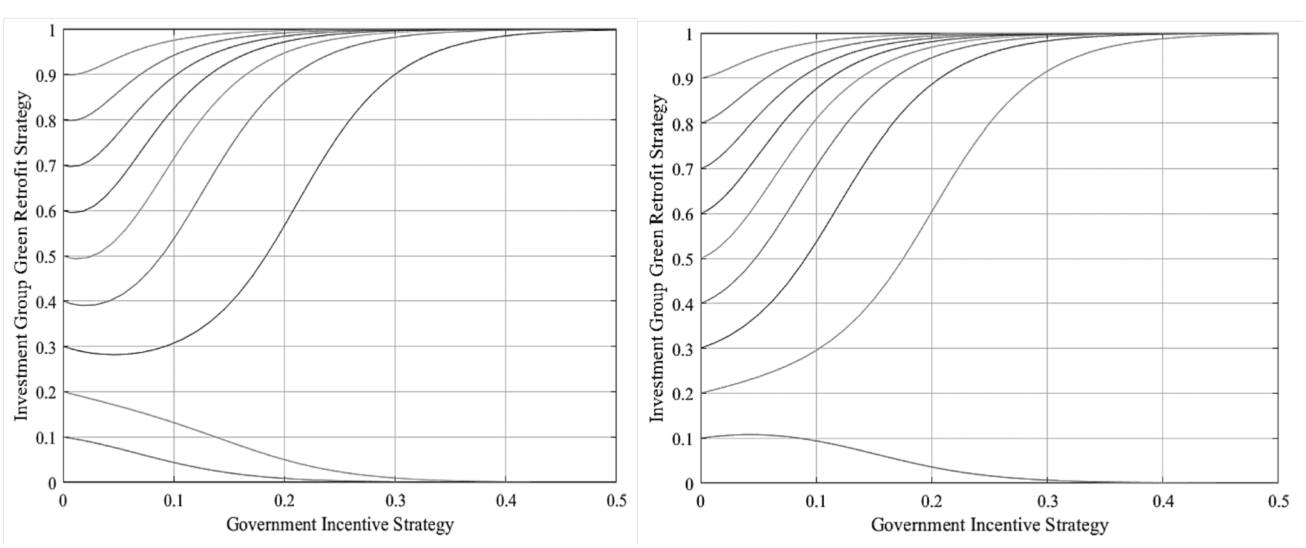
implement green retrofits is increased to 26%. Similar to the circumstances of increasing additional benefits of incentive measures, it is not possible to urge all the investment groups to implement green retrofits, even if the government groups highly encourage green retrofits.

(3) Both increasing benefits and reducing costs

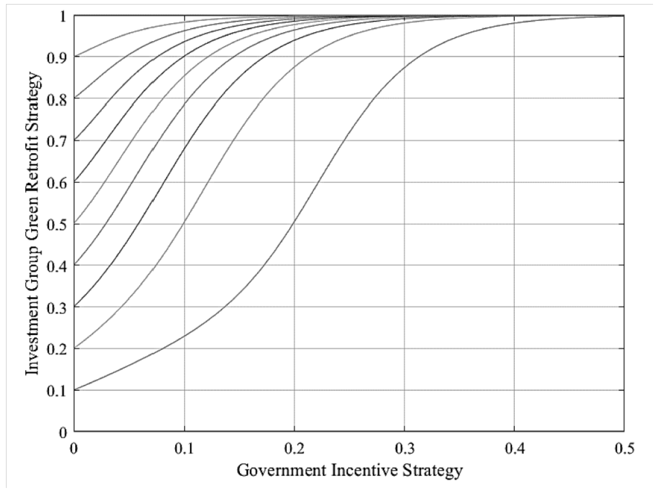
Reducing the incremental costs or increasing the additional benefits can stimulate the investment groups to implement green retrofits for PPP-BR to a certain extent, but the effect is not good. Therefore, the saddle point (0.50, 0.20) is obtained by using the incentive measure which both increases benefits and reduces costs. The probability that the government groups do not encourage green retrofits and the investment groups do not implement green retrofits is reduced to 10%. The probability that the government groups encourage green retrofits and the investment groups implement green retrofits is increased to 40%. The strategy of government groups x is taken as 0.4, 0.6 or 0.8 to view the change in the investment group strategy y (Fig. 7).

Compared with the results of a single incentive measure, the coincentive measures can effectively promote the investment groups to implement green retrofits for PPP-BR. When the government groups highly encourage the green retrofit (x ¼ 0.8), all of investment groups will implement green retrofits.

4.2.2. Simulated incentive measures from the perspective of positive and negative policies



(a) (b)



(c)

Fig. 7. Dynamic evolution process of investment group strategy under both increasing benefits and reducing costs: (a) x ¼ 0.4 (b) x ¼ 0.6 (c) x ¼ 0.8.

In fact, it is difficult for some PPP-BR projects to increase additional benefits (e.g., public non-profit projects) and reduce incremental costs (e.g., the difficulty of green retrofit technology innovation). The above two incentives need a specific environment; that is, there are some limitations to implement increasing benefits or reducing costs measures. Policy incentives are less affected by the objective environment and easier to implement. According to the reinforcement theory, for the investment groups, the government increasing direct subsidies for PPP-BR (m4) and increasing special funds for the technological upgrading of green retrofits (m5) are the positive policy incentive measures. To promote green retrofits, the government increases tax of non-green retrofits (n_5), which can be seen as punishing measures. It is a negative policy incentive measure. In this part, we analyze the incentive effect from positive and negative policies.

(1) Positive policy incentive measure

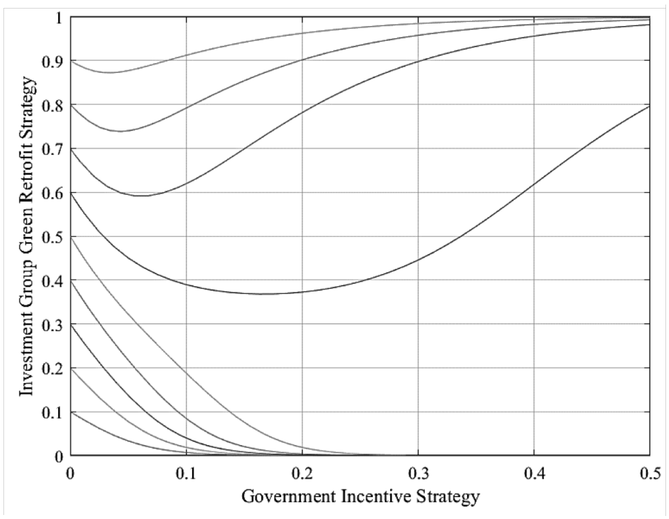
According to Table 5, the saddle point is changed to (0.80, 0.32) by changing the value of financial incentive costs (m_4) and technological innovation costs (m_5). The probability that government groups do not encourage green retrofits and the investment groups do not implement green retrofits is increased to 25.6%. The probability that government groups encourage green retrofits and the investment groups implement green retrofits is increased to 13.6%. The strategy of the government groups x is taken as 0.4, 0.6 or 0.8 to view the change in the investment group strategy y (Fig. 8).

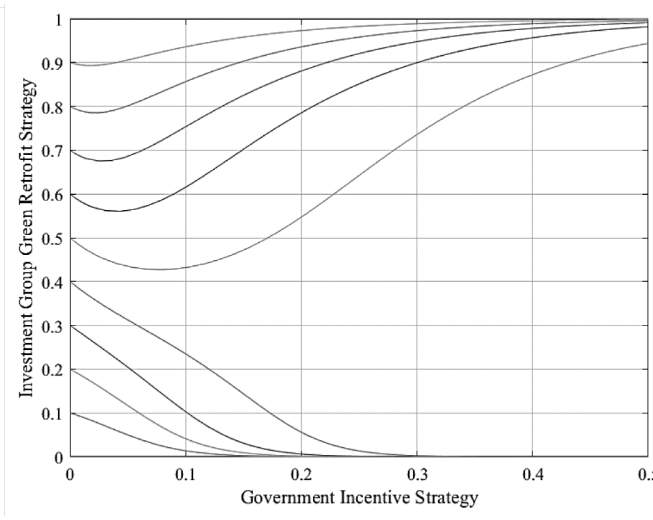
There is an interesting phenomenon to be found. Compared with the initial parameters, the probabilities of $\{G_1, I_1\}$ and $\{G_2, I_2\}$ are both rising. When the government groups highly encourage the green retrofit (x ¼ 0.8), there are still some investment groups that do not implement green retrofits for PPP-BR. In addition, the amount of investment groups who are non-implementing green retrofits is more than that of the initial parameters. This means the positive policy incentive measure is ineffective. The possible reasons for this result will be analyzed in Section 5.

(2) Negative policy incentive measure

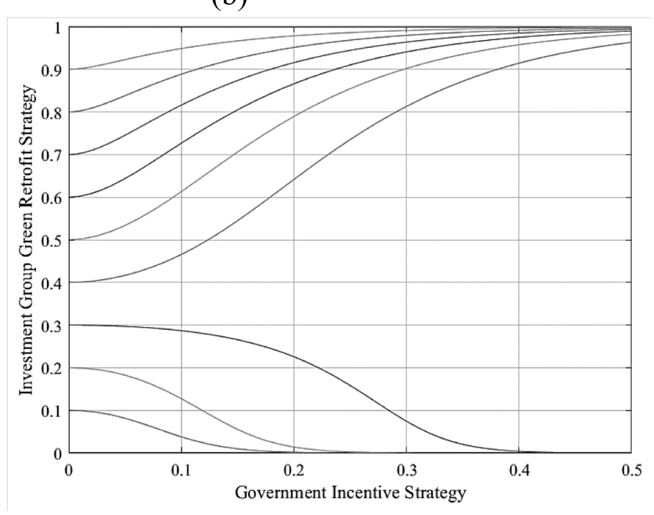
The saddle point is changed to (0.65, 0.06) by changing the value of (n_5). The probability that the government groups do not encourage green retrofits and the investment groups do not implement green retrofits is sharply reduced to 3.9%. The probability that the government groups encourage green retrofits and the investment groups implement green retrofits is increased to 32.9%. The strategy of the government groups x is taken as 0.4, 0.6 or 0.8 to view the change in the investment group strategy y (Fig. 9).

Contrary to the positive policy incentive measure, the effect of the negative one is very obvious.





(a) (b)



(c)

Fig. 8. Dynamic evolution process of investment group strategy under the positive policy incentive measure: (a) x ¼ 0.4 (b) x ¼ 0.6 (c) x ¼ 0.8.

Even if the government groups moderately encourage green retrofit (x ¼ 0.6), all the investment groups will implement green retrofits. The effectiveness of the negative incentive measure is better than that of the positive one. According to the reinforcement theory, negative incentive measure has good effectiveness, but it might cause some social problems such as reducing the satisfaction of investment, causing social unrest or negative emotions. Therefore, a combination measure of positive and negative incentives is proposed.

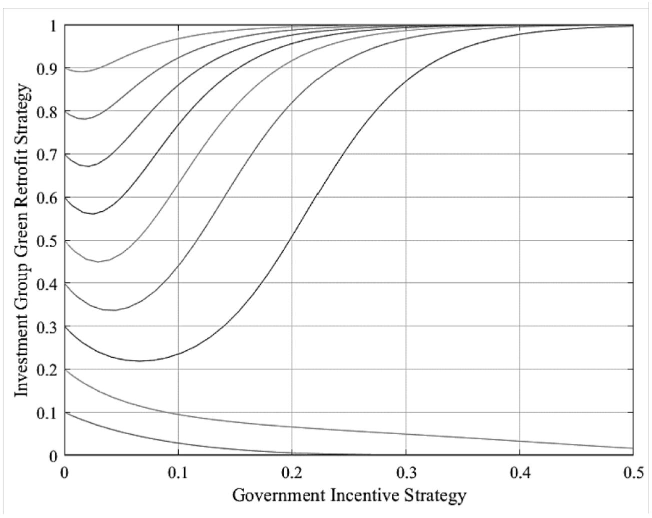
(3) The combination policy incentive measure

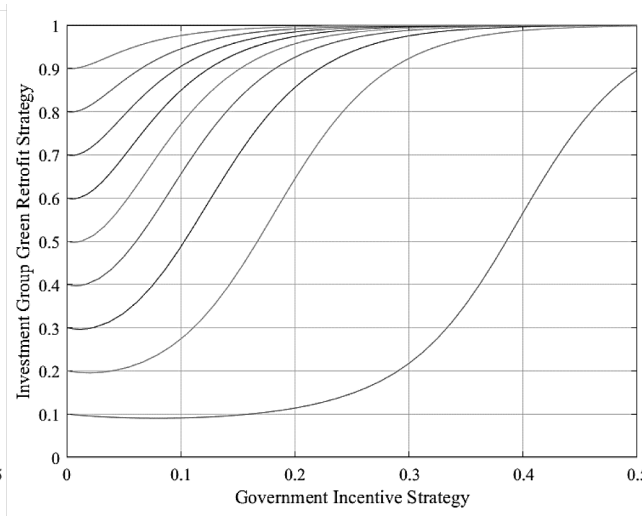
The saddle point is (0.60, 0.19) under the combination policy incentive measure. The probability that the government groups do not encourage green retrofits and the investment groups do not implement green retrofits is reduced to 11.4%. The probability that government groups encourage green retrofits and the investment groups implement green retrofits is increased to 28.4%. The strategy of the government groups x is taken as 0.4, 0.6 or 0.8 to view the change in the investment group strategy y. (Fig. 10).

Compared with the single negative incentive measure, the incentive effectiveness decreased a little. When the government groups highly encourage the green retrofit (x ¼ 0.8), all the investment groups will implement green retrofits. The effectiveness is similar to the effectiveness of the incentive measure of both increasing benefits and reducing costs. This is a more moderate incentive measure, which could achieve good effectiveness.

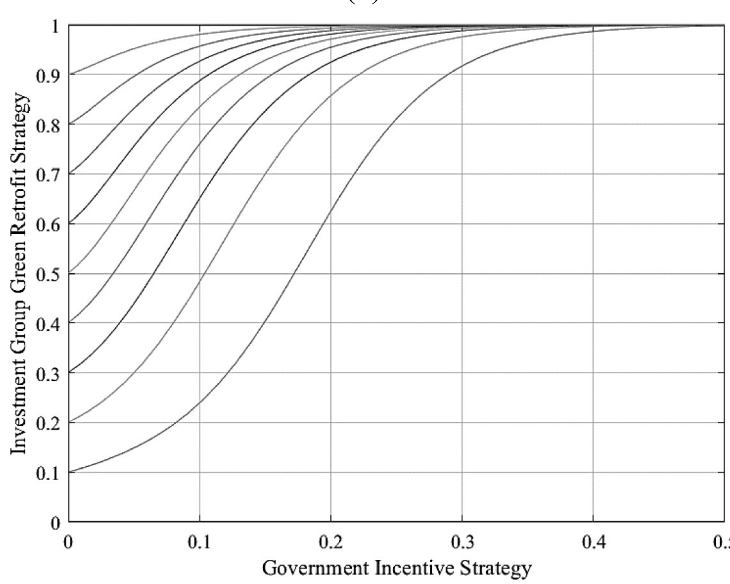
5. Discussion

This paper established the evolutionary game optimization model of green retrofits for PPP-BR and determined the incentive simulation method. From the case simulation, the more highly the government groups encourage green retrofits, the more willingly the investment groups implement green retrofits. There will be different incentive effectiveness because of the different incentive measures. The comparison results of the initial parameters and the different incentives are summarized in the Table 7.





(a) (b)



(c)

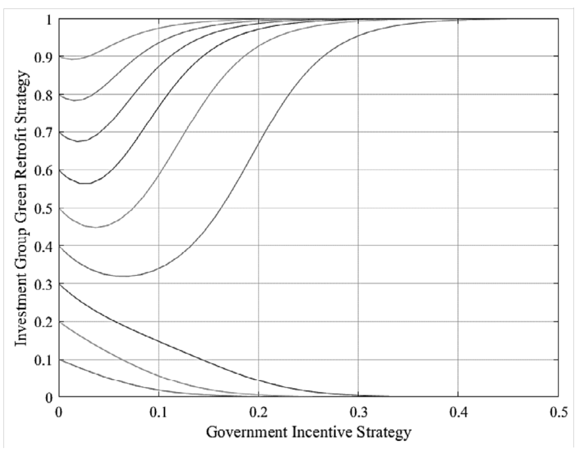
Fig. 9. Dynamic evolution process of investment group strategy under the negative policy incentive measure: (a) x ¼ 0.4 (b) x ¼ 0.6 (c) x ¼ 0.8.

Compared with the reference, all of the probabilities of {Encouraging green retrofits G_1, Implementing green retrofits I_1} increase. The increased benefits and reduced costs have the best incentive effectiveness. Except for the positive policy incentive measure, all the other probabilities of {Non-encouraging green retrofits G_2, Non-implementing green retrofits I_2} decrease. The negative policy incentive measure has the best incentive effectiveness. For the investment group strategy, increasing additional benefits or reducing incremental costs alone could promote investment groups to implement green retrofits. However, it is unable to urge all of the investment groups to implement green retrofits, when the government groups encourage green retrofit highly. Both increasing benefits and reducing benefits measures will achieve the better incentive effectiveness.

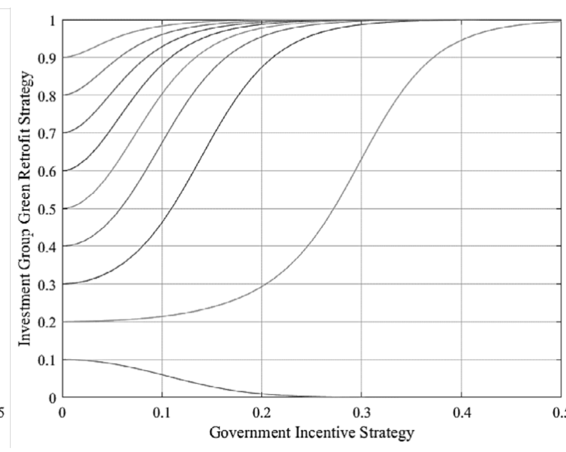
The positive policy incentive measure will reduce the amount of investment groups which implement green retrofits, while the negative policy incentive measure will achieve a very strong effectiveness. However, the strong effectiveness may incur problems, and the combination policy incentive measure may get a better and more moderate effectiveness.

This paper could illustrate that both reducing incremental costs and increasing additional benefits could improve the willingness to implement green retrofits. Although the incentive effect of only increasing benefits is not good, it is better than that of not doing any measures in the short term. In the short term, it is more feasible to find ways to increase additional benefits than to upgrade the technology to reduce costs. Therefore, in the short term, increasing additional benefits is a good incentive measure.

From the perspective of policy incentives, positive policy incentive measure will achieve negative effects (Harrison and Seiler, 2011). Although this phenomenon is not a systematic study, based on the results, the probability of {Non-encouraging green retrofits G_2, Non-implementing green retrofits



(a)



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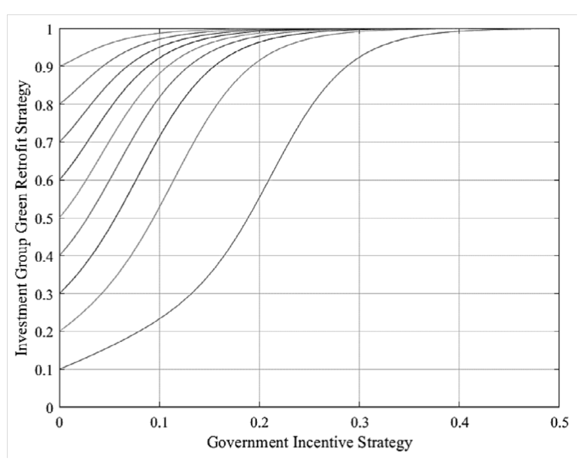

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Fig. 10. Dynamic evolution process of investment group strategy under the combination policy incentive measure: (a) x ¼ 0.4 (b) x ¼ 0.6 (c) x ¼ 0.8.

I_2} increases, and the probability is greater than that of {Encouraging green retrofits G_1, Implementing green retrofits I_1}. This indicates that the probability of evolution into {Non-encouraging green retrofits G_2, Non-implementing green retrofits I_2} is greater. From an economic perspective, this result validates the reinforcement theory. When the incentive scarcity and exclusiveness are lacking, the incentives will fail (Skinner, 1948). In the short term, the positive policy incentives will promote green retrofits (Gou et al., 2013). This is because such incentives are needed by the investment groups; and there are fewer groups investing green retrofits, so that the incentives are scarce and exclusive. However, in the long term, despite the degree of the incentives is increase, excessive positive policy incentives gradually lose their scarcity. More and more investment groups, as time goes by, begin to implement green retrofits that will lead to the lack of exclusiveness (Skinner, 1948; Aronowitz and Weinberg, 1966). Lack of scarcity and exclusiveness of incentives will reduce the proportion of green retrofits. It can be seen that if positive policy incentive measures are used on their own, they cannot effectively promote the green retrofits. This obviously refutes the studies claiming that “promoting positive incentive measures can promote green retrofits” (Kubba, 2010; Fuerst and McAllister, 2011).

Tax incentives do have negative consequences (Koppenjan, 2015). Although this measure has not been implemented in many countries, the simulation results are gratifying. The negative policy incentive measure can promote all the investment groups to sharply implement green retrofits, which can be regarded as an inevitable choice to avoid punishment. However, according to the reinforcement theory, negative incentives may lead to side effects (although this paper has studied these side effects in detail). Therefore, the combination of positive and negative incentives could get the better and more moderate incentive result (Skinner, 1948; Koppenjan, 2015). The policy incentive measures are less constrained by the objective environment; therefore, comparing the measure of both increasing benefits and reducing costs, combination policy incentives measure are the best way to promote green retrofits for PPP-BR.

6. Conclusion and prospects

6.1. Conclusion

On the basis of the literature analysis, this paper established an evolutionary game optimization model of green retrofits for PPP-BR and a case simulation analysis framework of incentive measures. It also reveals the game strategy change of the government groups and the investment groups and the effectiveness of different incentive measures.

Table 7
Game results of initial parameters and the different incentives.

Incentive measures	Saddle point	Probability of {G_2, 2} and comparison with reference	Probability of {G_1, 1} and comparison with reference	The investment group strategy of green retrofits for PPP-BR	Barriers of implementing incentives
Non-incentives (Reference)	(0.9,0.2)	18%	8%	Not all of investment groups implement	e

				green retrofits (x ¼ 0.8)	
Incentive measures from the perspective of benefit and cost	Increasing additional benefits	(0.725,0.2) 14.5%Y	22%[	Not all of investment groups implement green retrofits (x ¼ 0.8) The amount is less than that of reference	The difficulty to increase benefits for some public nonprofit projects
	Reducing incremental costs	(0.675,0.2) 12.5%Y	26%[	Not all of investment groups implement green retrofits (x ¼ 0.8) The amount is less than that of reference	The difficulty to reduce costs for Upgrading green retrofit technology
	Increasing benefits and reducing costs	(0.5,0.2) 10%Y	40%[[13.6%[	All of investment groups implement green retrofits (x ¼ 0.8)	Same to the above e
Incentive measures from the perspective of positive and negative policies	Positive policy incentive measure	(0.8,0.32) 25.6%[		Not all of investment groups implement green retrofits (x ¼ 0.8) The amount is more than that of reference	
	Negative policy incentive measure	(0.65,0.06) 3.9%YY	32.9%[[	All of investment groups	Maybe causing problems
	Combination policy incentive measure	(0.6,0.19) 11.4%Y	28.4%[		e

implement green retrofits (x ¼ 0.6)
All of investment groups implement green retrofits (x ¼ 0.8)

(1) The government groups and the investment groups will eventually evolve into the final strategies of {Encouraging green retrofits G_1, Implementing green retrofits I_1} and {Nonencouraging green retrofits G_2, Non-implementing green retrofits I_2}. D (x^*, y^*) is the saddle point affecting the changes in game evolution. When the position of the saddle point is closer to (0,0), the government groups are inclined to encourage green retrofits and the investment groups are inclined to implement green retrofits.

(2) Comparing the results of the incentive simulation with those of the initial parameters, using the measures of increasing benefits and reducing costs could obtain better incentive effectiveness. Additionally, the combination policy incentive measure is the best incentive measure to promote green retrofits for PPP-BR.

6.2. Implications for theory and practice

The findings of this study have two implications and contributions for theory. First, after redefining PPP-BR, analyzing the barriers and incentives of green retrofits, the game optimization model and case simulation framework are established, providing the quantitative analysis method of green retrofits for PPP-BR. It means if the government groups encourage green retrofits, the investment groups will eventually implement green retrofits, and vice versa. The more active the government groups are encouraging green retrofits, the more active the investment groups tend to be in implementing green retrofits. Second, referring to reinforcement theory, this paper uses positive reinforcement and negative reinforcement to analyze how to motivate green retrofits by policy incentives. It expands the application field of reinforcement theory. According to the reinforcement theory, the effect of negative policy incentive measure is the best, but it may produce some side effects. The combination of policy incentive measure will be the better one to promote more investment groups to implement green retrofits more harmoniously. The implications and contribution for practice of this paper is mainly to propose incentive measures to promote the private sectors to implement green retrofits, to achieve functional strengthening and an environmentally friendly coexistence of building regeneration and promote urban sustainable green development. The specific incentives include:

(1) From the perspective of benefits and costs, the government should assist investment enterprises to conduct an in-depth analysis of PPP-BR projects and reasonably explore the expansive benefits of green retrofits in the short term. It will realize the stability and multichannel of its capital gains and promote the market operation of green retrofits. In the long run, the government should encourage enterprises related to green retrofit technologies to take development thinking as the guide, and help to reduce the green retrofit costs. It should support PPP-BR projects to explore expansive benefits and promote incentive measures of the comprehensive optimization of benefits and costs.

(2) From the perspective of policy incentives, the financial incentives should increase appropriately, and the non-green retrofit tax for PPP-BR projects should increase reasonably. This means the joint implementation of positive and negative policy incentive measures will better promote the green retrofits for PPP-BR.

In summary, the game strategy and incentive measures proposed in this paper are of great significance for promoting green retrofits of existing buildings, achieving energy efficiency, reducing environmental pollution and improving the quality of life and work efficiency. It also provides ways to solve the shortage of green retrofits for PPP-BR. The results can help the government to put forward policies to guide urban green construction and regeneration, which is of great significance for realizing the urban green and sustainable urban development.

6.3. Limitations and future study

As with any study, this study is not without limitations. First, the case focuses on the particularity of retrofits and public welfare, so the project is not comprehensive and lacks the expansion of benefits. Second, to determine the effect of parameters, this paper only uses the case simulation. It needs to be further analyzed with the actual data. Third, although it is proposed that using positive policy incentive measures alone will result in a negative effect, there is no in-depth analysis of the reason for this. There is also no detailed description of the possible side effects of only using negative incentives. These problems need to be explored in a future study.

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