https://doi.org/10.1016/j.buildenv.2020.106972

Evolutionary game theory analysis for understanding the decision-making mechanisms of governments and developers on green building incentives

Ke Fan [a,*], Eddie C.M. Hui [b]

[a] School of Design and Environment, National University of Singapore, Singapore
[b] Department of Building and Real Estate, Faculty of Construction and Environment, The Hong Kong Polytechnic University, 11 Yuk Choi Rd, Hung Hom, Hong Kong SAR, China

A B S T R A C T

Green building incentives are widely implemented. Under each incentive, governments and developers have different payoffs and dominant strategies that affect incentive effectiveness. Existing studies have examined incentive effectiveness through different methods but have failed to reveal the decision-making mechanisms of governments and developers in a dynamic process of a game. As governments and developers have bounded rationality, and their strategies may change from time to time, this study employed evolutionary game theory to model the evolutionary behaviours of two players, thus providing a quantitative method to illustrate the effectiveness of incentives and the strategy changes of the players. This study concluded that four types of interactions between governments and developers affect incentive effectiveness, namely, 1) governments' dominant strategies depend on developers' choices; 2) developers' dominant strategies rely on governments' choices; 3) two parties' dominant strategies are independent; 4) their dominant strategies are interdependent. Under these interactions, the price premium of green building and the level and affordability of incentives were found to be the critical factors for the decision makings of the leading players. Policy recommendations were proposed accordingly. This study adopted a mathematical approach to investigate the conflicts of interests between governments and developers. It also provided a general model which can fit various contexts. In addition, the research introduced a valuable angle of government payoffs. Results can advance policymakers' understanding of green building incentives, help policymakers predict developers' behaviours and the incentive effectiveness in the long run and justify the design or improvement of multinational incentives.

Keywords:
Green building incentives Incentive effectiveness
Evolutionary game theory
Government Developer

1. Introduction

In 2018, a total of 136 countries mentioned the emissions of buildings in their Nationally Determined Contributions under the Paris Agreement [1], indicating that building energy consumption is attracting governments' attention globally. Building energy consumption accounts for 40% of energy, and it continuously increases in recent years, highlighting the urgent need for policymakers and investors to take action [2]. Green building (GB), as one of the solutions to reduce building energy consumption and construction waste, becomes a growing tendency. GB is considered a priority for the sustainable development of the world and has been accepted by developing and developed countries [3,4]. However, various barriers to GB adoption have emerged, such as social and psychological barriers [5], institutional barriers [6] and cost barriers [7]. Researchers in different countries and regions, such as mainland China, Hong Kong, Canada, Ireland, Brazil, Sweden and Ghana, have investigated GB barriers [7]. GB barriers are recognised as common issues all over the world.

In recent years, many governments have implemented GB incentives to address the barriers and facilitate the adoption of GB. In academia, studies focus on GB incentives, such as the review of GB incentives [8,9], costs and benefits of GB incentives [10,11], transaction cost of GB incentives [12] and the evaluation of the adaptability of GB incentives [13]. Given that GB incentives consume social resources, their effectiveness are significant and should gain further attention. Olubunmi et al. [8] claimed that further studies on the effectiveness of GB incentives across the world are needed to inform the generalisability of incentive effectiveness and justify government policies. Existing literature, which evaluates the effectiveness of GB incentives, usually use the methods of systematic literature review, classic game theory and survey to analyse GB incentives and propose policy recommendations. However, these approaches fail to address the decisions and interactions between governments and developers in a dynamic process of a game. Such decisions and interactions are crucial to understand the strategy changes of the two parties and to justify the design and improvement of GB incentives in the long run.

Although the interactions between governments and enterprises in the field of environmental issues are of interest to researchers, existing studies on GB incentives have done little on the behaviours and decisions of governments and developers [14,15]. Regarding GB incentives, the two players' interactions change with the contexts within which governments implement various incentive instruments, and governments and developers obtain different payoffs from the incentives. In the interaction process, two parties observe, imitate and learn from each other and change their strategies. To reveal the decision-making mechanisms of governments and developers, this study employs evolutionary game theory for analysing the dynamic evolution processes of games. Evolutionary game theory is an important branch of classic game theory. It fills the gaps of classic game theory which assumes that players are rational and focuses on strategic decision making in a static game. The research objectives of this study are to formulate a game model of a generic GB incentive, to work out the payoff situations of governments and developers, to simulate the interactions between governments and developers and to illustrate the incentive effectiveness and strategy changes of the two players.

The research rationale is shown in Fig. 1. This paper contributes to the design and revision of GB incentives by providing an overview of how developers and governments interact with each other under different contexts and explain incentive effectiveness. Given the many incentive instruments for policymakers that bring different payoffs to governments and developers, this study also serves as a guidance of how to select or improve GB incentives to address market barriers and failures. The research outcome is to provide general insights into multinational policy analyses or designs.

2. Literature review

2.1. GB incentives

GB incentives are designed to address the market barriers and failures of GB development. Many countries and regions have implemented GB incentives, such as tax reduction, subsidies, loan incentives, density bonus, fee reduction and grants and have expedited permitting process. Given that GB incentives consume social resources, their effectiveness is essential and should obtain further attention. Olubunmi et al. [8] claimed that additional studies are needed to uncover the effectiveness of GB incentives worldwide for the purpose of informing the generalisability of incentive effectiveness and justifying government investments.

Existing studies have investigated the effectiveness of GB incentives from different perspectives, such as economic perspective [10,16], transaction cost perspective [12], stakeholder behaviour perspective [17] and policy overview in China [18] and across the globe [8].

Researchers have adopted different methods to investigate stakeholders' behaviour and decision making, such as questionnaire survey [19], classic game theory [20,21] and systematic literature review [17]. The survey method allows researchers to look into the details of GB incentives within a particular context but fails to look at broad areas. Portnov et al. [22] believed that the results from the survey on stakeholders' decision making should be considered as place- and time-specific. Moreover, a systematic review approach provides an overview of existing studies beyond geographical areas, but the overall research outcome is somewhat constrained by the methodology of the existing approach. Game theory is a powerful tool to model stakeholders' decision making. Most existing studies, such as Liang et al. [23], Cohen et al. [20] and Li et al. [21], have applied classic game theory and modelled static games in a certain context with multiple players or two players in private sectors (e.g. developers and clients) and ignored the dynamic process of games.

As GB incentives are closely related to governments' payoffs and in turn affect their policy making, governments should be included in the game model. Developers are the key implementors of GB incentives, and their decisions significantly influence the effectiveness of GB incentives. Therefore, modelling the interactions between governments and developers is significant to understand their decision-making mechanisms and incentive effectiveness. In addition, many types of GB incentives are implemented in various contexts. Governments and developers have different interactions, and their strategies vary from time to time. Thus, revealing the dynamic process of games and understanding their strategy changes are important. Few studies have focused on the decision makings of governments and developers and their interactions in the dynamic process of a game under generic GB incentives. This study fills such a gap.

2.2. Evolutionary game theory

Game theory focuses on the interactions amongst agents, formulating the hypothesis of their behaviours and predicting the end results [24]. It uses mathematical models to foresee the behaviour of players in situations of cooperation and conflict [25]. Game theory is commonly applied to environmental policies [26–28].

An important type of game theory is evolutionary game theory, which was first introduced by biologists [29]. In contrast to classic game theory, evolutionary game theory shifts the focus away to dynamic theories which explicitly model how one reaches to where it is [30]. However, evolutionary game theory is not limited to dynamics and equilibrium, as it also describes that players can imitate successful behaviours or calculate best responses to the current population by observing history information on the success and failures of various choices [31]. Thus, low payoff strategies tend to be replaced with high payoff ones over time [32], and players only need to know what was successful in the past, rather than why it was successful [31]. Smith and Price [33] introduced the concept of evolutionary stable strategy (ESS), that is, the core concept of equilibrium. ESS must be able to resist invasion by alternative strategies [34]. Many researchers have applied evolutionary game theory to environmental issues. For example, Estalaki et al. [35] used this approach to resolve the conflicts of interests arising amongst different dischargers of river water. Wu et al. [36] applied this method to analyse governments' low-carbon strategies. Therefore, evolutionary game theory is an effective approach for policy making.

Regarding GB incentives, governments want additional GBs to reduce energy consumption and construction waste [37]. However, developers are usually unwilling to construct GB as it is more costly than CB and may not have a high price premium to offset the extra cost [10]. Therefore, governments must provide incentives for developers that can cost governments and may make governments hesitate to implement incentives. In this sense, conflicts of interests between governments and developers have emerged. To investigate this issue, game theory is appropriate to conduct a mathematical study of situations of conflicts of interests. This approach can also provide a general model that can fit various contexts and be unconstrained by a particular context or geographical area. Thus, the conclusions are useful for multinational policy design and improvement.

Classic game theory focuses on the strategic decision making and assumes that players are rational, ignoring the dynamic process of the game and the fact that players have bounded rationality [38]. As GB incentives are still evolving, and two players can compare payoffs and adjust strategies, this study adopts evolutionary game theory to investigate the long-term dynamic game between the bounded rational players.

2.3. Costs and benefits of GB incentives

Implementing incentives brings costs and benefits to governments and developers, and these costs and benefits change with the incentive design. For example, if governments implement economic incentives, such as subsidies and tax reduction, then the incentive degree can affect governments' costs and

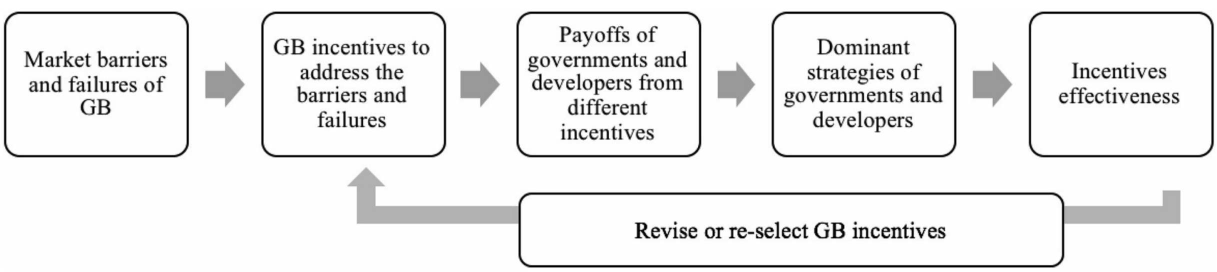


Fig. 1. Research rational.

developers' benefits and is constrained by governments' financial muscle [9,10]. In this sense, although implementing GB incentives can increase the market share of GB and benefit the built environment, governments must still consider their financial capability [19]. Certain kinds of incentives which are unconstrained by governments' budget exist, such as density bonus and gross floor area concession. However, governments must still consider the negative impacts of too much density bonus on the built environment, such as effects of street canyon and urban heat island [39]. Moreover, designing and implementing incentives incur transaction costs borne by governments, such as information searching, coordination, monitoring and approval costs [12,40]. Therefore, governments should bear additional costs if they implement GB incentives, either actual or transaction costs. In this sense, governments' strategies may change with their net benefits.

For developers, the degree of GB incentives directly determines the amount of developers' benefits. In certain countries, however, developers' benefits rely on not only government incentives but also the market price of GB. For example, in Singapore, the United Kingdom and some cities in mainland China, the GB has a higher price than CB [41–43]. Thus, developers can obtain incentives from the property market. By contrast, in Israel and Hong Kong, residents do not value green features; location and property price are more important factors for them [22,44]. Thus, making GB enjoy a higher price than CB is difficult. Other incentives of constructing GB for developers exist, such as good reputation and energy savings [10,45]. In terms of costs, developers bear additional actual and transaction costs if they participate in GB incentive schemes, such as high construction cost, information searching cost and approval cost [12,22]. If transaction costs are large, then developers can choose not to participate in the incentive schemes [12].

3. Evolutionary game model analysis

Various GB incentives have been implemented worldwide and brought governments and developers different costs and benefits. For governments, the implementation of GB incentives requires the collaboration of departments, such as Buildings Department, Land Department and Department of Finance. These departments are regarded as a government group. Developers benefit from government incentives and bear the costs of participating in incentive schemes. They have different views towards government incentives. Similarly, all developers in the market are seen as a developer group. Governments and developers have preferences for different strategies. Two groups can observe, imitate and learn from each other, and thus their behaviours are evolved. By constant learning and trial and error, two groups can eventually identify their appropriate strategies. *3.1. Assumptions and payoff matrix*

(1) **Players:** Assume that two groups exist in the game, namely, governments and property developers. The players attempt to maximise their profits but have bounded rationality.
(2) **Strategies:** As implementing GB incentives can promote GB but induce costs to governments, certain departments are for providing incentives, but some are against. Assume that governments have two pure strategies: with incentives and without incentives, denoted by *GðiÞ* and *G*, respectively. Developers are free to choose between GB and CB, denoted by *D*1 and *D*0, respectively. Governments and developers are randomly paired to join the game. During

the *t* period, the proportion (or probability) of governments implementing GB incentives is x ($0 \le x \le 1$), whereas the share of developers constructing GB is y ($0 \le y \le 1$).

(3) **Payoff matrix:** For governments: (1) G_0 is the net benefit of governments when developers tend to go for CB without GB incentives, where R_G and C_G are the benefits and costs, respectively. (2) G_1 is governments' net benefit when developers prefer to go for GB without GB incentives, where B_{GB} refers to governments' extra benefits when developers tend to construct GB, such as environmental benefits; (3) G_{I0} is the net benefit of implementing GB incentives when developers tend to go for CB, where B_{I0} refers to the benefits of designing GB incentives, such as good reputation and increased public awareness of GB, and C_{I0} refers to the costs of designing GB incentives, such as information and communication costs; (4) G_{I1} is the net benefit of implementing GB incentives when developers choose GB, where λS_G is the benefit relevant to GB incentives. When developers earn profits from GB incentives, these profits can be absorbed partly or fully by governments through property tax, land lease or any other ways. The benefit absorbed by governments is denoted by λS_G ($\lambda \ge 0$). βS_G refers to the costs of implementing GB incentives, such as subsidies and tax reduction.

For developers: (1) D_0 is the net benefit of constructing CB when no GB incentives exist, where R_E and C_E are the benefits and costs, respectively; (2) D_1 is the net benefit of building GB when no GB incentive exists, where γR_E and δC_E are the extra benefits and costs of constructing GB, respectively; (3) D_{I0} is the net benefit of constructing CB when GB incentives exist, where T_0 refers to the cost of not constructing GB under government incentives, such as weak product competitiveness and opportunity costs; $T_0 > 0$. (4) D_{I1} is the net benefit of going for GB when GB incentives exist, where S_G is the benefit from GB incentives.

The payoff matrix is established and shown in Table 1.

Table 1
Payoff matrix.

	GB (y)	OB $(1 - y)$
With incentives (x)	$(G_{I1}; D_{I1})$	$(G_{I0}; D_{I0})$
Without incentives $(1 - x)$	$(G_1; D_1)$	$(G_0; D_0)$

Note.
$G_{I1} = R_G + B_{GB} + B_{I0} + (\lambda - \beta)S_G - C_G - C_{I0}$
$D_{I1} = (1 + \gamma)R_E + S_G - (1 + \delta)C_E$
$G_{I0} = R_G + B_{I0} - C_G - C_{I0}$
$D_{I0} = R_E - C_E - T_0$
$G_1 = R_G + B_{GB} - C_G$
$D_1 = (1 + \gamma)R_E - (1 + \delta)C_E$ $G_0 = R_G - C_G$
$D_0 = R_E - C_E$

3.2. Replicator dynamic system

$$U_{G(I)} = y*G_{I1} + (1 - y)*G_{I0}$$

$$U_G = y*G_1 + (1 - y)*G_0$$

$$\overline{U_G} = x*U_{G(I)} + (1 - x)U_G$$

$$U_{D1} = x*D_{I1} + (1 - x)*D_1$$

$$U_{D0} = x*D_{I0} + (1 - x)*D_0$$

$$\overline{U_D} = y*U_{D1} + (1 - y)U_{D0}$$

$U_{G(I)}$, U_G, U_{D1} and U_{D0} are the expected payoffs of governments and developers respectively choosing the strategies of $G(I)$, G, $D1$ and $D0$. Their weighted average expected payoffs are $\overline{U_G}$ and $\overline{U_D}$. According to the replicator dynamics introduced by Taylor and Jonker [46], the replication dynamics equation of governments and developers are as follows:

$$\frac{dx}{dt} = f_G(x;y) = x\left(U_{G(I)} - \overline{U_G}\right) = x(1 - x)[y(G_{I1} - G_{I0} - G_1 + G_0) + (G_{I0} - G_0)] \tag{1}$$

$$\frac{dy}{dt} = f_D(x;y) = y\left(U_{D1} - \overline{U_D}\right) = y(1 - y)[x(D_{I1} - D_{I0} + D_0 - D_1) + (D_1 - D_0)] \tag{2}$$

According to Equations (1) and (2), the strategies that make governments and developers receive high payoffs can gain their popularity in the next round of the game.

3.3. Analysis model

Let Equations (1) and (2) be equal to zero, that is,

$$f_G(x,y)=\frac{dx}{dt}=x(1-x)\{y[(G_{l1}-G_1)+(G_0-G_{l0})]-(G_0-G_{l0})\} \quad (3)$$

$$f_D(x,y)=\frac{dy}{dt}=y(1-y)\{x[(D_{l1}-D_{l0})+(D_0-D_1)]-(D_0-D_1)\} \quad (4)$$

According to Equations (3) and (4) and $(x,y)\in[0,1]\times[0,1]$, four pure strategies equilibrium points, namely, A (0,0), B (0,1), C (1,0), D (1,1) and mixed strategy equilibrium point $E(x^*,y^*)$ can work out, where

$$x^*=\frac{D_0-D_1}{(D_{l1}-D_{l0})+(D_0-D_1)}$$

$$y^*=\frac{G_0-G_{l0}}{(G_{l1}-G_1)+(G_0-G_{l0})}$$

To identify the evolutionary stable strategy, the stability of these equilibrium points must be analysed. According to Friedman [32], the Jacobian matrix is applicable to evaluate the evolution equilibrium stability. The Jacobian matrix is given by:

$$J=\begin{bmatrix}\frac{\partial f_G}{\partial x} & \frac{\partial f_G}{\partial y}\\ \frac{\partial f_D}{\partial x} & \frac{\partial f_D}{\partial y}\end{bmatrix}$$

The corresponding trace and determinants are as follows:

$$T_r(J)=\frac{\partial f_G}{\partial x}+\frac{\partial f_D}{\partial y}$$

$$Det(J)=\frac{\partial f_G}{\partial x}*\frac{\partial f_D}{\partial y}-\frac{\partial f_G}{\partial y}*\frac{\partial f_D}{\partial x}$$

According to the partial stability analysis method of the Jacobian matrix:

(1) If $T_r(J)<0$, $Det(J)>0$, then the corresponding equilibrium point is stable, and the point is ESS;

(2) If $T_r(J)<0$, $Det(J)>0$, then the corresponding equilibrium point is unstable;

(3) If $T_r(J)=0$, $Det(J)>0$, then the corresponding equilibrium point is unstable;

(4) If $Det(J)=0$, then the corresponding equilibrium point is unknown.

(5) If $Det(J)<0$, then the corresponding equilibrium point is a saddle point.

The Jacobian matrices at the five possible equilibrium points are listed below:

$$J(0,0)=\begin{pmatrix}-(G_0-G_{l0}) & 0\\ 0 & -(D_0-D_1)\end{pmatrix}$$

$$J(0,1)=\begin{pmatrix}G_{l1}-G_1 & 0\\ 0 & D_0-D_1\end{pmatrix}$$

$$J(1,0)=\begin{pmatrix}G_0-G_{l0} & 0\\ 0 & D_{l1}-D_{l0}\end{pmatrix}$$

Jð1;1Þ¼ð ðG_I1 G_1Þ00 ðD_I1 D_I0ÞÞ
0
B 0
* * B

ðD_I1 D_I0ÞðD_0 D_1Þ ½ðG 2 I1 G_1Þ þ ðG_0 G_I0ÞC
½ðD_I1 D_I0Þ þ ðD_0 D_1Þ

1Jðx ;y Þ¼B C
@ ðG_0 G_I0ÞðG_I1 G_1Þ
C A

2 ½ðD_I1 D_I0Þ þ ðD_0 D_1Þ 0
½ðG_I1 G_1Þ þ ðG_0 G_I0Þ

where

G_{I1} G_1 ¼ B_{I0} C_{I0} þ ðλ θÞS_G

G_0 G_{I0} ¼ C_{I0} B_{I0}

D_{I1} D_{I0} ¼ γR_E þ S_G þ T_0 δC_E

D_0 D_1 ¼ δC_E γR_E ðD_{I1} D_{I0}ÞþðD_0 D_1Þ¼γR_E þS_G þT_0 δC_E þ δC_E γR_E ¼S_G þ T_0 >0

Given that ðD_{I1} D_{I0}Þþ ðD_0 D_1Þ > 0, D_{I1} D_{I0} and D_0 D_1 cannot be less than 0 simultaneously, 12 scenarios relevant to the stability of these equilibrium points are worked out and presented in Table 2. The 12 scenarios also represent the 12 payoff situations of governments and developers in the real world. In Table 2, if G_{I1} $G_1 > 0$, then G_{I1} has a relative advantage. The same logic applies to the other formulas in Table 2.

4. Model results

With the analysis above, the replicator dynamic results of the five equilibrium points in 12 scenarios are worked out and shown in Table 3. The evolution path and equilibrium stability of the strategic interactions of the two players in the 12 scenarios are illustrated from Figs. 2–13.

Scenario 1: If G_{I1} $G_1 < 0$, G_0 $G_{I0} < 0$ and D_0 $D_1 < 0$, then D_{I1} $D_{I0} > 0$. Thus, the ESS is B (0,1). In this situation, regardless of whether governments implement GB incentives or not, doing GB is always more profitable than constructing CB. Therefore, the proportion of developers constructing GB gradually increases to 1. When developers choose to construct GB, governments tend to do nothing with the GB market. When developers prefer CB, they tend to implement incentives. In this sense, governments' dominant strategies rely on developers' choices. Given that developers' dominant strategy is GB, the market can become stable when all developers construct GB, and no GB incentives exist, as illustrated in Fig. 2. This scenario is an ideal one, that all countries and regions are in pursuit of, because the built environment can become green with zero extra cost borne by governments. The GB market can sustain itself.

Table 2

Scenarios	Equilibrium				
	A (0,0)	B (0,1)	C (1,0)	D (1,1)	E ð***x*** ;***y*** Þ
Scenario 1	Unstable	**Stable**	Saddle	Saddle	Not exist
Scenario 2	Saddle	Saddle	Saddle	Saddle	Center
Scenario 3	Saddle	Saddle	**Stable**	Unstable	Not exist
Scenario 4	Saddle	**Stable**	Unstable	Saddle	Not exist
Scenario 5	**Stable**	Saddle	Unstable	Saddle	Not exist
Scenario 6	**Stable**	Saddle	Saddle	Unstable	Not exist
Scenario 7	Unstable	Saddle	Saddle	**Stable**	Not exist
Scenario 8	Saddle	Unstable	Saddle	**Stable**	Not exist
Scenario 9	Saddle	Unstable	**Stable**	Saddle	Not exist
Scenario 10	Saddle	Saddle	Unstable	**Stable**	Not exist
Scenario 11	**Stable**	Unstable	Unstable	**Stable**	Unknown

Scenario 12	**Stable**	Unstable	Saddle	Saddle	Not exist

12 scenarios about the combinations of positive and negative symbols.

Scenarios	G_{I1} G_1	G_0 G_{I0}	D_0 D_1	D_{I1} D_{I0}
Scenario 1	-	-	-	þ
Scenario 2	-	-	þ	þ
Scenario 3	-	-	þ	-
Scenario 4	-	þ	-	þ
Scenario 5	-	þ	þ	þ
Scenario 6	-	þ	þ	-
Scenario 7	þ	-	-	þ
Scenario 8	þ	-	þ	þ
Scenario 9	þ	-	þ	-
Scenario 10	þ	þ	-	þ
Scenario 11	þ	þ	þ	þ
Scenario 12	þ	þ	þ	-

Table 3

State of five equilibr um points in 12 scenarios.

To achieve the ideal outcome, GB must have a higher price premium ($\gamma R_E > 0$) than CB, and the high premium can at least offset the extra cost of GB ($\delta C_E \gamma R_E < 0$). Thus, GB development cannot rely on government incentives. For governments, $G_0 G_{I0} < 0$ means $C_{I0} B_{I0} < 0$, indicating that the cost of developing incentives (e.g. information and coordination costs) is less than its benefit (e.g. reputation, public awareness). Given that $G_{I1} G_1 < 0$; where $B_{I0} C_{I0}$ þ ðλ βÞ$S_G < 0$, the benefits of developing incentives plus the absorbed developers' benefits from incentives (if any) exceed the costs of developing and implementing incentives. Therefore, when developers go for GB, governments tend not to implement incentives. The incentives in this scenario are unaffordable for governments and unimportant for developers.

Scenario 2: If G_{I1} $G_1 < 0$, G_0 $G_{I0} < 0$, D_0 $D_1 > 0$ and D_{I1} $D_{I0} > 0$, then no ESS exists in this scenario in which developers' construction of GB depends on the existence of GB incentives. That is, GB incentives in this scenario can definitely incentivise developers to do GB. However, governments tend not to provide incentives if developers prefer GB. Thus, with incentives, the proportion of developers going for GB increases gradually. As a result, governments tend to remove the incentives to maximise their profits because $G_{I1} G_1 < 0$. If governments do so, then developers can change their strategies to go for CB. Thus, the proportion of developers going for GB can decrease gradually. Consequently, governments can change their strategy and tend to develop GB incentives to improve their profits. Therefore, the market can never become stable. Essentially, in this scenario, the choice of one player depends on that of the opposite player. The two players' evolution paths are cyclical and can never reach stable points, as illustrated in Fig. 3.

In practice, this scenario is the case when the high price premium ($\gamma R_E > 0$) of GB cannot offset its extra cost ($\delta C_E \gamma R_E > 0$) or no price difference exists between GB and CB (γR_E ¼ 0), but government incentives can help cover the costs. Hence, incentives are needed, and their level must be attractive to developers. For governments, given that $G_0 G_{I0} < 0$; where $C_{I0} B_{I0} < 0$, the cost of designing GB incentives (e.g. information cost) is less than its benefit (e.g. reputation, public awareness). This condition explains why governments prefer to develop

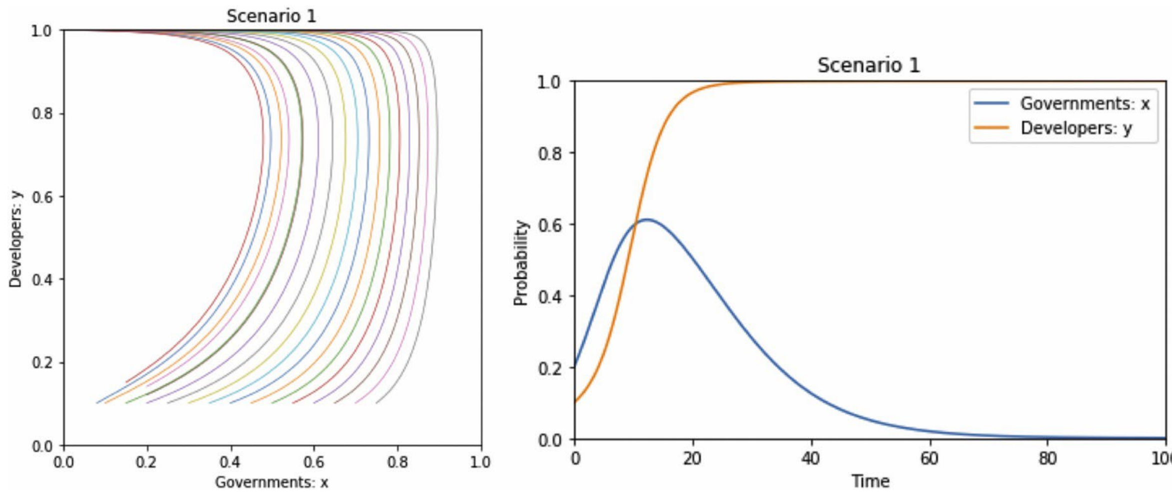


Fig. 2. Dynamic evolution process of Scenario 1. Note: The ESS is (0,1), as shown in the left figure. The right figure illustrates that developers and governments spend 30 and 80 units of time reaching points 1 and 0, respectively, indicating that developers reach the point faster than governments.

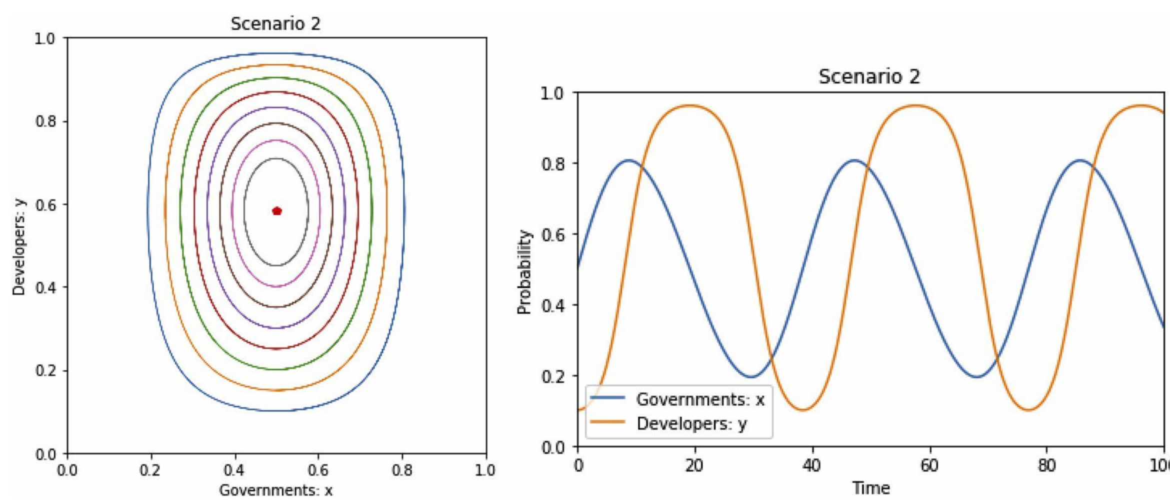


Fig. 3. Dynamic evolution process of Scenario 2. Note: The choice of one player depends on that of the opposite player. Two players' evolution paths are cyclical that they can never reach stable points.

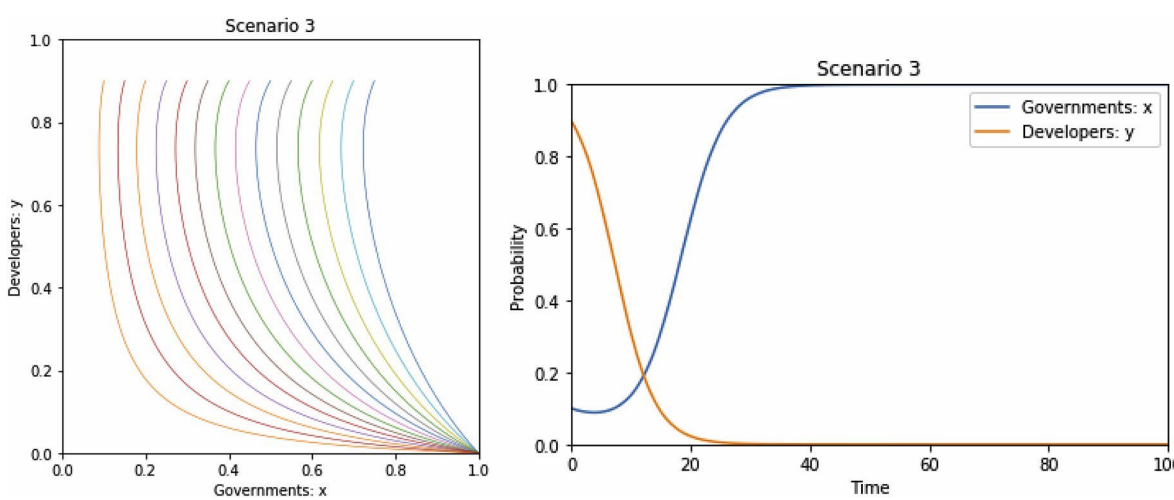


Fig. 4. Dynamic evolution process of Scenario 3. Note: The ESS is (1,0), as displayed in the left figure. Developers spend 30 units of time reaching point 0, whereas governments spend 40 units of time reaching point 1, as illustrated in the right figure.

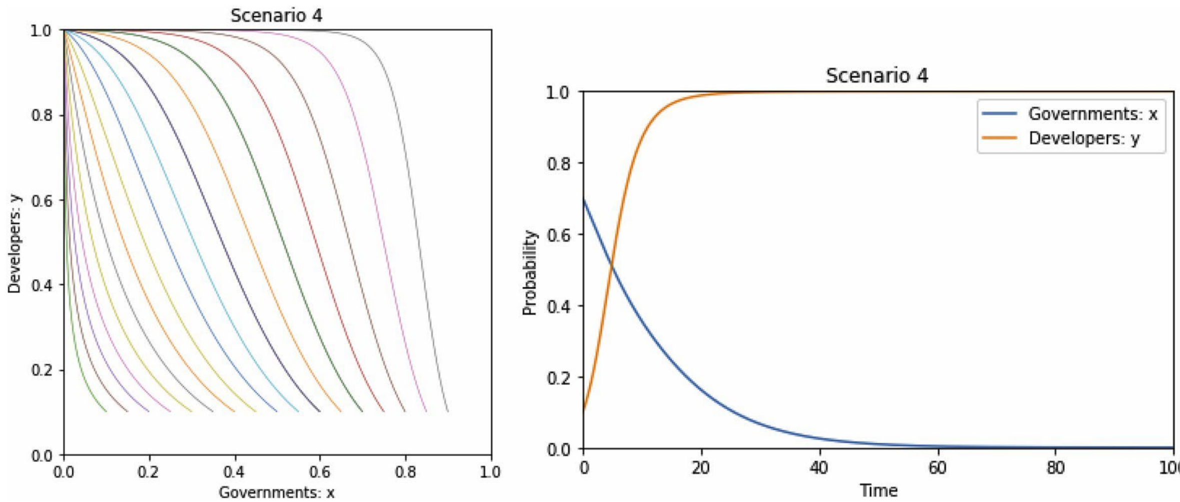


Fig. 5. Dynamic evolution process of Scenario 4. Note: The ESS is (0,1), as shown in the left figure. The right figure indicates that developers and governments take 30 and 60 units of time to reach points 1 and 0, respectively.

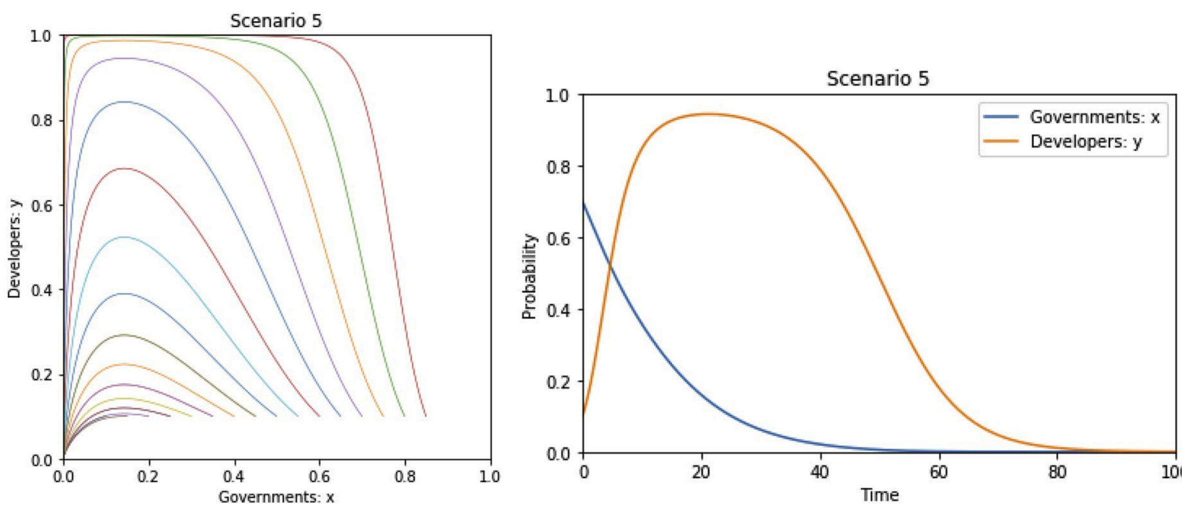


Fig. 6. Dynamic evolution process of Scenario 5. Note: The ESS is (0,0), as displayed in the left figure. Developers and governments respectively spend 90 and 60 units of time to reach point 0, as shown in the right figure.

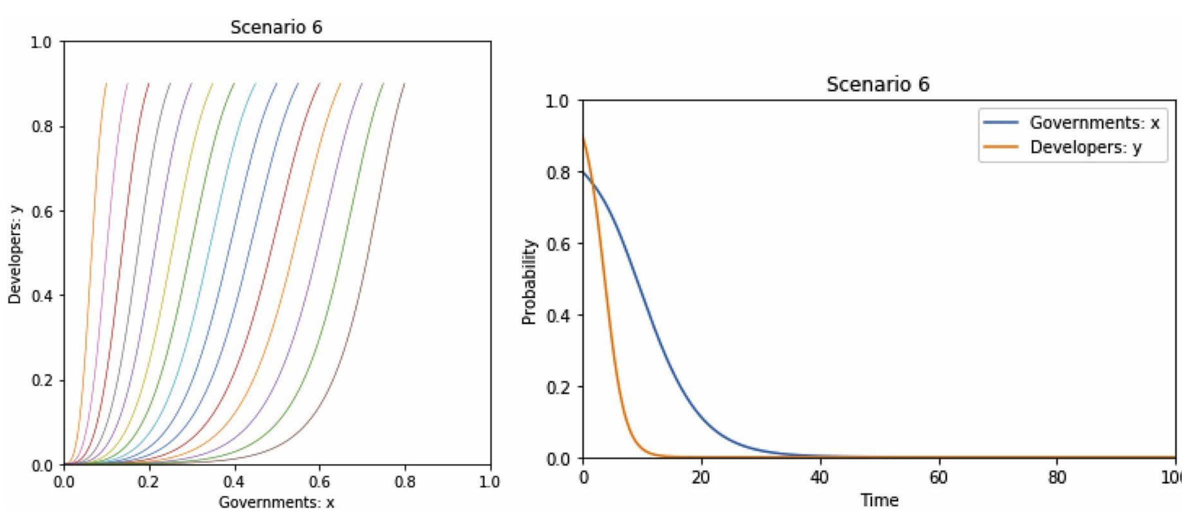


Fig. 7. Dynamic evolution process of Scenario 6. Note: The ESS is (0,0), as shown in the left figure. The right figure illustrates that developers and governments take 15 and 40 units of time to reach point 0, respectively.

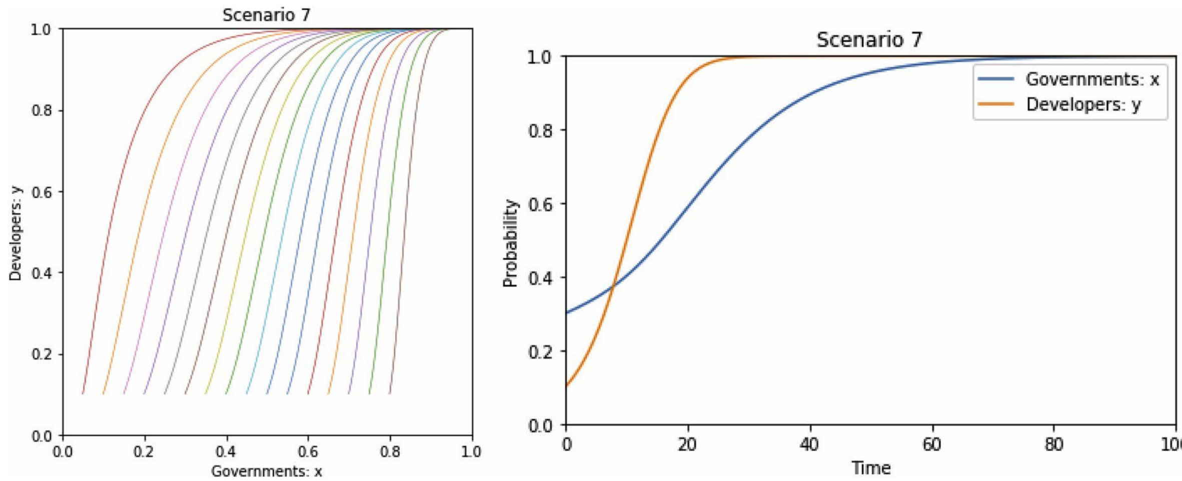


Fig. 8. Dynamic evolution process of Scenario 7. Note: The ESS is (1,1), as displayed in the left figure, whereas the right figure indicates that developers and governments take 30 and 75 units of time to reach point 1, respectively.

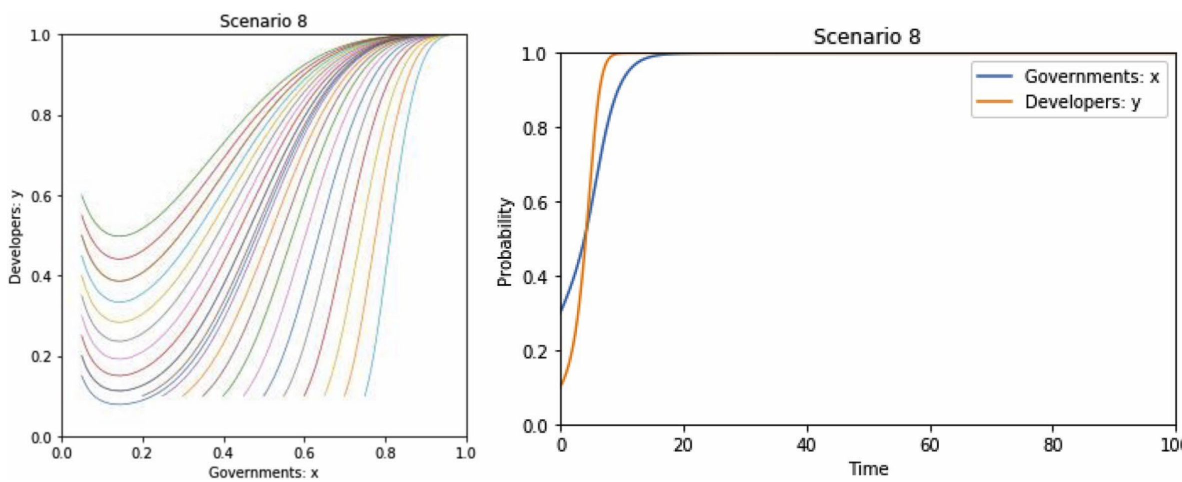


Fig. 9. Dynamic evolution process of Scenario 8. Note: The ESS is (1,1), as displayed in the left figure. Developers and governments respectively spend 10 and 20 units of time reaching point 1, as illustrated in the right figure.

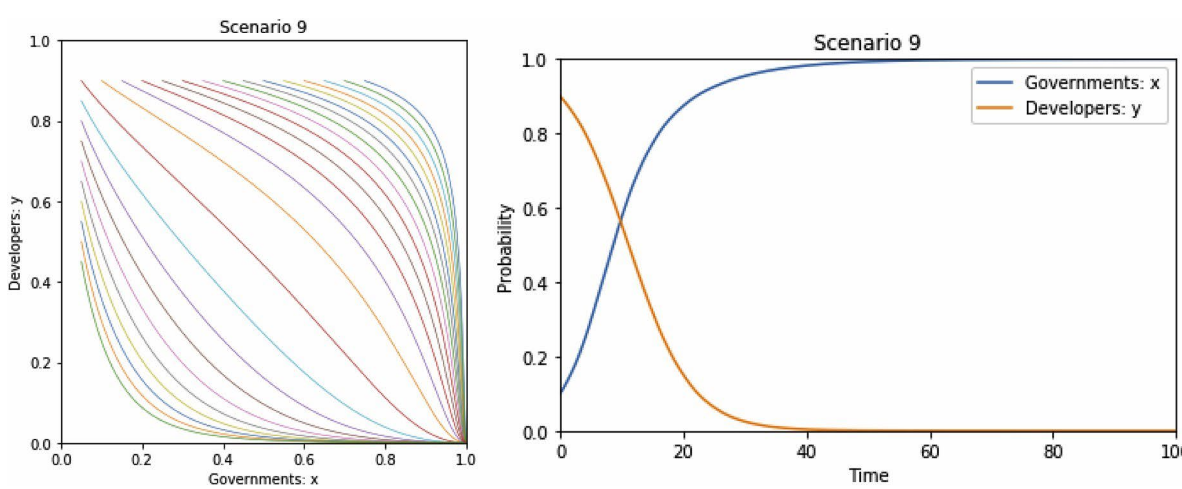


Fig. 10. Dynamic evolution process of Scenario 9. Note: The ESS is (1,0), as displayed in the left figure. The right figure shows that developers and governments spend 40 and 50 units of time reaching points 0 and 1, respectively.

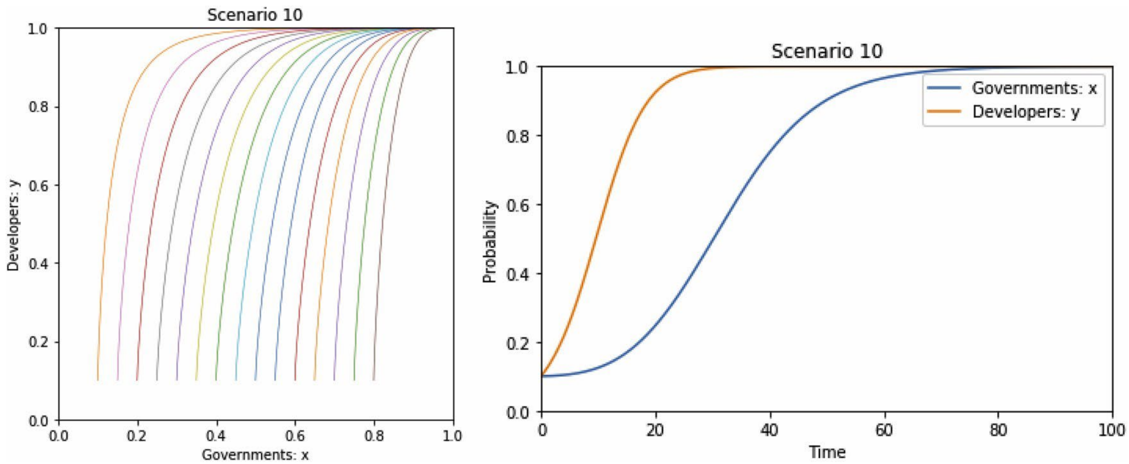


Fig. 11. Dynamic evolution process of Scenario 10. Note: The ESS is (1,1), as shown in the left figure. Developers and governments respectively take 30 and 75 units of time to reach point 1, as illustrated in the right figure.

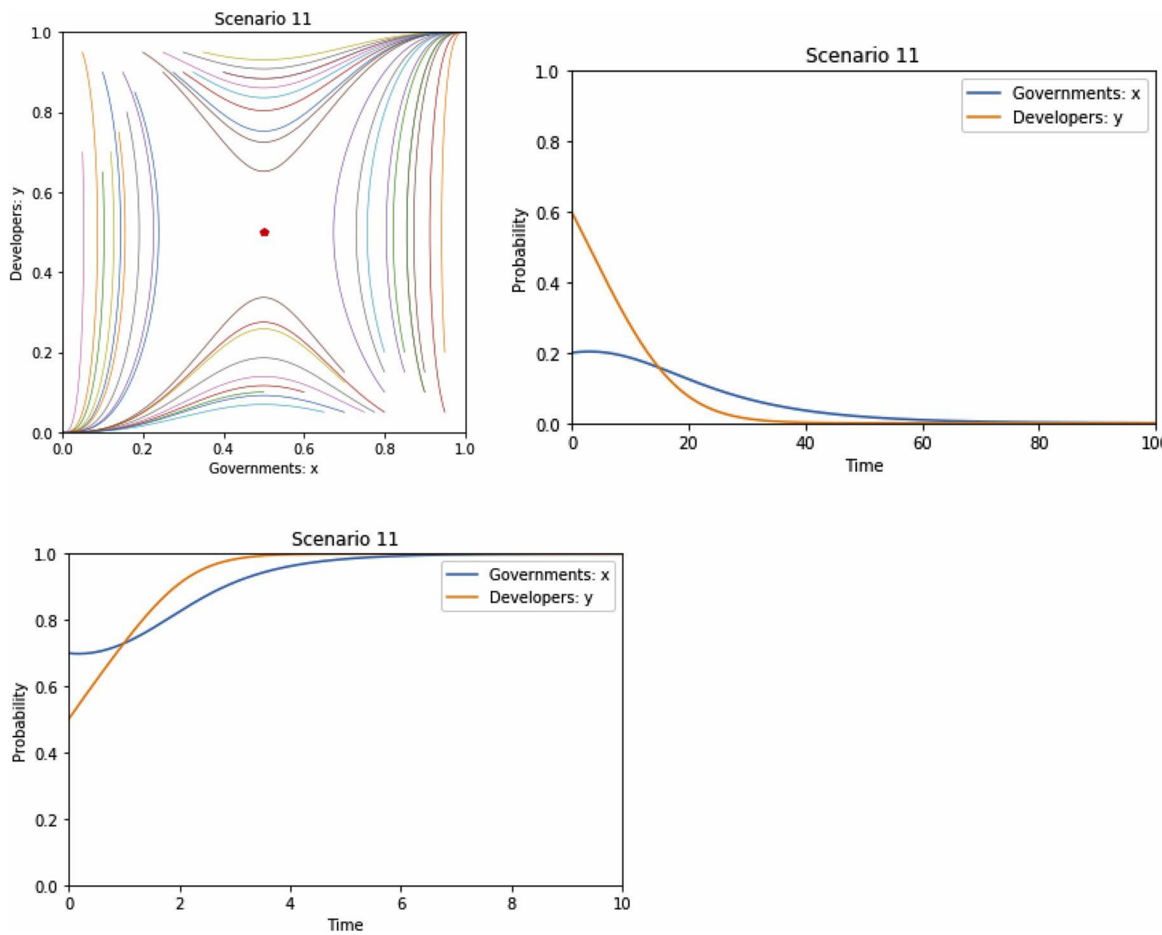


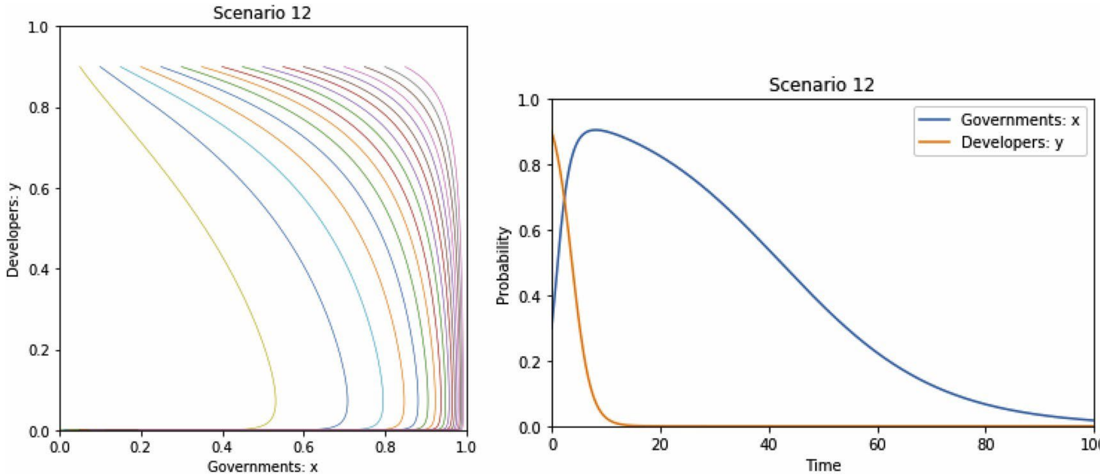
Fig. 12. Dynamic evolution process of Scenario 11. Note: Two ESSs, namely, (0,0) and (1,1) are presented. To determine which ESS depends on where the two players start, as shown in the top left figure. The top right figure illustrates that developers and governments spend 40 and 70 units of time to reach point 0, respectively. The bottom left figure indicates that developers and governments take four and seven units of time to reach point 1, respectively.

incentives if developers go for CB. Moreover, given that $G_{I1}\ G_1 < 0$; where $B_{I0}\ C_{I0}$ þ ðλ βþ$S_G < 0$, the benefit of implementing incentives is less than its cost, indicating that governments cannot afford to implement incentives.

Although the incentive in this scenario is attractive to developers, it burdens governments in terms of implementing incentives and thus the incentive is unsustainable. Therefore, governments should re-select affordable incentives. One typical example of this situation is that governments grant developers' attractive subsidies if they construct GB, but governments cannot sustain subsidies due to the limited budget. In this sense, changing the subsidies to density bonus, which attracts developers and releases governments' financial burden, is suggested.

Scenario 3: If G_{I1} $G_1 < 0$, G_0 $G_{I0} < 0$, D_0 $D_1 > 0$ and D_{I1} $D_{I0} < 0$, then the ESS is C (1,0). This scenario indicates that regardless of

Fig. 13. Dynamic evolution process of Scenario 12. Note: The ESS is (0,0), as shown in the left figure. Developers and governments respectively spend 15 and over 100 units of time to reach point 0, as illustrated in the right figure.



governments' strategy, developers' dominant strategy is to construct CB. As for governments, if developers go for CB, then governments prefer to implement incentives. Otherwise, they tend not to provide incentives. Therefore, governments' dominant strategies depend on developers' choices. The numerical simulation of the evolution paths of the two players is displayed in Fig. 4. When the proportion of developers constructing CB gradually increases to 1, governments tend to implement GB incentives to maximise their profits. Thus, the market can become stable.

In practice, this scenario appears when the high price premium ($\gamma R_E > 0$) of GB cannot offset its extra cost ($\delta C_E\ \gamma R_E > 0$) or GB has no price difference with CB (γR_E ¼ 0), and the benefits from government incentives plus the high price premium of GB (if any) are insufficient to cover the extra cost of GB (γR_E þ S_G þ $T_0\ \delta C_E < 0$). That is why developers' dominant strategy is to go for CB. For governments, $G_0\ G_{I0} < 0$ means $C_{I0}\ B_{I0} < 0$, suggesting that the cost of developing GB incentives (e.g. information cost) is less than its benefit (e.g. reputation, public awareness). Moreover, $G_{I1}\ G_1 < 0$; where $B_{I0}\ C_{I0}$ þ ðλ θÞ $S_G < 0$, indicates that the costs of developing and implementing incentives are more than the benefit of absorbed benefits (if any) plus the benefit of developing incentives. Therefore, in this scenario, developing incentive is affordable and beneficial for governments, but implementing them is unaffordable. The incentive level is unattractive to developers.

Scenario 4: If G_{I1} $G_1 < 0$, G_0 $G_{I0} > 0$ and D_0 $D_1 < 0$, then $D_{I1}\ D_{I0} > 0$, and the ESS is B (0,1). In this scenario, the dominant strategy of developers is to construct GB whether incentives exist or not. Thus, the proportion of developers doing GB gradually increases to 1. In terms of governments, regardless of developers' choice, governments' dominant strategy is always not to implement incentives. Thus, in this scenario, the two players' dominant strategies are independent, and the GB market can sustain itself without incentives. The market becomes stable when all the developers construct GB and no incentives exist, as shown in Fig. 5. This situation is ideal and similar to Scenario 1. The reason that developers prefer GB is because GB enjoys high price premium ($\gamma R_E > 0$) in the market that can cover its extra cost ($\delta C_E\ \gamma R_E < 0$). Thus, governments' incentives become unimportant. For governments, different from Scenario 1, where $G_0\ G_{I0} < 0$, the cost of developing incentives is more than its benefit in Scenario 4 ($G_0\ G_{I0} > 0$, where $C_{I0}\ B_{I0} > 0$). Therefore, governments prefer not to develop incentives when developers go for CB. Moreover, given that $G_{I1}\ G_1 < 0$; where $B_{I0}\ C_{I0}$ þ ðλ θÞ$S_G < 0$, the costs of developing and implementing incentives are more than the benefits (if any) of absorbed developers and developing incentives. In short, governments cannot afford to develop or implement incentives irrespective of developers' strategies, and the incentive in this scenario is unimportant for developers.

Scenario 5: If G_{I1} $G_1 < 0$, G_0 $G_{I0} > 0$, D_0 $D_1 > 0$ and D_{I1} $D_{I0} > 0$, then the ESS is A (0,0). This scenario shows that whether developers tend to go for GB depends whether governments provide incentives or not. As for governments, whether developers construct GB or not, not implementing incentives has high payoffs and thus becomes governments' dominant strategy. Therefore, both parties eventually choose to do nothing with the GB market. In this scenario, developers' dominant strategies depend on governments' choices. The simulation of the interaction between the two players is shown in Fig. 6.

This scenario happens when the high price premium of GB ($\gamma R_E > 0$) cannot offset its extra cost ($\delta C_E\ \gamma R_E > 0$) or GB has no price difference with CB (γR_E ¼ 0), but governments' incentives can help cover the extra costs (γR_E þ S_G þ $T_0\ \delta C_E > 0$). That explains why developers' dominant strategies rely on governments' choices. As for governments, the cost of developing incentives is more than its benefits because $G_0\ G_{I0} > 0$; where $C_{I0}\ B_{I0} > 0$. Moreover, as $G_{I1}\ G_1 < 0$; where B_{I0} C_{I0} þ ðλ θÞ$S_G < 0$, the costs of developing and implementing incentives are still more than the absorbed benefits and the benefits of developing incentives. That is why when developers prefer GB, governments tend not to provide incentives.

Although the incentive in this scenario is attractive to developers, it burdens governments in terms of developing and implementing incentives. Different from Scenario 2, governments in this scenario tend not to develop incentives in the first place due to the huge developing cost.

Scenario 6: If G_{I1} $G_1 < 0$, G_0 $G_{I0} > 0$, D_0 $D_1 > 0$ and D_{I1} $D_{I0} < 0$, then the ESS is A (0,0). In this scenario, regardless of governments' strategies, doing CB is always more profitable than doing GB. Thus, the proportion of developers going for GB gradually decreases to 0. Governments can always have high payoffs if they do not provide incentives, irrespective of developers' choices. Therefore, the two players' dominant strategies are independent. As a consequence, all developers prefer CB, and governments tend not to provide incentives. The market eventually becomes stable at (0,0), as shown in Fig. 7. In practice, this scenario can occur when the high price premium

($\gamma R_E > 0$) of GB is less than its extra cost ($\delta C_E \gamma R_E > 0$) or GB has no price difference with CB (γR_E ¼ 0). Even if governments provide incentives, the total extra benefits are insufficient to offset the extra costs (γR_E þ S_G þ $T_0 \delta C_E < 0$). The incentive level in this scenario is unattractive to developers, indicating why developers always prefer CB. For governments, given that $G_0 G_{I0} > 0$; where $C_{I0} B_{I0} > 0$, the cost of designing incentives is more than its benefit. Therefore, when developers prefer CB, governments tend not to develop incentives.

Moreover, considering that $G_{I1} G_1 < 0$, $B_{I0} C_{I0}$ þ ðλ θÞ$S_G < 0$, the total benefits of developing incentives and the absorbed benefits (if any) are less than the total costs of developing and implementing costs. This factor explains why governments tend not to provide incentives if developers go for GB. The incentive in this scenario is unaffordable for governments and unattractive to developers.

Scenario 7: If G_{I1} $G_1 > 0$, G_0 $G_{I0} < 0$ and D_0 $D_1 < 0$, then $D_{I1} D_{I0} > 0$. The ESS is D (1,1). This scenario indicates that regardless of whether governments implement GB incentives or not, developers' dominant strategy is to go for GB. As for governments, irrespective of developers' choice, governments' dominant strategy is to always provide incentives. Therefore, the two players' dominant strategies are independent. In the end, the market becomes stable when all developers construct GB and governments implement incentives, as shown in Fig. 8.

The reason why GB is developers' dominant strategy is that GB has a high price premium ($\gamma R_E > 0$) which can cover its extra cost ($\delta C_E \gamma R_E > 0$). When governments provide incentives, developers can benefit more from incentives (γR_E þ S_G þ $T_0 \delta C_E > 0$). For governments, $G_0 G_{I0} < 0$; where $C_{I0} B_{I0} < 0$, indicating that the cost of developing incentives is less than its benefits. Therefore, when developers tend to go for CB, governments prefer to develop incentives. Moreover, as G_{I1}

$G_1 > 0$; where $B_{I0} C_{I0}$ þ ðλ θÞ$S_G > 0$, the absorbed benefits (if any) together with the benefits of developing incentives are more than the costs of developing and implementing incentives. That is why if developers prefer GB, then governments tend to implement incentives. In this scenario, the incentive is affordable for governments, but unimportant for developers.

Scenario 8: If G_{I1} $G_1 > 0$, G_0 $G_{I0} < 0$, D_0 $D_1 > 0$ and D_{I1} $D_{I0} > 0$, then the ESS is D (1,1). In this scenario, if governments provide incentives, then developers can benefit from going for GB. Otherwise, they tend to construct CB. In this sense, developers' dominant strategies depend on governments' choices, indicating that the incentive level in this scenario is attractive to developers. As for governments, regardless of whether developers construct GB or not, governments can always benefit from implementing incentives. Therefore, governments prefer to implement incentives and thus developers tend to construct GB. The market becomes stable at (1,1). The evolution paths of the two players are illustrated in Fig. 9.

In practice, this situation occurs when the high price premium ($\gamma R_E > 0$) of GB cannot cover its extra cost ($\delta C_E \gamma R_E > 0$) or no price difference exists between GB and CB (γR_E ¼ 0), but government incentives can help offset the extra costs (γR_E þ S_G þ $T_0 \delta C_E > 0$). This factor explains why developers prefer GB if governments provide incentives. For governments, $G_0 G_{I0} < 0$; where $C_{I0} B_{I0} < 0$; suggesting that the cost of developing incentives is less than the benefit. Therefore, governments prefer to develop incentives if developers go for CB. As $G_{I1} G_1 > 0$; where $B_{I0} C_{I0}$ þ ðλ θÞ$S_G > 0$, the absorbed benefits (if any) plus the benefit of developing incentives are more than the costs of developing and implementing incentives. Therefore, governments prefer to provide incentives regardless of developers' choices. The incentive in this scenario is affordable for governments and attractive to developers.

Scenario 9: If G_{I1} $G_1 > 0$, G_0 $G_{I0} < 0$, D_0 $D_1 > 0$ and D_{I1} $D_{I0} < 0$, then the ESS is D (1,0). In this scenario, developers always prefer to go for CB even when incentives exist, whereas governments' dominant strategy is to provide incentives irrespective of developers' decision. Thus, the two players' dominant strategies are independent. Governments eventually tend to provide incentives, and developers prefer CB. The market becomes stable at (1,0), as shown Fig. 10.

The reasons for developers' dominant decision are that GB's high price premium ($\gamma R_E > 0$) cannot offset its extra cost ($\delta C_E \gamma R_E > 0$) or GB has no price difference with CB (γR_E ¼ 0), and even if governments provide incentives, the incentive level is insufficient to cover the extra costs (γR_E þ S_G þ $T_0 \delta C_E < 0$). This factor explains why developers' dominant strategy is CB. As for governments, given that $G_0 G_{I0} < 0$; where $C_{I0} B_{I0} < 0$, the cost of developing incentives is less than the benefit. Therefore, governments tend to develop incentives if developers tend to construct CB. In addition, G_{I1} $G_1 > 0$; where B_{I0} C_{I0} þ ðλ θÞ$S_G > 0$, indicating that the absorbed benefits (if any), together with the benefits of developing incentives, are more than the costs of developing and implementing incentives. That is why governments prefer to implement incentives regardless of whether developers tend to construct GB or CB. The incentive in this scenario is affordable for governments, but unattractive to developers.

Scenario 10: If G_{I1} $G_1 > 0$, G_0 $G_{I0} > 0$, D_0 $D_1 < 0$ and D_{I1} $D_{I0} > 0$, then the ESS is D (1,1). This scenario is quite similar to Scenario 7. In Scenario 10, GB is more profitable than CB regardless of government incentives and thus developers' dominant strategy is GB. Similarly, governments can always benefit from implementing GB incentives if developers prefer GB and thus their dominant strategy is to provide incentives. Otherwise, governments tend not to provide incentives. In this scenario, governments' dominant strategies rely on developers' choices. The market can become stable at (1,1). The evolution paths of governments and developers are illustrated in Fig. 11.

The reasons why developers' dominant strategy is GB are because GB's high price premium ($\gamma R_E > 0$) can cover its extra cost ($\delta C_E \gamma R_E < 0$), and governments' incentives make GB attractive to developers (γR_E þ S_G þ $T_0 \delta C_E > 0$). As for governments, given that $G_0 G_{I0} > 0$; where $C_{I0} B_{I0} > 0$, the benefit of developing incentives is less than its cost. $G_{I1} G_1 > 0$; where $B_{I0} C_{I0}$ þ ðλ θÞ$S_G > 0$, ðλ θÞ$S_G > 0$ and thus $\lambda S_G > 0$, indicating that governments absorb developers' benefits from incentives and the incentive level is so high that after covering the extra cost of GB, governments must still absorb other benefits. Moreover, the absorbed benefits plus the benefit of developing incentives are more than the costs of developing and implementing incentives ($B_{I0} C_{I0}$ þ ðλ θÞ$S_G > 0$), suggesting governments' dominant strategies.

In this scenario, developers can obtain enough benefits from the property market to cover the extra cost of GB, and governments can receive sufficient benefits from implementing incentives to offset the corresponding costs. The incentives are unimportant for developers, but governments provide high level incentives, where benefits are eventually absorbed by governments.

Scenario 11: If G_{I1} $G_1 > 0$, G_0 $G_{I0} > 0$, D_0 $D_1 > 0$ and D_{I1} $D_{I0} > 0$, then the ESSs are A (0,0) and D (1,1). To attainment of a stable point depends on the starting positions of the two players, illustrated by the numerical simulation of Scenario 11 in Fig. 2. Whether developers construct GB depends on whether governments provide incentives and vice versa. The figure of the simulation shows that at the beginning stage, if most developers prefer to do GB, and governments tend not to provide incentives, then the proportion of developers constructing GB can decrease to 0. The market becomes stable at (0, 0). If most developers tend to go for CB at the beginning, and governments tend to implement incentives, then the proportion of developers doing GB can increase to 1. Thus, the market can become stable at (1, 1).

This situation appears when the cost of constructing GB is more than the benefit because $D_0 D_1 > 0$; where $\delta C_E \gamma R_E > 0$, and governments' incentives can help cover the extra costs (γR_E þ S_G þ $T_0 \delta C_E > 0$). Therefore, governments' incentives in this scenario are necessary for GB promotion. For governments, the cost of developing incentives is more than its benefits ($C_{I0} B_{I0} > 0$). Thus, governments tend not to develop incentives if developers tend to go for CB. Moreover, given that $G_{I1} G_1 > 0$; where $B_{I0} C_{I0}$ þ ðλ βÞ$S_G > 0$, ðλ βÞ$S_G > 0$ and thus $\lambda S_G > 0$, which suggests that governments absorb developers' benefits from incentives, and the incentive level is so high for developers that after covering the extra cost of GB, governments must still absorb other benefits. Moreover, governments' benefits of developing incentives plus the absorbed benefits can cover the costs of developing and implementing incentives ($B_{I0} C_{I0}$ þ ðλ βÞ$S_G > 0$). This factor explains why governments tend to implement incentives if developers prefer GB.

In this scenario, the incentive is important and attractive to developers and affordable and beneficial to governments. However, considering that the dominant strategy of one player relies on that of the opposite, one player may choose to do nothing with the GB market at the beginning, resulting in the same choice of the opposite. Therefore, ESS has two points.

Scenario 12: If G_{I1} $G_1 > 0$, G_0 $G_{I0} > 0$, D_0 $D_1 > 0$ and D_{I1} $D_{I0} < 0$, then the ESS is D (0,0). In this scenario, CB is more profitable than GB regardless of whether governments provide incentives or not. If developers tend to construct CB, then the best choice for governments is not to implement incentives. Otherwise, governments tend to provide incentives. The dominant strategies of governments depend on those of developers. Two players can eventually choose to do nothing with GB, and the market becomes stable at (0,0), as illustrated in Fig. 13.

The reason why developers' dominant strategy is CB is that GB's high price premium ($\gamma R_E > 0$) cannot offset its extra cost ($\delta C_E \gamma R_E > 0$) or no price difference exists between GB and CB (γR_E ¼ 0), but GB is costly ($\delta C_E > 0$). Even if governments provide incentives, the incentive levels in this scenario are unattractive to developers because they cannot offset the extra costs (γR_E þ S_G þ $T_0 \delta C_E < 0$). That is why developers prefer CB irrespective of incentives. In this case, governments tend not to develop incentives because the cost of designing incentives is more than the benefit ($G_0 G_{I0} > 0$; where $C_{I0} B_{I0} > 0$.

5. Discussions

5.1. Interactions between governments and developers

The model results have revealed the incentive effectiveness of the 12 scenarios and explained the decision makings of the two players under each scenario. Basically, four types of interactions have emerged between governments and developers, namely, 1) governments' dominant strategies depend on developers' choices; 2) developers dominant strategies rely on governments' choices; 3) two parties' dominant strategies are independent; 4) their dominant strategies are interdependent. Under each type of interaction, the level and affordability of incentives and the price premium of GB in the property market determine the incentive effectiveness of each scenario. Governments can only affect developers' choices by adjusting the incentive levels.

(1) Governments' dominant strategies depend on developers' choices

incentive level are critical for developers' decision makings. When GB has a higher price premium than CB that can cover the extra cost of GB,

Table 4
The summary of incentive effectiveness, equilibrium points and industry conditions.

Incentive effectiveness	Equilibrium point	Incentive scenario	Industry condition
GB is developers' dominant strategy	D (1,1)	Scenario 7	GB's high price premium can cover its extra cost. Incentive level is unimportant. Governments can afford to design or implement GB incentives.
		Scenario 8	GB's high price premium cannot offset its extra cost. Incentive level is attractive. Governments can afford to design or implement attractive incentives.
		Scenario 10	GB's high price premium can cover its extra cost. Incentive level is unimportant. Governments can afford to implement GB incentives if developers construct GB.
		Scenario 11	GB's high price premium cannot offset its extra cost. Incentive level is attractive. Governments can afford to implement attractive incentives and to absorb developers' benefits from GB incentives if developers construct GB. Developers tend to choose GB or governments prefer to provide incentives at the beginning.
	B (0,1)	Scenario 1	GB's high price premium can cover its extra cost. Incentive level is unimportant. Governments cannot afford to implement any incentives but can afford to design them.
		Scenario 4	GB's high price premium can cover its extra cost. Incentive level is unimportant. Governments cannot afford to develop or implement any incentives.

CB is developers' dominant strategy	C (1,0)	Scenario 3	GB's high price premium fails to cover its extra cost. Incentive level is low. Governments cannot afford to implement low-level incentives but can afford to develop them.
		Scenario 9	GB's high price premium fails to cover its extra cost. Incentive level is low. Governments can afford to design or implement low-level incentives.
	A (0,0)	Scenario 5	GB's high price premium cannot offset its extra cost. Incentive level is attractive. Governments cannot afford to design or implement attractive incentives.
		Scenario 6	GB's high price premium cannot offset its extra cost. Incentive level is low. Governments cannot afford to design or implement low-level incentives.
		Scenario 11	GB's high price premium cannot cover its extra cost. Incentive level is attractive. Governments can afford to implement attractive incentives and to absorb developers' benefits from GB incentives if developers construct GB. Developers tend not to choose GB or governments prefer not to provide incentives at the beginning.
		Scenario 12	GB's high price premium cannot offset its extra cost. Incentive level is low. Governments cannot afford to design low-level incentives.
NA	NA	Scenario 2	GB's high price premium fails to cover its extra cost. Incentive level is attractive. Governments cannot afford to implement attractive incentives but can afford to design such incentives.

In Scenarios 1, 3, 10 and 12, where the markets become respectively stable at (0,1), (1,0), (1,1) and (0,0), governments' dominant strategies depend on developers' choices. In this case, GB's price premium and the developers tend to construct GB irrespective of governments' incentives (i.e. Scenarios 1 and 10). When GB's high price premium covers its extra cost or no price difference exists between GB and CB, the incentive level becomes critical for developers' decision makings. In Scenarios 3 and 12, developers prefer CB because the incentive levels (if any) are insufficient to cover the extra cost of GB.

(2) Developers' dominant strategies rely on governments' choices

In Scenarios 5 and 8, where the markets respectively become stable at (0,0) and (1,1), developers' dominant strategies rely on governments' choices. In these scenarios, GB has no price difference with CB or its price is slightly higher than CB that cannot cover the extra cost of GB. Therefore, developers must rely on governments' incentives. In this situation, the affordability of incentives is crucial for governments' decision makings and further affects developers' dominant strategies. If governments can afford attractive incentives, then developers can always prefer GB (i.e. Scenario 8). Otherwise, they tend to construct CB (i. e. Scenario 5). In this case, governments should re-select incentives, such as changing subsidies to density bonus, to release the financial burden and keep the incentive level attractive.

(3) Independent dominant strategies of governments and developers

In Scenarios 4, 6, 7 and 9, whose markets are respectively stable at (0,1), (0,0), (1,1) and (1,0), the dominant strategies of governments and developers are independent. The high price premium of GB and the affordability and level of incentives are critical for the decision makings of developers. If GB's high price premium can cover its extra cost, then developers' dominant strategy is GB (i.e. Scenarios 4 and 7). If GB's high price premium (if any) cannot offset its extra cost, and governments fail to afford any incentives, then developers do not rely on governments' incentives and always prefer CB (i.e. Scenario 6). If no or little price difference exists between GB and CB, and the incentive level cannot offset the extra cost of GB, then developers do not rely on governments' incentives and always tend to construct CB (i.e. Scenario 9). In this case, governments may be able to afford attractive incentives, but they just do not know the appropriate incentive level.

(4) Interdependent dominant strategies of governments and developers

In Scenarios 2 and 11 whose markets are unstable and stable at (0,0) or (1,1), respectively, the dominant strategies of governments and developers are interdependent. The dominant strategy of one player relies on that of the opposite. In this situation, GB's high price premium cannot offset its cost and thus developers must rely on governments' incentives, which are attractive to developers in both scenarios. Therefore, the affordability of incentives is critical for governments and further affects developers' choices. To afford attractive incentives, governments should bear the costs of developing and implementing incentives. Although incentives in Scenario 2 are attractive to developers, governments cannot afford the cost of implementing incentives. By contrast, governments can afford the cost of implementing attractive incentives in Scenario 11. In this scenario, if one of the two players tends to go for GB, then the opposite goes for GB as well. Otherwise, both tend to go for CB. Therefore, if one player tends to go for GB at the beginning, then the market becomes stable at (1,1); otherwise, the market becomes stable at (0,0). In Scenario 11, the incentive level is so high that after covering the costs of developing and implementing incentives, governments must still absorb other benefits. Governments can design a special high-level incentive and make itself absorb the benefits to offset the incentive cost. Thus, both parties have the motivation to contribute to the GB market.

5.2. Summary of findings

On the basis of the research results and the above discussions, the incentive effectiveness of the 12 scenarios, equilibrium points and their industry conditions have been categorised and summarised in Table 4. The summary makes the identification of relevant cases easy for policymakers.

6. Conclusion

Various barriers and failures exist in the GB market that prevent developers from constructing GBs. Hence, governments' incentives are needed to address these barriers and failures. Governments' incentives in essence distribute costs and benefits to governments and developers. Such distribution affects their payoffs and decision makings and in turn influences incentive effectiveness. To reveal the decision-making mechanisms of the two players and the effectiveness of incentives, this study employs evolutionary game theory to analyse the interactions and decision makings of governments and developers. The results illustrate the incentive effectiveness in the long run and explain the two parties' decision makings on whether to provide incentives and their levels and whether to participate in the incentive schemes. The results can also advance policymakers' understanding of GB incentives, help policymakers predict developers' behaviours and incentive effectiveness and justify the design or revision of GB incentives. Moreover, this study provides a general model that can fit various contexts.

The research claims that four types of interactions between governments and developers affect evolutionary outcomes, namely, 1) governments' dominant strategies depend on developers' choices; 2) developers' dominant strategies rely on governments' choices; 3) two parties' dominant strategies are independent; 4) their dominant strategies are interdependent. The conclusions stress the importance of interaction types and are supported by Perc et al. [47] who believed that the emergence of cooperation in a complex system depends on the interaction structure, type of interaction and number and type of competing strategies. The present study examines the strategy sets between the two players under consideration. Further studies may apply complex systems theory to further investigate how interaction structures affect evolutionary outcomes.

Under these interactions, the price premium of GB in the property market and the level and affordability of incentives are critical factors for the decision makings of the leading players. The conclusions have several policy implications:

1) GB's price premium plays an important role in GB promotion. Governments should improve public awareness of GB and make it more attractive to clients than CB, especially when governments cannot afford to implement incentives for developers. The GB market can sustain itself when GB's high price premium can cover its extra cost.

2) The incentive level is key when GB development must rely on governments' incentives. Governments ought to identify the appropriate incentive level so that they can effectively motivate developers. Even if a low incentive level fails to motivate developers, its existence can still be beneficial to governments, such as increased public awareness of GB and improved government reputation. Designing incentives is also worth doing.
3) If the affordability of incentives is crucial, then governments can make it affordable by reducing the costs of developing and implementing incentives, resulting in sustainable incentives. One way is to reduce transaction costs, such as information and coordination costs at the developing stage and monitoring and approval costs at the implementation stage. Another way is to re-select attractive incentives that are unconstrained by governments' budget, such as density bonus and expediting permission process.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

[1] I.E.A. Global, Status Report: towards a Zero-Emission, Efficient and Resilient Buildings and Construction Sector, International Energy Agency, 2018.
[2] Iea, Global Status Report for Buildings and Construction 2019, IEA, Paris, 2019.
[3] F.M. Butera, Climatic Change and the Built Environment Advances in Building Energy Research, Routledge, 2010, pp. 55–86.
[4] Y. Geng, H. Dong, B. Xue, J. Fu, An overview of Chinese green building standards, Sustain. Dev. 20 (2012) 211–221.
[5] A.J. Hoffman, R. Henn, Overcoming the Social and Psychological Barriers to Green Building vol. 21, Organization & Environment, 2008, pp. 390–419.
[6] G.R. Richardson, J.K. Lynes, Institutional motivations and barriers to the construction of green buildings on campus: a case study of the University of Waterloo, Ontario, Int. J. Sustain. High Educ. 8 (2007) 339–354.
[7] A. Darko, A.P. Chan, Review of barriers to green building adoption, Sustain. Dev. 25 (2017) 167–179.
[8] O.A. Olubunmi, P.B. Xia, M. Skitmore, Green building incentives: a review, Renew. Sustain. Energy Rev. 59 (2016) 1611–1621.
[9] S. Shazmin, I. Sipan, M. Sapri, Property tax assessment incentives for green building: a review, Renew. Sustain. Energy Rev. 60 (2016) 536–548.
[10] K. Fan, E. Chan, C. Chau, Costs and benefits of implementing green building economic incentives: case study of a gross floor area concession scheme in Hong Kong, Sustainability 10 (2018) 2814.
[11] K. Fan, W. Gu, Q.K. Qian, E.H.W. Chan, Costs and Benefits of Implementing Green Building Policy. The World Sustainable Built Environment Conference (WSBE17):: Transforming Our Built Environment through Innovation and Integration: Putting Ideas into Action Hong Kong, Construction Industry Council, 2017, pp. 741–746.
[12] K. Fan, E.H.W. Chan, Q.K. Qian, Transaction costs (TCs) in green building (GB) incentive schemes: gross floor area (GFA) concession scheme in Hong Kong, Energy Pol. 119 (2018) 563–573.
[13] S. Gündes¸, S.U. Yildirim, The use of incentives in fostering green buildings, METU J. Fac. Archit. 32 (2016).
[14] S.G.J. Naini, A.R. Aliahmadi, M. Jafari-Eskandari, Designing a mixed performance measurement system for environmental supply chain management using evolutionary game theory and balanced scorecard: a case study of an auto industry supply chain, Resour. Conserv. Recycl. 55 (2011) 593–603.
[15] J. Sheng, W. Zhou, B. Zhu, The coordination of stakeholder interests in environmental regulation: lessons from China's environmental regulation policies from the perspective of the evolutionary game theory, J. Clean. Prod. (2020) 119385.
[16] S. Shazmin, I. Sipan, M. Sapri, H. Ali, F. Raji, Property tax assessment incentive for green building: energy saving based-model, Energy 122 (2017) 329–339.
[17] S. Hu, D. Yan, E. Azar, F. Guo, A Systematic Review of Occupant Behavior in Building Energy Policy, Building and Environment, 2020, p. 106807.
[18] G. Liu, Y. Tan, X. Li, China's policies of building green retrofit: a state-of-the-art overview, Build. Environ. 169 (2020) 106554.
[19] I.J. Onuoha, G.U. Aliagha, M.S.A. Rahman, Modelling the effects of green building incentives and green building skills on supply factors affecting green commercial property investment, Renew. Sustain. Energy Rev. 90 (2018) 814–823.
[20] C. Cohen, D. Pearlmutter, M. Schwartz, Promoting Green Building in Israel: A Game Theory-Based Analysis, Building and Environment, 2019, p. 163.
[21] M. Li, W. Wu, G. Wu, Promotion mechanism of the green building based on the stakeholder theory from the perspective of game theory, J. Civ. Eng. Manag. 34 (2017) 20–26.
[22] B.A. Portnov, T. Trop, A. Svechkina, S. Ofek, S. Akron, A. Ghermandi, Factors affecting homebuyers' willingness to pay green building price premium: evidence from a nationwide survey in Israel, Build. Environ. 137 (2018) 280–291.
[23] X. Liang, Y. Peng, G.Q. Shen, A game theory based analysis of decision making for green retrofit under different occupancy types, J. Clean. Prod. 137 (2016) 1300–1312.
[24] C. Bohringer, M. Finus, C. Vogt, Controlling Global Warming: Perspectives from€ Economics, Game Theory, and Public Choice, Edward Elgar Publishing, 2002.
[25] C. Cohen, D. Pearlmutter, M. Schwartz, A game theory-based assessment of the implementation of green building in Israel, Build. Environ. 125 (2017) 122–128. [26] D.M. Kilgour, Y. Wolinsky-Nahmias, Game Theory and International Environmental Policy. Models, Numbers, and Cases: Methods for Studying International Relations, 2004, p. 317.
[27] E.C. Hui, H. Bao, The logic behind conflicts in land acquisitions in contemporary China: a framework based upon game theory, Land Use Pol. 30 (2013) 373–380.
[28] H. Folmer, A. De Zeeuw, Game Theory in Environmental Policy Analysis, Chapters, 1999.
[29] P. Hammerstein, R. Selten, Game theory and evolutionary biology, Handb. Game Theor. Econ. Appl. 2 (1994) 929–993.
[30] J.W. Weibull, Evolutionary Game Theory, MIT press, 1997.
[31] G.J. Mailath, Introduction: Symposium on Evolutionary Game Theory, Elsevier, 1992.
[32] D. Friedman, On economic applications of evolutionary game theory, J. Evol. Econ. 8 (1998) 15–43.
[33] J.M. Smith, G.R. Price, The logic of animal conflict, Nature 246 (1973) 15.
[34] J. Apaloo, J.S. Brown, T.L. Vincent, Evolutionary game theory: ESS, convergence stability, and NIS, Evol. Ecol. Res. 11 (2009) 489–515.
[35] S.M. Estalaki, A. Abed-Elmdoust, R. Kerachian, Developing environmental penalty functions for river water quality management: application of evolutionary game theory, Environ. Earth Sci. 73 (2015) 4201–4213.
[36] B. Wu, P. Liu, X. Xu, An evolutionary analysis of low-carbon strategies based on the government–enterprise game in the complex network context, J. Clean. Prod. 141 (2017) 168–179.
[37] V.W. Tam, J.L. Hao, S. Zeng, What affects implementation of green buildings? An empirical study in Hong Kong, Int. J. Strat. Property Manag. 16 (2012) 115–125.
[38] Q. Liu, X. Li, M. Hassall, Evolutionary game analysis and stability control scenarios of coal mine safety inspection system in China based on system dynamics, Saf. Sci. 80 (2015) 13–22.
[39] Fan K, Qian QK, Chan EHW. Floor area concession incentives as planning instruments to promote green building: a critical review of International practices. SMart and Sustainable Built Environments (SASBE) Conference 9–11. Pretoria, South Africa2015.
[40] M. Sander, The rise of governments in global oil governance: historical dynamics, transaction cost economics, and contemporary implications, Energy Res. Soc. Sci. 17 (2016) 82–93.
[41] F. Fuerst, P. McAllister, Green noise or green value? Measuring the effects of environmental certification on office values, R. Estate Econ. 39 (2011) 45–69.
[42] Y. Deng, Z. Li, J.M. Quigley, Economic returns to energy-efficient investments in the housing market: evidence from Singapore, Reg. Sci. Urban Econ. 42 (2012) 506–515.
[43] J.J. Jia, H.-Q. Wu, H.-G. Nie, Y. Fan, Modeling the willingness to pay for energy efficient residence in urban residential sector in China, Energy Pol. 135 (2019) 111003.

[44] Q.K. Qian, K. Fan, E.H.W. Chan, Regulatory incentives for green buildings: gross floor area concessions, Build. Res. Inf. 44 (2016) 675–693.
[45] A.O. Olanipekun, B. Xia, C. Hon, Y. Hu, Project owners' motivation for delivering green building projects, J. Construct. Eng. Manag. 143 (2017), 04017068.
[46] P.D. Taylor, L.B. Jonker, Evolutionary stable strategies and game dynamics, Math. Biosci. 40 (1978) 145–156.
[47] M. Perc, J.J. Jordan, D.G. Rand, Z. Wang, S. Boccaletti, A. Szolnoki, Statistical physics of human cooperation, Phys. Rep. 687 (2017) 1–51.