Decision Model to Optimize Long-term Subsidy Strategy for Green Building Promotion

Yongsheng Jiang, PhD [1], Tao Hu[1], Dong Zhao, PhD [2,3*], Bingsheng Liu, PhD [4], Yunjia Zhang[1], Zihao Xu[1], Hanzhe Zhang, PhD [5]

1. School of Management Engineering, Shandong Jianzhu University, China
2. School of Planning, Design and Construction, Michigan State University, USA
3. Department of Civil and Environmental Engineering, Michigan State University, USA
4. School of Public Affairs, Chongqing University, China
5. Department of Economics, Michigan State University, USA

* Corresponding author. Dr. Dong Zhao, Associate Professor, Michigan State University, 552 W Circle Dr, East Lansing, MI 48824, USA; Email: dzhao@msu.edu.

Abstract:
Green buildings reduce energy consumption and CO_2 emissions and improve quality of life toward the sustainable built environment and cities. The literature highlights that the last milestone in the progress of green building movement is “public behavior” measured by market acceptance. Both developers and homebuyers are two key players in the process, representing the supply side and demand side. The barriers to green building acceptance include the incremental cost for developers and the premium price for homebuyers. A premium is an extra cost that consumers are willing to pay to obtain an additional quality of product, i.e., green building benefits. In this case, various subsidy programs are offered by government agencies to offset the high costs. However, there is a lack of knowledge and evidence of what subsidy strategy can maximize green building acceptance as well as societal benefits. The objective of this study is to create a decision model to identify the optimal subsidy strategy for joint benefits of government, developer, and homebuyer. The decision model is based on the evolutionary game theory that seeks the shared interest of all players rather than the interest of any single player. Demonstrated via a real project, the decision model finds the optimal strategy and the reasonable range of factors, e.g., subsidy allocation, subsidy proportion, and premium reduction. The results of the case study recommend a strategy that combines subsidy to homebuyers and price control. Findings suggest two moderators on the market expansion – the premium reduction and subsidy proportion – which depend on government’s budget (how much they can offer) and ambitions (how fast they envision the expansion). Overall, the decision model offers policymakers a tool to imply how to effectively implement a green building subsidy program in the long term.

Keywords: green building movement; decision making; premium pricing; evolutionary game

Declarations of interest: None

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1. Introduction

Buildings consume huge natural resources and cause serious environmental problems (Zuo et al. 2017). Based on the International Energy Agency (IEA 2019), building construction and operation are responsible for 36% of global energy consumption and 40% of CO_2 emissions. The growth of world population and improvement of living quality continue to challenge the built environment. In this background, the green building movement has emerged globally to improve energy efficiency, health, and comfort in the built environment (Baird et al. 2012; Leaman et al. 2007; Lin et al. 2016; Zhao et al. 2018).

The green building movement framework (Zhao et al. 2019) highlights four milestones in the progress toward the green building adoption and acceptance: (1) the establishment of government agencies and regulations, (2) operations of professional organizations and industry standards, (3) promotion of public policy, and (4) influence on public behavior. The advances in green building technology reflect that public behaviors are currently the essential barrier to green building adoption. The green building movement framework specifies two types of public behaviors, i.e., developer behavior and homebuyer behavior. From the developer's perspective, green buildings require higher development costs and should have a premium price as viewing energy efficiency to be an extra value for profit (Darko and Chan 2017; Feng et al. 2021; Hwang and Tan 2012; Kats 2003; Yudelson 2010). For example, the literature has found that green buildings projects cost 1–12.5% more for development (Portnov et al. 2018) and 3.1–9.4% more for the green building certification (Sisson and Van Aerschot 2007; Uğur and Leblebici 2018). From the homebuyer's perspective, green buildings have a higher price and they are willing to pay the premium only when they can obtain a greater benefit (Kahn and Kok 2014; Ofek and Portnov 2020). For example, the average transaction price of certified green building is found to be 6.9% higher in the Chinese real estate market (Zhang et al. 2017).

A dilemma has emerged to reach the last milestone in the green building movement, particularly about the public adoption and acceptance. On one hand, developers prefer green building projects only if a premium price is expected to cover the extra design and construction costs and bring additional profits (Council 2013; Kats 2003). On the other hand, homebuyers prefer green buildings but hesitate to pay the premium (Federico and Marta 2021). In practice, developers pass 10–31% of the extra development costs for green buildings to homebuyers to obtain a higher profit (Portnov et al. 2018). In other words, developers will not adopt green building technology in their projects if homebuyers are not willing to pay the premium price. Often, both developers and homebuyers intend not to change their behaviors due to psychological routines (Zuo and Zhao 2014). In this context, GB subsidy programs become a critical government policy used in many countries to promote the public acceptance of green buildings (Olubunmi et al. 2016; Wang et al. 2021; Zou et al. 2017).

A green building subsidy, i.e., government incentives, is a form of financial aid with a goal to promote the adoption of green building technologies and the acceptance of green buildings in the market. The subsidy can be extended to a developer, e.g., in China (Kong and He 2021), or a homebuyer, e.g., in Israel (Cohen et al. 2019). The subsidy strategy for developers includes monetary reimbursement, tax deduction, and floor area ratio benefits (Diyana and Abidin 2013; Olubunmi et al. 2016; Zou et al. 2017). The subsidy strategy for homebuyers includes monetary rebates, high mortgage lines, low mortgage rates, and tax deductions (Li et al. 2014). However, there is a lack of agreement and evidence showing what subsidy strategy could promote the public acceptance of green buildings and maximize societal benefits.

The objective of this study is to create a decision model to optimize the subsidy strategy that can achieve joint benefits for government agencies, developers, and homebuyers. We apply the evolutionary game theory to develop our decision model. In the game model, government agencies, developers, and homebuyers are the three key players (Ding et al. 2018; Feng et al. 2020). Their interests are different and conflicting: (1) government agencies seek the environmental benefit and social credibility but have a limited budget to offer subsidy (Chen et al. 2021); (2) developers seek profits (Council 2013; Kats 2003) but need to invest a higher development cost (Hu et al. 2014); and (3) homebuyers seek low energy expenditure and better living quality but have a limited willingness to pay (Heerwagen 2000; Kats 2003). The outputs seek a joint, balanced benefit across the three players and imply for policymakers how to effectively implement a green building subsidy program in the long run (Menassa and Baer 2014).

2. Model Development

The evolutionary game theory emphasizes a simultaneous process to reach system equilibrium. (Smith and Price 1973) presented the concept of evolutionary, stable strategy that considers players to play multiple games and dynamically adjust their strategies. The evolutionary game theory has been applied in the building literature to examine factors on green building construction (Feng et al. 2020), carbon tax policy (Qiang et al. 2021), building technology adoption (Chen et al. 2021), and green building incentives (Fan and Hui 2020; Fan and Wu 2020). In this study, we use the evolutionary game theory to create a mathematical decision model to optimize the green building subsidy strategy among government agencies, developers, and homebuyers.

2.1. Players and decisions

Our model includes three players: government agencies, developers, and homebuyers. We assume they are limited rational economic parties. That is, their strategies cannot reach equilibrium at the beginning of the game and could reach an optimal strategy profile to fit the interest of all parties through a process of continuous learning and correction.

Figure 1 displays the decision structure for each of the three players: (1) government agencies have two choices to offer GB subsidy (G_1 with a probability = x) or not offer (N_1 with a probability = 1–x); (2) developers have two choices to build either GB projects (G_2 with a probability = y) or non-GB projects (N_2 with a probability = 1–y); and (3) homebuyers have two choices to purchase either GB home (G_3 with a probability = z) or non-GB homes (N_3 with a probability = 1–z).

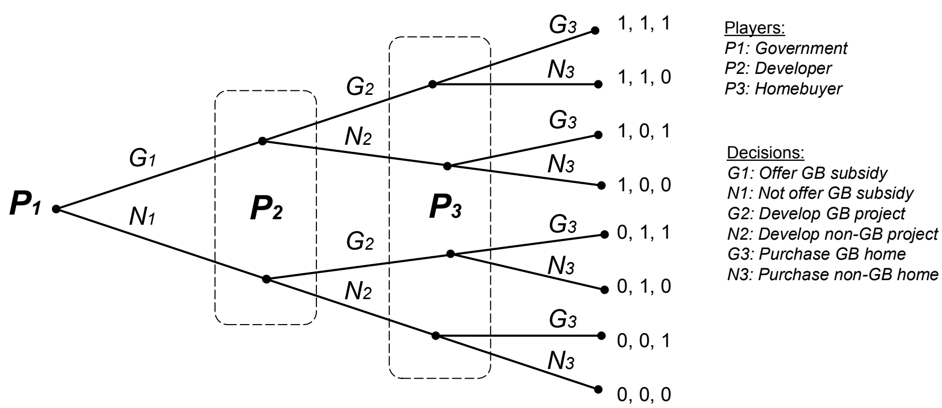


Figure 1. Structure of players and decisions in the evolutionary game

2.2 Variables and payoff matrix

Table 1 lists the 15 variables in the evolutionary game. Table 2 represents the payoff matrix for each of the six subsidy strategies based on the model setup for players and decisions. The payoff mechanisms are explained as follows.

- A green building subsidy by a government agency can compensate for the incremental cost at $\alpha \Delta C$ $(\alpha >= 0)$ for a developer when switching the choice of non-GB to GB. The subsidy can also compensate the premium price at $\beta \Delta R$ $(\beta >= 0)$ for a homebuyer when switching the choice of non-GB to GB.
- A homebuyer can gain the extra benefit at $\gamma \Delta U$, based on the level of awareness about

GB benefits, e.g., better thermal comfort, productivity, and health (Heerwagen 2000; Kats 2003). The literature has identified that the awareness level affects the GB demand (He et al. 2022). That is, a strong γ (i.e., more a homebuyer understands GB benefits) increases the willingness to pay for GB (Ofek and Portnov 2020).

- In case homebuyers choose to purchase GB and developers choose not to build GB, they will pursue other developers who meet their demand.

Table 1. List of Variables in the Game

Variable	Description
R_1	The price to purchase a green building home (GB)
R_2	The price to purchase a conventional building home (non-GB)
ΔR	The premium to purchase green building, $\Delta R=R_1-R_2>0$
C_1	The cost to develop a green building home (GB)
C_2	The cost to develop a conventional building home (non-GB)
ΔC	The incremental cost to develop green building, $\Delta C=C_1-C_2>0$
U_1	The benefit of living in a green building (GB)
U_2	The benefit of living in a conventional building (non-GB)
ΔU	The marginal benefit to live in a green building, $\Delta U=U_1-U_2>0$
S	The societal benefits when offering green building subsidy, e.g., reputation gains for a government agency
T	The penalty to develop conventional buildings over green buildings, e.g., carbon tax or energy tax
α	The proportion of increment cost shared by government subsidy
β	The proportion of premium shared by government subsidy
γ	The level of awareness about the environmental, societal, and life-cycle cost benefits of green buildings
k	The tax rate that developers need to pay

Table 2. Payoff Matrix for the Players

Payoff	Government	Developer	Homebuyer
(1,1,1)	$kR_1+S-\alpha\Delta R$	$(1-k)R_1-C_1+\alpha\Delta C$	$U_2+\gamma\Delta U-R_1+\beta\Delta R$
(1,1,0)	$S-\alpha\Delta C$	$\alpha\Delta C-C_1$	U_2-R_2
(1,0,1)	$S+T$	$-C_2-T$	$U_2+\gamma\Delta U-R_1+\beta\Delta R$
(1,0,0)	kR_2+S+T	$(1-k)R_2-C_2+T$	U_2-R_2
(0,1,1)	kR_1	$(1-k)R_1-C_1$	$U_2+\gamma\Delta U-R_1$
(0,1,0)	0	$-C_1$	U_2-R_2
(0,0,1)	0	$-C_2$	$U_2+\gamma\Delta U-R_1$
(0,0,0)	kR_2	$(1-k)R_2-C_2$	U_2-R_2

2.3 Replicator dynamics

The expected benefits and replicator dynamics for green building promotion for each player decision are explained as follows:

Let B_{11} be the benefit when government agencies choose to offer GB subsidy (decision G_1):

$$B_{11} = yz(kR_1 - \beta\Delta R) - y(kR_2 + \alpha\Delta C + T) + kR_2 + S + T$$

Let B_{12} be the benefit when government agencies choose to not offer GB subsidy (decision N_1):

$$B_{12} = yzk(R_1 + R_2) - ykR_2 - zkR_2 + kR_2$$

Then, the replicator dynamics equation for government agency is:

$$F(x) = \frac{dx}{dt} = x(1-x)(B_{11} - B_{12}) = x(1-x)[S + T - yz\beta\Delta R - y(\alpha\Delta C + T)]$$

(1) Let B_{21} be the benefit when developers choose to develop GB project (decision G_2):

$$B_{21} = x\alpha\Delta C + z(1-k)R_1 - C_1$$

Let B_{22} be the benefit when developers choose to develop non-GB project (decision N_2):

$$B_{22} = -xT + (1-z)(1-k)R_2 - C_2$$

Then, the replicator dynamics equation for developer is:

$$F(y) = \frac{dy}{dt} = y(1-y)(B_{21} - B_{22}) = y(1-y)[x(\alpha\Delta C + T) + z(1-k)(R_1 + R_2) - (1-k)R_2 - \Delta C]$$

(2) Let B_{31} be the benefit when homebuyers choose to purchase GB home (decision G_3):

$$B_{31} = x\beta\Delta R + U_2 + \gamma\Delta U - R_1$$

(3) Let B_{32} be the benefit when homebuyers choose to purchase non-GB home (decision N_3):

$$B_{32} = U_2 - R_2$$

Then, the replicator dynamics equation for homebuyer is:

$$F(z) = \frac{dz}{dt} = z(1-z)(B_{31} - B_{32}) = z(1-z)(x\beta\Delta R + \gamma\Delta U - \Delta R)$$

2.4 Stability analysis for government agency

The first derivative of government's replicator dynamics is:

$$F(x)' = \frac{\partial F(x)}{x} = (1-2x)[S + T - yz\beta\Delta R - y(\alpha\Delta C + T)]$$

Let $F(x) = 0$ and we found three solutions: $x^* = 0$, $x^* = 1$ and $y^* = \frac{S+T}{z\beta\Delta R + \alpha\Delta C + T}$ (although y^* is not a certain number). Accordingly, we discuss the three solutions as follows:

(1) if $y \equiv y^* = \frac{S+T}{z\beta\Delta R + \alpha\Delta C + T}$, $F(x) \equiv 0$, then regardless of variable values, x is constant over time, indicating that the decision of G_1 or N_1 is not stable for government.

(2) if $0 < y < \frac{S+T}{z\beta\Delta R + \alpha\Delta C + T}$, let $F(x) = 0$, solve that $x^* = 0$, $x^* = 1$, then $F(0)' > 0$ and

$F(1)' < 0$. According to the principle of stability of replicator dynamics, this strategy is stable only when $F(x)' < 0$. Thus, $x^* = 1$ is a stable point, indicating that government will eventually choose the decision G_1 – "offering GB subsidy" (see Figure 2a).

(3) if $\frac{S+T}{z\beta\Delta R+\alpha\Delta C+T} < y < 1$, let $F(x) = 0$, solve that $x^* = 0$, $x^* = 1$, then $F(0)' < 0$ and $F(1)' > 0$. Thus, $x^* = 0$ is a stable point, indicating that government will eventually choose the decision N_1 – "not offering GB subsidy" (see Figure 2b).

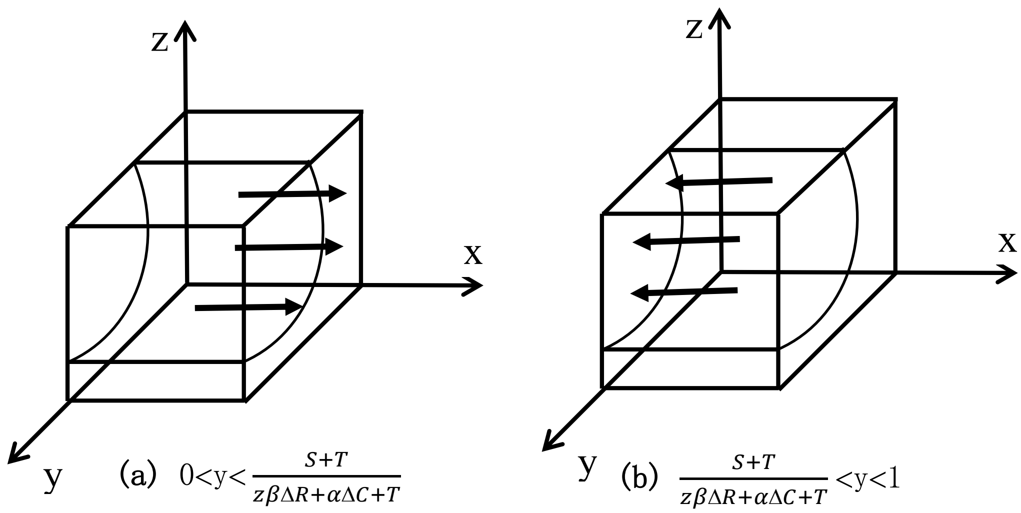


Figure 2. The evolutionary trajectory of government strategy

The stability analysis suggests that government offer GB subsidy and keep the budget within a reasonable range. First, the societal benefits harvested by government are assumed to be greater than the total subsidy spent: $S > \alpha\Delta C + \beta\Delta R$ and then $\frac{S+T}{z\beta\Delta R+\alpha\Delta C+T} > 1$, which indicates that the evolutionary game should always evolve to offer GB subsidy. Second, given a huge subsidy budget, the subsidy spent is possible to be greater than the societal benefits: $S < \alpha\Delta C + \beta\Delta R$. In this case, the evolutionary game should evolve to not offer GB subsidy.

2.5 Stability analysis for developer

The first derivative of developer's replicator dynamics is:

$$F(y)' = \frac{\partial F(y)}{y} = (1-2y)[x(\alpha\Delta C + T) + z(1-k)(R_1+R_2) - (1-k)R_2 - \Delta C]$$

Let $F(y) = 0$ and three solutions are found: $y^* = 0$, $y^* = 1$, and $x^* = \frac{\Delta C+(1-k)R_2 - z(1-k)(R_1+R_2)}{\alpha\Delta C+T}$. Accordingly, we discuss the three solutions as follows:

(1) if $x \equiv x^* = \frac{\Delta C+(1-k)R_2 - z(1-k)(R_1+R_2)}{\alpha\Delta C+T}$, $F(y) \equiv 0$, then y will not change over time, indicating that developing GB or non-GB project is not stable for developer.

(2) if $0 < x < \frac{\Delta C+(1-k)R_2 - z(1-k)(R_1+R_2)}{\alpha\Delta C+T}$, let $F(y) = 0$, solve that $y^* = 0$ and $y^* = 1$, then $F(0)' < 0$ and $F(1)' > 0$. Thus, $y^* = 0$ is a stable point, indicating that developers will eventually choose the decision G_2 – "developing GB project" (see Figure 3a).

(3) if $\frac{\Delta C+(1-k)R_2 - z(1-k)(R_1+R_2)}{\alpha\Delta C+T} < x < 1$, let $F(y) = 0$, solve that $y^* = 0$, $y^* = 1$, then $F(0)' > 0$ and $F(1)' < 0$. Thus, $y^* = 1$ is the stable point, indicating that developer will eventually choose the decision N_2 – "developing non-GB project" (see Figure 3b).

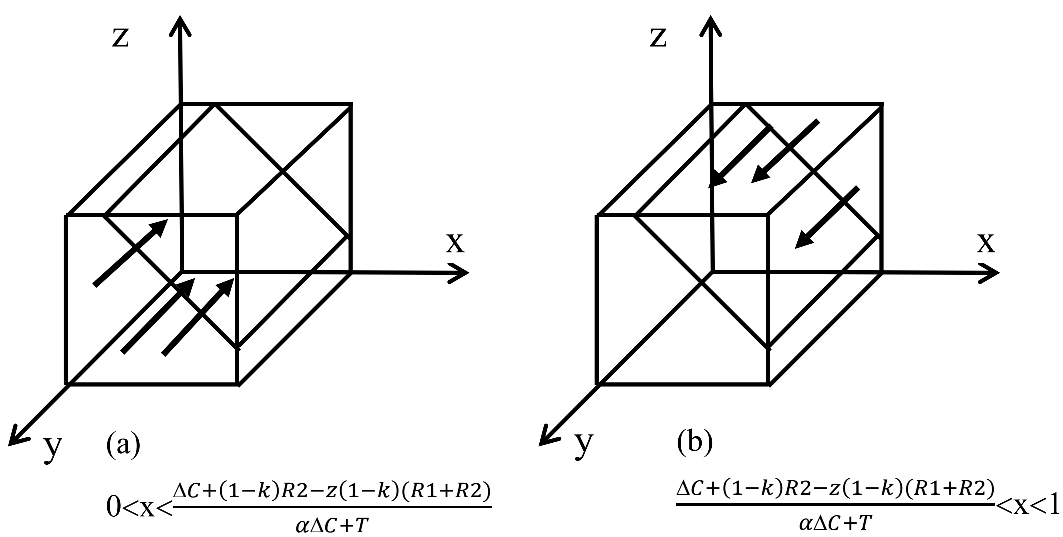


Figure 3. The evolutionary trajectory of developer strategy

The stability analysis suggests multiple findings to promote GB development. First, the high participation of government and homebuyer increases the likelihood for developers to build GB projects. Second, the simultaneous use of subsidy and penalty is effective to increase the likelihood for developers to build GB projects. Third, a higher premium price also increases the likelihood for developers to build GB projects, although this may increase homebuyer's financial burden.

2.6 Stability analysis for homebuyer

The first derivative of homebuyer's replicator dynamics is:

$$F(z)' = \frac{\partial F(z)}{z} = (1 - 2z)(x\beta\Delta R + \gamma\Delta U - \Delta R)$$

Let $F(z) = 0$ and three solutions are found: $z^* = 0$, $z^* = 1$, and $x^* = \frac{\Delta R - \gamma\Delta U}{\beta\Delta R}$. Accordingly, we discuss the three scenarios as follows:

(1) if $x \equiv x^* = \frac{\Delta R - \gamma\Delta U}{\beta\Delta R}$, $F(z) \equiv 0$, then z is constant over time, indicating that purchasing GB or non-GB home is not stable for homebuyer.

(2) if $0 < x < \frac{\Delta R - \gamma\Delta U}{\beta\Delta R}$, let $F(z) = 0$, solve that $z^* = 0$ and $z^* = 1$, then $F(0)' < 0$ and $F(1)' > 0$. Thus, $z^* = 0$ is a stable point, indicating that homebuyers will eventually choose the decision G_3 – "purchasing GB home" (see Figure 4a).

(3) if $\frac{\Delta R - \gamma\Delta U}{\beta\Delta R} < x < 1$, let $F(z) = 0$, solve that $z^* = 0$, $z^* = 1$, then $F(0)' > 0$ and $F(1)' < 0$. Thus, $z^* = 1$ is the stable point, indicating that homebuyers will eventually choose the decision N_3 – "purchasing non-GB home" (see Figure 4b).

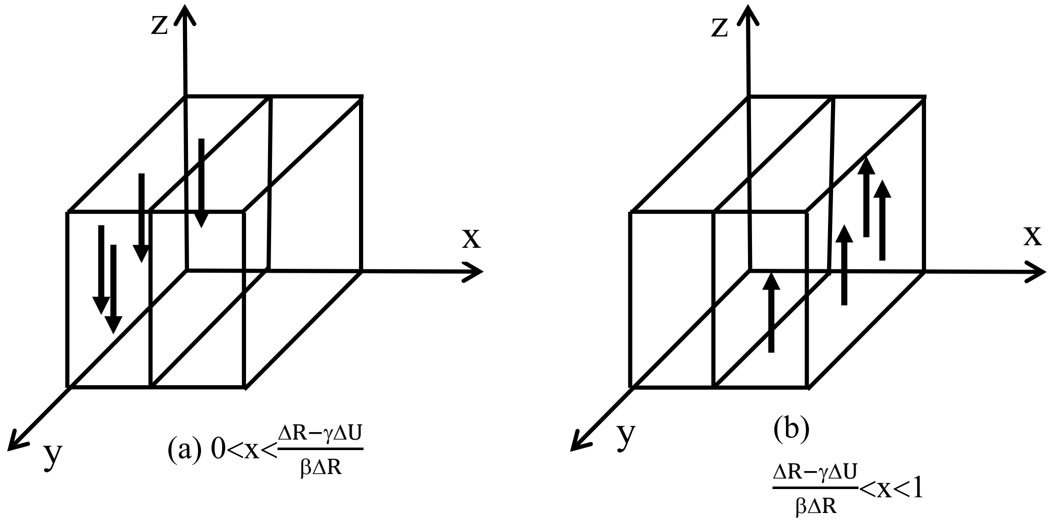


Figure 4. The evolutionary trajectory of homebuyer strategy

The stability analysis suggests multiple findings to promote GB sales. First, homebuyers are more likely to purchase GB when they see a greater benefit than the premium price. Second, the subsidy helps offset the premium and is effective to increase the likelihood for homebuyers to choose GB, although the premium borne by homebuyers may cause a problem in the long run. Third, a stronger awareness of GB benefits can increase the willingness to pay and stimulate homebuyers to purchase GB.

3. Model Demonstration and Case Study

We applied our decision model to a real-world project to identify the optimal subsidy strategy to promote green buildings in the long term. The case demonstrated how to use our decision model to find the subsidy on developers (i.e., α, the proportion of increment cost shared by government subsidy) and homebuyers (i.e., β, the proportion of premium price shared by government subsidy). The case project was from a certified 3-star green residential project located in Tianjin city, China.

In this case, the initial probabilities of the three players (i.e., x, y, and z) were set as follows:

(1) $x = 0.8$, considering the Chinese government has a strong administrative role in regulating the housing market (Harrington and Hsu 2018); (2) $y = 0.7$, considering new green building area should account for 70% in Chinese cities and towns by 2022; and (3) $z = 0.5$ considering the finding of (Du et al. 2020). The variable values were listed in Table 3. For easy calculation, the base unit of price is 10^2 CNY/m^2. The simulations were performed in MATLAB 2018a.

Table 3. List of Variable Values and Explanations in Case Study

Variable	Explanation
ΔC=5×10^2 CNY/m^2	According to the project data
R_1=170×10^2 CNY/m^2	According to the house price data, R_1=170×10^2 CNY/m^2
R_2=160×10^2 CNY/m^2	In China, the premium of green-certified projects compared with non-green certified projects is 6.9% (Zhang et al. 2017), it can be inferred that the price of surrounding conventional houses is about R_2=160×10^2 CNY/m^2.
ΔR=10×10^2 CNY/m^2	$\Delta R=R_1-R_2$=10×10^2 CNY/m^2
ΔU=12.5×10^2 CNY/m^2	Green buildings can generate benefits 10 times as great as incremental cost (Kats 2003). Based on the 2015 National Green Building Evaluation and Labeling Statistics Report, the incremental cost of three-star GB is 125. So set incremental benefits to be ΔU=12.5×10^2 CNY/m^2
T=1.3×10^2 CNY/m^2	Every square meter of reinforced concrete buildings emits 3.16 tons of carbon dioxide during a 50-year service life (You et al. 2011). The Ministry of Finance recommends that the carbon tax rate for 2020 be set at 40 CNY/t. So T=1.3×10^2 CNY/m^2
S=2.7×10^2 CNY/m^2	As there are few studies to quantitatively measure the social benefits of green buildings, we borrow the data of (Chen et al. 2021) here.
α=0.16	In 2012, the "Implementation Opinions on Accelerating the Development of my country's Green Buildings" was issued, which determined the award standard for three-star green buildings of 80 CNY/m^2. So, the initial value of α is 0.16.
γ=0.7	(Ofek and Portnov 2020) conducted a questionnaire survey of 438 potential home buyers. 26%-31% of them are unaware of the benefits of reducing water and energy. Based on this, we set a reasonable value of γ=0.7.
k=0.25	(Chen et al. 2021) was in accordance with the "Regulations for the Implementation of the Enterprise Income Tax Law of the People's Republic of China", the income tax is 25%. Set k=0.25.

3.1 Strategy 1: Subsidy to developers

In this strategy, government subsidy is used to compensate developers (Vyas and Jha 2018). The simulation demonstrates how this strategy influences the choices of developers and homebuyers under various subsidy proportions (α). The results (Figure 6a) show that developers would eventually "build non-GB" ($y = 0$) and homebuyers would then "purchase non-GB" ($z = 0$), regardless of the subsidy proportion (α from 0.16 to 1.16). It is noteworthy that the choices of developers (build non-GB) and homebuyers (purchase non-GB) do not change even if the subsidy can completely cover the incremental cost for developers ($\alpha >= 1.0$). The results (Figure 6b) show that the relationships of decisions among the three players do not change, suggesting the incremental cost is not a major obstacle to GB adoption (Hoffman 2008; Nguyen et al. 2017). Given the existence of government subsidy (i.e., x approaching 1.0), developers are likely to "build non-GB" and homebuyers are likely to "purchase non-GB", and the likelihoods increase more sharply when the subsidy proportion decreases. Overall, findings indicate that this strategy is not effective in the long term.

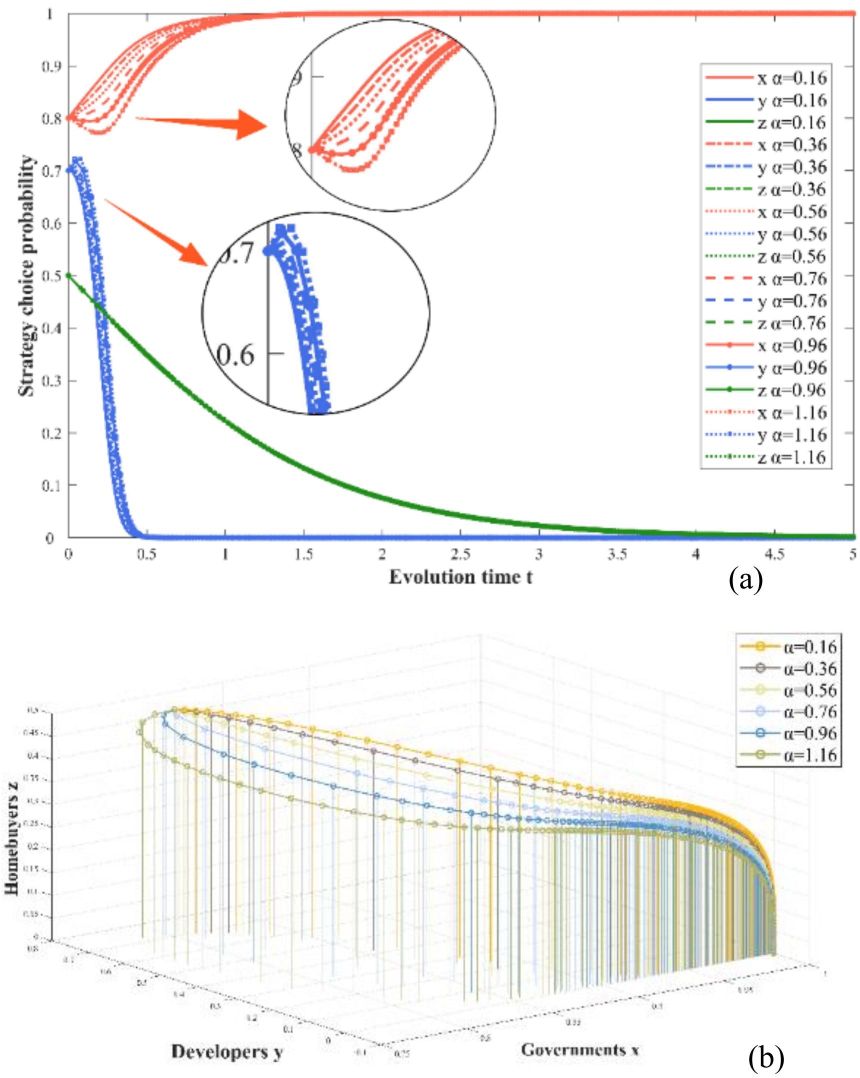
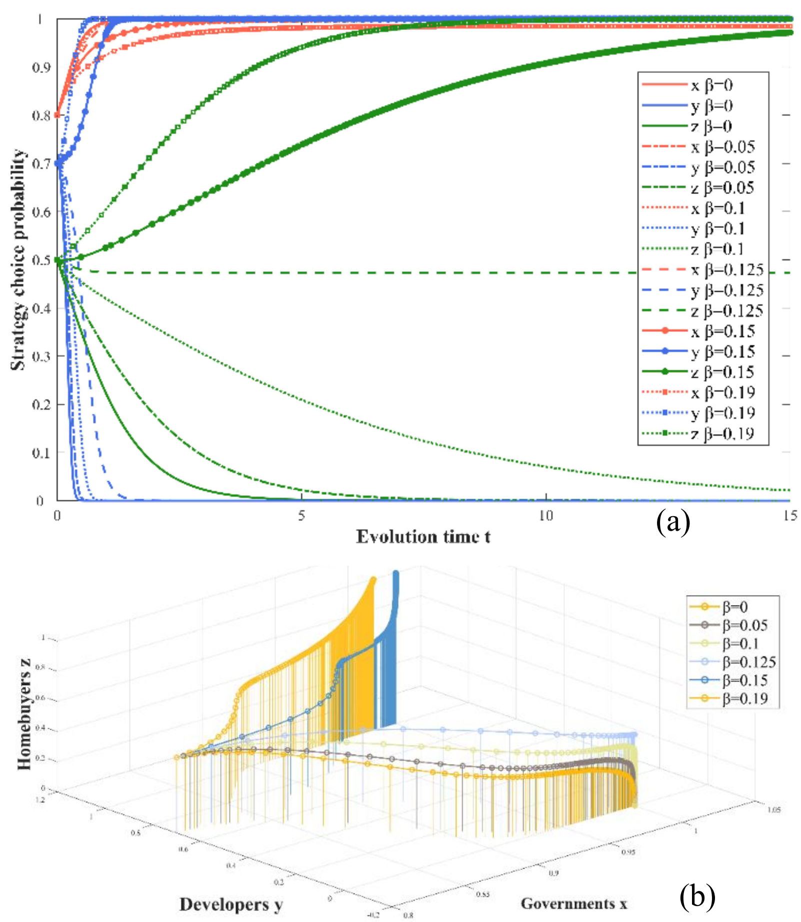


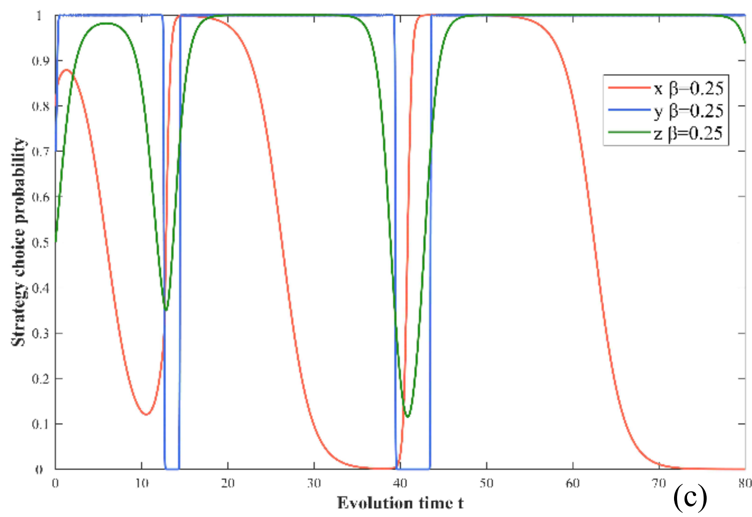
Figure 6. Decision evaluation of government (*x*), developer (*y*), and homebuyer (*z*) when green building subsidy is only provided to developers.

3.2 Strategy 2: Subsidy to homebuyers

In this strategy, government subsidy is used to compensate homebuyers (Vyas and Jha 2018). The results (Figure 7a) show that developers change their decision to eventually "build GB" (y = 1) and homebuyers also change their decision to "purchase GB" (z = 1) when subsidy covers more than 15% of the premium for homebuyers ($\beta >= 0.15$, 1.5×10^2 CNY/m^2 in this case). The results (Figure 7b) show that developers are likely to "build GB" and homebuyers are likely to "purchase

GB” given a considerable subsidy proportion ($\beta >= 0.15$), and vice versa. The results (Figure 7c) show an unsolvable situation when subsidy proportion increases to be higher than 19%, for example, 25%, suggesting that a very strong homebuyer subsidy can reduce the willingness to buy GB (Portnov et al. 2018). This indicates that subsidy to homebuyers only functions in a certain range ($0.15 < \beta < 0.19$ in this case). Overall, findings indicate that this strategy (homebuyers) is effective in the long term. The subsidy must be equivalent to 15%–19% of the premium (1.5–1.9 $\times 10^2$ CNY/m^2 in this case) and a higher subsidy proportion can accelerate the GB acceptance in the market (faster).





(c)

Figure 7. Decision evaluation of government (x), developer (y), and homebuyer (z) when green building subsidy is only provided to developers.

3.3 Strategy 3: Price control with no subsidy

In this strategy, government agencies use administrative measures, rather than incentive measures, to control GB sale price and ensure the premium (also developer profit) is within a reasonable range. The simulation demonstrates how this strategy influences the choices of developers and homebuyers under various premium reductions. The results (Figure 8) show that developers change their decision to eventually "build GB" (y = 1) when the premium reduces by 12.5% or more (1.25×10^2 CNY/m^2 in this case) and homebuyers change their decision to "purchase GB" (z = 1) when the premium reduces by 15% or more (1.5×10^2 CNY/m^2 in this case). Although a reduced premium lowers the developer's profit, the premium (ΔR=10×10^2 CNY/m^2) is greater than the incremental cost (ΔC=5×10^2 CNY/m^2). In other words, developers are profitable to build GB projects when $\Delta R > \Delta C$. Overall, findings indicate that this strategy (price control) is effective in the long term. The price reduction should be in the range of 15%–50% of the premium (1.5–5.0 ×10^2 CNY/m^2 in this case).

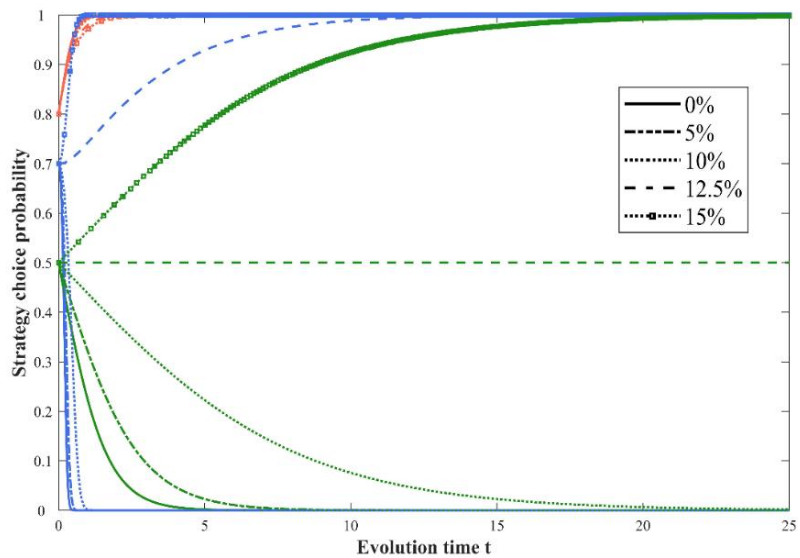


Figure 8. Decision evaluation of developer (y) and homebuyer (z) under price control

3.4 Strategy 4: Subsidy to developers combined with price control

In this strategy, government agencies provide subsidy to developers and control GB price. The results (Figure 9a and 9b) show that, when the premium reduces by less than 12.5%, developers eventually "build non-GB" ($y = 0$) and then homebuyers eventually "purchase non-GB" ($z = 0$), regardless of the subsidy proportion. The results (Figure 9c) show that when the premium reduces by 12.5% or more, developers eventually "build GB" ($y = 1$), regardless of the subsidy proportion. The results (Figure 9d) show that when the premium reduces by 15% or more, developers eventually "build GB" ($y = 1$) and homebuyers eventually "purchase GB" ($z = 1$), regardless of the subsidy proportion. Noteworthy is that given a strong initial subsidy ($\alpha >= 0.56$), government can eventually "not offer subsidy" ($x = 0$). Overall, findings indicate that this strategy is effective in the long term when the premium is reduced by at least 15%. The findings are consistent with strategy 3 but with the help of subsidy the game equilibrium can be achieved faster.

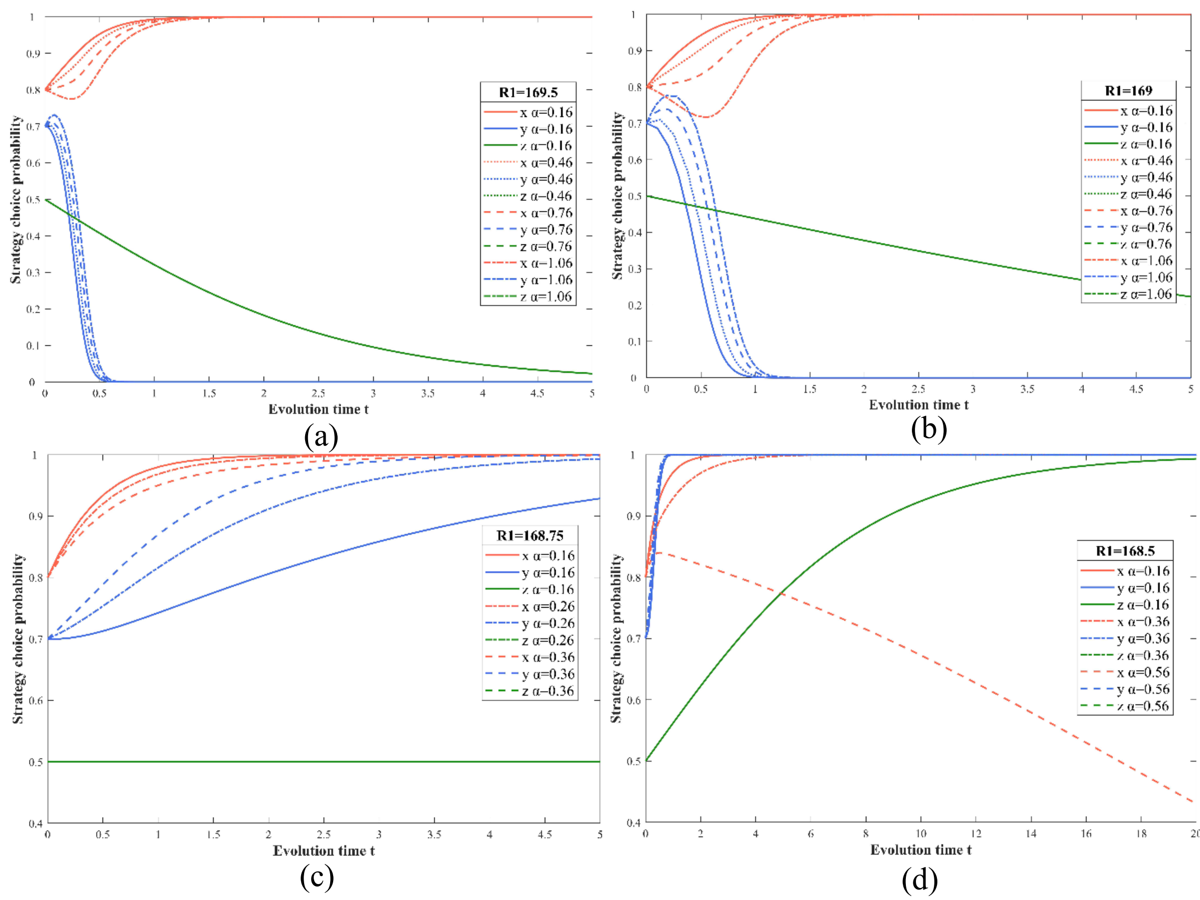


Figure 9. Decision evaluation of government (x), developer (y), and homebuyer (z) when subsidy is provided to developers and premium is reduced.

3.5 Strategy 5: Subsidy to homebuyers combined with price control

In this strategy, government agencies provide subsidy to homebuyers and control GB price. The results (Figure 10a-10c) show that, when the premium reduces less by 12.5%, the subsidy can moderate both developers and homebuyers to eventually "build GB" (y = 1) and "purchase GB" (z = 1). The required subsidy proportion is reliant on the premium reduction. That is, a larger amount of premium reduction would require a smaller subsidy proportion to change the choices of developers and homebuyers. The results (Figure 10d) show that, when the premium reduces by more than 12.5%, developers eventually "build GB" (y = 1) and homebuyers eventually "purchase GB" (z = 1), regardless of the subsidy proportion. Here, the subsidy proportion moderates the speed to reach equilibrium. Overall, findings indicate that this strategy is effective in the long term. The premium reduction can save the subsidy and accelerate green building acceptance in the market.

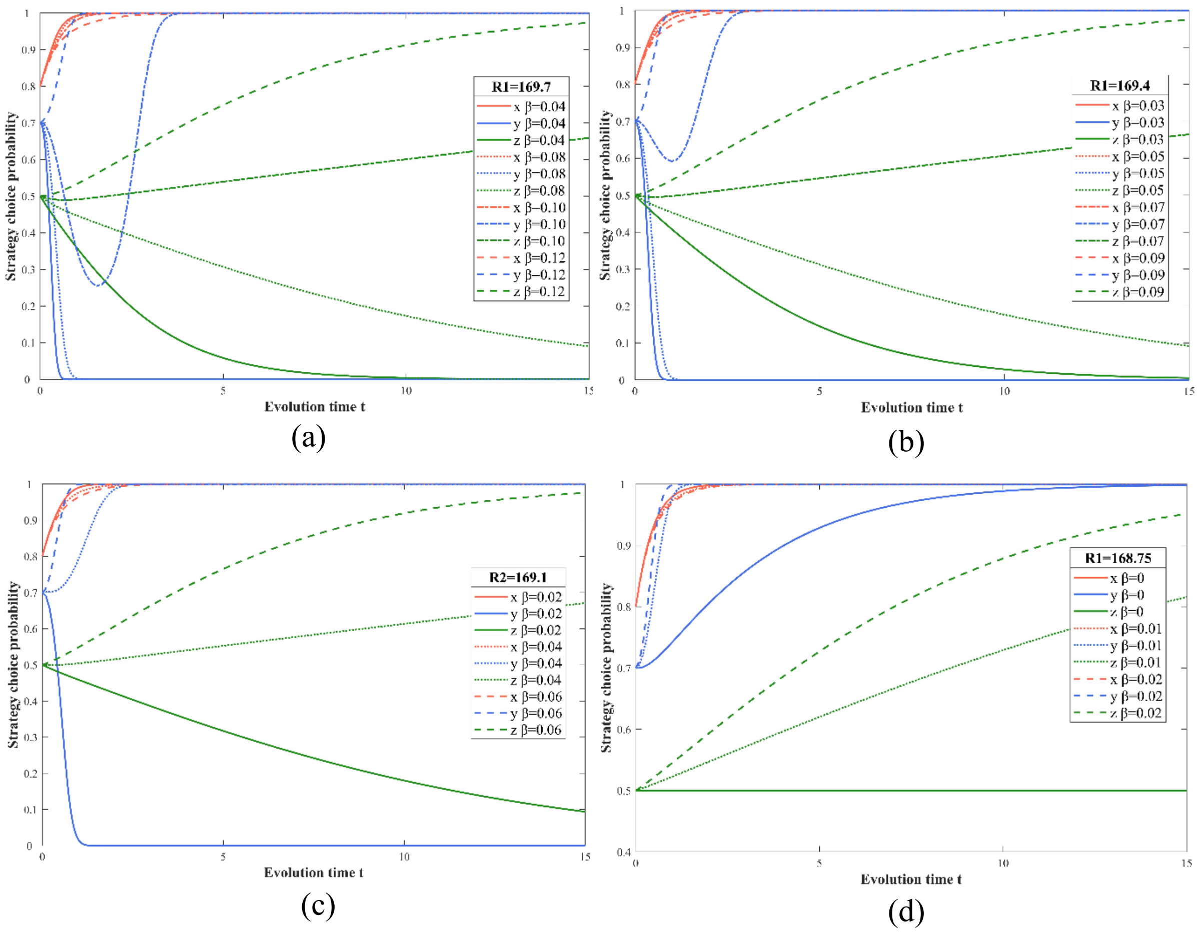


Figure 10. Decision evaluation of government (x), developer (y), and homebuyer (z) when subsidy is provided to homebuyer and premium is reduced.

3.6 Summary

Five strategies are analyzed using our decision model. The results show that four out of the five strategies are effective in the long term under various conditions. The administrative measures on GB price control can be a great supplement to the subsidy policies; however, a great social cost might have to be paid by government to implement administrative measures to intervene in the market. Overall, the premium reduction and subsidy proportion are two moderators to determine how fast the equilibrium can be obtained. Back to this case project, our decision model recommends the strategy 5 (subsidy to homebuyers combined with price control) to be the optimal solution and provides the effective range of variables, for example, subsidy proportion. The final subsidy specifics are depending on government's budget (how much they can offer) and ambitions (how fast they envision the change).

4. Discussion

4.1 Subsidy allocation between developer and homebuyer

The green building movement needs the buy-in from developers (supply side) and homebuyers (demand side). Both of them suffer from a high cost to build GB or purchase GB (McCoy et al. 2018; Zhao et al. 2016). Government subsidy has been used in many countries and regions to offset the high costs. Our model confirms that "offering subsidy" should be an effective strategy in the long run. Moreover, our decision model identifies the optimal trade-off showing how to allocate subsidies between the supply side and demand side. Based on the simulation in the case demonstration, subsidy to the demand side (homebuyers) seems more effective than the supply side (developers) to increase green building market acceptance in the long term. In other words, the market demand plays a more important role in the continuous growth of green buildings. As explained by (Carter 2006), the growth in customer demand encourages developers to apply sustainable features to building projects.

4.2 A reasonable premium

A premium is the extra cost that consumers are willing to pay for additional quality to regular products. By paying for the premium, homebuyers can enjoy energy efficiency, indoor air quality, and quality of life that are rooted in the feature of green buildings. The premium is always a reward for developers to apply energy-efficient technologies, materials, and equipment in construction projects. However, the premium is way too high in the current market that can be triple the incremental development cost. The excessive premium transferred to homebuyers, compared to the incremental development cost, becomes a key factor to hinder green building acceptance. Our decision model allows identifying the reasonable range of premium that ensures a long-term healthy market. The reasonable premium can lead to long-term green building growth, and can also catalyze the impact of subsidy and accelerate rapid growth of green buildings in the market. The premium reduction can be reached by administrative measures from government or market behaviors from developers. The market expansion and fast delivery could marginalize the incremental development costs (Rehm and Ade 2013). In other words, a lower premium allows developers to win a bigger market and retain profit.

5. Conclusion

This study reports a decision model to optimize the green building subsidy strategy. The model is developed based on the evolutionary game theory that seeks a stable equilibrium for all players. In the green building context, our decision model pursues the mutual benefits for government, developer, and homebuyers, rather than the interest of any single player. Our decision model can identify the optimal strategy and the reasonable range of strategy factors (e.g., subsidy allocation, subsidy proportion, and premium reduction). A real-world project is used as a case study to demonstrate the application of our decision model. The case study elucidates that the combined strategy of homebuyer subsidy and price control can maximize the long-term growth of green buildings. The findings suggest that the premium reduction and subsidy proportion moderate the speed of market expansion. The specifics of the two moderators are determined by government's budget (how much they can offer) and ambitions (how fast they envision the change). Overall, the decision model provides policymakers a tool to decide on long-term subsidy policy; and the findings generated from the case study provide insights into green building promotion.

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