Pricing and Incentive Mechanism for Green Building Supply Chain with Reference Price

Wen Jiang*, Xiaoyan Huang, Menglin Liu
College of Architecture and Urban-Rural Planning, Sichuan Agricultural University, Chengdu, Sichuan, 611830, P.R. China
*Corresponding author’s e-mail:xuezhongsha_wen@163.com

Abstract. Based on the stackable game theory, this paper studies the pricing and incentive mechanism of a two-echelon green building supply chain consisting of a developer and a contractor. We build the profit maximization models of the developer and the contractor for three scenarios that without reference price and incentive mechanism, with the reference price but no incentive mechanism and with the reference price and incentive mechanism. Then study the optimal decisions of the developer and the contractor in different situations. The results show that introducing incentive mechanism and reference price into building supply chain pricing can effectively increase the profit of developers and contractors. In addition, it can also improve the level of green buildings and promote the sustainable development of the construction industry. Finally, the sensitivity analysis shows that the optimal pricing increases as the initial reference price increases; The optimal pricing, incentive intensity and green building level are increasing in initial green building level and decreasing in increment cost coefficient.

1. Introduction
Greenhouse gas emissions not only pollute the air but also cause global warming, which poses a threat to the environment and human health [1]. In the process of urbanization in China, building carbon emissions account for a large proportion of energy consumption [2]. In response to this challenge, Li et al. introduced the carbon tax policy into the prefabricated building supply chain to study the wholesale price and green technology investment decisions of suppliers and the pricing decisions of assemblers under decentralized decision-making and centralized decision-making [3]. Green building is hailed as an environmentally friendly building. It not only reduces energy consumption, mitigates the adverse effects of construction activities on the environment and climate change, but also improves user satisfaction [4]. In addition, research shows that consumers with green preferences are willing to pay higher prices to buy green products, which increases the demand for green products [5]. In order to meet government policy and consumer demand, developers have to develop green buildings, but green building construction requires contractors to invest incremental costs. Therefore, developers must motivate contractors to innovate green technology.

The research related to this paper mainly includes two aspects: product pricing with reference price effects and financial incentive on green building.

Reference price is an intrinsic standard on which consumers evaluate the selling price of a product [6]. Winer constructed a brand selection model that considers the reference price effect. The empirical results show that when predicting the consumer purchasing probability, the model considering the reference price effect is better than the model considering only the selling price [7]. Zhang et al. proposes a dynamic cooperative advertising model for a manufacturer retailer supply chain and analyzes how the...
reference price effect would influence the decisions of all the channel members [8]. Popescu et al. hypothesized that demand is influenced by current product prices and consumer internal reference prices, and studies the dynamic pricing of monopolistic retailers [9].

Bonus incentive mechanism is one of the most common methods used by construction supply chain companies to achieve goal optimization [10]. Based on the ecological perspective, Li et al. used the eco-environmental benefits of green buildings as an important compensation factor to construct a green building developer loss-type compensation model and a green building eco-environmental effect compensation model [11]. Wu et al. proposed an effective incentive mechanism for the contractor by using game theory and achieved the optimal incentive intensity of the developer and the optimal green level of the contractor [12]. Shazmin et al. Identified three types of property tax assessment incentive models that can be used to encourage green building development, including deductions, exemptions, and tax refunds [13].

The above literature lay a foundation for the research on the pricing and incentive mechanism of green building supply chain with reference price. From the above research, we know that it is necessary to consider consumer reference price effect in product pricing. In addition, contractors play an important role in the construction of green buildings. However, there are few studies on encouraging contractors to build green buildings. Therefore, this paper aims to address this research gap by focusing on the incentive mechanism of the contractor with reference price.

This paper introduces the reference price into the green building supply chain, and studies the optimal decision of developer and contractor in three different situations. The developer established an incentive mechanism to encourage the contractor to achieving high green building level before the project starts. Then, the contractor decides the green building level to be achieved in the completion of the construction process. Finally, the developer decides the selling price. This study covers the following key issues:

1. What is the optimal incentive intensity setting for the developer to encourage the contractor to achieve high green building level?
2. What is the optimal green building level for the contractor under the incentive mechanism?
3. What is the optimal selling price of the developer with reference price?

The rest of this paper is organized as follows. The model description and assumptions are presented in Section 2. The base model and its optimal decision are obtained in Section 3. The model with reference price and its optimal decision are obtained in Section 4. The model with reference price and incentive mechanism, and its optimal decision are obtained in Section 5. Section 6 is the effect of reference price and incentive mechanism. Sensitivity analysis of optimal decision is discussed in Section 7. Section 8 is the conclusion and future research.

2. Model Descriptions and Assumption

In this paper, we propose a stackable game between a construction developer and a construction contractor. Assume that the developer is the stackable leader and the contractor is the stackable follower.

In this paper, we use the parameters and variables as the following notations in Table 1.
First, we consider the basic model without reference price and incentive mechanism. In this section, the contractor decides the green building level and then the developer decides the selling price. The contractor’s profit is denoted as $\pi^c(g)$ and the decision model for the developer’s profit maximization is $\max_p \pi^d(p)$ where $\pi^d(p) = (p - C_o)(a + b g - \delta p) - C_s$.

$$\pi^d(p) = (p - C_o)(a + b g - \delta p) - C_s \tag{2}$$

Then the decision model for the developer’s profit maximization is $\max_p \pi^d(p)$ and the decision model for the contractor’s profit maximization is $\max_g \pi^c(g)$.

For the optimal green building level $g^*$ of the contractor and the optimal selling price $p^*$ of the developer without reference price and incentive mechanism, the following proportion is obtained.

**Proposition 1.** $g^* = g_0, \quad p^* = \frac{a + b g_0 + C_s \delta}{2\delta}.$

**Proof.** The second deviation is $\frac{d^2 \pi^c}{dg^2} = -\mu < 0$, therefore the profit function of contractor is a convex function of $g$. From $\frac{d \pi^c}{dg} = 0$, the best response of the contractor is $g^* = g_0$. Submit $g^* = g_0$ and the contractor’s profit is $\max_g \pi^c(g)$.

### Table 1 Notations

| Notation | Description |
|----------|-------------|
| $I$      | The bonus intensity of the construction developer |
| $g$      | The green building certification level of the contractor |
| $g_0$    | The initial green building certification level of the construction developer required, $g \geq g_0$. |
| $C_o$    | Unit operating cost of the construction developer |
| $C_b$    | Unit construction cost of the contractor |
| $C_s$    | Unit construction investment of the construction developer |
| $C_c$    | Unit total construction investment the construction developer |
| $G$      | Unit incremental cost of green technology investment |
| $\mu$    | Increment cost coefficient of green technology investment |
| $r(t)$   | Reference price at time $t$ |
| $r_0$    | The initial reference price |
| $p$      | Unit selling price |
| $D_t$    | Market demand at time $t$ |

In addition, to make the model more practical and meaningful, the parameters must satisfy some certain conditions, so we assume:

1. The bonus is a linear function related to bonus intensity and green building level, that is $B(I) = I(g - g_0)$.
2. The incremental cost of green investment is a quadratic function of green building level, that is $G(g) = \frac{1}{2} \mu (g - g_0)^2$.
3. The market demand is a linear function related to price, green building level and reference price, that is $D_t(p, g) = a + b g - \delta p - \theta (p - r(t)) (a, b, \delta, \theta > 0)$. Let $c = \delta + \theta$, the demand function can be simplified to $D_t(p, g) = a + b g - cp + \theta r(t)$ [8].
4. The evolution equation of the reference price is $\dot{r}(t) = \frac{dr(t)}{dt} = a[p - r(t), \quad r(0) = r_0 > 0$ [8]. Solve the above differential equation then we can get $r(t) = p + Ce^{-at}$, $C$ is an arbitrary constant. Substituting the boundary condition $r(0) = r_0$ into $r(t)$ we can obtain $r(t) = p + (r_0 - p)e^{-at}$

$$r(t) = p + (r_0 - p)e^{-at} \tag{1}$$

3. **The Base Model**

First, we consider the basic model without reference price and incentive mechanism. In this section, the contractor decides the green building level and then the developer decides the selling price. The developer’s profit is denoted as $\pi^d(p)$ and the contractor’s profit is denoted as $\pi^c(g)$.

$$\pi^d(p) = (p - C_o)(a + b g - \delta p) - C_s \tag{2}$$

$$\pi^c(g) = C_s - C_b - G = C_s - C_b - \frac{1}{2} \mu (g - g_0)^2 \tag{3}$$

The decision model for the developer’s profit maximization is $\max_p \pi^d(p)$ and the decision model for the contractor’s profit maximization is $\max_g \pi^c(g)$.

For the optimal green building level $g^*$ of the contractor and the optimal selling price $p^*$ of the developer without reference price and incentive mechanism, the following proportion is obtained.

**Proposition 1.** $g^* = g_0, \quad p^* = \frac{a + b g_0 + C_s \delta}{2\delta}.$

**Proof.** The second deviation is $\frac{d^2 \pi^c}{dg^2} = -\mu < 0$, therefore the profit function of contractor is a convex function of $g$. From $\frac{d \pi^c}{dg} = 0$, the best response of the contractor is $g^* = g_0$. Submit $g^* = g_0$.
into equation (2), we get \( \pi^d(p) = (p - C_o)(a + bg_0 - \delta p) - C_s \). Then \( \frac{d^2 \pi^d}{dp^2} = -2\delta < 0 \). Hence, the profit function of developer \( \pi^d \) is a convex function of \( p \). Let \( \frac{d\pi^d}{dp} = 0 \) we get \( p^* = \frac{a + bg_0 + C_o \delta}{2\delta} \). This completes the proof.

This proposition means that without reference price and incentive mechanism, the optimal green building level of the contractor and optimal selling price of the developer are existent and unique.

4. The Model with Reference Price

In this section, we discuss the model with reference price. Demand is not only affected by price and green building level but also by reference price. The developer’s profit is denoted as \( \pi^d_r(p_r) \) and the contractor’s profit is denoted as \( \pi^c_r(g_r) \).

\[
\pi^c_r(g_r) = \int_0^T e^{-\rho t} \left[ (p_r - C_o)(a + bg_r - cp_r + \theta r(t)) \right] dt - C_s 
\]

(4)

Then the decision model for the developer’s profit maximization is \( \max_{p_r} \pi^d_r(p_r) \) and the decision model for the contractor’s profit maximization is \( \max_{g_r} \pi^c_r(g_r) \).

For the optimal green building level \( g_r^* \) of the contractor and the optimal selling price \( p_r^* \) of the developer with reference price, the following proportion is obtained.

\[
\frac{\partial^2 \pi^d_r}{\partial p_r^2} = -2(\theta M + \delta N) < 0 \]

where \( N = \frac{1}{\rho} (1 - e^{-\rho T}) \), \( M = \frac{1 - e^{-(\rho + \alpha)T}}{\rho + \alpha} \).

**Proof.** From the proof of proposition 1 we get \( g_r^* = g^* = g_0 \). Submit (1) and \( g_r^* = g_0 \) into equation (4), we get \( \pi^d_r(p_r) = (p_r - C_o)[M \theta (r_0 - p_r) + N(a + bg_0 - \delta p_r)] - C_s \), where \( N = \frac{1}{\rho} (1 - e^{-\rho T}) \), \( M = \frac{1 - e^{-(\rho + \alpha)T}}{\rho + \alpha} > 0 \). The second deviation is \( \frac{d^2 \pi^d_r}{dp_r^2} = -2(\theta M + \delta N) < 0 \). Let \( \frac{dp^d_r}{dp} = 0 \) we get \( p_r^* = \frac{\theta M(r_0 + C_o) + N(a + bg_0 + \delta C_o)}{2(\theta M + \delta N)} \). This completes the proof.

This proposition means that with reference price, the optimal green building level of the contractor and optimal selling price of the developer are existent and unique. \( g_r^* = g^* = g_0 \) indicates that the contractor’s decision is not affected by the reference price.

5. The Model with Reference Price and Incentive Mechanism

In this section, we discuss the model with reference price and incentive mechanism. The decision problem faced by the developer is to decide the bonus intensity and selling price. The contractor must decide the green building level. The developer’s profit is denoted as \( \pi^d_{rl}(p_{rl}, I) \) and the contractor’s profit is denoted as \( \pi^c_{rl}(g_{rl}) \).

\[
\pi^c_{rl}(g_{rl}) = \int_0^T e^{-\rho t} \left[ (p_{rl} - C_o)(a + bg_{rl} - cp_{rl} + \theta r(t)) \right] dt - I(g_{rl} - g_0) - C_s 
\]

(6)

Then the decision model for the developer’s profit maximization is \( \max_{p_{rl}} \pi^d_{rl}(p_{rl}, I) \) and the decision model for the contractor’s profit maximization is \( \max_{g_{rl}} \pi^c_{rl}(g_{rl}) \).

For the optimal green building level \( g_{rl}^* \) of the contractor and the optimal bonus intensity \( I^* \) and selling price \( p_{rl}^* \) of the developer under incentive mechanism, the following proportion is obtained.

\[
I^* = bN \left( \frac{2\mu(\theta M(r_0 + C_o) + N(a + bg_0 + \delta C_o) - b^2 N^2)}{4\mu(\theta M + \delta N) - b^2 N^2} - \frac{\theta M(r_0 + C_o) + N(a + bg_0 + \delta C_o)}{2(\theta M + \delta N)} \right), \quad g_{rl}^* = \frac{\theta M(r_0 + C_o) + N(a + bg_0 + \delta C_o)}{2(\theta M + \delta N)}
\]
\[ bN \left( \frac{2M(bM(r_0 + C_0) + N(a + b g_0 + \delta c_0) + b^2 N c_0)}{2\mu} - C_0 \right) + g_0. \]

**Proof.** The second deviation is \( \frac{d^2 \pi r}{d g r^2} = - \mu < 0. \) From \( \frac{d \pi r}{d g r} = 0, \) the best response of the contractor is a function of 1, \( g_{ir}(l) = \frac{1}{\mu} + g_0. \) Submit (1) and \( g_{ir}(l) = \frac{1}{\mu} + g_0 \) into equation (6), we get

\[
\pi_{ir}^d(p_{ir}) = (p_{ir} - C_0)(M \theta (r_0 - p_{ir}) + N(a + b g_0 + \frac{b \delta}{\mu} g_{ir})] - C_0 - \frac{l^2}{\mu}. \]

Then

\[
\frac{d^2 \pi_{ir}^d}{d p_{ir}^2} = -2(\delta N + \theta M) < 0. \]

Similarly, \( \frac{d^2 \pi_{ir}^d}{d l^2} = -\frac{2}{\mu} < 0. \) Hence, the profit of the developer is a convex function of \( l. \) Let \( \frac{d \pi_{ir}^d}{d p_{ir}} = 0 \) and \( \frac{d \pi_{ir}^d}{d l} = 0, \) we can get the optimal bonus intensity \( I^*, \) selling price \( p_{ir}^* \) of the developer and the optimal decision \( g_{ir}^* \) of the contractor. This completes the proof.

This proposition means that under the incentive mechanism, the optimal bonus intensity and selling price of the developer and optimal green building level of the contractor are existent and unique.

### 6. The Effect of Reference Price and Incentive Mechanism

This part of the study attempts to analyse the impact of reference price and incentive mechanism. The following three propositions are obtained.

**Proposition 4.** \( \pi_{ir}^d(p_{ir}^*) > \pi_{ir}^d(p^*) \)

**Proof.** Submit \( g^* \) and \( p^* \) into \( \pi_{ir}^d, \) we can get the maximum profit of the developer \( \pi_{ir}^d(p^*). \) Similarly submit \( g_{ir}^* \) and \( p_{ir}^* \) into \( \pi_{ir}^d, \) we get the maximum profit of the developer with reference price \( \pi_{ir}^d(p_{ir}^*). \) Then \( \pi_{ir}^d(p_{ir}^*) - \pi_{ir}^d(p^*) = (p_{ir}^* - C_0)[M \theta (r_0 - p_{ir}^*) + N(a + b g_0 - \delta p_{ir}^*)] - (a + b g_0 - \delta c_0)^2 > 0. \) This completes the proof.

This proposition shows that with the reference price, the maximum profit of developers is increased.

**Proposition 5.** \( g_{ir}^* \geq g_{ir}^* \)

**Proof.** From Proposition 2 and Proposition 3 we can get

\[ g_{ir}^* - g_{ir}^* = \frac{2\mu N[BM(r_0 + C_0) + N(a + b g_0 + \delta c_0) + b^2 N c_0]}{4\mu(\theta M + \delta N - b^2 N^2)} - \frac{b N c_0}{2\mu} > 0. \]

This completes the proof.

This proposition shows that with the establishment of incentive mechanism, the optimal green building level of the contractors is increased.

**Proposition 6.** \( \pi_{ir}^d(g_{ir}^*) > \pi_{ir}^d(g_{ir}^*), \) and \( \pi_{ir}^d(p_{ir}^*, I) > \pi_{ir}^d(p_{ir}^*) \)

**Proof.** Submit \( g_{ir}^* \) into \( \pi_{ir}^d, \) we have the maximum profit of the contractor is \( \pi_{ir}^d(g_{ir}^*) = C_s - C_b. \) Submit \( g_{ir}^* \) into \( \pi_{ir}^d, \) we get the contractor’s maximum profit with incentive mechanism is \( \pi_{ir}^d(g_{ir}^*) = C_s - C_b + \frac{l^2}{2\mu}. \) Then \( \pi_{ir}^d(g_{ir}^*) - \pi_{ir}^d(g_{ir}^*) = \frac{l^2}{2\mu} > 0. \) Similarly, we can get \( \pi_{ir}^d(p_{ir}^*, I) - \pi_{ir}^d(p_{ir}^*) > 0. \) This completes the proof.

This proposition shows that with the establishment of incentive mechanism, both the profits of the developers and contractors are increased.

### 7. Sensitivity Analysis

To better understand the impact of other parameters, including the initial reference price, initial green building level and increment cost coefficient on optimal decisions, this part applies sensitivity analysis on the parameter \( r_0, \mu \) and \( g_0. \) The following propositions are obtained.

**Proposition 7.** The optimal pricing \( p_{ir}^* \) with reference price increases as the initial reference price \( r_0 \) increases.

**Proof.** From proposition 2, we have \( p_{ir}^* = \frac{BM(r_0 + C_0) + N(a + b g_0 + \delta c_0)}{2(\theta M + \delta N)}, \) then

\[ \frac{dp_{ir}^*}{dr_0} = \frac{\theta M}{2(\delta N + \theta M)} > 0. \]

This means that \( p_{ir}^* \) increases as \( r_0 \) increases. This completes the proof.

This proportion indicates that the higher the initial reference price the higher the optimal selling price.
of the developer.

**Proposition 8.** All of \( I^* \), \( p_{IR}^* \) and \( g_{IR}^* \) are increasing in \( g_0 \) and decreasing in \( \mu \).

**Proof.** From proposition 3, we get \( I^* \), \( p_{IR}^* \) and \( g_{IR}^* \). Then \( \frac{\partial I^*}{\partial g_0} = \frac{\mu b^2 N^2}{4\mu (\theta M + \delta N) - b^2 N^2} > 0 \), \( \frac{\partial p_{IR}^*}{\partial g_0} = \frac{-b^2 N^2}{[4\mu (\theta M + \delta N) - b^2 N^2]^2} < 0 \), \( \frac{\partial g_{IR}^*}{\partial \mu} = \frac{-b^2 N^2 \Delta}{[4\mu (\theta M + \delta N) - b^2 N^2]^2} < 0 \). Thus, all of \( I^* \), \( p_{IR}^* \) and \( g_{IR}^* \) are increasing in \( g_0 \) and decreasing in \( \mu \). This completes the proof.

This proportion indicates the higher initial green building level the higher optimal bonus intensity, selling price and green building level. Moreover, the optimal decision of developer and contractor is affected by increment cost coefficient. To maximize his own profit, the contractor decreases the green building level as the increment cost coefficient increases. Then the optimal bonus intensity and selling price of developer will also decrease.

8. **Conclusion**

This paper introduces the reference price into the green building supply chain pricing, which can increase the developer's profit. Moreover, promote the development of green building through the incentive of the contractor. We use the stackable game principle to study the optimal decision of the developer and contractor in three different situations. The study found that considering the reference price in pricing can increase the developer's profit; under the incentive mechanism, the profit of both the developer and contractor increased, and the green building level also improved. Sensitivity analysis shows that the green investment cost coefficient is the key to the developer decides whether to motivate the contractor and whether the contractor will raise the green building level. The higher the contractor's increment cost efficiency, the less profit the contractor and the developer will get. Similar to many other previous studies, this research has some limitations which open avenues for future research. For example, this paper does not consider the market advantages and random demand for green buildings. If these factors can be incorporated into the model, the research will be more realistic and more challenging.

**Acknowledgments**

This research is partially supported by National Natural Science Foundation of China (No.71972136, No.71602134), Youth Foundation for Humanities and Social Sciences of Ministry of Education of China (No.19YJC630063), Research Project of Education Department of Sichuan Province (No. 17ZB0335) and Social Science Special Project of Sichuan Agricultural University (No.2019PTYB08).

**Reference**

[1] Fan, Y. V., Perry, S., Klemes, J. J. & Lee, C. T. (2018) A review on air emissions assessment: Transportation. Journal of Cleaner Production, 194:673–684

[2] Liu, Q., Zhao, J.Y. (2018) Building carbon emissions prediction research based on system dynamics [J]. Science and Technology Management Research, 38(09):219-226

[3] Li, J., Yuan, L., Jiang, W. (2019) Pricing and green technology investment of prefabricated building supply chain with carbon tax. In Proceedings of the Twelfth International Conference on Management Science and Engineering Management, Cham: Springer International Publishing, 1429–1438

[4] Khoshbakht, M., Gou, Z.H., et al. (2018) Are green buildings more satisfactory? A review of global evidence [J]. Habitat International, 74:57–65

[5] Laroche, M., Bergeron, J., Barbaro-Forleo, G. (2001) Targeting consumers who are willing to pay more for environmentally-friendly products [J]. Journal of Consumer Marketing, 18(6):503-520

[6] Monroe, K. B. (1973) Buyers’ subjective perceptions of price [J]. Journal of Marketing Research, 10(1): 70-80

[7] Winer, R. S. (1986) A reference price model of brand choice for frequently purchased products [J].
[8] Zhang, J., Gou, Q., Liang, L. & Huang, Z. (2013) Supply chain coordination through cooperative advertising with reference price effect [J]. Omega 41, 345–353
[9] Popescu, I., Wu, Y. (2007) Dynamic pricing strategies with reference effects [J]. Operations Research, 55(3): 413-429
[10] Shr J F, Chen W T. Setting maximum incentive for incentive/disincentive contracts for highway projects[J]. Journal of Construction Engineering and Management, 2004, 130(1): 84–93.
[11] Li, M., Li, G. B. (2017) Research on Incentive Mechanism of Green Building Based on Ecological Environment Benefit Compensation. Science & Technology Progress and Policy, 34:136–140
[12] Jiang, W., Wu, L.J. (2019) Green building incentive approach: The developer perspective. In: Earth and Environmental Science. Shen Zhen. pp. 052052.
[13] Shazmin, S. A. A., Sipan, I. & Sapri, M. (2016) Property tax assessment incentives for green building: A review. Renewable and Sustainable Energy Reviews 60, 536–548.