Decision-Making Study of Assembly Building Supply and Demand Bodies Under Different Government Subsidy Strategies

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Abstract. In this study, we construct a decision-making model for the market of assembled dwellings considering the level of subsidy and set up three strategies of cost subsidy, price subsidy and no subsidy for comparative analysis, in order to explore how to promote the rapid development of assembled buildings through lower regulatory costs. It is found that the strength of government subsidy and consumers' environmental awareness are the main factors influencing their purchase of assembled homes. When the subsidy strength is low, the effects of the two strategies are similar, but as the subsidy strength increases, the price subsidy can be more effective in boosting consumers' purchasing motivation and developers' income.

Keywords: assembly building; consumer utility; game theory

1 Introduction

The Research Report on Energy Consumption and Carbon Emission in China's Buildings (2022)[1] shows that in 2020, the total carbon emission from the whole process of the nation's buildings will be 5.08 billion tonnes of carbon dioxide, accounting for 50.9% of the nation's carbon emission. Carbon emissions from the construction industry are too high, so there is an urgent need for an effective measure to reduce carbon emissions from the construction industry. Assembly is an important way to solve the "high energy consumption and high pollution" of the traditional construction industry, and its advantages include rapid delivery, reduction of construction waste, reduction of carbon emissions, and improvement of building volume[2,3,4]. Although assembly building was introduced to China in the last century, high development costs and low subsidies[5] have slowed down the promotion of assembly building. Therefore, in order to reduce the level of carbon emissions in the construction industry, there is an urgent need for a reasonable and effective subsidy strategy to promote assembled buildings. Some scholars have analysed the shortcomings from the perspective of government incentives and proposed relevant initiatives[6]. However, in the study, only the presence or absence of

T. Yao et al. (eds.), *Proceedings of the 2024 3rd International Conference on Engineering Management and Information Science (EMIS 2024)*, Advances in Computer Science Research 111,
https://doi.org/10.2991/978-94-6463-447-1_42

subsidy measures is analysed as a parameter, and the impact of subsidy strength on the development of assembled buildings is not studied.

In summary, assembled homes are green and low-carbon and are one of the effective means to address the high carbon emissions of the construction industry. However, the excessive cost for developers in developing assembled homes inhibits developers' incentive to develop assembled homes. It has been reported that some green consumers are willing to pay a premium for green products[7], and the higher the assembly rate, the higher the level of greenness[8], the more green consumers like it, but the high assembly rate brings a high selling price[9] and seriously inhibits consumers from purchasing assembled homes. In order to motivate developers and increase consumers' willingness to buy, which subsidy strategy and subsidy payment is the most appropriate has become the key to promote assembled houses.

2 Methodology

2.1 Basic Assumptions of the Game Model

Assumption 1: The residential market is identified as a duopoly consisting of a conventional residential developer and an assembly residential developer, with the two types of developers developing homes with different levels of assembly rates.

Assumption 2: Government subsidies can be classified into three categories: no-subsidy strategy, developer-cost subsidy strategy and consumer-price subsidy strategy, which are denoted by the superscripts of SN, SC and SP respectively. The unit product subsidy coefficient determined by the government is denoted by r , $r = t(g1 - g2)$, where t is the adjustment factor of the subsidy coefficient, $0 \le t \le 1$, and the amount of subsidy per unit product is $S = P_L r = P_L t(g_1 - g_2)$.

Assumption 3: Developers will pay additional technical and management costs to increase the level of residential assembly rate β , this paper assumes that this cost is quadratic with the level of assembly rate, i.e. $\beta = mn_i^2 / 2(i = 1,2)$, m are the cost coefficients of the level of assembly rate.

Assumption 4: The residential market capacity is normalised to 1 , and consumer demand for assembled homes is Q_1 , and demand for ordinary homes is Q_2 .

Assumption 5: Use θ to denote the degree of consumer preference for the level of assembly rate, where θ obeys a uniform distribution on $[0,1]$.

2.2 Game Model Construction

Based on the above assumptions, consumer utility is set to be U , and consumers' willingness to purchase assembled homes and ordinary homes are denoted by $Z1$ and $Z2$, respectively, where $Z_1 = n_1 k$, $Z_2 = n_2 k$, and k are the consumers' preference payment coefficients for the assembly rate, and the levels of assembly rates of assembled homes and ordinary homes are denoted by n_1 and n_2 , respectively. The marginal production costs and prices of manufacturers of assembled homes and ordinary homes are denoted by C_1, C_2 and P_1, P_2 , where $n_1 > n_2$, $C_1 > C_2$ $P_1 > P_2$ respectively.

According to the consumer utility theory, the utility of purchasing an assembled home U_1 and an ordinary home U_2 without government subsidy and with developer cost subsidy is: $U_1 = \theta n_1 k - P_1$, $U_2 = \theta n_2 k - P_2$.

Under the price subsidy strategy, the price at which consumers purchase an assembled home is $P_1 - P_1 * t * (n_1 - n_2)$. Therefore, the utility of a consumer purchasing an assembled home or an ordinary home under the price subsidy strategy is: $U_1^{SP} = \theta n_1 k - [P_1 - P_1 t(n_1 - n_2)]$, $U_2^{SP} = \theta n_2 k - P_2$.

When $U_1 > U_2$ and $U_1 > 0$, consumers buy assembled buildings; when $U_1 < U_2$ and $U_2 > 0$, consumers buy ordinary buildings; when and $U_2 < 0$, i.e. $0 < \theta < P_2 / n_2 k$, consumers choose not to buy. Under the developer's cost subsidy strategy, the developer's profit per unit for developing assembled houses is $P_1 - C_1 + P_1 t(n1 - n2)$, at which point the developer's profit function under the three models can be obtained as:

$$\begin{cases} \Pi_1^{SN} = (P_1 - C_1)\left[1 - \dfrac{P_1 - P_2}{k(n_1 - n_2)}\right] - \dfrac{1}{2} m n_1^2 \\ \Pi_2^{SN} = (P_2 - C_2)\left[\dfrac{P_1 - P_2}{k(n_1 - n_2)} - \dfrac{P_2}{n_2 k}\right] - \dfrac{1}{2} m n_2^2 \end{cases} \tag{1}$$

$$\begin{cases} \Pi_1^{SC} = [P_1 - C_1 + P_1 t(n_1 - n_2)]\left[1 - \dfrac{P_1 - P_2}{k(n_1 - n_2)}\right] - \dfrac{1}{2} m n_1^2 \\ \Pi_2^{SC} = (P_2 - C_2)\left[\dfrac{P_1 - P_2}{k(n_1 - n_2)} - \dfrac{P_2}{n_2 k}\right] - \dfrac{1}{2} m n_2^2 \end{cases} \tag{2}$$

$$\begin{cases} \Pi_1^{SP} = (P_1 - C_1)\left[1 - \dfrac{P_1 - P_2 - P_1 t(n_1 - n_2)}{k(n_1 - n_2)}\right] - \dfrac{1}{2} m n_1^2 \\ \Pi_2^{SP} = (P_2 - C_2)\left[\dfrac{P_1 - P_2 - P_1 t(n_1 - n_2)}{k(n_1 - n_2)}\right] - (P_2 - C_2)\dfrac{P_2}{n_2 k} - \dfrac{1}{2} m n_2^2 \end{cases} \tag{3}$$

Because $\partial^2 \Pi_1 / \partial^2 P_1 = -2 / k(n_1 - n_2) < 0$, $\partial^2 \Pi_2 / \partial^2 P_2 = -2n_1 / n_2 k(n_1 - n_2) < 0$. Description of the developer's profit function Π_1 and Π_2 were about P_1, P_2 convex function, so that $\partial \Pi_1 / \partial P_1 = 0$, $\partial \Pi_2 / \partial P_2 = 0$ parallel solution, you can get the optimal price of two types of residential products P_1^* and P_2^*, substitute into the consumer utility function can get Q_1^* and Q_2^* .Developers and consumers make decisions with the objectives of profit maximisation and benefit maximisation, respectively. By substituting the optimal price P_1^*, P_2^* and market demand Q_1^*, Q_2^* into the consumer utility function and the developer's profit function, the optimal revenue of the developer and the optimal utility of the consumer can be obtained under the three subsidy strategies:

$$\begin{cases} \Pi_1^{SN^*} = \left(P_1^{SN} - C_1\right)Q_1^{SN} - \frac{1}{2}mn_1^2 \\ \Pi_2^{SN^*} = \left(P_2^{SN} - C_2\right)Q_2^{SN} - \frac{1}{2}mn_2^2 \end{cases} \tag{4}$$

$$\begin{cases} \Pi_1^{SC^*} = [P_1 - C_1 + P_1 t(n_1 - n_2)]Q_1 - \frac{1}{2}mn_1^2 \\ \Pi_2^{SC^*} = (P_2 - C_2)Q_2 - \frac{1}{2}mn_2^2 \end{cases} \tag{5}$$

$$\begin{cases} \Pi_1^{SP^*} = \left(P_1^{SP^*} - C_1\right)Q_1^{SP^*} - \frac{1}{2}mn_1^2 \\ \Pi_2^{SP^*} = \left(P_2^{SP^*} - C_2\right)Q_2^{SP^*} - \frac{1}{2}mn_2^2 \end{cases} \tag{6}$$

$$\begin{cases} U_1^{SN^*} = \theta n_1 k - \frac{2C_1 n_1 + C_2 n_1 + 2n_1^2 k - 2n_1 n_2 k}{4n_1 - n_2} \\ U_2^{SN^*} = \theta n_2 k - \frac{C_1 n_2 + 2C_2 n_1 - n_2^2 k + n_1 n_2 k}{4n_1 - n_2} \end{cases} \tag{7}$$

$$\begin{cases} U_1^{SC^*} = \theta n_1 k - \frac{C_2(n_1 + n_1^2 t - n_1 n_2 t) + 2C_1 n_1}{(4n_1 - n_2)(n_1 t - n_2 t + 1)} - \frac{k(2tn_1^3 - 4tn_1^2 n_2 + 2n_1^2 + 2tn_1 n_2^2 - 2n_1 n_2)}{(4n_1 - n_2)(n_1 t - n_2 t + 1)} \\ U_2^{SC^*} = \theta n_2 k - \frac{C_2(2n_1 - 2n_1^2 t - 2n_1 n_2 t) + C_1 n_2}{(4n_1 - n_2)(n_1 t - n_2 t + 1)} - \frac{k(tn_1^2 n_2 - 2tn_1 n_2^2 + n_1 n_2 + tn_2^3 - n_2^2)}{(4n_1 - n_2)(n_1 t - n_2 t + 1)} \end{cases} \tag{8}$$

$$\begin{cases} U_1^{SP^*} = \theta n_1 k - \left[P_1^{SP^*} - P_1^{SP^*} t(n_1 - n_2)\right] \\ U_2^{SP^*} = \theta n_2 k - P_2^{SP^*} \end{cases} \tag{9}$$

3 Parametric Analysis

Proposition 1: The optimal return to the developer under the developer cost subsidy strategy is obtained by taking the partial derivatives of k , n_1 and comparing the results with $\frac{\partial \Pi_1^{SC^*}}{\partial k} > 0, \frac{\partial \Pi_2^{SC^*}}{\partial k} > 0, \frac{\partial \Pi_1^{SC^*}}{\partial n_1} > 0, \frac{\partial \Pi_2^{SC^*}}{\partial n_1} < 0$.

From Proposition 1, it can be seen that when the government provides subsidy support to developers, as the consumer payment preference coefficient k increases, the profits of both types of developers will increase. From Conclusion 1 and Conclusion 2, it can be seen that the increase of k will cause the price and demand of the whole residential market to increase, so the profits of both types of developers increase, and at the same time, it shows that increasing the consumers' awareness of the green environment is beneficial to both types of developers; as the level of assembly rate of assembled residential units n_1 increases, the profits of assembled residential units developers increase, and the profits of ordinary residential units developers decrease.

Proposition 2: The optimal utility of consumers under the developer's cost-subsidy strategy is obtained by taking the partial derivatives of k , $n1$ and comparing the results with $\frac{\partial U_1^{SC^*}}{\partial k} > 0, \frac{\partial U_2^{SC^*}}{\partial k} > 0, \frac{\partial U_1^{SC^*}}{\partial n_1} > 0, \frac{\partial U_2^{SC^*}}{\partial n_1} < 0$.

From Proposition 2, under the developer's cost-subsidy strategy, the utility of purchasing either an assembled home or an ordinary home increases as k increases; the utility of purchasing an assembled home gradually increases and the utility of purchasing an ordinary home gradually decreases as n_1 increases, suggesting that an increase in the level of assembly rate of an assembled home will help the consumer to make the decision to purchase an assembled home.

The impacts under the consumer price subsidy strategy and the developer cost subsidy strategy are roughly the same, while the type of subsidy strategy that maximises the developer's revenue and the consumer's utility needs to be further explored through numerical simulation.

4 Numerical Simulation

Using MATLAB 2023a software, take a residential project as an example, the residential project is located in Jinan High-tech Zone, The project has a total of 7 buildings #1, #2, #3, #5, #6, #7, and #8. This article takes #1 and #8 residences as an example. Details of residences #1 and #8 are shown in Table 1.

Table 1. The effect of t on demand and price

	Layer Number	Ground floor area	Assembly rate	Cost	category
#1	17	8954.01㎡	50%	1260.69 /㎡	Cast-in-place
#8	17	10295.72㎡	25%	1419.32/㎡	assembly

4.1 Analysis of the Impact of Unit Subsidy Coefficients

Parameters were set in conjunction with the research of Ying et al. [10] and Table 1: $C_1 = 7$, $C_2 = 6$, $n_1 = 0.6$, $n_2 = 0.3$, $m = 0.2$, $\theta = 0.5$, $k = 20$.

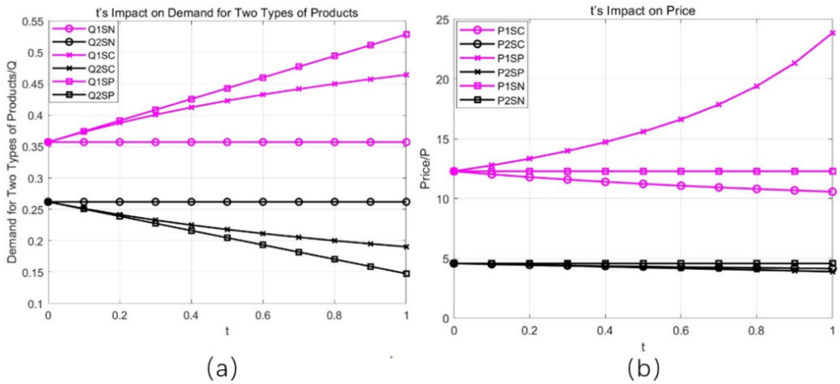

Fig. 1. The effect of t on demand and price

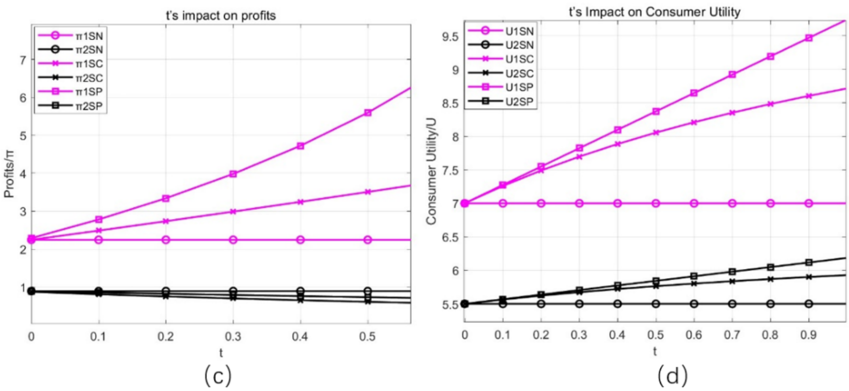

Fig. 2. The effect of t on profits and utility

From Fig. 1(a) it can be seen that under the two types of subsidy strategies as t increases there is a significant increase in the demand for assembled dwellings while there is a significant decrease in the demand for ordinary dwellings, while price subsidies to consumers result in a greater increase in the demand for assembled dwellings and a greater decrease in the demand for ordinary dwellings compared to cost subsidies. From Fig. 1 (b), it's evident that under the price subsidy strategy, the price of assembled dwellings rises with the increment of t, while under the cost subsidy strategy, the price decreases with the increment of t. This occurs because when the government subsidizes consumers, demand for assembled dwellings increases, enabling developers to raise prices to maximize revenue. However, due to the subsidy, this price increase doesn't affect consumers' actual payment. In Fig. 2(d), with low government subsidy, the impact of the three subsidy strategies on consumer utility is minor. As subsidy strength increases, the price subsidy strategy significantly boosts consumer utility, surpassing the other two strategies, mirroring the profit trends of assembled housing developers in Fig. 2(c).

Analysing Figures 1 and 2 together, the removal or reduction of subsidies when the market is mature (higher demand) will cause fluctuations in supply and demand in the market, and as subsidies are withdrawn, competition in the assembled building market is likely to increase. Manufacturers will have to compete more fiercely on price, quality and innovation to attract more customers. There will also be some developers who choose to develop traditional buildings, so when the market matures incentives and penalties will have to be put in place, such as a carbon tax.

4.2 Analysis of the Impact of Assembly Rate Preference

Parameters were set in conjunction with the research of Ying et al. [10] and Table 1: $C_1 = 7$, $C_2 = 6$, $n_1 = 0.6$, $n_2 = 0.3$, $m = 0.2$, $\theta = 0.5$, $t = 0.5$.

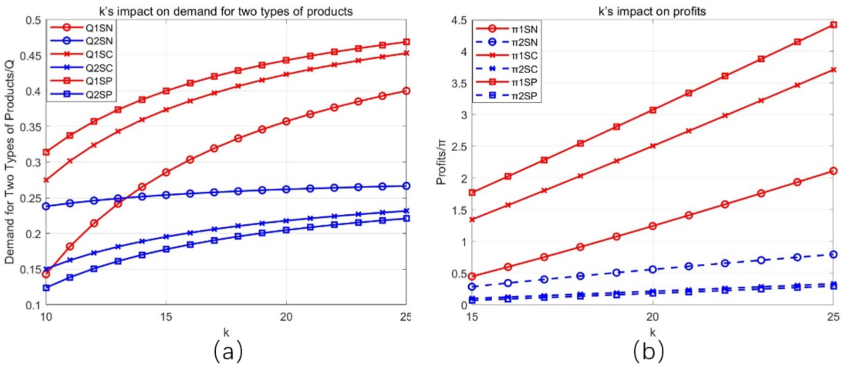

Fig. 3. Assembly rate preference payment factor impact

Fig. 3(a) shows that when the government provides subsidy support for developers and consumers, the demand for green homes and its growth rate is significantly higher than that of ordinary homes, indicating that government subsidies can guide consumers' green home purchasing behaviour, which is beneficial to promoting the development of green homes. Fig. 3(b) shows that when k is low, the profits of the two types of residential developers are very different, and at this time, the development and construction of green houses cannot attract the investment of developers, but with the gradual increase of k, the profits of green house developers will be significantly higher than the profits of ordinary house developers, which indicates that in the late stage of green house development, when the government's market intervention behaviour is gradually weakened or disappeared, improving the low-carbon awareness of consumers will be the key to prompting developers to carry out green house development. This suggests that when the government's market intervention gradually weakens or disappears in the late stage of green housing development, raising consumers' low-carbon awareness will be the most effective means to prompt developers to carry out green housing.

5 Conclusion

This paper constructs a decision-making model of supply and demand in the assembled housing market through the consumer utility function and developer profit function, and explores the optimal decisions of developers and consumers under different subsidy strategies. The final conclusions of the study are as follows.

In the assembly housing market, consumer utility maximizes through purchasing when there's heightened green awareness or government subsidies. Developer profit is influenced by scale and subsidy strategies; larger developers or those with assembly technology or cost subsidies maximize profits.Both cost and price subsidies aid developers and consumers in investing in or Build prefabricated buildings. The disparity in effectiveness between the two subsidy strategies is negligible with low government subsidies, but as subsidies increase, the price subsidy strategy boosts consumer utility more and ensures profitability for developers of assembly houses.

This paper offers management insights: 1) Increasing the preference payment coefficient for consumers' assembly rate positively impacts assembly house development. Therefore, the government should enhance green and low-carbon awareness to underscore the role of assembly houses in resource conservation, environmental protection, and creating safe, healthy living environments, laying a foundation for their widespread adoption. 2) Early-stage government subsidy support is crucial for guiding developers in assembly project construction. Initially, subsidies can target developers or consumers, but as subsidies increase, focusing on consumer subsidies maximizes developers' income and consumer utility. 3) Consideration could be given to removing the subsidy policy when the market matures, at which point it would cause fluctuations in supply and demand in the market, and competition in the assembly building market might intensify. Developers will have to compete more fiercely in terms of price, quality and innovation to attract more customers. Because of the profit-seeking nature of developers, some developers will also choose to give up on continuing to develop assembled buildings at this point, so it is important to establish a mechanism of rewards and penalties for developers or industry regulations when the market matures to prevent the supply side from shrinking and undermining the development of the assembled market.

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