Competitive Behavior of Developers' Development Scale in the Assembled Construction Market: An Analysis Based on Game Theory

Gangqiang Luo* and Qin Wang

1Department of Civil and Construction Engineering, Guangdong institute of Arts and Sciences, Zhanjiang, Guangdong, 524400, China
2Department of Finance and Accounting, Guangdong institute of Arts and Sciences, Zhanjiang, Guangdong, 524400, China

Abstract. The paper constructs the oligopoly models of assembled building developers based on Cournot model and Stackelberg model of development scale competition. Based on the comparison of the profit of the regional assembled building market, which is obvious in product homogeneity and multi oligopoly, a game analysis is carried out for the development pattern of assembled building developers. On the basis of the above models, we get the equilibrium solution of developers' Cournot competition and the sub game refining Nash equilibrium solution of the developers' Stackelberg competition respectively. Based on the different N values, we compare the development scale, the development income and the market price of the two competitive modes. Combining with the above game equilibrium, this paper makes a concrete analysis of the actual situation of the competition of assembled building developers in China.

1 Introduction

With the adjustment of national industrial structure and the advocacy of green energy-saving building concept in construction industry, the development of assembled building has attracted more and more attention, and the competition in the assembled building market has become one of the focuses of attention[1] [2]. The decision-making of output and price between developers will affect the regional market and other competitors, so the decision-making of developers is interdependent and mutually restrictive[3] [4]. Western economics defines oligopolistic market as a market structure in which a few firms completely control an industry[5] [6]. On the one hand, as far as China's current situation is concerned, the regional assembled building market is obviously characterized by oligopoly, so it is regarded as a monopolistic market with multiple oligarchs[7]. Because the assembled building market also has obvious characteristics of product homogeneity, this article is based on the establishment of Cournot model and Stackelberg model[8]. We use the profit comparison in the multi-oligopoly market structure to analyze the development scale game of the assembled building developers in China.

2 The oligopoly of developers on the development scale of assembled buildings: Cournot competition and Stackelberg competition

2.1 Cournot competition model for developers of multi-oligopoly monopoly[9][10]

The following assumptions are made for the Cournot competition model of developers in the assembled building market:

(1) There are n developers of similar assembled building development (homogeneous products) in the same area of the assembled building market, and developers make decision on development scale after observing the development scale (output) of competitors.

(2) The inverse demand function of the buyer in the assembled building market is linear curvilinear form

\[ P = a - bQ, \quad P = P(Q), \quad Q = q_1 + q_2 + \cdots + q_n, \quad i=1,2,\cdots,n, \quad q_i \text{ is the development scale of the developer.} \]

The price of the assembled building P depends on the total development amount of n developers in the assembled building market. The cost function of developer i is \( C(q_i) = cq_i \), c is the marginal cost of similar assembled building development in the same area (set fixed cost as 0), where \( b > 0, \ a > c > 0 \).
In Cournot competition game, the developer's strategic variable is the scale of assembled building development (output). Under the strategic combination \( Q = (q_1, q_2, \cdots, q_n) \), the payment of developer is development income.

\[
\pi_i(Q) = P(Q)q_i - C(q_i)
\]  

(1)

The strategic portfolio \( Q^* \) is balanced, which means for every developer \( i \) there is:

\[
\pi_i(Q^*) \geq \pi_i(q_i, q_{-i}^*) \quad \forall q_i \geq 0
\]  

(2)

That is to say, given the development scale of other developers to choose \( q_{-i}^* \), each developer achieves its own profit maximization in \( q_i^* \), or developer \( i \) pursues the maximum development benefits as follows:

\[
\max_{q_i} \pi_i = \max_{q_i} \left[ a - b \sum_{i=1}^{n} q_i - c_i(q_i) \right] q_i
\]  

(3)

The Nash equilibrium solution of the developer's Cournot competition model is:

\[
q_i = q_i = \cdots = q_i = \frac{a - c_i}{b(n+1)} \Rightarrow Q = q_1 + q_2 + \cdots + q_n = \frac{n(a - c)}{b(n+1)}
\]  

(4)

Formula (4) shows that when developers simultaneously develop similar assembled buildings in the same area to achieve Cournot competition equilibrium, each developer chooses the same equilibrium development scale \( q^* = (a - c)/b(n+1) \), the equilibrium price of assembled building products \( P^* = (a + nc)/(n+1) \), the equilibrium income of assembled development \( \pi^* = (a - c)^2/(b(n+1)^2) \), and the total development scale \( Q = na - c)/(b(n+1) \).

2.2 Oligopolistic developers' Stackberg competition model\(^{[11]}\)\(^{[12]}\)

The following assumptions are made for the Stackberg competition model of the developer in the assembled building market.

(1) There are \( n \) developers in a city's assembled building market with similar assembled building development (homogeneous products) in the same area at the same time. Assuming that the developer \( G_i \) is the market leader starting assembled building development at first, while \( G_i \) is not aware of the development scale decisions of other developers \( G_i \) \((i = 2, \cdots, n)\) will follow; the following developers' action will be decided based on the development scale of the observed developer \( G_i \). None of the developers \( G_i \) \((i = 2, \cdots, n)\) knows any rival's development scale decision-making.

(2) The inverse demand function of the buyer in assembled building market is linear curve \( P = a - bQ \),

\[
P = P(Q), \quad Q = q_1 + q_2 + \cdots + q_n, \quad i = 1, 2, \cdots, n
\]

\( q_i \) is the development scale of developer \( i \). The price of assembled building products \( P \) depends on the total development scale \( Q \) in the assembled building market.

The cost function of developer \( i \) is \( C(q_i) = cq_i \), and \( c \) is the marginal cost of similar assembled building development in the same area (fixed cost is 0), where \( b > 0, \quad a > c > 0 \).

In the Stackberg competition game, the leading developer \( G_1 \) first chooses the development scale \( q_{1s} \geq 0 \), followed by the developer \( G_i \) \((i = 2, \cdots, n)\) to observe the development scale of \( G_1 \), and then chooses its own development scale according to \( q_{is} \). Therefore, on the basis of the strategic choice \( q_{is} \) \((i = 2, \cdots, n)\) of the first developer \( G_1 \), the strategy of the second developer is a function from \( Q_{is} \) (the development scale of the leading developer \( G_1 \)) to \( Q_{fs} \) (the sum of the development scale of all the followers of the developer), that is \( S_f: Q_{is} \rightarrow Q_{fs} \).

It can be seen that Stackelberg competition of developers has the characteristics of complete information dynamic game, and the reverse induction method can be used to find out the optimal combination \((q_{1s}^*, q_{2s}^*, \cdots, q_{ns}^*)\) of the development scale of the Stackberg competition model.

The backward game method is used to find the sub game refining equilibrium of the model:

In the second stage of the game, given the development scale \( q_{is} \) of the leading developer \( G_1 \), how to choose the best development scale \( q_{is} \) \((i = 2, \cdots, n)\) to obtain the maximum development benefits following developer \( G_i \)?

\[
\max_{q_i} \pi_i = \max_{q_i} \left[ \sum_{j=1}^{n} q_j - C(q_j) \right] q_i, \quad i = 2, \cdots, n
\]  

(5)

By substituting the inverse demand linear function and the cost function into formula (5), and according to the first-order condition of optimization, the optimal development scale \( q_{is} \) of the following developer \( G_i \) can be obtained:

\[
q_{is}^* = \frac{a - c_i - q_{is}}{2b(n-1)}, \quad i = 2, \cdots, n
\]  

(6)

In the first stage of the game, because the leading developer \( G_1 \) predicts that the following developer \( G_i \) will choose the best development scale \( q_{is}^* \) according to formula (3). In order to pursue the maximum
development revenue, the problem of the leading developer is transformed into:

$$\max_{q_i} = \max_{q_i} P \left( \sum_{i=1}^{n} q_i^* + q_i \right) q_i - C(q_i)$$  \hspace{1cm} (7)

By substituting inverse demand linear function and cost function into formula (7), and according to the first-order condition of optimization, the optimal development scale of the leading developer $G_1$ and that of the following developer $G_i$ can be obtained respectively:

$$q_1^* = \frac{a - c}{2b}$$  \hspace{1cm} (8)

$$q_i^* = \frac{a - c}{4b(n-1)}, \quad i = 2, \ldots, n$$  \hspace{1cm} (9)

Thus, the optimal development scale of the Stackelberg competition model is obtained, namely sub game refining equilibrium $(q_1^*, q_2^*, \ldots, q_n^*)$. As a result, the developer $(G_1)$ as the leader and other developers $(G_i, i = 2, \ldots, n)$ as followers participate in the development scale competition. The development benefits of the leading developer and the following developer are as follows:

$$\pi_1^* = \frac{(a-c)^2}{8b}$$

$$\pi_i^* = \frac{(a-c)^2}{16b(n-1)}, \quad i = 2, \ldots, n$$  \hspace{1cm} (10)

3 Comparison of competition between Cournot competition and Stackelberg competition under multi oligopoly

3.1 N=1

As $n=1$, there is only one developer in the market, which belongs to the monopolistic assembled building market structure. Therefore, it is considered that when $n \geq 2$, multiple developers compete.

3.2 N=2

As $n = 2$, there are two developers competing in the market, so there are simplified dual duopoly developers Cournot competition and duopoly Stackelberg competition model.

Under other assumptions unchanged, the game of Cournot competition between duopoly developers can be expressed as follows: the participants of the game are developers 1 and 2; developers 1 and 2 act simultaneously; no developer knows each other's development scale decision-making when acting; payment (development revenue) is a function of the total development scale of two developers; each developer needs to make strategic choices on the scale of development to maximize their own development revenue.

Under other assumptions unchanged, the game of duopoly Stackelberg competition can be expressed as follows: developers who participate in the game are two developers; developer 1 takes action first for assembled building development; developer 1 does not know the development scale decisions of developer 2; developer 2 actions according to the development scale decisions of developer 1. Each developer needs to make strategic choices on the scale of development to maximize their own development revenue.

The equilibrium solution of Cournot competition model of duopoly developer is as follows:

$$q_1 = q_1 = \frac{a-c}{3b}$$

$$p = \frac{a+2c}{3}$$

$$\pi_1 = \pi_1 = \frac{(a-c)^2}{9b}$$

$$\pi_2 = \pi_2 = \frac{2(a-c)^2}{9b}$$  \hspace{1cm} (11)

The equilibrium solution of Stackelberg competition model of duopoly developer is as follows:

$$q_1 = q_1 = \frac{a-c}{2b}$$

$$q_2 = q_2 = \frac{a-c}{4b}$$

$$p = \frac{a+3c}{4}$$

$$\pi_1 = \pi_1 = \frac{(a-c)^2}{8b}$$

$$\pi_2 = \pi_2 = \frac{3(a-c)^2}{16b}$$

(12)

Based on the above results, the game equilibrium of duopoly developers is shown in Figure 1.
By comparing the equilibrium solutions of the duopoly developer competition model in Table 1, we can see that:

| N   | Equilibrium Competition | Development Scale | Development Revenue | Market Price |
|-----|-------------------------|-------------------|---------------------|--------------|
| n=2 | Cournot Competition     | \( q_1^* = q_2^* = \frac{a-c}{3b} \) | \( \pi_1^* = \pi_2^* = \frac{(a-c)^2}{9b} \) | \( p^* = \frac{a+2c}{3} \) |
|     | Stackberg Competition   | \( q_1^* = \frac{a-c}{2b}, q_2^* = \frac{a-c}{4b} \) | \( \pi_1^* = \frac{(a-c)^2}{8b}, \pi_2^* = \frac{(a-c)^2}{16b} \) | \( p^* = \frac{a+3c}{4} \) |
| n>2 | Cournot Competition     | \( q_1^* = \frac{a-c}{b(n+1)} \) | \( \pi_1^* = \frac{(a-c)^2}{b(n+1)^2} \) | \( p^* = \frac{a+nc}{(n+1)^2} \) |
|     | Stackberg Competition   | \( q_1^* = \frac{a-c}{2b}, q_2^* = \frac{a-c}{4b(n-1)} \) | \( \pi_1^* = \frac{(a-c)^2}{8b}, \pi_2^* = \frac{(a-c)^2}{16b(n-1)} \) | \( p^* = \frac{a+3c}{4} \) |

(1) The total scale of Stackberg competition's assembled building development is larger than that of Cournot competition \( (3(a-c)/4b>2(a-c)/3b) \), and the leading developers in Stackberg competition have a greater first mover advantage than the following developers in the development scale \((a-c)/2b > (a-c)/4b\); the price of Stackberg competition is also lower than that of Cournot competition \((a+3c)/4<(a+2c)/3\). Therefore, the development scale of Stackberg competition is large and the price is low to increase the assembled building selectivity and reduce the assembled building expenditure.

(2) Gross revenue of Cournot competition is larger than that of Stackberg competition \( (2(a-c)^2/9b>3(a-c)^2/16b) \), and the best development revenue of the developers in the Stackberg competition is larger than that of the following developers \((a-c)^2/8b>(a-c)^2/16b\). That is to say, the followers who have the advantage of development scale information are at a disadvantage in the development revenue, which also reflects the leading developers' pioneering advantages.

(3) In the Cournot competition, developers' assembled building development scale and development benefits are better than those of the following developers in Stackberg competition \((a-c)^2/3b>(a-c)^2/4b, (a-c)^2/9b>(a-c)^2/16b\).

### 3.3 N>2

As \( n > 2 \), by comparing the equilibrium solutions of N developers' competition models, we can see that:

(1) The total scale of the assembled building development of Stackberg competition is less than that of Cournot competition \((3(a-c)/4b\leq n(a-c)/b(n+1))\), and the total gross income of Stackberg competition is larger than that of Cournot competition \((3(a-c)^2/16b\leq n(a-c)^2/b(n+1)^2)\).

(2) In the Stackberg competition, the development revenue of the leading developers who are in the first move advantage is greater than that of the developer's development income \(( (a-c)^2/8b > (a-c)^2/16b(n-1))\). Meanwhile, the development scale and development income of the leading developers are larger than that of the developers in the Cournot competition and the development revenue \( ( (a-c)^2/8b > (a-c)^2/16b(n-1))\).
The development scale of the developers who follow the developers in the Stackberg competition is less than the development proceeds and the development proceeds of the developers in Cournot competition can be compared as follows:

\[ \Delta \pi = \frac{(a-c)^2}{16b(n-1)^2} - \frac{(a-c)^2}{b(n+1)^2}, \]

there is:

\[ \Delta \pi = \frac{(a-c)^2}{16b(n+1)^2(n-1)}(n^2-14n+17) \quad (13) \]

It can be found that as \( 2 < n \leq 12, \Delta \pi < 0 \), that is, the development revenue of the following developers in Stackberg competition is less than that of developers in Cournot competition. If \( n \geq 13, \Delta \pi > 0 \), the results are contrary to those mentioned above.

4 Conclusion

(1) When the number of competing developers in the market is small in order to obtain a larger proportion of assembled building development scale and price advantage, the predominant action choice of developers is to take active action to compete with other developers at the same time under the constraints of the total market size and development cost.

(2) When the number of developers participating in the competition is large, the dominant choice of the developers in the condition of getting the first move advantage is to take the lead first, and choose the scale of development before the competitors in the first place. The dominant choice of the developers is to abandon Cournot competition and take the initiative to become the Stackberg competition. The followers of developing developers can only get a lower proportion of assembled building development scale and a lower price.

(3) In the assembled building market, the \( N \) value representing the number of developers has a very important impact on the competitive behavior of developers. It is an important variable to determine the business decision-making of developers. For example, it provides a strong criterion for the strategic transfer of developers when the scale of development and the income disadvantage are in the backward condition.

To some extent, the above conclusions can explain the competition on the assembled building development scale in China. For example, in the downturn period, the total supply scale of assembled building market is not only reduced, but also developers are hoarding and waiting, even under the pressure of high credit cost. When competitors reveal real development intentions, they begin to test their actions and adopt the Stackberg strategy. When the market is in good condition, the assembled building supply scale continues to increase under the condition of favourable economic environment. Developers are rushing to take the lead to launch early projects, hoping to occupy a larger market share so as to share “a cup of delicious soup”. These two strategies are obviously beneficial to developers, but at the same time, we can also find that the result is that the "overheating" or "supercooling" of assembled building development in the period of market fluctuation intensifies, which promotes the spread of market ripple effect.

Acknowledgments

This research project was supported by the Science and Technology Tackling Project of Zhanjiang, Innovation and Strong School Project funding of Guangdong institute of Arts and Sciences and the Special Funds for Education Development at Guangdong Provincial Level in 2019 (Development Direction of Private Education). Financial support was gratefully acknowledged. All errors were the sole responsibility of the authors. The authors wished to thank Chuansheng Luo, Xianying Hu, Anxing Wang, Changli Li for their helpful comments and suggestions. The authors also wished to acknowledge assistance and encouragement from colleagues of the department of civil and construction engineering.

References

1. Li, Z.F., Li, X.D., Han, X. (2017) Research hotspots and development trends in the field of industrial architecture in China. Journal of Civil Engineering and Management. Commun., 34: 8–14.
2. Chen, H.Z., Fang, Z.G., et al. (2014) The optimal cost-sharing incentive strategy of main manufacturer-suppliers for complex product. Chinese Journal of Management Science. Commun., 22: 98–105.
3. Hn, A., Aa, E. (2004) Chaotic dynamics in nonlinear duopoly game with heterogeneous players. Applied Mathematics and Computation. Commun., 149: 843–860.
4. Hwang, H.B., Xie, N. (2008) Understanding supply chain dynamics: a chaos perspect- ve. European Journal of Operational Research. Commun., 184: 1163–1178.
5. Ball, M., Lizieri C. (1998) The economics of commercial property markets. Routledge, London.
6. Wei, Y., Wang, H., Qi, C. (2013) The impact of stock-dependent demand on supply chain dynamics. Applied Mathematical Modelling. Commun., 37: 8348–8362.
7. Lu, Y.L. (2012) Analyze on the model and dynamics of a master-slave bertrand price game. Systems Engineering. Commun., 30: 91–94.
8. Dong, W.B., Fan, M., Du, J.G. (2014) Chaos analysis of duopoly price game model with bounded rationality. Statistics and Decision. Commun., 5: 35–39.
9. Ma, J.H., Wu, K.F. (2013) Four-oligarchy price game and its delayed decision in Chinese beer market. Journal of Systems Engineering. Commun., 28: 717–728.
10. Long, J.J., Zhao, H. (2015) Analysis of cluster spillovers' impact on the price equilibrium among...
duopoly bertrand competition. Science Research Management. Commun., 36: 145–151.

11. Yao, Z., Leung, S.C., Lai, K.K. (2008) Analysis of the impact of price-sensitivity factors on the returns policy in coordinating supply chain. European Journal of Operational Research. Commun., 187: 275–282.

12. Hu, R., Chen, Q. (2011) Competition analysis and chaos control in duopoly of bounded rationality with learning ability. Control and Decision. Commun., 26: 133–136.