Resource utilization research on construction waste based on game theory

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Abstract. The resource utilization of urban construction waste has become one of the important topics of scientific research. Construction waste resource companies are not only the key to the reuse of construction waste, but also the key to the government's policy on construction waste resource development. A Starkberg model has been constructed in this paper to study the response behavior of governments and construction waste resource companies to maximize their own interests under a reward and punishment mechanism.

1. Introduction
As urbanization continues, the amount of construction waste is increasing. Some data show that, China produced about 3.5 billion tons of construction waste in 2015, accounting for 40% of the total urban waste [1]. It is estimated that the total amount of construction waste will reach 7.3 billion tons by 2030. Although progress has been made in resource utilization, the utilization rate of construction waste resources is low. There are many problems in the recycling of construction waste in China, such as the relevant laws and regulations are not perfect. There is also a lack of perfect construction waste management methods and scientifically effective and economically feasible disposal technologies. The development of waste resourceization lags behind, and construction waste brings increasingly serious problems to society. Therefore, it is urgent to effectively improve the level of resource utilization of construction waste in China.

2. Literature review
The resource utilization of urban construction waste has become an important topic of scientific research, many scholars in China have conducted research on the resourceization of construction waste. Lan Cong and Lu Jialin proposed that the resource utilization of construction waste requires both active enterprise behavior and market operation, as well as the coordination and unification of governmental management departments, so as to form an effective institutional constraint on market and government behavior[2]. In reality, the various subjects of construction waste resource utilization have not formed effective cooperation. Combining the existing technical and economic conditions and using various economic, operation research and hierarchical utilization theory of waste materials, Du Bo put forward the idea of gradient utilization of construction waste and came up with the best system of construction waste recycling network [3]. Some scholars have studied the construction waste industry chain. Chen Kejia introduced manufacturing reverse supply chain thinking and operational processes from the perspective
of construction waste recycling so that it promotes construction waste recycling [4]. In addition, to address the slow development of the construction waste resourceization industry, Gao Qingsong and Xie Long built a structural model of the construction waste resourceization industry chain, analyzed its operation mechanism, and found that the supply of raw materials and the sale of resourceized products are the two key nodes of the industry chain [5]. Li Hongxuan innovate in reverse logistics and establish a reverse logistics network for construction waste based on the cost-recovery ratio trade-off, and point out the influence of incentive behavior on reverse logistics of construction waste. [6]

The above literature provides important references and help for this paper. Although there is a lot of literature on construction waste resources in China, only a few research papers on construction waste resources are available in combination with government incentives and penalties and using a game theory approach. Therefore, this paper uses the Starkberg model in game theory to investigate the response behavior of governments and construction waste resource companies.

3. Starkberg model

In the Starkberg "leader-follower" model, there are two parties. One is more powerful as a leader, the other as a follower. Both sides will maximize their own interests by making their own optimal choices. In this case, the leader is in the dominant position and has the advantage of being one step ahead, while the other vendor can only follow. This means that the leader make decisions first, so the leader must consider in advance how his followers will react to his decision. The leader then decides his profit-maximizing decision based on the way his followers react to it. In other words, leaders decide their profit-maximizing choices based on knowing the response function of their followers.

In the game theory of one master and one follower, the leader has the ability to get the followers to accept his or her strategy choice. Either participant must consider the conditions of the other in order for themselves to be optimal [7]. This is fully applicable to the boomerang analysis of government and construction waste resource companies at the construction waste resourceization stage. Some hypothetical variables are introduced in this paper to reflect the magnitude of government reward and punishment and the resourceization level of the resourceizing companies. Also we establish a game model between the government and construction waste resource companies to study how both sides can maximize their profits.

4. Research model

4.1. Problem description

Construction waste recycling enterprises have the characteristics of an "economic man", whose behavior is mainly driven by short-term interests. In order to pursue higher profits, enterprises must try to keep costs down, which will reduce the level of construction waste resourceization. In that way, the environmental and social benefits of construction waste are ignored. In this regard, the government has implemented a system of incentives and penalties for the resource use to achieve a higher level of resource use and greater environmental benefits. Enterprises are constrained in their behavior, and the government sets minimum resource levels for resource companies and determines the level of reward and punishment. There is a cost associated with a system of reward and punishment for resource-based enterprises.

4.2. Assumptions

Hypothesis 1: \( R_G \) indicates the resource level required by the government, and \( R_B \) represents the actual resource level of the construction waste resource enterprises. When \( R_B - R_G > 0 \), the government will give reward and punishment and when \( R_B - R_G < 0 \), the government will punish the enterprises. \( K(R_B - R_G) \) is the size of reward and punishment, \( K (K > 0) \) is the level of government reward and punishment for the unit resourceization level of the resourceizing enterprise, which is determined by the government.
Hypothesis 2: Ignoring the fixed cost of construction waste resourceization. In order to improve the resource level of construction waste, enterprises need to increase investment in technology research and development, which requires a research and development cost \( RD_{(R_b)} \). The higher the resource level, the higher the input cost, i.e. \( RD'_{(R_b)} > 0 \). As the level of resourceization is invested, the increase in resourceization costs becomes smaller and the marginal benefits diminish. It is assumed that the cost of R&D is quadratic with the level of resourcefulness\[8,9\], i.e. the cost of R&D \( RD_{(R_b)} = \varphi R_b^2 \), where \( \varphi \) is The R&D capability or R&D efficiency of the construction waste recycling enterprise \((\varphi > 0)\). In addition, set the variable cost of production per unit of the enterprise to be \( C (C > 0) \) and the total amount of construction waste to be \( Q (Q > 0) \).

Hypothesis 3: Let \( K(R_b - R_c) + \frac{1}{2} \lambda K^2 \) be the cost of government incentive mechanism \[10\], \( \lambda \) is the cost input coefficient of the government to implement the reward and punishment mechanism \((\lambda > 0)\). In addition, the government needs to treat the construction waste which fails to achieve the expected recycling effect, and the pollution treatment cost is recorded as \( D \).

4.3. Solution
The government decision should first consider the reaction function of the resourceization enterprise, so the reaction function of the construction waste resourceization enterprise should be found first.

Based on the previous assumptions, it is easy to know that the profit equation of the construction waste resourceization enterprise is

\[
\pi_b = -CQ - \varphi R_b^2 + K(R_b - R_c)Q
\]

(1)

The first-order conditions for maximizing corporate profits are

\[
\frac{\partial \pi_b}{\partial R_b} = -2\varphi R_b + KQ = 0
\]

(2)

the response function of the construction waste resource enterprise as follows

\[
R_b = \frac{KQ}{2\varphi}
\]

(3)

Since the second derivative \( \frac{\partial^2 \pi_b}{\partial R_b^2} = -2\varphi < 0 \), \( \pi_b \) is a convex function about \( R_b \), \( \pi_b \) has a maximum value, \( R_b \) is the optimal solution.

Based on the assumption that it is easy to know that the government's profit equation is

\[
\pi_G = -D - QK(R_b - R_c) - \frac{1}{2} \lambda K^2 Q
\]

(4)

Substituting the firm's response function equation into the government's profit equation, the government's profit function equation is rewritten as follows

\[
\pi_G = -D - QK\left(\frac{KQ}{2\varphi} - R_c\right) - \frac{1}{2} \lambda K^2 Q
\]

\[
= -D - \frac{K^2 Q^2}{2\varphi} + QKR_c - \frac{1}{2} \lambda K^2 Q
\]

(5)

The first-order conditions for maximizing government profits are
\[
\frac{\partial \pi_G}{\partial K} = -\frac{KQ^2}{\varphi} + QR_G - \lambda KQ = 0
\] (6)

After calculation, the solution is obtained
\[
K = \frac{\varphi R_G}{Q + \varphi \lambda}
\] (7)

Since the second-order derivative \(\frac{\partial^2 \pi_G}{\partial K^2} = -\frac{Q^2}{\varphi} - \lambda Q < 0\), \(\pi_G\) is a convex function about \(K\), \(\pi_G\) has a maximum value, and \(K\) is the optimal solution from the above equation.

Substituting (7) into (3), the solution is
\[
R_B = \frac{R_G Q}{2(Q + \varphi \lambda)}
\] (8)

5. Empirical analysis
This section conducts an arithmetic analysis with the following parameters in order to verify the validity of the previous findings, \(R_G=500\), \(\varphi=2\), \(\lambda=1\), \(C=8\), \(Q=300\), \(D=50\).

The equilibrium solution can be obtained as \(K = \frac{\varphi R_G}{Q + \varphi \lambda} = 3.31, R_B = \frac{R_G Q}{2(Q + \varphi \lambda)} = 248.34\), Put it into the profit formula to get max \(\pi_G = 248294.335\) yuan, max \(\pi_B = -375643.89\) yuan.

Assign values to the above parameters to obtain the following table.

### Table 1. Profits at different levels of reward and punishment

| Reward and punishment: K | 2   | 3.31 | 5   | 10  | 15  | 20  |
|--------------------------|-----|------|-----|-----|-----|-----|
| Government profits: \(\pi_G\) (yuan) | 208,750 | 248,290 | 183,700 | -22,650,500 | -2,812,660 | -6,100,050 |

### Table 2. Companies’ cost at different resource levels, \(K = 3.31\)

| Level of resourcing: \(R_B\) | 220 | 230 | 240 | 248.34 | 250 | 260 |
|-----------------------------|-----|-----|-----|--------|-----|-----|
| Resource-based enterprise costs(yuan) | -377,240 | -376,310 | -375,780 | -375,640 | -375,650 | -375,920 |

Table 1 shows that when \(K = 3.31\), the government profit is largest at 248290\(\) yuan. As rewards and penalties continue to increase, government profits will decrease rapidly.

In Table 2, Since the government specifies the size of the rewards and penalties in consideration of maximizing its own profits, the firm will choose the resourceization level under the condition of \(K = 3.31\). When \(K=3.31\), the profit of the resourceization enterprise at different resourceization levels is negative. When the profit is negative, the largest profit is the smallest cost, so when \(R_B=248.34\), the construction waste resourceization enterprise profit is the largest, - 375640 \(\) yuan. Resource levels continue to increase and corporate profits decrease.
6. Conclusion

The government has implemented a system of rewards and penalties for construction waste resource companies so that they can improve their own resource levels. At the same time, enterprises have gained economic benefits from the resourceization of construction waste, as well as environmental benefits.

In reality, if the government only thinks about maximizing its own profits, it will often result in low or no economic profit for resource-based businesses. Therefore, the government should not only consider its own interests, but also the environmental benefits. In this way, we can promote the healthy development of construction waste resourceization.

This study can be further expanded in the following aspects: (1) Research on the multi-party game between the government and construction waste resource companies, construction companies, transport companies, etc. (2) How does the price of construction waste recycling and the market price of construction recycling products affect the decisions of construction waste resource companies?

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References

[1] Zheng Lei, Zhang Yifan. International Experience and Implications of Market-oriented Reform of Construction Waste Treatment Industry[J]. Finance, 2017.7:43-48
[2] Lan Cong, Lu Jialin, et al. Analysis of the current status and development of resource utilization of construction waste in China[J]. Jiangxi Building Materials 2018,(8):19
[3] Du Bo. Construction waste recycling network system and model construction [D]. Nanjing University of Technology, 2012.
[4] Chen Kejia. Research on Reverse Supply Chain Cooperation Model in Construction Industry [D]. Tianjin University, 2012.
[5] Gao Qingsong, Xie Long. Study on the key nodes of construction waste resources industry chain and the driving force of industrial development[J] . Ecological Economy, 2014, 30(6): 137-141.
[6] Li Hongxuan. Multi-objective optimization-based reverse logistics network design of construction waste and recovery game analysis. [D]. Zhejiang Technology and Business University, 2018
[7] Yao Weiming. Research on the whole process management game of construction waste [D]. Beijing Jiaotong University,2015.
[8] Yi Yuyin, Liang Jiamil. Closed-loop supply chain coordination for remanufacturing under reward and punishment mechanism[J]. Computer Integrated Manufacturing Systems, 2013,1(4):841-849.
[9] Hong, I.H., Ke, J. S. Determining advanced recycling fees and subsidies in “E-scrap”reverse supply chains[J].Journal of Environmental Management, 2011, 92:1495-1502.
[10] Wang Wenbin, Zhang Yu, Fan Lingling et al. Research on the reward and punishment mechanism of reverse supply chain under different governmental decision objectives[J]. China Management Science, 2015,23(7):68-76.