Financial strategy optimization of Municipal solid waste clean incineration power generation based on multi-agent evolutionary game model

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Abstract. Waste incineration has gradually become the mainstream way of municipal solid waste treatment. Government in China has brought out various financial policies to provide guide and support, but there are still some enterprises that do not incinerate waste according to the cleaner standard. In view of the insufficient guidance of the current financial strategy, the paper firstly constructs a multi-dimensional evolution game model of government, enterprise and residents, secondly analyzes the stable solution and convergence interval of enterprise cleaner incineration behavior strategy. Finally, the optimization proposal of financial strategy has been put forward. The result shows that the government should choose financial strategy according to the development level of cleaner incineration behaviour taken by enterprises, to improve the overall performance of social garbage disposal.

1. Introduction
The quantity of municipal solid waste was 2 million tons in 2016, and is 5% more than that in 2015. The higher requirements for the harmless treatment of garbage have been put forward, and the number of urban incineration plants is increased from 69 in 2006 to 249 in 2016. These developments benefit from the government's continuous financial guidance policy. In the aspect of direct support means, power grid enterprises take full purchase of electricity from waste incineration power generation plants, and calculate the amount of electricity in 280 kilowatt hours / tons of garbage. The electricity price is set at 0.65 Yuan / KWh. The indirect support means include tax preference, equipment purchase deductible tax and so on.

But a variety of problems have emerged, such as low configuration specifications of waste incineration power generation equipment, clean incineration treatment not completely according to the harmless incineration standards, supplemented by coal-fired power generation, increased pollutant emissions, which has damaged the public interest, and caused public protests. Therefore, it is urgent to study on how to optimize the decision of government financial support means, in order to guide enterprises to take clean incineration treatment behavior effectively.

Domestic and foreign scholars have analyzed the influence of the government financial support strategy. One species has established a multi-stage game between the government and enterprise. Xu Bing (2013) constructed a three-stage game model of government, manufacturer and retailer, and analyzed government subsidy strategy [1]. Zhu Qing-hai (2016) established a three-stage evolutionary game model based on the rational decision of enterprises and consumers [2]. The other one species has analyzed the influence of different subsidy methods. Mitra and Webster (2008) analyzed the effect of three subsidy modes, including the government separately subsidized manufacturers, remanufacturers.
and the two parties on remanufacturing activities [3]. Sheng Guang-hua (2015) proposed government subsidy of innovation investment, and the subsidy of innovation product, which have different influence on the evolution direction of the cost dominant enterprise group and the cost inferior enterprise group [4]. Jia et. al (2017) introduced the mechanism of punishment and subsidy, and analyzed the effect of different combination scheme of subsidies and penalty conditions [5].

In summary, there is not much research on the influence of government financial support strategy on enterprise cleaner incineration behavior strategy. Therefore, the paper, aiming at the existing problems of government financial support means, establishes a multi-agent evolutionary game model of government, enterprise and residents, and provides reference suggestions for the government to optimize the fiscal support policy, in order to improve performance of fiscal policy and the waste clean incineration level.

2. Model design

2.1 Basic hypothesis

Hypothesis 1: the behavior of government, enterprise and residents is bounded rationality.

Hypothesis 2: the government can choose two kinds of strategy, including direct support and indirect support. The probability of direct support strategy selection is x, and indirect support probability is 1-x respectively. The direct support is mainly electricity price subsidy, and the indirect support is mainly tax incentives and equipment purchase deduction tax.

Hypothesis 3: the enterprise can choose two kinds of strategies, including clean incineration disposal and violation incineration disposal. The probability of clean incineration disposal is y, and violation incineration disposal probability is 1-y.

Hypothesis 4: the residents have two choose strategies, including support projects strategy with probability of z, and nonsupport projects strategy with probability of 1-z. It is assumed that the project can be carried out normally when the residents support the project, and the project would stop when the residents do not support the project.

2.2 Related variable settings

2.2.1. Enterprise variables settings. In the aspect of income variables, the annual waste incineration amount of the enterprise is $Q$ tons. The electricity net price of coal-fired power generation is $b_0$ Yuan per kilowatt hour. The subsidy of the electricity price using garbage incineration power generation online is $b$ Yuan per kilowatt hour. The amount of power generation per ton of garbage is $D$, and the fee of per ton garbage disposal is $a$ Yuan.

In the aspect of enterprise cost, the paper mainly considers the key cost of waste cleaner incineration power generation. First one is equipment, and set the annual cost of equipment purchase is $C_2$. Secondly, it is the cleaner incineration process of garbage. It is necessary to remove the non combustible, toxic and harmful waste, so that the garbage can be burned fully, and reduce the dioxin. At the same time, the waste leachate was collected. Flue gas, slag and fly ash should be treated with, and purified. The average annual cost of refuse incineration is $C_3$ per ton. If the enterprise purchases inferior equipment and does not deal with garbage according to the clean standard, the cost saving coefficient is $\theta$, and the enterprise would lose reputation cost $SC$ for residents resisting because of the violation exposure.

2.2.2 Government variables settings. The government's direct support measures include electricity subsidy, which is $b$ Yuan per kilowatt hour, and garbage disposal fee, which is $a_1$ Yuan per ton. In the aspect of indirect support measures, including preferential tax, and equipment purchase cost can be tax deduction. Set value added tax rate is $s$, the tax rebate rate is $\alpha$, and equipment purchase's tax credit rate is $\beta$. 

2
In the aspect of government regulation, set the cost of supervision is CG, the exposure rate is w, and the penalty for illegal enterprise is F. In addition, if the project encounters the residents' resistance, the government would suffer a reputation loss of SG.

2.2.3 Resident variables settings. The relocation compensation provided by the government to the residents is B, the health loss of the surrounding residents caused by the waste incineration project is H Yuan per ton, and the garbage disposal fee paid by the residents is $a_2$ Yuan per ton. It is assumed that the residents should pay higher electricity price when the government electricity price subsidy for waste cleaner incineration power generation is paid, and residents may pay the electricity fee of P_1 Yuan per kilowatt hour. Otherwise, residents may pay lower electricity fee of P_0 Yuan per kilowatt hour, if the government does not pay the electricity price subsidy.

2.3 Income function

2.3.1 Income matrix

| Table 1. Tripartite Agent Income matrix |
|----------------------------------------|
| **Resident support project** | **Enterprise clean incineration power generation** | **Enterprises Illegal procurement and incineration** |
| **Government support** | \(s[aQ+280(b+b_0)Q+b_0Q(D-280)-C_2-C_3]\) | \(w[aQ+(b+b_0)Q+(b+b_0)Q(D-280)-0(C_2+C_3Q)]\) |
| **Directly** | \((-s)[aQ+280(b+b_0)Q+b_0Q(D-280)-C_2]\) | \(w[-a_1Q-C-G-a Q-\theta(C_2+C_3Q)]\) |
| **Government support** | \((1-s)[aQ+280(b+b_0)Q+b_0Q(D-280)-C_2]\) | \((-a_1Q-C-G-a Q-D_0Q)\) |
| **Indirectly** | \(B-H-a_2Q-P_0Q\) | \((B-a_2Q-P_0Q)\) |

| **Resident resistance project** | **Enterprise clean incineration power generation** | **Enterprises Illegal procurement and incineration** |
|---------------------------------|---------------------------------|---------------------------------|
| **Government support** | 0; | \(-SG\cdot w+0(1-w);\) |
| **support** | 0; | \(-w\cdot Sc;\) |
| **Indirectly** | \(-CD-a_2Q-P_0Q\) | \(-CD-a_2Q-P_0Q;\) |
| **Government support** | 0; | \(-SG\cdot w+0(1-w);\) |
| **support** | 0; | \(-w\cdot Sc;\) |
| **Indirectly** | \(-CD-a_2Q-P_0Q\) | \(-CD-a_2Q-P_0Q;\) |

2.3.2 Income of each agent. Set \(\pi_1\) to express the expected income of the government by using direct support means such as electricity price subsidies, set \(\pi_2\) to express the expected income of the government's indirect support means such as tax incentives, equipment purchase tax deduction and other means, and set \(\pi\) to represent the average expected revenue of the government. Thus:

\[\pi = x\pi_1 + (1-x)\pi_2\]

Set \(R_1\) to represent the expected income of enterprises for waste cleaner incineration power generation, set \(R_2\) to indicate enterprises for using waste non-cleaner incineration power generation, and set \(R\) to express the average expected income of enterprises.

\[R = yR_1 + (1-y)R_2\]

Set \(M_1\) to represent the expected income of residents in waste incineration power generation project, set \(M_2\) to express the expected income of residents if they resist the waste incineration project, and set \(M\) to express the average expected income of the residents.

\[M = zM_1 + (1-z)M_2\]
3. Multi-agent evolutionary game model

3.1 Dynamic replicating equation of evolutionary game

3.1.1 Dynamic replicating equation of the government’s evolutionary game. Set \( K_1 = s(1-\alpha)(aQ+bQD)-280(1-s)bQ, \) \( K_2 = s(1-\alpha)(C_2+C_3Q), \) then the dynamic replicating equation of government’s direct support means choose is shown as follows:

\[
F_1(x) = \frac{dx}{dt} = x(\pi_1 - \pi) = x(1-x)z\{(y[(K_1+K_2+\beta C_2)-(1-w)(K_1-\theta K_2+\theta \beta C_2)] + (1-w)(K_1-\theta K_2+\theta \beta C_2)} \tag{1}
\]

3.1.2 Dynamic replicating equation of enterprise’s evolutionary game. Set \( K_3 = aQ+bQD-C_2-C_3Q, K_4 = aQ+bQ-(\theta(C_2+C_3Q), \) then the dynamic replicating equation of enterprise’s waste cleaner incineration power generation strategy is shown as follows:

\[
F_2(y) = \frac{dy}{dt} = y(R_1 - R) = y(1-y)\{s(1-\alpha)(1-w)k_4 - s(1-\alpha)k_3 + (1-s)bQw + F - wF - w\beta C_2] + z[(1-\alpha)k_3 - (1-ws - \alpha + w\alpha s)k_4 + wF + w\beta C_2] + (1-z)wS_c \} \tag{2}
\]

3.1.3 Dynamic replicating equation of residents’ evolutionary game. The dynamic replicating equation of residents choosing to accept incineration power generation projects is:

\[
F_3(z) = \frac{dz}{dt} = z(M_1 - M) = z(1-z)[xywQ(P_1-P_0)-xQ(P_1-P_0)(1-w)+y(-B+\delta H+a_2Q+P_0Q)+2B-2\delta H-a_2Q-P_1Q+C_D] \tag{3}
\]

3.2 Stability analysis of evolutionary game

According to the dynamic replication equation set (1), (2) and (3), the equilibrium point of the three party’s evolutionary game can be solved. From \( F_1(x) = 0, \) the equilibrium solutions can be solved that \( x=0, x=1, \) or \( z=0, \) and

\[
y_0 = \frac{(1-w)(k_1+\theta \beta k_2)}{(\theta - w\theta - 1)(k_2 + \beta k_2) + wS_c} \tag{4}
\]

From \( F_2(y) = 0, \) the equilibrium solutions can be solved that \( y=0, y=1, \) and

\[
x_0 = \frac{y_0wQ(P_1-P_0)-Q(P_1-P_0)(1-w)}{y_0wQ(P_1-P_0)-Q(P_1-P_0)(1-w)} \tag{5}
\]

Then, from \( F_3(z) = 0, \) the equilibrium solution can be obtained that \( z=0, z=1, \) and

\[
x_0 = \frac{y_0wQ(P_1-P_0)-Q(P_1-P_0)(1-w)}{y_0wQ(P_1-P_0)-Q(P_1-P_0)(1-w)} \tag{6}
\]

Furthermore, the stability of evolutionary game is analyzed, and each of the dynamic replicating equations are derived, there are

\[
\begin{align*}
F_1'(x) &= (1-2x)(\pi_1 - \pi_2) \\
F_2'(y) &= (1-2y)(R_1 - R_2) \\
F_3'(z) &= (1-2z)(M_1 - M_2) \tag{7}
\end{align*}
\]

If the policy \( (x, y, z) \) satisfies \( F_1'(x) < 0, F_2'(y) < 0, F_3'(z) < 0, \) then the strategies \( (x, y, z) \) denote the stable strategies adopted by the government, enterprises and residents in the process of evolution. The asymptotic stability of each agent is analyzed respectively as follows.

3.2.1 The analysis of the government’s asymptotic stability. According to \( F_1'(x) = (1-2x)(\pi_1 - \pi_2), \) if \( \pi_1 - \pi_2 = 0, \) then \( F_1'(x) \equiv 0, \) thus \( z=0, \) or \( y=y_0 \) is the ESS, Stable state is shown as \( S_{OAFB} \) in figure 1(a), and \( S_{JDE} \) in figure 1(b).
If \( \pi_1 - \pi_2 > 0 \), \( z[y[(k_1 + k_2 + \beta c_2) - (1 - w)(k_1 + \theta k_2 + \theta \beta c_2)] + (1 - w)(k_1 + \theta k_2 + \theta \beta c_2)] > 0 \), \( y > y_0 \), \( F_1'(0) > 0 \), \( F_1'(1) < 0 \), that \( x=1 \) is the ESS. As shown in figure 1(c), when the initial state is in region \( \text{①} \), the stable state is in SJHFE.

If \( \pi_1 - \pi_2 < 0 \), \( z[y[(k_1 + k_2 + \beta c_2) - (1 - w)(k_1 + \theta k_2 + \theta \beta c_2)] + (1 - w)(k_1 + \theta k_2 + \theta \beta c_2)] < 0 \), \( y < y_0 \), and \( F_1'(0) < 0 \), \( F_1'(1) > 0 \), thus \( x=0 \) is the ESS. As shown in figure 1(d), when the initial state is in region \( \text{②} \), the stable state is in SCDI.

Furthermore, analyzes governments adopt indirect support measures, thus when \( x=0 \) is ESS, \( \pi_1 - \pi_2 < 0 \), \( (1-s)bQ(1-w+yw) > s(1-\alpha)[y(k_1 + (1-\gamma)(1-w)k_2] + \beta c_2(1-w-yw) \), so that, When the tax preference \( \alpha \) increases, the range of electricity price subsidy \( b \) is further relaxed, and can obtain lower effective value, which makes the government tend to choose indirect support means.

3.2.2 Analysis of Asymptotic Stability of Enterprises. According to \( F_2'(y) = (1-2y)(R_1 - R_2) \), if \( R_1 - R_2 = 0 \), thus \( F_2'(y) \equiv 0 \), \( zx[s(1-\alpha)(1-w)k_4 - s(1-\alpha)k_3 + (1-s)bQw + F - wF - w\beta C_2] + z[(1-as)k_3 - (1-ws-\alpha + was)k_4 + wF + w\beta C_2] + (1-z)wS_c = 0 \), \( z=z_0 \) is the ESS. As shown in figure 2(a), the stable state is in SLMNP.

If \( R_1 - R_2 > 0 \), thus when \( zx[s(1-\alpha)(1-w)k_4 - s(1-\alpha)k_3 + (1-s)bQw + F - wF - w\beta C_2] + z[(1-as)k_3 - (1-ws-\alpha + was)k_4 + wF + w\beta C_2] + (1-z)wS_c > 0 \), \( F_2'(0) > 0 \), \( F_2'(1) < 0 \), and \( y=1 \) is the ESS. As shown in figure 2(b), when the initial state is in region \( \text{③} \), the stable state is in SPHN.

If \( R_1 - R_2 < 0 \), thus when \( zx[s(1-\alpha)(1-w)k_4 - s(1-\alpha)k_3 + (1-s)bQw + F - wF - w\beta C_2] + z[(1-as)k_3 - (1-ws-\alpha + was)k_4 + wF + w\beta C_2] + (1-z)wS_c < 0 \), \( F_2'(0) < 0 \), \( F_2'(1) > 0 \), and \( x=0 \) is the ESS. As shown in figure 1(d), the stable state is in SCLMAO.

Further analysis, when enterprises choose waste cleaner incineration power generation treatment, that is when \( y=1 \) is ESS, \( R_1 - R_2 > 0 \), and

\[
b > \frac{[s(1-\alpha)k_3 + (1-ws-\alpha + was)k_4 - wF - w\beta C_2 - (1-z)wS_c/s]}{[s(1-\alpha)(1-w)k_4 + s(1-\alpha)k_3 - F + wF + w\beta C_2].}
\]

Because of the coefficient of \( \alpha \) is \( \frac{s-1}{x} \) \( k_3 + (s-sw) \left( 1 - \frac{1}{x} \right) k_4 \), s and x are both less than 1, so the coefficients of \( K_3 \) and \( K_4 \) are both less than 0, and the coefficient of \( \alpha \) is less than 0, thus the effective range of electricity price subsidy \( b \) can be smaller when the tax preferences \( \alpha \) is increased.
3.2.3 Analysis of the asymptotic stability of residents. According to \( F'_2(z) = (1-2z)(M_1 - M_2) \), if \( M_1 - M_2 = 0 \), thus \( F'_2(z) \equiv 0 \), \( xywQ(P_1 - P_0) - xQ(P_1 - P_0)(1-w) + y(-B + \delta H + a_z Q + P_0 Q) + 2B - 2\delta H - a_z Q - P_1 Q + C_D = 0 \), \( x = x_0 = \frac{y_d(-B + \delta H + a_z Q + P_0 Q) + 2B - 2\delta H - a_z Q - P_1 Q + C_D}{y_d w Q(P_1 - P_0) - Q(P_1 - P_0)(1-w)} \) is the ESS. As shown in figure 3(a), the stable state is in curved surface \( S_{QRST} \).

If \( M_1 - M_2 > 0 \), thus \( xywQ(P_1 - P_0) - xQ(P_1 - P_0)(1-w) + y(-B + \delta H + a_z Q + P_0 Q) + 2B - 2\delta H - a_z Q - P_1 Q + C_D > 0 \), \( F'_3(0) > 0 \), \( F'_3(1) < 0 \) can be satisfied, and \( z=1 \) is the ESS. As shown in figure 3(b), when the initial state is in region \( \delta \), the stable state is in \( S_{QRST} \).

If \( M_1 - M_2 < 0 \), thus when \( xywQ(P_1 - P_0) - xQ(P_1 - P_0)(1-w) + y(-B + \delta H + a_z Q + P_0 Q) + 2B - 2\delta H - a_z Q - P_1 Q + C_D < 0 \), \( F'_3(0) < 0 \), \( F'_3(1) > 0 \) can be satisfied, and \( z=0 \) is the ESS. As shown in figure 3(c), when the initial state is in region \( \delta \), the stable state is in \( S_{ORSB} \).

The function images between \( x \), \( y \), and \( z \) in the above three groups of asymptotic stability evolution model diagrams are only schematic, and the real functions are analyzed according to the change of parameters. The ideal state of stability is that the enterprises treat waste incineration in a cleaner way, and the residents accept the waste incineration power generation project, which requires \( y=1, z=1 \) are ESS. Then the initial state should be in region \( \delta \) and region \( \delta \). If the initial state is in region \( \delta \), then the game converges to the strategy of \((1,1,1)\), and the government tends to adopt the method of direct electricity price subsidy, and if the initial state is in region \( \delta \), \( \delta \) and \( \delta \), then the government tends to adopt indirect financial support policy.

4. Conclusions

Conclusion 1: When making a strategic decision of financial support means, the government should take into account the level of clean incineration of enterprise and the approved support level of residents. When the initial state is in region \( \delta \) and \( \delta \), the government strategy converges to 1 and 0 respectively. Therefore, when the probability of clean treatment is higher \((y>y_0)\), the government can adopt direct financial support policy. When the probability of clean treatment behavior is lower \((y<y_0)\), the government should guide the clean incineration behavior more effectively by adopting indirect financial support policy.

Conclusion 2: when the initial state is in region \( \delta \), it cannot completely rely on the direct financial support policy. Increasing electricity prices subsidy cannot completely guide enterprises to take clean incinerate behavior. Enterprises choose non-clean treatment with lower cost. Therefore, it is necessary to set the electricity price subsidies reasonably, and supplement other indirect financial support means, such as improve the supervision in the whole operation process.

Conclusion 3: when the initial state is in region \( \delta \), the guiding effect of indirect financial support policy should be optimized, and the direct financial support cost should be reduced. Firstly, equipment tax credits can guide enterprises to purchase high-quality equipment. Secondly, it is necessary to enrich the means of tax support, such as improve the tax policy in the field of garbage incineration and power generation.
To sum up, through the stability analysis of evolutionary game, government departments should optimize financial decisions, combine direct and indirect means of financial support reasonably, and give full play to the functions and guidance of financial support. It can effectively guide enterprises to clean incineration and achieve the goal of clean treatment in the whole process of garbage disposal.

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