Research on the principal-agent problems in China's low-carbon ecological urban construction

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Abstract

In the game of the interest bodies of low-carbon ecological urban construction, the central government, as a principal, will lose some interests in some ways because of information disadvantages, whereas the local governments, as agents, will make use of their information advantages to make profitable action choices for more interests. As a result, moral risks will appear for the latter. This paper attempts to construct a mathematical model of the game theory for the principal-agent problems in the low-carbon ecological urban construction and analyses the choice actions involved. The conclusion is drawn that for the optimal balance of the game to be realized between the central and local governments, a relevant system must be established. This system is expected to change the information asymmetry by increasing the central government's ability to acquire information while stimulating or restraining the local governments' choice actions so that the external pressure on the local governments will be turned into their internal actions in a low-carbon ecological urban construction.

Keywords: low-carbon ecological cities and towns, agency by agreement, information asymmetry, system

1 Introduction

Urbanization refers to the shifts and aggregations of the population and production factors from rural areas to old or new cities and towns, including the increase of a city's or town's population and number and the modernization of the urban and rural economy and society. Since the reform and opening toward the outside, Chinese urbanization construction has achieved a remarkable development. The urbanization rate increased to 53.73% in 2013 from 12.5% in the early 1980s, which is an increase of 41% (2013). However, it is evident that with the increased rate of urbanization, the huge increase in resource consumption and the rapid expansion of the city scale have caused significant impacts on the original functions and structures of cities and towns. For example, some external problems, such as resource shortages and environmental pollution, are increasingly serious. Chinese urbanization has faced great pressure from population, resource and environment aspects, so China must choose the development path of low-carbon ecological urbanization.

The theory of ecological environment management is mainly based on the European practice, and the early theory includes three points as follows: effective economic development, social justice development and environmentally friendly development (Fan, 2011). It is a double-win model of the economy and environment by nature, holding that economic increases and environmental protection should be coordinated. There is a view that the realization of ecological management relies largely on the innovation of science and technology, not changes to the basic social system, holding that social structural change is made to promote environmentally friendly production and consumption (Christoff, P., 1996). This view holds that ecological management refers to the adjustment of a capitalist political and economic structure to promote environmentally benign development and that only when the capitalist internal unreasonable structure is fully adjusted under the current basic political and economic system will the environmentally benign development occur (White, D. F., 2002). The adoption of cleaner production technologies and preventive environmental protection measures are cases of this view. Such views belong to the preventive strategic theory. Another view proposes setting up theoretical and practical models of ecological management from the perspective of environmental protection and industrial transformation (Gerald, B. et al., 2001). It belongs to the selective reform theory.

At the beginning of the 21st century, the concept of "low-carbon city" has appeared in foreign countries. In 2004, Japanese governments and scholars began studying the model of a low-carbon city and its development paths. For example, Japanese experts held that the system design and construction of a low-carbon city should be combined with the status quo of the local system, economy, environment, history and value (Aoki, 2009). The UK is the forerunner in the design and practice of the low-carbon city. English scholars think the design of the low-carbon city should be part of overall planning, taking

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seven aspects into consideration, namely the centre of cities and towns, the centre of the city edge, the inner city area, the industrial zone, the suburbs, the stretch area, and the rural area (Thuli, N. M. et al., 2010) . Glaeser and Kahn (2001) noted in their study of carbon emission, city scale and land development that the city scale is directly proportional to carbon emissions, i.e., with the expansion of the city scale, the per capita carbon emissions of the newly added population are higher than the average emissions of the original population. Jenny Crawford and Will French (2008) studied the relation between English space planning and the low-carbon goal, thinking that the understanding and adaptability of new technologies in English planning are crucial to making low-carbon space come true and pointing out the best effective development of a low-carbon city is to adopt flexible measures according to specific conditions. In addition, some works provide specific measures to solve the environmental pollution of cities and towns. For instance, based on recycling agriculture, Diana, M. L., et. al (2006) proposed "sustainable agriculture" to solve the environmental pollution of American small towns in the country; other experts, such as Elizabeth Economy (2006), combine economic methods with material balance theory to propose their environmental management measures for cities and towns.

Currently, based on a large number of Chinese domestic research literature about the ecological environment of urbanization, scholars have performed studies on environmental pollution management theories of urbanization, but most of them are limited to the simple application analysis of economic theories. To sum up, their studies focus mainly on the following two aspects:

The first is analytical investigation based on macro-economics. Hu A. G., et. al., (2012) held that the low-carbonization city is an important aspect in the process of Chinese economic transformation from high-carbon to low-carbon, including low-carbon energy, increasing gas popularity rate, increasing city greening rate, increasing waste processing rate, and so on. Qiu Baoxing (2012) suggested rethinking the city construction ideas and development models to explore city development paths suitable for China's actual conditions and ecological civilization construction. Li Kexin (2009) held that the theoretical basis of low-carbon city construction is "environmental harmony theory", i.e., to build liveable cities with sustainable development. Hong Dayong (2012) noted that the existing binary structure of the social system has much to do with the fact that medium and small towns self-pollute, and some pollution is uncontrollable for a long time.

The second is the analytical investigation based on micro-economics. Such research works mainly cover the external analysis, the social economic factors and the economic loss evaluation of the small town environmental pollution problems. For example, Meng Xuejing and Shang Jie (2012) proposed with their economic analysis that the environmental pollution of rural urbanization is caused mainly by three factors: market failure, governmental failure and the simultaneous failure of the market and government. Jang, H. L., et. Al. (2010) argued that there are prominent institutional obstacles and specific implementation problems in the prevention and control of the environmental pollution of Chinese cities and towns, which is mainly manifested in the lack of an effective management system of environmental pollution and an incentive mechanism of environmental and economic policy, in the serious interest conflicts between interest bodies involved in the prevention and control of small towns' pollution, in the ignorance of residents' dominant role in protecting the environment and preventing pollution, and so on. Cai Yuqiu and Yu Xiaochen (2011) proposed a management model of city/town ecological environment, i.e., to strengthen residents' awareness of environmental protection, to establish a sound early warning and monitoring network project of the ecological environment, to integrate small villages and establish the management model with the top-down vertical leadership. Li Yinming and Song Jianxin (2011) studied the key operating factors, management levels and typical models of the environmental self-governance system of small towns and put forward a frame system that can be used for reference by the environmental self-governance system of Chinese small towns.

The above reviews of domestic and foreign research have revealed that domestic and foreign scholars have presented many opinions on the ecological environmental management of cities and towns from different perspectives and have made some achievements. However, generally speaking, those studies seldom systematically analyse the ecological environmental management on the background of urbanization, and they rarely mention any game behaviours between the central government and local governments in the construction of low-carbon cities/towns. Therefore, this paper attempts to construct a mathematical model of the game theory for the principal-agent problems between the central and local governments in low-carbon ecological urban construction and analyses their choice actions and corresponding results with the aim of establishing an institutional and policy system to solve practical problems more systematically.

2 The analysis of the interest demands of local governments in the ecological management game during the new-type urbanization

An urbanization construction and an urban ecological environment are a unity of opposites, so their mutual relations should be treated carefully. The former needs a great number of material resources, which resorts to a good ecological environment as a supply security. However, urbanization construction inevitably destroys the ecological environment, which will do harm to its

own development basis; therefore, ecological environmental management in urbanization is necessary (Yang, 2007). The participants of urbanization construction are made up of diverse interest bodies, so the ecological environmental management in the process of urbanization is a cooperative management of all interest bodies. The ecological environmental problems in the process of urbanization are the external cost of the urbanization construction, which is caused by the interest demand motivations of different interest bodies. The utilitarianism of interest bodies' demands will distort their decision-making behaviours and will eventually cause increasingly serious ecological environmental problems for cities.

According to the principal-agent theory, the central government is the principal and the local governments are the agents of the central government, as well as of their local people. The local governments must ensure their social public interests so that they can be accepted by the principals—the central government and the local people. However, the "economic men's" feature of politicians has caused local governments to be selfish, as well as to be of social public interest. Their pursuits of political capital cause the local governments to have too many selfish behaviours, so the rapid growth of GDP and financial revenue become the basic goals of their policies and behaviours, whereas the ecological environment is out of their consideration or only counts very little, especially in some remote and backward areas that face the huge pressure of economic development and financial gaps. Local governments often neglect or even permit the ecological pollution of some factories.

In the 1990s, when China began the reform of decentralization and social economic transformation, policy instability and the imperfection of the market economy system existed in China. So the local governments as agents had information advantages over the central government as a principal. They were motivated enough to make use of the long information chain to conceal information from the central government for their private interests. The lower the level of the local governments are, the more private interests they demand, so they have more serious ecological problems in the process of urbanization.

3 Research methods

In an agency by agreement, the principal will ask the agent to act for his own interests, but because of information asymmetry, the former cannot comprehensively master the latter's choice behaviours. The principal can only know partial information about the agent's actions, so the problem the principal needs to solve is how to encourage the agents to choose actions for the principal's interests with rewards and punishments according to the partial information. Here are two formulations for the principal to restrain the agents with a dominant motivation system:

3.1 STATE-SPACE FORMULATION

Suppose A is the combination of all of the agent's choice behaviours; α represents the one-dimensional variable of the agents' effort level; θ is an exogenous random variable beyond the formulation (natural state). θ's value scope is Θ; G(θ) and g(θ) are the distribution function and density function, respectively (θ ∈ Θ). When an agent chooses an action α, the principal will get his own income result π(α,θ), and at the same time can know the actions' result of the agents x(α,θ). Assume that π is α's increasing concave function (under a given θ, agents' gains are proportional to the degree of its own efforts, but their efforts' marginal productivity decreases), and π is also an increasing function of θ. Now the principal needs to design a contract S(X) and rewards or punishes the agents according to the results of their actions x(α,θ).

Then, the principal and agents' expected utility function can be expressed as: $v\left(\pi-s\left(x\right)\right)$, $u\left(s\left(\pi\right)\right)-c\left(a\right)$, and $c\left(a\right)$ is the agent's cost function. From the previous statements, we get: $v'>0,\ v''\le 0;\ u'>0,\ u''\le 0;\ c'>0,\ c''>0$. When both the principal and the agent are risk-neutral and their effort's marginal productivity decreases, $v'>0$ indicates that the principal expects the agent to make greater efforts, and $c'>0$ indicates that the agent does not want to give more to the principal. In this case, these two parties are in an interest conflict with each other. Therefore, the principal needs to design a reasonable contract to stimulate the agent to give more. On the other hand, the expected utility function of the agent (P) can be expressed as: $\int v(\pi(a,\theta)-s(x(a,\theta)))g(\theta)d\theta$. To maximize the principal's utility function, the agent needs to meet two constraints. One is the individual rationality constraint (IR), which means that the agent will get more utility if he accepts the principal's contract than if he refuses. If $\bar{u}$ indicates the total utility the agent gets when he refuses the principal's contract and acts according to his own willingness, then IR can be expressed as: $\int u(s(x(a,\theta)))g(\theta)-c(a)\ge\bar{u}$. The second constraint is the incentive compatibility constraint (IC), which means that under the natural state θ, the principal cannot know the agent's behaviours a when the agent is likely to maximize his own interests by choosing the low effort behaviour aL, though the principal expects the agent to choose the high effort behaviour aH. The condition of solving their conflicts is that the agent can get more utility if he chooses the high effort behaviour aH than if he chooses the low effort behaviour aL. In this case, IC can be expressed as: $\int u(s(x(a^H,\theta)))g(\theta)d\theta-c(a^H)\ge\int u(s(x(a^L,\theta)))g(\theta)d\theta-c(a^L),\forall a^L\in\wedge$.

To sum up, if the expected utility function of the principal (P) wants to get the maximum value, the two constraints (IR and IC) must be satisfied, namely:

$$\max_{a\ s(x)} \int v(\pi(a,\theta)-s(x(a,\theta)))g(\theta)d\theta$$
$$\begin{cases} \int u(s(x(a,\theta)))g(\theta)d\theta - c(a) \ge \bar{u} \\ \int u(s(x(a^H,\theta)))g(\theta)d\theta - c(a^H) \ge \int u(s(x(a^L,\theta)))g(\theta)d\theta - c(a^L), \forall a^L \in \wedge \end{cases}$$

3.2 PARAMETERIZED DISTRIBUTION FORMULATION

The parameterized distribution formulation is used to transform the distribution function under the natural state of the state-space formulation into the distribution function with x and π as results. For every a, there is a distribution function of x and π. From the original distribution function $G(\theta)$, we can derive a new distribution function $F(x,\pi,a)$ and a new density function $f(x,\pi,a)$. In the state-space formulation, the utility function gets the expected value from the θ of the natural state, whereas in the parameterized distribution formulation, the utility function gets the expected value from the variable x. In the latter formulation, the expected utility function (P) of the principal gets its maximum on the conditions as follows:

$$\begin{cases} \max\limits_{a\ s(x)} \int v(\pi - s(x)) f(x,\pi,a)dx \\ \int u(s(x)) f(s,\pi,a)dx - c(a) \ge \bar{u} \\ \int u(s(x)) f(s,\pi,a^H)dx - c(a^H) \ge \int u(s(x)) f(s,\pi,a^L)dx - c(a^L), \forall a^L \in \wedge \end{cases}$$

4 The principal-agent models of the central and local governments in the construction of low-carbon ecological cities

4.1 THE PRINCIPAL-AGENT MODEL

According to the previous analysis, the central government and local governments have formed the principal-agent relationship in the process of urbanization construction.

The variable $a(a>0)$ is a one-dimensional effort variable, representing the effort level of the local governments in conducting the contract of the central government. $A(A>0)$ is the subjective action ability level of the local governments. $B(B>0)$ is a constant, standing for the scale of the local government resources. t is a time variable, and I is an input variable. $\eta(\eta>0)$ is the adjustment coefficient. θ is the uncertain factor beyond the formulation, the random variable of the normal distribution with the mean value 0 and variance σ^2. The utility linear function of local governments can be expressed as: $\pi = \eta tI(A+B)a + \theta$, so the utility expected value is: $E\pi = \eta tI(A+B)a$.

Suppose the central government is risk-neutral and the local governments are risk-averters. When the local governments choose to conduct the contract of the central government, their contract's equation is $s(\pi) = \alpha + \beta\pi$ (α is the fixed gain of the local governments in urbanization construction and it is not related with the output π; β is the contract's incentive strength, namely the proportional coefficient between the effort level of the local governments and the output π; β =0 means that the local governments choose the maximum cost). Therefore, if the equation of a given commission contract is $s(\pi) = \alpha + \beta\pi$, then the expected gain of the central government can be expressed as: $Ev(\pi - s(\pi)) = (1-\beta)\eta tI(A+B)a - \alpha$.

On the other hand, suppose the equation of the effort cost for the local governments to perform the central government's contract is $c(a) = ba^2/2$ (b>0; b is the cost coefficient). If the cost the local governments pay with the same efforts is directly proportional to b, then the actual gain of the local governments can be expressed as: $w = s(\pi) - c(a) = \alpha + \beta(tI(A+B)a + \theta) - ba^2/2$.

The certain equivalent gain is: $W = Ew - \rho\beta^2\sigma^2/2 = \alpha + \beta\eta tI(A+B)a - ba^2/2 - \rho\beta^2\sigma^2/2$.

In this equation, Ew is the expected income of the local governments, $\rho\beta^2\sigma^2/2$ is the cost risk of the local governments, ρ is the degree of the local governments' risk-aversion ($\rho>0$ means risk-aversion and $\rho=0$ means risk-neutral). From the above derivation, it can be obtained that the central government's goal is to maximize its expected gain $Ev(\pi - s(\pi))$, and the local governments' goal is to maximize the certain equivalent gain W. Suppose the retained gain of the local governments is a constant $\bar{w}$. If the certain equivalent gain the local governments obtain after performing the central government's contract is less than their retain gain $(W < \bar{w})$, the moral risk will appear. In conclusion, the individual rationality constraint (IR) of the local governments can be expressed as: $W = \alpha + \beta\eta tI(A+B)a - ba^2/2 - \rho\beta^2\sigma^2/2 \ge \bar{w}$.

The incentive compatibility constraint (IC) of the local governments can be expressed as: $\alpha + \beta\eta tI(A+B)a^H - b(a^H)^2/2 - \rho\beta^2\sigma^2/2 \ge \alpha + \beta\eta tI(A+B)a^L - b(a^L)^2/2 - \rho\beta^2\sigma^2/2, \forall a^L \in \wedge$.

4.2 INFORMATION ASYMMETRY

On the condition of information asymmetry, the principal (the central government) can observe the effort level of the agent (the local government) in performing the contract. In such a case, the local governments cannot wantonly choose effort levels to maximize their own interests, and the incentive compatibility constraint (IC) becomes invalid. Therefore, as long as the individual rationality constraint (IR) is met to perform the central

government's contract $s(\pi)$, the local government can choose any effort level a. However, in urbanization construction, the realization of the principal's (the central government's) interests depends on the agent's (the local government's) performance, and the principal does not usually participate in the administration decisions of urbanization. In addition, China is in the reform of decentralization and social economic transformation, and some things like policy instability and the imperfection of the market economy system exist in China and cause significant information asymmetry. For those reasons, the central government cannot observe the local governments' efforts level a. In this condition, the incentive compatibility constraint (IC) is valid, and the central government aims to realize the contract $s(\pi)$ by solving the following optimization problems through choosing $(\alpha \ \beta)$:

$$\begin{cases} \max\limits_{\alpha.\beta.a} Ev(\pi - s(\pi)) = \max\limits_{\alpha.\beta.a}\left[(1-\beta)\eta tI(A+B)a - \alpha\right] \\ \alpha + \beta\eta tI(A+B)a - ba^2 - \rho\beta^2\sigma^2/2 \geq \overline{w} \\ \alpha + \beta\eta tI(A+B)a^H - b(a^H)^2/2 - \rho\beta^2\sigma^2/2 \geq \\ \alpha + \beta\eta tI(A+B)a^L - b\left(a^L\right)^2/2 - \rho\beta^2\sigma^2/2, \forall a^L \in \wedge \end{cases}$$

Through the above formulae, the IR and IC can be expressed as follows (IR): $\alpha + \beta\eta tI(A+B)a - ba^2/2 - \rho\beta^2\sigma^2/2 = \overline{w}$, (IC): $a = \beta\eta tI(A+B)/b$.

Now, put IR and IC into the objective function of the central government's expected income and get:

$$\max_{\alpha.\beta.a} Ev(\pi - s(\pi)) = \max_{\alpha.\beta.a}\begin{bmatrix} \beta\eta^2t^2I^2(A+B)^2/b - \\ \beta\eta^2t^2I^2(A+B)^2/2b - \rho\beta^2\sigma^2/2 - \overline{w} \end{bmatrix}$$

Take the derivative of β and let the first derivative be zero, then you can get the first order conditions:

$$\frac{\partial Ev}{\partial\beta} = \eta^2t^2I^2(A+B)^2/b - \eta^2t^2I^2(A+B)^2\beta/b - \rho\beta\sigma^2 = 0$$

The solution is:

$$\begin{cases} \beta' = \dfrac{1}{1+\rho b\sigma^2/\eta^2t^2I^2(A+B)^2} \\ a = \beta'\eta tI(A+B)/b \\ \alpha' = \overline{w} + ba^2/2 + \rho\beta'^2\sigma/2 - \beta'\eta tI(A+B)a \end{cases} . \quad (1)$$

Then, the function of the central government's development contract is: $s(\pi) = \alpha' + \beta'\pi$ and the marginal cost and the marginal expected utility of the local government efforts, respectively, are: $c'(a) = \left(ba^2/2\right)' = ba = \beta'\eta tI(A+B)$.

And $\left[\mathrm{E}\pi(a)\right]' = \eta tI(A+B)$. The local government always tries to avoid risks, so $\rho > 0$, $0 < \beta' < 1$. Thus, the marginal cost of the local government's effort is less than its marginal expected utility, and its highest effort level a^H will not be reached, namely: $a = \beta'\eta tI(A+B)/b < a^H$. In such a case, the expected effectiveness of the central government, the actual effectiveness of the local government and the agency cost of the central government are, respectively, as follows:

$$\begin{aligned} Ev &= \beta'\eta^2t^2I^2(A+B)^2/2b - \overline{w} \\ &= \frac{\eta^2t^2I^2(A+B)^2}{2b\left(1+\rho b\sigma^2/\beta^2t^2I^2(A+B)^2\right)} - \overline{w} < Ev^* \end{aligned} \quad (2)$$

,

$$w = \overline{w} + \frac{\beta'^2\rho\sigma^2}{2\left(1+\rho b\sigma^2/\eta^2t^2I^2(A+B)^2\right)^2} > w^* \quad (3)$$

,

$$AC = Ev^* - Ev = \frac{\rho\sigma^2}{2(1+\rho b\sigma^2/\eta^2t^2I^2(A+B)^2)} . \quad (4)$$

4.3 THE INFORMATION ASYMMETRY AFTER ADDING VARIABLES

It follows that the central government's expected effectiveness will not reach its objective effectiveness, whereas the local government's actual effectiveness will be larger than its expected effectiveness. From this analysis, it can be concluded that because of information asymmetry, the central government as the principal (with the information disadvantages) will suffer a certain loss, whereas the local government as the agent (with the information advantages) will get more actual effectiveness by choosing low-effort-degree actions. Therefore, the question for the central government is how to design an incentive system to increase the local government's effort degree and to avoid the moral risks for the purpose of avoiding the central government's agency risks and increasing its expected effectiveness. Next, we analyse the previous principal-agent model. In urban construction, the local government will get the fixed gains α as well as share the surplus gains $\beta\pi$. Here, the gain π not only depends on the its effort level but is also influenced by the uncertain factor θ. The previous effectiveness function of the local government shows that the gain π is simultaneously influenced by the local government's capacity level A, hardware strength *B*, effort level *a* and the uncertain factor θ. Thus, π is not a sufficient statistic but a noisy signal about coefficient A, B and *a* .Therefore, the agency contract about $s(\pi)$ makes the local government face

extra risks, which disagrees with the optimal risk allocation theory. Therefore, such a contract is a suboptimal solution. Now we assume that the central government can observe a new variable k (k has nothing to do with the effort level of the local government but is associated with the uncertain factor B), and the mean value of k is zero with a normally distributed variance. The new contract can be expressed as: $s(\pi,k)=\alpha+\beta(\pi+\phi k)$ (here ϕ means the coefficient between the local government's gain and the variable k.)

The expected gain of the central government is $Ev=(1-\beta)\eta tI(A+B)a-\alpha$, and the fixed equivalent gain of the local government is: $\mathrm{W}=\alpha+\beta\eta tI(A+B)a-ba^2/2$ $-\rho\beta^2(\sigma^2+\varphi^2\sigma_k^2+2\varphi\mathrm{cov}(\pi,k))/2$.

On the same condition of information asymmetry, the central government's goal is to choose α and β to solve the following optimization equations:

$$\begin{cases}\max\limits_{\beta\ \varphi} Ev=\max\limits_{\beta\ \varphi}[(1-\beta)\eta tI(A+B)a-\alpha\\ \alpha+\beta\eta tI(A+B)a-ba^2/2-\rho\beta^2(\sigma^2+\varphi^2\sigma_k^2+2\varphi\mathrm{cov}(\pi,k))/2\geq\overline{w}\\ \alpha+\beta\eta tI(A+B)a^H-b(a^H)^2/2-\rho\beta^2(\sigma^2+\varphi^2\sigma_k^2+2\varphi\mathrm{cov}(\pi,k))/2\geq\\ \alpha+\beta\eta tI(A+B)a^L-b(a^L)^2/2-\rho\beta^2(\sigma^2+\varphi^2\sigma_k^2+2\varphi\mathrm{cov}(\pi,k))/2,\forall a^L\in\wedge\end{cases}$$

So now IR and IC are as follows:

(IR):

$$\alpha+\beta\eta tI(A+B)a-ba^2/2-\rho\beta^2(\sigma^2+\varphi^2\sigma_k^2+2\varphi\mathrm{cov}(\pi,k))=\overline{w}$$

(IC): $a=\beta\eta tI(A+B)/b$

Put them into the objective function, and then we get the equation as follows:

$$\max_{\beta\ \varphi} Ev=\max_{\beta\ \varphi}[\beta\eta^2t^2I^2(A+B)^2/b-\beta^2\eta^2t^2I^2(A+B)^2/2b$$
$$-\rho\beta^2(\sigma^2+\varphi^2\sigma_k^2+2\varphi\mathrm{cov}(\pi,k))/2-\overline{w}]$$

Take the first derivative of β and φ from the central government's objective function, let it be zero, and we get the two optimized first-order conditions:

$$\begin{cases}\dfrac{\partial(Ev)}{\partial\beta}=\eta^2t^2I^2(A+B)^2/b-\beta^2\eta^2t^2I^2(A+B)^2/b\\ -\rho\beta(\sigma^2+\varphi^2\sigma_k^2+2\varphi\mathrm{cov}(\pi,k))=0\\ \dfrac{\partial(Ev)}{\partial\varphi}=\varphi\sigma_k^2+\mathrm{cov}(\pi,k)=0\end{cases}$$

The solution is:

$$\begin{cases}\varphi=-\mathrm{cov}(\pi,k)/\sigma_k^2\\ \beta=\dfrac{1}{1+\rho b(\sigma^2-\mathrm{cov}^2(\pi,k)/\sigma_k^2/\eta^2t^2I^2(A+B)^2}\end{cases}$$

So $\sigma^2\sigma_k^2\geq\mathrm{cov}^2(\pi,k)$ and $\sigma^2\geq\mathrm{cov}^2(\pi,k)/\sigma_k^2$. Combine the above two equations and we get:

$$\beta=\frac{1}{1+\rho b(\sigma^2-\mathrm{cov}^2(\pi,k)/\sigma_k^2/\eta^2t^2I^2(A+B)^2}\geq$$
$$\frac{1}{1+\rho b\sigma^2/\eta^2t^2I^2(A+B)^2}=\beta'$$

$$a=\beta\eta tI(A+B)/b$$
$$=\frac{\eta tI(A+B)}{b(1+\rho b(\sigma^2-\mathrm{cov}^2(\pi,k)/\sigma^2)/\eta^2t^2I^2(A+B)^2}$$

From the comparison between these two equations and equation (1), it can be concluded that by putting a noticeable variable k into the agency contract of the central government, and with the function of the incentive system, the local government will enhance its effort level of participating in urban construction, and the corresponding surplus portion it shares will increase. Now the expected gain of the central government, the actual gain of the local government, and the agency cost of the central government are, respectively, as follows:

$$Ev=\frac{\eta^2t^2I^2(A+B)^2}{2b(1+\rho b(\sigma^2-\mathrm{cov}^2(\pi,k)/\sigma_k^2/\eta^2t^2I^2(A+B)^2)}-\overline{w}$$

$$w=\overline{w}+\frac{\rho\sigma^2}{2(1+\rho b(\sigma^2-\mathrm{cov}^2(\pi,k)/\sigma_k^2/\eta^2t^2I^2(A+B)^2)^2}$$

$$AC=\frac{\rho(\sigma^2-\mathrm{cov}^2(\pi,k)/\sigma_k^2}{2(1+\rho b(\sigma^2-\mathrm{cov}^2(\pi,k)/\sigma_k^2/\eta^2t^2I^2(A+B)^2)}$$

Compare the previous equations (2), (3) and (4) with the above equations and we can see that both the central government's expected gain and the local government's actual gain are much greater than when they rely on only the one variable π and that the total agency cost of the central government also decreases significantly.

5 Conclusion and policy suggestions

The above analysis of the principal-agent model shows that in the process of low-carbon ecological urban construction, the central government has the disadvantage of information asymmetry. For any new noticeable variable k (only if observing k does not cause any cost or if the cost of observing k is less than the reduced agency cost it brings about will k be meaningful), as long as k contains more information about θ or a than the given variable π contains, and k is put into the incentive contract as a new term, the central government's agency cost will be greatly reduced and the central government's expected gain will be increased. For the central government, both the rationality of awarding or punishing the local government and the executive cost of supervision and inspection are mainly determined by the information content the central government acquires. Sufficient information not only ensures that the central government makes reasonable regulations but also prevents the local governments from the "moral risks" in low-carbon urban construction, which is helpful for promoting the development of the urban recycling economy. Therefore, to realize the optimal balance in the game of low-carbon ecological urban construction between the central government and the local government, we must design a system that can change the information asymmetry status to strengthen the central government's ability to acquire information and to stimulate or restrict

the local government's action choice. It can turn the external pressure of low-carbon ecological urban construction into the local government's own internal actions. The policy suggestions are as follows:

(1) Strengthen the awe and reliability of the agency policy and perfect the central government's monitoring mechanism. Now that the individual in the game is rational, whether the agent would provide the true information is decided by whether it can get more gains than if it hides the true information. Therefore, if the principal wants to achieve maximum utility, it pays the agent in such a way that the latter knows that providing the true information is its optimal choice. With a lack of a direct or indirect information channel, the central government can get a low-information-cost contract by changing the game rules, i.e., seeking an optimal institutional arrangement.

(2) Establish the "reputation" of a city's ecological environment and the mechanism of publicly releasing the environmental information. In some sense, for the final establishment of an urban environmental management system, only the tangible system of restricting the local government is not enough, and it is necessary to establish an intangible system - "reputation". By strengthening the propaganda of the urban ecological environmental "reputation", the local government is forced to disclose the environmental information and to regard the construction of its own social image as one of the construction goals, with a huge pressure from public opinion, which will unify the economic and social benefits.

(3) Establish an effective mechanism of information exchange and promotion. This plays an extremely important role in reducing transaction costs and in realizing the optimal game balance. Firstly, better information openness of the local governmental affairs means asking the relevant departments to timely provide environmental information, such as information about the companies that produce waste, information about the waste's features and potential value, information about the circulation companies and their market access, information about the latest recycling technologies, and information about the policy support. This will promote the spread of environmental information and entirely change the current information asymmetry status in the process of developing a recycling economy. Secondly, gradually perfect the operation mechanism of marketizing the environmental information, greatly promote the rapid development of the medium organizations of environmental protection information, and establish a highly efficient exchange platform of recycling economy information to make up for the deficiency of the local governmental information openness.

(4) Foster the public subject consciousness of recycling economy and perfect the information feedback mechanism. The complexity of the resource and environment problems determines the necessity of the wide participation in the development of the recycling economy, and the public participation scale and quality is determined by the public ideas about ecological protection. First, the central government should create an environmental information publishing network and a green service centre. They can be used to strengthen the propaganda and education of green knowledge and the effective communication with the public. Finally, make full use of news media and non-governmental organizations. The news media widely represent the public opinions and have a non-obligatory supervision function, so their reports of hot issues and market quotations can speed the development of information openness to a certain degree. Non-governmental organizations can also timely reflect the public demands. The environmental protection they launch helps to promote green consumption and to increase the level of market openness and norms. Therefore, encourage their relevant propagandas and fully exert their function of conveying information. They can introduce the community and market incentive mechanism into the control of environmental products and set up a communication bridge between social members.

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