Research on A Government-Enterprise Game in the Green Supply Chain Based on the KMRW Reputation Model

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Abstract—At present, due to the information asymmetry between government and enterprises, in the process of government granting carbon abatement cost subsidies to upstream manufacturers of the green supply chain under the dual carbon background, there are many opportunistic behaviors of enterprises to conceal information for obtaining high government subsidies. In response to this problem, this paper uses the KMRW reputation model to analyze the game between government and enterprises. The analysis results show that manufacturers will make decisions according to the characteristics of different game stages. Based on this result, reasonable suggestions are put forward for the government to ensure that manufacturers in the green supply chain provide correct information, and encourage enterprises to actively respond to the national dual carbon policy and significantly reduce carbon emissions.

Keywords-KMRW model; green supply chain; Carbon abatement cost subsidies; game

1 INTRODUCTION

On September 22, 2020, during the United Nations general debate, General Secretary Xi Jinping formally proposed that China's carbon dioxide emissions strive to peak by 2030 and achieve the dual carbon goal of carbon neutrality by 2060. Since then, topics such as green supply chain and low-carbon emissions have attracted strong attention from the outside world, and the state has gradually improved the policy guidance mechanism to support the 'double carbon' goal. For example, it was officially released that the 'Opinions of the State Council of the Central Committee of the Communist Party of China on the complete, accurate and comprehensive implementation of the new development concept to do a good job of carbon neutralization at carbon peak' on October 24, 2021. This document carried out systematic planning and overall deployment for the major work of 'double carbon'.

To encourage manufacturers to increase low-carbon technology investment, the Chinese government has given low-carbon emission reduction subsidies to many green supply chain manufacturing enterprises such as new energy vehicles [1]. However, due to the information asymmetry between government and enterprises, the government cannot fully and accurately grasp the actual carbon emissions of enterprises. Many manufacturers take the opportunity to conceal the government and obtain high subsidies. For the government, in the case of asymmetric information on carbon emissions, corporate underreporting has seriously affected the normal implementation of the low-carbon subsidy strategy. Therefore, it is an urgent problem to be

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solved that how to prevent manufacturers and enterprises in the green supply chain from distorting information, defrauding subsidies, and increasing the promotion of the dual-carbon policy reasonably and effectively.

On the research of low-carbon subsidies between the government and enterprises, Dong Lili [2] et al. constructed an evolutionary game model under the two situations of supervision and non-supervision and proposed three government regulatory strategies. Based on blockchain technology, Zhang Lingrong [3] et al. established a three-stage game modeled by the government and followed by manufacturers and retailers in four situations and discussed the optimal problem of government low-carbon subsidy strategy. Zhao Liming [4] et al. studied the game of carbon emission reduction between government and enterprises in the context of carbon quota and carbon tax and pointed out that the government can control carbon emissions by determining the carbon tax level and carbon emission quota, thereby affecting the emission reduction decision of enterprises. Chen Jianhua [5] et al. used the Stackelberg game model to compare the optimal carbon emission reduction level of manufacturers under the two modes of no government subsidy and government subsidy. It can be seen from the above literature that most of the existing literature analyzes the low-carbon subsidy problem between government and enterprises from the perspective of establishing a game model, studies the influence of subsidy policy on the decision-making of supply chain enterprises, and a small number of studies on the optimal subsidy strategy of the government. However, it does not study the influence of corporate reputation on the low-carbon subsidy problem from the perspective of enterprises. Therefore, based on this problem, the author constructs an incomplete information dynamic game model based on the KMRW reputation model to study the government carbon emission reduction cost subsidy concealment problem.

2 THE APPLICATION ANALYSIS OF KMRW REPUTATION MODEL IN GOVERNMENT-ENTERPRISE GAME OF GREEN SUPPLY CHAIN

2.1 KMRW reputation model theory

Kreps, Willson, Roberts, Milgrom established the KMRW reputation model in 1982 and introduced incomplete information into repeated games. It is proved that as long as the number of repeated games is enough, cooperative behavior will appear infinite games. In the context of the low-carbon supply chain, according to the KMRW theorem, the repeated game between the government and manufacturers is that although manufacturers have the motivation to conceal carbon emission information from the government to obtain high subsidies, if they choose to conceal it, they will expose their types of dishonesty and lose the opportunity to obtain long-term benefits of low-carbon subsidies [6]. Therefore, at the beginning of the game, although manufacturers may not be honest enterprises, manufacturers will show good faith for long-term benefits. Only in the final stage of the game, manufacturers will choose to expose dishonesty.

2.2 Basic assumptions and model building

The following is a reputation model of a government-enterprise game based on a low-carbon subsidy strategy. The game subjects are the government and manufacturers in the low-carbon

supply chain. Assuming that both sides of the game are rational economic people, in the context of information asymmetry, the government believes that manufacturers have two types: integrity and non-integrity.

Based on the application of the KMRW reputation model proposed by Barro (1986) and Vickers (1986) to government monetary policy, it is assumed that the government's single-stage utility function is as follows [7]:

$$W(\pi) = -\frac{1}{2}\pi^2 + b(\pi - \pi^e). \quad (1)$$

Where, $\begin{cases} b = 0, The\ manufacturer\ are\ honest\ type. \\ b = 1, The\ manufacturer\ is\ non-honest\ type. \end{cases}$

Here π is the manufacturer's actual revenue occupancy rate (manufacturer's profit caused by dishonest behavior), and π^e is the manufacturer's revenue occupancy rate estimated by the government. Suppose only π=0 and π=1. π=0 represents manufacturer providing accurate low-carbon consumption information to the government p_0. π=1 represents manufacturer providing wrong carbon emission information to the government. Due to the information asymmetry between the government and enterprises, the government cannot determine the true type of manufacturer, assuming that the government believes that the enterprise is a good faith prior probability p_0, non-good faith prior probability 1-p_0.When the manufacturer is honest, that is, b=0, $W(\pi) = -\frac{1}{2}\pi^2$. We can see that the maximum utility of the enterprise is 0, and π=0, which means that the enterprise must comply with credit and provide accurate information. When the manufacturer is dishonest, that is, b=1, $W(\pi) = -\frac{1}{2}\pi^2 + \pi - \pi^e$, meaning the rational manufacturer will choose to maintain its reputation to obtain the maximum utility value. Before the last government-enterprise game, it is honest, to obtain government trust. This process π^e will continue to decrease until:

$$W(\pi) = -\frac{1}{2}\pi^2 + \pi - \pi^e \geq 0.$$

3 LOW CARBON SUBSIDY GAME MODEL BASED ON KMRW REPUTATION THEORY

3.1 Single-stage game analysis

For (1) formula $\frac{\partial W}{\partial \pi} = -\pi + b$. Let $\frac{\partial W}{\partial \pi} = 0$ so the optimal actual profit occupation rate of the manufacturer π^*=b=1 and the utility level $W = -\frac{1}{2}$, which indicates that if the government only gives the manufacturer one-time subsidies, the manufacturer will choose to conceal information.

3.2 Repeated T stage game analysis

Assume that the game repeats stage T, let y_t be the probability that the dishonest manufacturer chooses zero real profit encroachment rate in stage t (that is, the probability of pretending to be an honest enterprise), and x_t be the probability that the government considers the enterprise to be honest after assessment and supervision. In the equilibrium state, $x_t = y_t$. If the government does not observe the profit encroachment of the enterprise in stage t, according to Bayes' theorem,

the posterior probability p_{t+1} that the government considers the enterprise to be honest in stage t+1 is:

$$p_{t+1}(b=0|\pi_t=0)=\frac{p_t\times 1}{p_t\times 1+(1-p_t)x_t}\geq p_t. \tag{2}$$

Among them,1 is the probability that honest enterprises do not obtain real income encroachment. From $p_{t+1}\geq p_t$, it can be seen that if enterprises choose to maintain their reputation within the t stage, the government's trust in enterprises will increase in the next stage. But if an enterprise chooses to conceal it from the government and shows dishonest behavior, the following is established:

$$p_{t+1}(b=0|\pi_t=1)=\frac{p_t\times 0}{p_t\times 0+(1-p_t)x_t}=0. \tag{3}$$

It shows that once the government finds that enterprises have concealed reporting behavior, it will terminate the subsidies to enterprises and implement punishment.

3.3 The last two-stage game analysis

The solutions of the last two stages, namely, T-1 and T stage models, are considered below.

1)T-1 stage game analysis: To change the default and adjust the template as follows. Now consider the T-1 stage of enterprise decision-making, if the non-honest enterprise provides accurate information in the T-1 stage, the total utility function is as follows (4):

$$W_{t-1}(1)+\delta W_t(1)=-\frac{1}{2}\pi_{t-1}^2+\pi_{t-1}-\pi_{t-1}^e+\delta\left(-\frac{1}{2}\pi_t^2+\pi_t-\pi_t^e\right). \tag{4}$$

δ is a discount factor, which refers to the time discount rate. It can be understood as the degree of attention to the expected subsidies generated by enterprises in the future. Since the profit obtained by non-honest enterprises in the T-1 stage without concealing is higher than the profit obtained by exposing themselves in this stage, Equation (5) is satisfied:

$$-\frac{1}{2}-\pi_{t-1}^e-\frac{1}{2}\delta\leq-\pi_{t-1}^e+\delta\left(p_t-\frac{1}{2}\right). \tag{5}$$

Because in the equilibrium state, $y_{t-1}=x_{t-1}=1$, $p_{t-1}=p_t$ can be obtained by substituting it into Eq.(2), and then $p_t\geq\frac{1}{2\delta}$. It is proved that in the T-1 stage, if the probability that the government believes that the enterprise is honest is not less than $\frac{1}{2\delta}$, the non-honest enterprise will pretend to be honest. That is, the higher the reputation of the enterprise, the more the government believes that the enterprise is honest, the more willing the enterprise is to maintain its reputation, which reflects the incentive effect of reputation on the behavior of enterprises to maintain integrity. In particular, when $P_{t-1}\to\frac{1}{2\delta}$, $y_{t-1}\to 1$. If non-honest enterprises choose to conceal the information at this time, the utility value is: $W_{t-1}(1)=\frac{1}{2}-W_{t-1}^e<1.$, but the utility value in the t stage becomes $W_t(1)=-\frac{1}{2}<P_t-\frac{1}{2}$. At this time, when P_{t-1} is large enough and δ is close to 1, the optimal choice of non-honesty enterprises is to perform good-faith behavior at stage t-1[8].

2)T stage game analysis: To change the default, adjust the template as follows.

In the T stage (final stage), the non-honest manufacturer no longer needs to maintain its reputation.At this time,the optimal benefit choice is π_t=b=1, π_t^e= 1-p_t, and the utility function of the non-honest manufacturer is:

$$W_t = -\frac{1}{2}{\pi_t}^2 + (\pi_t - \pi_t^e) = -\frac{1}{2} + [1 - (1 - p_t)] = p_t - \frac{1}{2} \quad (6)$$

It is easy to know that the utility W_t of non-honest enterprises is an increasing function of corporate reputation p_t, which explains why enterprises actively maintain a strong reputation in the T-1 stage. It should be noted that if the regulatory constraints are not strict enough,non-honest companies will use the reputation established before in the final t stage to choose to conceal higher returns.

3.4 Summary of game results

From the above game analysis of different stages, it can be seen that manufacturers will make different decisions according to different game stages. If the manufacturer is an honest enterprise, it will always provide accurate carbon emission quota information to the government, and if it is a dishonest enterprise, then:

- In the single-stage game process, concealment will be chosen to obtain maximum utility.
- In the repeated T-stage game process, in any t-stage, if the enterprise chooses to conceal the report and is found by the government, the enterprise will lose the subsidy opportunity given by the government and the long-term income. In the t-1 stage, when the government fully believes that enterprises are integrity and enterprises pay more attention to future subsidies, non- integrity enterprises will still show integrity behavior. In the final stage, dishonest enterprises may choose to show dishonest behavior to cheat subsidies.

4 COUNTERMEASURES AND CONCLUSION

Reputation has a great influence on behavior decision-making. Enterprises with higher reputations tend to pay more attention to long-term interests. According to the results of the game analysis, the author puts forward the following suggestions:

- Building blockchain regulatory platform. Blockchain technology has obvious inalterability and real-time. The government can obtain accurate carbon emission information of enterprises through a blockchain platform, trace the source of low-carbon products, and make consumers more trust the enterprise, which is also conducive to the maintenance of the reputation of enterprises [9].
- Establishing a reputation evaluation system. The model analysis shows that the higher the reputation of enterprises, the stronger the enthusiasm to maintain their reputation. Given this, the reputation evaluation system can be established, and the evaluation system of enterprise reputation can be constructed by factor analysis and other evaluation methods [10]. A comprehensive score of reputation can be obtained, and the reward system can be implemented for enterprises with active maintenance of reputation and high reputation information, and additional subsidies can be carried out.

- Strengthening the subsidy amount and punishment. In the repeated game stage, the manufacturer is likely to choose to conceal the report in the final stage, damaging the reputation. To ensure the long-term game between government and enterprises, the government can appropriately increase the amount of low-carbon consumption subsidies, encourage enterprises to respond to national policies, and vigorously invest in low-carbon technology research and development to strengthen supervision [11]. On the existing basis to strengthen the punishment of dishonest enterprises, thereby increasing the discount factor δ of enterprises, so that enterprises realize that the long-term benefits of low carbon consumption subsidies are far greater than the unfair benefits of speculation.

At present, the application analysis of the KMRW reputation model in the government-enterprise game of green supply chain is rare, and there is no use of this model to solve the problem of enterprises cheating government low carbon subsidies in the green supply chain under the background of dual carbon. As an incentive condition, reputation is one of the key factors to solve the problem of low carbon subsidies. Therefore, the author uses the KMRW reputation model to establish the dynamic game model of incomplete information between the government and manufacturers in the green supply chain, proves that the establishment of enterprise reputation has a profound incentive effect on the government's subsidies, finds the conditions for maintaining the benign game between the government and manufacturers, and puts forward reasonable countermeasures and suggestions on how to reduce the opportunistic behavior of enterprises' concealing the government to obtain subsidies, which provides theoretical support for promoting the implementation of low-carbon subsidy policy [12].

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