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Impact of Shareholding Reforms of State-owned Enterprises on Environmental Pollution Prevention Policy

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Abstract: *This paper establishes a three-stage mixed monopoly model, and deeply discusses the impact of the shareholding reform on environmental tax rate or reward and subsidy intensity, green research and development level, environmental damage and social welfare under the two policies of collecting environmental tax and issuing incentive subsidy funds, and analyses the effect of the two policies. The results show that when implementing the environmental tax policy, the low degree of privatisation of state-owned enterprises will cause less damage to the environment and social welfare; when implementing the reward and subsidy policy, the higher degree of privatisation will cause less damage to the environment and social welfare. Comparing the effects of the two policies, it is better to implement the reward and subsidy fund policy when the privatisation degree of state-owned enterprises is relatively high. If the privatisation degree is not high, the policy choice is related to the social goals expected by the government.*

Keywords: *Mixed duopoly, Shareholding reform of state-owned enterprises, "Green" R&D, Emission taxation*

JEL classification*: E61; G38; H23*

1. Introduction

Since the late 1990s, China's economy has achieved rapid development, and the resulting environmental pollution is also increasing rapidly. The development model of "pollution first, treatment again" not only consumes a lot of human resources and economic resources, but also cannot play an ideal role in pollution control. However, China soon realised the price paid by the natural environment for economic development. In 2013, China proposed to "deepen the reform of the ecological civilisation system closely

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around building a beautiful China" and "promote a new pattern of modernisation of harmonious development between man and nature". Since then, the prevention and control of environmental pollution has been placed in an important position. Till the present day, the 20th National Congress of the Communist Party of China still emphasises pollution control and ecological protection. The meeting proposed to "jointly promote carbon reduction, pollution reduction, green expansion and growth, and promote ecological priority, conservation and intensive, green and low-carbon development."

On the way to prevent and control environmental pollution, it is necessary to use government policy tools. The two more common ways are taxation and subsidies. As early as in 1920, Pigou analysed and proposed to control environmental pollution by taxation in Welfare Economics, that is, to implement the Pigou tax. He also put forward the principle of "polluter pays" in 1932, that is, to internalise environmental externalities by collecting environmental taxes. Pearce (1991) first put forward the concept of "double dividend" of environmental tax, that is, the collection of environmental tax can not only improve the ecological environment quality, but also reduce the distortion of the existing tax revenue, promote economic growth and improve the social employment rate. Kato (2011) analysed the optimal environmental policy tools from the perspective of maximising social welfare, and compared the optimal emission tax with "Pigou tax". Li et al. (2021) pointed out that the increase in environmental tax rates does not necessarily promote pollution reduction, and that the tax rate is inversely "U-shaped" associated with emission reduction. There is more than one way of environmental protection. In addition to controlling enterprises to reduce pollutant emissions, there are also enterprises' "green" innovations, which enable polluting enterprises to reduce resource input and reduce environmental damage. However, Szücs (2018) believed that the high investment, high risk and positive externalities of "green" innovation would lead to insufficient innovation power of enterprises, and it was difficult to achieve rapid development only by relying on their own resources or market forces. Therefore, the government needed to take financial measures such as "green" innovation subsidies to encourage polluting enterprises to carry out "green" innovation. Kleer (2010) also recognised the effect of government subsidies and pointed out that the "certification effect" of government subsidies could add tangible and intangible assets to green innovation of enterprises. Luo et al. (2016) believed that in the transition economy, government subsidies would help supplement their own resources and significantly improve the innovation ability of manufacturing enterprises. Some scholars also confirmed the positive effect of enterprise innovation and R&D policy on emission reduction. Feng & Niu (2009) believed that the government should increase subsidies and other incentive policies to improve economic and environmental benefits and promote the development of low-carbon economy. Based on the perspective of game theory, Zhan (2016) found that both price subsidies and R&D subsidies could reduce domestic pollution emissions. For the comparison of the two policy tools, Hattori (2017) constructed a model of upstream monopoly innovators developing cleaner production technologies and authorising downstream polluting enterprises, and discussed the optimal environmental policy of the government in R&D subsidies, subsidies and emission taxes. Lu et al. (2019) found that environmental protection tax inhibits green innovation. Liu & Xiao (2022) found that the environmental protection tax promotes the transfer of technological innovation activities in other fields to green innovation, that is, the environmental protection tax promotes green innovation. This paper discusses the influence of two government subsidy policies on social welfare and supply chain members' profits.

There are many literatures on reducing pollution emissions with traditional oligopoly theory. For example, Liu & Zhou (2011) explored the effect of the environmental tax in the framework of the Stackelberg sequence game. Considering the complexity of the market structure, there is relatively less literature on emission reduction using the mixed oligo competition between state and private enterprises. Ding & Huang (2021) used a two-stage mixed oligopoly dynamic game model to explore the impact of the degree of management authorisation of state-owned enterprises on pollutant emissions and social welfare under different policies. However, in combination with the reality of China, there are not many literatures that further use the theory of mixed oligopoly competition between state-owned enterprises and private enterprises in shareholding reforms to study emission reduction. Xu (2010) found that when the government can control the proportion of state-owned shares and levy pollution taxes on enterprises, the proportion of state-owned shares and environmental taxes affects the output level of state-owned enterprises, which in turn causes changes in social welfare.

This paper constructs a three-stage game model based on a mixed duopoly market composed of a state-owned enterprise and a private enterprise. The influence of the privatisation of state-owned enterprises on the government's optimal environmental tax rate and incentive subsidy funds, and its influence on environmental damage and social welfare were explored, and the effect of the two policies was relatively analysed.

2. The Model

According to the research objectives of this paper, we build a mixed oligopoly model, and explored the relevant behaviours of state-owned enterprises and private enterprises under China's joint-stock reform when the government implements two different emission reduction measures. The specific assumptions were as follows:

Hypothesis 1: The domestic market is a mixed duopoly market composed of state-owned enterprises 0 and private enterprises 1 with shareholding reform. The two enterprises produce homogeneous products, and the two sides compete with each other around output (q).

The utility function of consumers is:

$$U(q_0, q_1) = a(q_0, q_1) - \frac{1}{2}(q_0 + q_1)^2 \tag{1}$$

Among them, q_0 and q_1 represent the output of state-owned enterprises and private enterprises respectively, and $a > 0$ is the market scale. Then consumer surplus can be expressed as:

$$CS = U(q_0, q_1) - p\sum_{i=0}^{1} q_i = \frac{1}{2}(q_0 + q_1)^2 \tag{2}$$

where p is the market price. According to the first order condition of maximising consumer surplus, the inverse demand function of the market can be obtained as follows:

$$p = a - q_0 - q_1 \tag{3}$$

Hypothesis 2: The two enterprises have the same production technology, and their production will cause environmental pollution. The government proposes two emission reduction measures to control the pollution emissions of enterprises: first, the government will take tax rate $\tau(\tau \geq 0)$ collect environmental taxes to control the pollution emissions of enterprises, and enterprises can reduce the burden of environmental taxes on enterprises through "green" research and development; The second is that the government grants incentive subsidy fund $\gamma(\gamma \geq 0)$ to enterprises for each "green" R&D to encourage enterprises to carry out "green" innovation and reduce environmental pollution.

Assume that the production cost function of the product is the following quadratic function form of output:

$$c(q_i) = F + q_i^2 \tag{4}$$

For the convenience of analysis and calculation, set $F = 0$. The cost function of each enterprise when the government collects environmental tax is:

$$e_i \quad i = 0, 1 \tag{5}$$

Among them, z_i is the "green" R&D level of the enterprise *i* and $\frac{1}{2} z_i^2$ is the "green" R&D investment of the enterprise *i*. The cost function of each enterprise when the government grants "green" R&D incentive subsidy funds is:

$$C_i^{\gamma} = q_i^2 + \frac{1}{2} z_i^2 - \gamma z_i \tag{6}$$

Hypothesis 3: The pollution discharge technologies of the two enterprises are the same, and the pollution discharged by the enterprises will damage the environment to a certain extent.

Assume that the net pollution emissions of enterprises are:

$$e_i = q_i - z_i \quad i = 0, 1 \tag{7}$$

It shows that the higher the enterprise's "green" R&D level, the less the enterprise's net pollution emissions. According to the usual setting method, the following quadratic function is used to measure the damage function of pollution to the environment:

$$D = \frac{1}{2} E^2 = \frac{1}{2} (\sum_{i=0}^{1} e_i)^2 \quad i = 0, 1 \tag{8}$$

E is the total amount of pollution emissions, $E = \sum_{i=0}^{1} e_i$. From then on, we can get the profit function and social welfare function of the two enterprises under the two emission reduction policies proposed by the government. The profit function and social welfare function of each enterprise when the government collects environmental tax are as follows:

$$\pi_i^{\tau} = pq_i - C_i^{\tau} - \tau e_i \quad i = 0, 1 \tag{9}$$

$$W^{\tau} = \frac{1}{2} (\sum_{i=0}^{1} q_i)^2 + \sum_{i=0}^{1} \pi_i^{\tau} + \tau \sum_{i=0}^{1} e_i - D \quad i = 0, 1 \tag{10}$$

The profit function and social welfare function of each enterprise when the government grants "green" R&D awards and subsidies are:

$$\pi_i^{\gamma} = pq_i - C_i^{\gamma} \quad i = 0, 1 \tag{11}$$

$$W^{\gamma} = \frac{1}{2}(\sum_{i=0}^{1} q_i)^2 + \sum_{i=0}^{1} \pi_i^{\gamma} - \sum_{i=0}^{1} \gamma z_i - D \quad i = 0, 1 \tag{12}$$

Considering that state-owned enterprises should not only pursue profit maximisation but also consider some negative externalities, such as environmental pollution brought by enterprises, based on the research of Xiang et al. (2008), the objective function of state-owned enterprises is set as:

$$V = (1-\theta)W + \theta\pi_0 \quad i = 0, 1 \tag{13}$$

where θ represents the degree of privatisation of state-owned enterprises. In order to make this analysis meaningful, $0 \le \theta \le 1$ is considered.

This paper constructs the following three-stage game model: In the first stage, the government formulates the environmental tax rate with the goal of maximising social welfare τ and bonus fund γ; In the second stage, the state-owned enterprises and private enterprises in the joint-stock reform observed the policies adopted by the government, and chose their own "green" R&D level with the goal of maximising social welfare and their own profits; In the third stage, the two enterprises conduct output competition at the same time after determining the R&D level. Next, the Nash equilibrium solution of the game model is derived by reverse induction.

3 Analysis results under the situation of state-owned enterprise shareholding reform

3.1. Environmental tax policy

In the third stage, state-owned enterprises aim to maximise social welfare and their own profits, while private enterprises aim to maximise their own profits and compete for output. The problems of state-owned enterprises and private enterprises are:

$$\max_{q_0} (1-\theta)(\frac{1}{2}(\sum_{i=0}^{1} q_i)^2 + \sum_{i=0}^{1} \pi_i^{\tau} + \tau\sum_{i=0}^{1} e_i - D) + \theta(pq_0 - C_0^{\tau} - \tau e_0)$$

$$\max_{q_1} pq_1 - C_1^{\tau} - \tau e_1$$

According to the first order conditions, the equilibrium output of the two enterprises can be obtained as follows:

$$q_0^\tau = \frac{-4(z_0 + z_1)(-1+\theta) + \alpha(2+\theta) + (2-5\theta)\tau}{14+\theta} \tag{14}$$

$$q_1^\tau = \frac{3\alpha + (z_0 + z_1)(-1+\theta) + (-4+\theta)\tau}{14+\theta} \tag{15}$$

It can be found that there is $\frac{\partial_{q_0^\tau}}{\partial_\tau} > 0$ in the range $[0, 0.4)$ of θ, that is, the collection of environmental tax will not reduce the production of state-owned enterprises in the shareholding reform, which has a large proportion of state-owned shares. This shows that, unlike enterprises with a high degree of privatisation, such state-owned enterprises will consider the size of social welfare more than their own profits.

In the second stage, the two enterprises decide the "green" R&D level at the same time under the same objectives as in the first stage. The problems of state-owned enterprises and private enterprises are:

$$\max_{z_0}(1-\theta)(\frac{1}{2}(\sum_{i=0}^{1} q_i)^2 + \sum_{i=0}^{1}\pi_i^\tau + \tau\sum_{i=0}^{1} e_i - D) + \theta(pq_0 - C_0^\tau - \tau e_0)$$

$$\max_{z_1} pq_1 - C_1^\tau - \tau e_1$$

Take the equilibrium q_0^τ and q_1^τ obtained in the third stage into the objective function of the two enterprises, and according to the first-order conditions, the equilibrium "green" R&D level and the total market R&D level of the two enterprises can be obtained as follows:

$$z_0^\tau = -\frac{a(-1+\theta)(-632+\theta(-352+\theta(38+\theta))) + (-72+\theta(-912+\theta(1996+\theta(112+\theta))))\tau}{(14+\theta)(-76+\theta(-62+\theta(62+\theta)))} \tag{16}$$

$$z_1^\tau = \frac{4a(-1+\theta)(-40+\theta(-51+\theta(45+\theta))) - (3520+\theta(2552+\theta(-2658+\theta(-40+\theta)\theta)))\tau}{3(14+\theta)(-76+\theta(-62+\theta(62+\theta)))} \tag{17}$$

$$Z^\tau = \frac{a(-1+\theta)(124+\theta(52+\theta)) - 2(118+\theta(-15+2\theta(60+\theta)))\tau}{3(-76+\theta(-62+\theta(62+\theta)))} \tag{18}$$

According to the balanced "green" R&D level solved, within the value range of θ, there are always $\frac{\partial_{z_1^\tau}}{\partial_\tau} > 0$ and $\frac{\partial_{Z^\tau}}{\partial_\tau} > 0$; When $0 \le \theta \le 0.5125$, there is $\frac{\partial_{z_0^\tau}}{\partial_\tau} < 0$; when $0.5125 < \theta \le 1$, there is $\frac{\partial_{z_0^\tau}}{\partial_\tau} > 0$. It shows that the increase of environmental tax will promote private enterprises to carry out "green" R&D, but its role in promoting the "green" innovation of state-owned enterprises can only be reflected when the degree of privatisation reaches above 0.5125. However, in general, the lack of privatisation of state-owned enterprises will not affect the incentive effect of environmental taxes on the overall level of "green" R&D in the whole market, which is consistent with the assumption in this paper.

Substituting the calculated equilibrium "green" R&D level of the two enterprises into equations (14) and (15), the equilibrium output of the second stage is:

$$q_0^\tau = \frac{-a(68+\theta(-18+(-6+\theta)\theta))+(-100+\theta(138+\theta(6+\theta)))\tau}{3(-76+\theta(-62+\theta(62+\theta)))} \tag{19}$$

$$q_1^\tau = \frac{-40a+a\theta(-51+\theta(45+\theta))+82\tau-\theta(-12+\theta(48+\theta))\tau}{3(-76+\theta(-62+\theta(62+\theta)))} \tag{20}$$

In the first stage, the government formulates the environmental tax rate τ, to maximise social welfare. The problems of the government's game at this stage are:

$$\max_{\tau} \frac{1}{2}\left(\sum_{i=0}^{1} q_i\right)^2 + \sum_{i=0}^{1}\pi_i^\tau + \tau\sum_{i=0}^{1} e_i - D$$

Substitute the equilibrium "green" R&D level and equilibrium output obtained in the second stage into the objective function, and the optimal environmental tax rate can be obtained according to the first-order conditions as follows:

$$\tau = \frac{a(-22246+\theta(4222816+\theta(-6401792+\theta(2608576+\theta(3362152+\theta(-207314+\theta(-20444+(-281+\theta)\theta)))))))}{9457024+2\theta(3428816+\theta(3512240+\theta(-5910604+\theta(8549576+\theta(989024+\theta(41090+\theta(716+5\theta)))))))} \tag{21}$$

According to the reality, $\tau \geq 0$, it can be determined that equation (21) needs to meet $\theta \in (0.0576,1]$. When θ meets the above value range, that is $\frac{\partial_{\tau}}{\partial_{\theta}} > 0$, the government can formulate corresponding environmental tax rates according to different levels of privatisation of state-owned enterprises to maximise social welfare. It can also be seen that higher privatisation of state-owned enterprises will prompt the government to set higher environmental tax rates (Figure 1). Based on the previous conclusions, the government can realise the incentive effect of increasing environmental tax rate on the "green" R&D level of private enterprises and state-owned enterprises with higher privatisation degree. Therefore, the government with higher privatisation degree of state-owned enterprises will naturally choose higher environmental tax rate to promote the "green" innovation of enterprises, so as to achieve the goal of energy conservation and emission reduction.

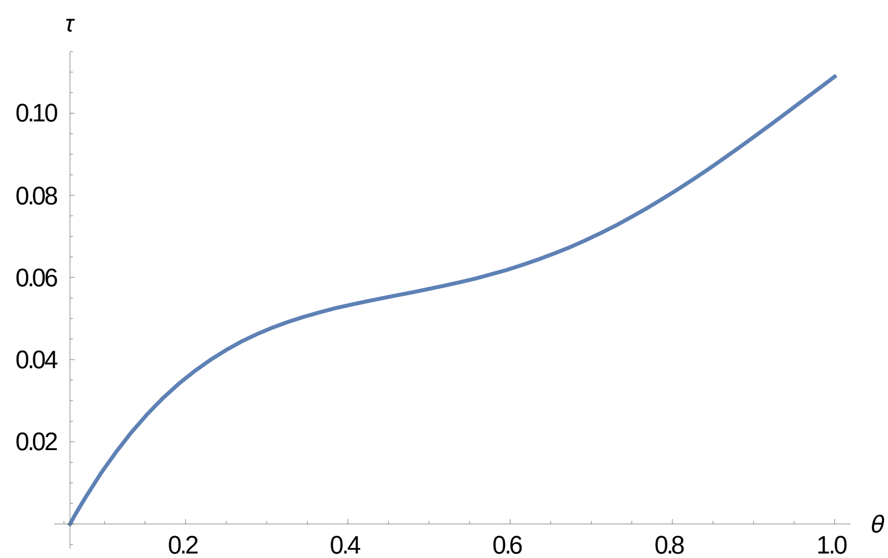

Figure 1: Relationship between privatisation degree of state-owned enterprises in shareholding reform and environmental tax rate under environmental tax policy (*a* = 1)

Now the optimal environmental damage function (*D*) and social welfare function (*W*) can be obtained according to the obtained balanced output, balanced "green" R&D level and optimal environmental tax rate, as shown below:

$$D^{\tau} = \frac{a^2(225472+\theta(-160664+\theta(-3063416+\theta(1712044+\theta(-1039835+\theta(183523+\theta(16294+\theta(331+\theta))))))))^2}{2(4728512+\theta(3428816+\theta(3512240+\theta(-5910604+\theta(8549576+\theta(989024+\theta(41090+\theta(716+5\theta))))))))^2} \quad (22)$$

$$W^{\tau} = -\frac{3a^2(-393472+\theta(-3518272+\theta(2022224+\theta(-531856+\theta(-1628980+\theta(-211408+\theta(8507+\theta(746+11\theta))))))))}{4(4728512+\theta(3428816+\theta(3512240+\theta(-5910604+\theta(8549576+\theta(989024+\theta(41090+\theta(716+5\theta))))))))} \quad (23)$$

Calculate the first derivative of θ in the environmental damage function. The results show that when $\theta \in (0.0576, 0.2615) \cup (0.9815, 1]$, there is $\frac{\partial_D}{\partial_\theta} < 0$; when $\theta \in (0.2615, 0.9815)$, there is $\frac{\partial_D}{\partial_\theta} > 0$. It can be seen that the environmental tax policy can achieve the goal of minimising environmental pollution, but it is affected by the degree of shareholding reforms of state-owned enterprises. When the degree of privatisation of state-owned enterprises is within a certain range, the damage to the environment caused by social pollution decreases with the increase in privatisation degree of state-owned enterprises (Figure 2). At this time, increasing the private shares of state-owned enterprises in shareholding reform can reduce the environmental pollution caused by enterprise production; However, if the degree of privatisation of state-owned enterprises in the shareholding reform is in the middle range, in order not to cause more pollution to the environment, the participation of private shares should be controlled.

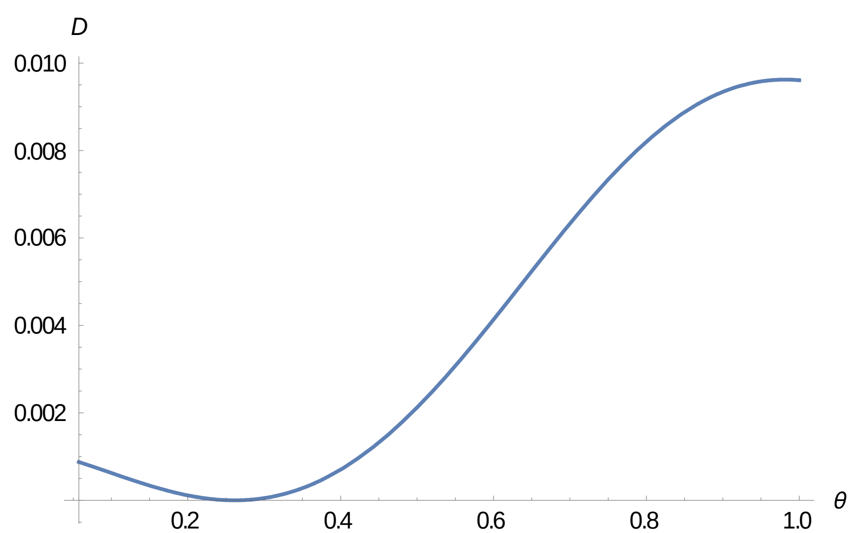

Figure 2: Relationship between privatisation degree of state-owned enterprises in shareholding reforms and environmental damage under environmental tax policy (*a*=1)

Similarly, the first derivative of θ in the social welfare function is calculated. The result shows that when $\theta \in (0.0576, 0.8930)$, there is $\frac{\partial_W}{\partial_\theta} > 0$; When $\theta \in (0.8930, 1]$, $\frac{\partial_W}{\partial_\theta} < 0$. It shows that when the degree of privatisation of state-owned enterprises reaches a certain level (about 0.2 here), there is an optimal environmental tax rate that maximises the social welfare. The social welfare of the country first increases with the degree of privatisation of state-owned enterprises. However, after the degree of privatisation $a > 0.8930$, the social welfare decreases with the degree of privatisation (Figure 3).

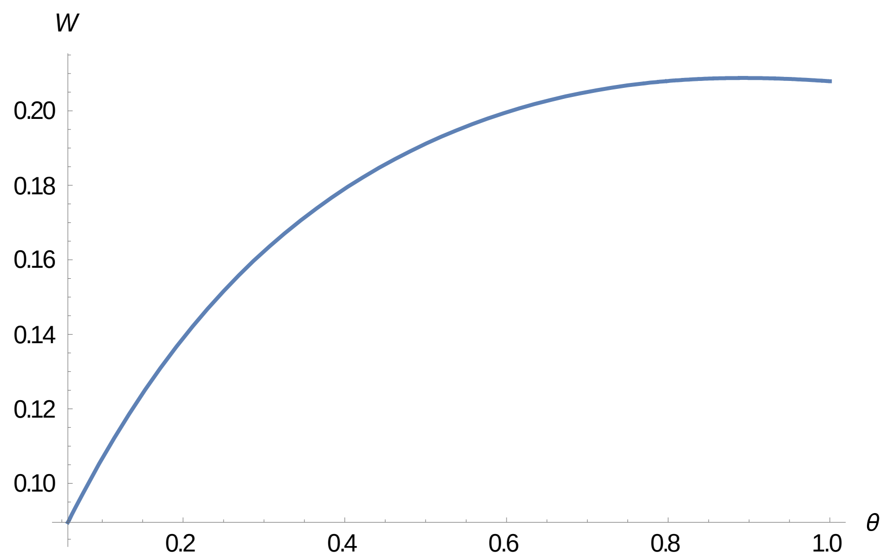

Figure 3: Relationship between privatisation degree of state-owned enterprises and social welfare under shareholding reform under environmental tax policy (*a* = 1)

The change of market size (*a*) will affect the degree of environmental damage and social welfare. Within the value range of θ, there are always $\frac{\partial_D}{\partial_a} > 0$ and $\frac{\partial_W}{\partial_a} > 0$. It shows that if the market scale gradually expands, the degree of environmental damage and social welfare will increase, indicating that the government's environmental tax policy cannot play a more active role in reducing emissions on a larger market scale, and all enterprises will ignore the environmental tax imposed by the government in the face of profits from large scale production.

The research on the environmental tax policy shows that the privatisation of state-owned enterprises in the shareholding reform has had an impact on the environmental tax rate, green innovation, environmental pollution and social welfare. There is a positive relationship between the degree of privatisation and the setting of government environmental tax rate; and only when the privatisation degree of state-owned enterprises is high, the increase of environmental tax rate will promote the "green" innovation of state-owned enterprises in shareholding reforms. On the whole, a lower degree of privatisation will cause less damage to the environment, but on the contrary, a higher degree of privatisation will produce more social welfare.

3.2. Policy of issuing "green" R&D awards and subsidies

Similarly, in the third stage, state-owned enterprises aim to maximise social welfare and their own profits, while private enterprises aim to maximise their own profits and compete for output. The problems of state-owned enterprises and private enterprises are:

$$\max_{q_0}(1-\theta)(\frac{1}{2}(\sum_{i=0}^{1}q_i)^2+\sum_{i=0}^{1}\pi_i^{\gamma}-\sum_{i=0}^{1}\gamma z_i-D)+\theta(pq_0-C_0^{\gamma})$$

$$\max_{q_1} pq_1-C_1^{\gamma}$$

According to the first order conditions, the equilibrium output of the two enterprises can be obtained as follows:

$$q_0^{\gamma}=\frac{-4(z_0+z_1)(-1+\theta)+a(2+\theta)}{14+\theta} \tag{24}$$

$$q_1^{\gamma}=\frac{3a+(z_0+z_1)(-1+\theta)}{14+\theta} \tag{25}$$

In the second stage, the two enterprises decide the "green" R&D level at the same time under the same objectives as in the first stage. The problems of state-owned enterprises and private enterprises are:

$$\max_{z_0}(1-\theta)(\frac{1}{2}(\sum_{i=0}^{1}q_i)^2+\sum_{i=0}^{1}\pi_i^{\gamma}-\sum_{i=0}^{1}\gamma z_i-D)+\theta(pq_0-C_0^{\gamma})$$

$$\max_{z_1} pq_1 - C_1^{\gamma}$$

Take the equilibrium q_0^{γ} and q_1^{γ} obtained in the third stage into the objective function of the two enterprises, and according to the first-order conditions, the equilibrium "green" R&D level and the total market R&D level of the two enterprises can be obtained as follows:

$$z_0^{\gamma} = -\frac{\gamma(14+\theta)(-164+\theta(298+91\theta))+3a(-1+\theta)(-376+\theta(-96+\theta(6+\theta)))}{(14+\theta)(-356+\theta(70+\theta(58+3\theta)))} \quad (26)$$

$$z_1^{\gamma} = \frac{4a(72-85\theta+12\theta^3+\theta^4)-\gamma(14+\theta)(360+\theta(-74+(-62+\theta)\theta))}{(14+\theta)(-356+\theta(70+\theta(58+3\theta)))} \quad (27)$$

$$Z^{\gamma} = \frac{-\gamma(1+\theta)(14+\theta)^2+a(-1+\theta)(60+\theta(20+\theta))}{-356+\theta(70+\theta(58+3\theta))} \quad (28)$$

According to the balanced "green" R&D level solved, there are always $\frac{\partial_{z_1^{\gamma}}}{\partial_{\gamma}} > 0$ and $\frac{\partial_{Z^{\gamma}}}{\partial_{\gamma}} > 0$ within the value range of θ; And when $0 \le \theta < 0.4800$, there is $\frac{\partial_{z_0^{\gamma}}}{\partial_{\gamma}} < 0$; when $0.4800 < \theta \le 1$, there is $\frac{\partial_{z_0^{\gamma}}}{\partial_{\gamma}} > 0$. It shows that the increase of incentive and subsidy funds is conducive to the "green" innovation of private enterprises. When the privatisation degree of state-owned enterprises is low, the increase of incentive and subsidy funds is not conducive to the "green" innovation of state-owned enterprises. Until the privatisation degree breaks through about 48%, the effect of enterprises' active "green" innovation can be reflected through the improvement of incentive and subsidy funds. In general, the government's incentive and subsidy fund policy has not played a good incentive role for state-owned enterprises with low degree of privatisation, but this does not affect the promotion of the policy on the overall innovation level of the market, so it can be considered that the policy is effective.

Substituting the calculated equilibrium "green" R&D level of the two enterprises into equations (24) and (25), the equilibrium output of the second stage is:

$$q_0^{\gamma} = \frac{4\gamma(-1+\theta)(1+\theta)(14+\theta) - a(68+\theta(-18+(-6+\theta)\theta))}{-356+\theta(70+\theta(58+3\theta))} \quad (29)$$

$$q_1^{\gamma} = \frac{-\gamma(-1+\theta)(1+\theta)(14+\theta) + a(-72+\theta(13+\theta(13+\theta)))}{-356+\theta(70+\theta(58+3\theta))} \quad (30)$$

In the first stage, the government formulated the "green" R&D award and subsidy fund γ to maximise social welfare. The problems of the government's game in this stage are:

$$\max_{\gamma} \frac{1}{2}(\sum_{i=0}^{1} q_i)^2 + \sum_{i=0}^{1} \pi_i^{\gamma} - D$$

Substitute the balanced "green" R&D level and the balanced output obtained in the second stage into the objective function, and the optimal R&D reward and subsidy fund can be obtained according to the first order conditions as follows:

$$\gamma = \frac{a(509760+\theta(-331232+\theta(164272+\theta(218464+\theta(43844+\theta(2084+\theta(281+27\theta)))))))}{2(14+\theta)(94320+\theta(-40876+\theta(36844+\theta(47169+2\theta(6782+\theta(412+15\theta))))))}$$

(31)

According to the actual situation, the reward fund $\gamma \geq 0$, it can be determined that equation (31) meets the original value range, $\theta \in [0,1]$. The result shows that all θ is satisfied, $\frac{\partial_{\gamma}}{\partial_{\theta}} < 0$, that is, the government can formulate the optimal reward and subsidy fund according to the privatisation level of state-owned enterprises to maximise social welfare. It can be seen that the higher degree of privatisation of state-owned enterprises will prompt the government to provide less R&D award and subsidy funds (Figure 4). In connection with the preceding conclusion, it can be concluded that the government is aware that the higher the degree of privatisation of enterprises in the market, the more obvious the incentive effect of bonus and subsidy funds on enterprises. At this time, the government can use less bonus and subsidy funds to achieve similar or even better incentive effects when the degree of privatisation of the market is not high.

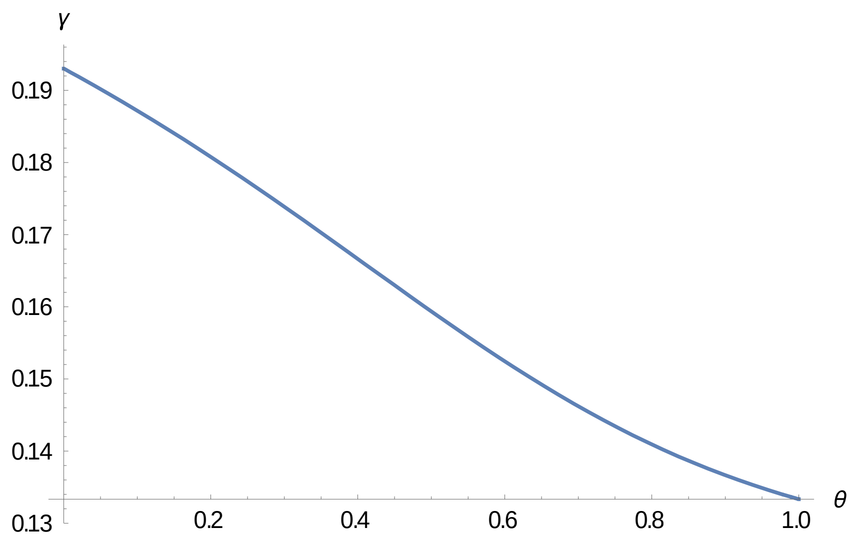

Figure 4: Relationship between privatisation degree of state-owned enterprises in joint-stock reform and "green" R&D reward and subsidy funds (*a* = 1)

Now the optimal environmental damage function (D) and social welfare function (*W*) can be obtained according to the obtained balanced output, balanced "green" R&D level and optimal R&D bonus and subsidy fund, as shown below:

$$D^{\gamma} = \frac{a^2(26640+\theta(-19608+\theta(18130+\theta(14237+\theta(1434+\theta(-349+16\theta))))))^2}{8(94320+\theta(-40876+\theta(36844+\theta(47169+2\theta(6782+\theta(412+15\theta))))))^2} \tag{32}$$

$$W^{\gamma} = \frac{a^2(80640+\theta(-34832+\theta(30888+\theta(40748+\theta(11669+\theta(606-119\theta))))))}{4(94320+\theta(-40876+\theta(36844+\theta(47169+2\theta(6782+\theta(412+15\theta))))))} \tag{33}$$

Calculate the first derivative of the environmental damage function with respect to θ, and the results show that in the value range of $\theta \in [0, 0.5071)$, there is $\frac{\partial_D}{\partial_\theta} < 0$; $\theta \in (0.5071, 1]$, there is $\frac{\partial_D}{\partial_\theta} > 0$. It can be seen that when the degree of privatisation of state-owned enterprises reaches a certain level, there is an optimal incentive subsidy fund to minimize environmental damage, and when the degree of privatisation of state-owned enterprises is not high, the damage to the environment caused by social pollution will decrease with the increase of the degree of privatisation of enterprises, but after the degree of privatisation exceeds the critical point of 0.5071, the blindly privatisation of state-owned enterprises is no longer a way to reduce environmental damage (Figure 5).

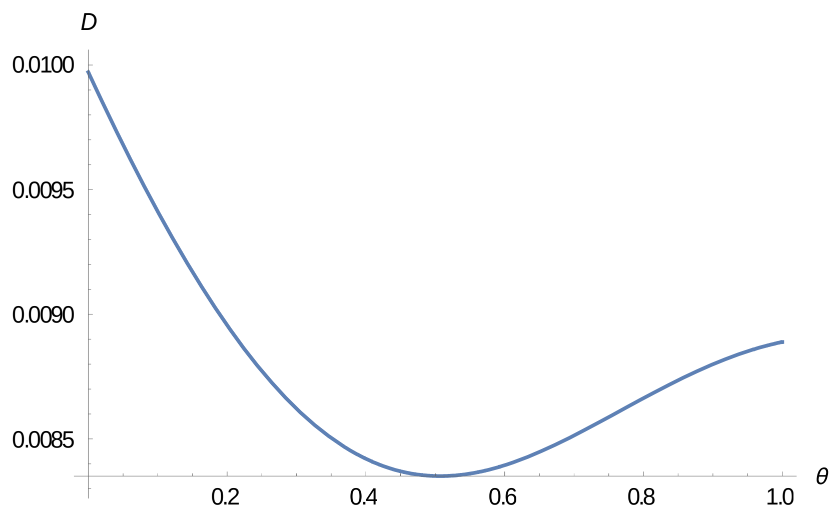

Figure 5: Relationship between privatisation degree of state-owned enterprises in shareholding reform and environmental damage under the incentive and subsidy policy (*a*=1)

At the same time, we also calculate the first derivative of the social welfare function on θ. The results show that when $\theta \in [0, 0.1082)$, there is $\frac{\partial_W}{\partial_\theta} > 0$; when $\theta \in (0.1082, 1]$, $\frac{\partial_W}{\partial_\theta} < 0$. That is, when the degree of privatisation of state-owned enterprises is not high, the social welfare is larger, and the domestic social welfare first increases with the increase of the degree of privatisation, but when the degree of privatisation increases to more than 0.1082, the social welfare decreases with the increase of the degree of privatisation (Figure 6).

Changes in market size will also affect the degree of environmental damage and social welfare. Within the value range of θ, there are always $\frac{\partial_D}{\partial_a} > 0$ and $\frac{\partial_W}{\partial_a} > 0$. It shows that if the market scale gradually expands, the degree of environmental damage and social welfare will increase

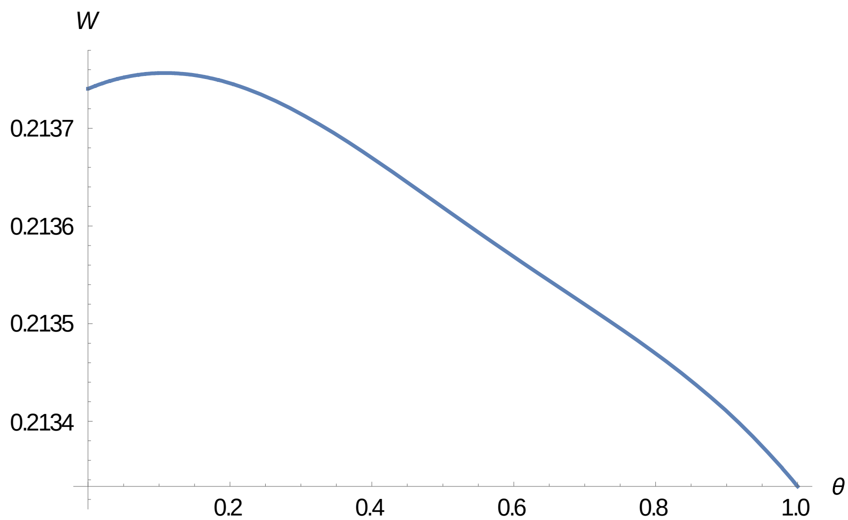

Figure 6: Relationship between privatisation degree of state-owned enterprises in shareholding reform and social welfare under the incentive and subsidy fund policy (*a*=1)

indicating that the government's "green" innovation incentive subsidy policy cannot play a more active role in reducing emissions in a larger market scale, and all enterprises can obtain more benefits from the profits of larger scale production than the incentive funds.

The research on the incentive and subsidy policy shows that the privatisation of state-owned enterprises in the joint-stock reform also has an impact on incentive funds, green innovation, environmental pollution and social welfare. There is a negative relationship between the degree of privatisation and the setting of bonus and subsidy funds; and only when the degree of privatisation of state-owned enterprises is high, the increase of the distribution intensity of bonus and subsidy funds will play a role in promoting the "green" innovation of state-owned enterprises in shareholding reform. In general, a higher degree of privatisation will cause less damage to the environment, but on the contrary, a lower degree of privatisation will produce more social welfare.

3.3. Comparison of two policies

As the reward and subsidy policy is meaningless within the scope of $\theta \in [0, 0.0576)$, this part compares the results of $\theta \in (0.0576, 1]$, and makes the market regulation under the two policies $a = 1$ for convenience. First, compare which policy is smaller in terms of social pollution emissions.

Subtract the social pollution emissions under the two policies to get the following formula:

$$D^{\tau} - D^{\gamma} = \frac{a^2(225472+\theta(-160664+\theta(-3063416+\theta(1712044+\theta(-1039835+\theta(183523+\theta(16294+\theta(331+\theta))))))))^2}{2(4728512+\theta(3428816+\theta(3512240+\theta(-5910604+\theta(8549576+\theta(989024+\theta(41090+\theta(716+5\theta))))))))^2} - \frac{a^2(26640+\theta(-19608+\theta(18130+\theta(14237+\theta(1434+\theta(-349+16\theta))))))^2}{8(94320+\theta(-40876+\theta(36844+\theta(47169+2\theta(6782+\theta(412+15\theta))))))^2} \tag{44}$$

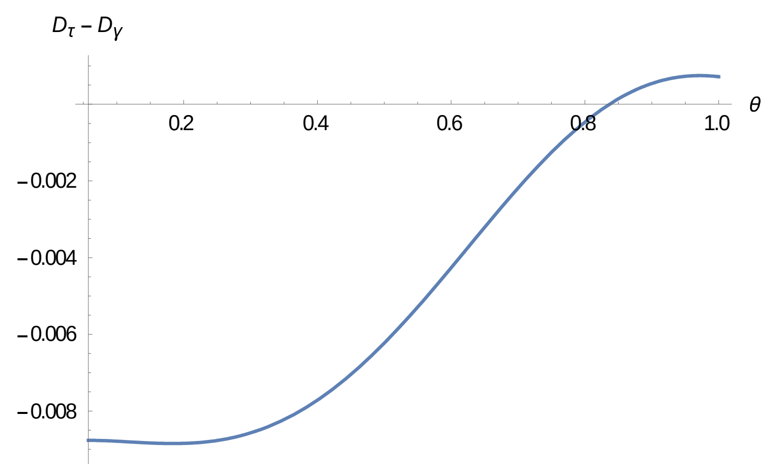

Figure 7: Comparison of pollution emissions under two policies

It can be seen from Figure 7 that when $0.0576 < \theta < 0.8366$, the social pollution emission under the implementation of environmental tax policy is smaller than that under the implementation of R&D subsidy policy; When $0.8366 < \theta \leq 1$, the social pollution emission under the implementation of environmental tax policy is more.

Then compare the social welfare under which policy is greater, and subtract the social welfare under the two policies to get the following formula:

$$W^{\tau} - W^{\gamma} = -\frac{3a^2(-393472+\theta(-3518272+\theta(2022224+\theta(-531856+\theta(-1628980+\theta(-211408+\theta(8507+\theta(746+11\theta))))))))}{4(4728512+\theta(3428816+\theta(3512240+\theta(-5910604+\theta(8549576+\theta(989024+\theta(41090+\theta(716+5\theta))))))))} - \frac{a^2(80640+\theta(-34832+\theta(30888+\theta(40748+\theta(11669+\theta(606-119\theta))))))}{4(94320+\theta(-40876+\theta(36844+\theta(47169+2\theta(6782+\theta(412+15\theta))))))} \tag{45}$$

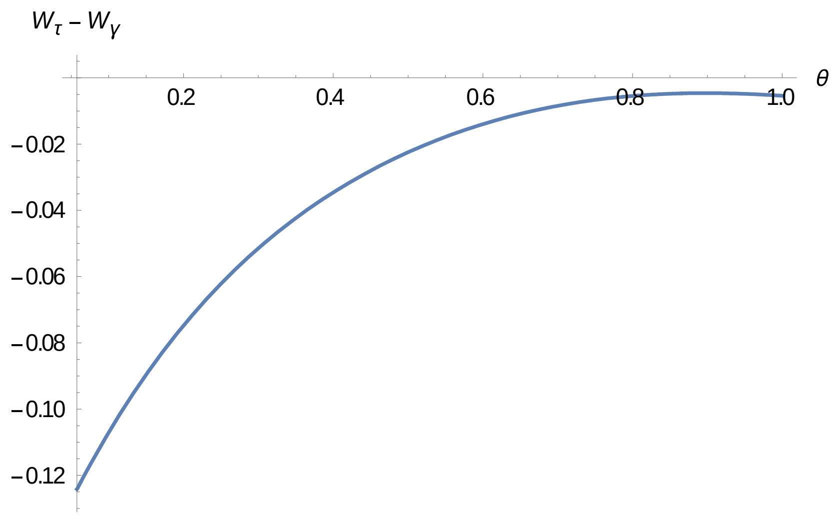

Figure 8: Comparison of social welfare under two policies

It can be seen from Figure 8 that no matter what the value of θ is, the social welfare under the "green" R&D incentive subsidy policy is greater.

The study of policy comparison shows that when the privatisation of state-owned enterprises in the shareholding reform is relatively high, the implementation of the incentive subsidy fund policy will be better than the environmental tax policy, but if the privatisation of state-owned enterprises cannot reach a higher level, the government can make different decisions according to different expectations.

4. Conclusion

This paper constructs and solves a three-stage dynamic game model of duopoly competition, deeply discusses the impact of state-owned enterprise shareholding reform on environmental tax rate or incentive intensity, green R&D level, environmental damage and social welfare under the two policies of levying environmental tax and granting incentive and subsidy funds, and makes a comparative analysis of the effects of the two policies. The results are as follows:

First, the degree of privatisation of state-owned enterprises in the joint-stock reform has a positive relationship with the setting of government environmental tax rates, but it has a negative relationship with the setting of incentive funds.

Second, only when the degree of privatisation of state-owned enterprises is high, will the increase of environmental tax rate play a role in promoting the "green" innovation of state-owned enterprises in shareholding reform. Similarly, only when the degree of privatisation of state-owned enterprises is high, will the increase of the distribution intensity of bonus and subsidy funds play a role in promoting the "green" innovation of state-owned enterprises in shareholding reform. It shows that if we want to encourage state-owned enterprises to carry out "green" innovation through policies, we need to let the state-owned enterprises of joint-stock reform absorb more social capital to improve the degree of privatisation of state-owned enterprises of joint-stock reform.

Third, when implementing the environmental tax policy, the lower degree of privatisation will cause less damage to the environment; when implementing the incentive and subsidy policy, the higher degree of privatisation will cause less damage to the environment.

Fourth, when implementing the environmental tax policy, a higher degree of privatisation will produce more social welfare; when implementing the incentive and subsidy policy, a lower degree of privatisation will produce more social welfare.

Fifth, when the degree of privatisation of state-owned enterprises in the joint-stock reform is high, the implementation of the incentive subsidy fund policy will be better than the environmental tax policy. However, if the degree of privatisation of state-owned enterprises cannot reach a high level, the government can make different decisions according to different expectations.

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