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Will Third-Party Treatment Effectively Solve Issues Related to Industrial Pollution in China?

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Abstract: China expanded the application of the third-party treatment model (TPTM) in 2017 for effectively tackling the issues related to industrial pollution on a trial basis, and the model could diversify the government's toolbox for addressing industrial pollution. With multiple players such as local governments, polluters, and environmental services providers (ESP) involved in the TPTM, appropriate guidance and coordination among the three players are critical to the success of the TPTM. This study constructs an evolutionary game model for the three players to capture their interaction mechanisms and simulates the three-player evolutionary game dynamics with the replicator dynamics equation. The simulation results show that heavier penalties for pollution and lower regulatory costs incurred by local governments could effectively improve the performance of the TPTM. Moreover, although environmental incentives provided by the central government to local levels do not affect the ultimate performance of the TPTM, they do shorten the time needed for the effect of the TPTM to emerge. The study concludes by proposing policy recommendations based on these results.

Keywords: industrial pollution; local governments; environmental service providers; third-party treatment of environmental pollution; evolutionary game

1. Introduction

Environmental problems affect a country's economic development, and the economic development level also restricts its ability to improve environmental quality. Based on empirical data, the Environmental Kuznets Curve shows an inverted U-shaped relationship between environmental quality and economic development [1]. In the early stage of economic development, environmental pollution is increasing with the increase in incomes. However, as the economy rises to a higher level, the income growth will reduce the pollution level and improve environmental quality. Andreoni et al. (2001) considered that consumers in countries with higher economic development level tend to have a higher preference for environmental goods and higher investment on the environment, which contribute to an inverted U-shaped relationship between economy and environment [2]. The curve emphasizes the unidirectional influence of economic development level on environmental quality. However, environmental quality also restricts the development of society and economy in reverse [3] because the economic development is established and developed on the basis of natural environment. Production activities are inseparable from natural resources. A good natural environment can reduce the cost of economic development and provide power support for sustainable economic development. Especially for many countries that have entered the middle-income stage of economic development, the control of the environmental pollution is not only related to the improvement of people's living environment, but is also affecting further economic growth, which in turn promotes

the improvement of environmental quality. As a result, environmental pollution has become an urgent problem for many countries whose economic development has reached the middle-income level.

In recent years, governments and researchers around the globe searched relentlessly for novel ways, including marketization, government initiatives, and third-party treatment to curb pollution. The first and the second models experienced frequent failures since only one of the players is responsible for the treatment, and the cost involved is prohibitive [4]. The third model, which engages multiple players, including governments, polluters, and treatment services providers, demonstrated remarkable advantages in solving issues related to environmental pollution [5]. The success of the model is attributable to its ability to promote marketization, specialization, regulatory compliance, and industrialization while preventing failures in government initiatives and marketization [6]. In fact, the model has already gained increasing popularity, and its effectiveness in curbing pollution is quite satisfactory [7]. In China, the opening-up policy has been very successful in realizing rapid economic development. However, it comes with great cost to the environment [8–11]. The issue was initially tackled by government initiatives [12]. In September 2017, the State Council issued the Opinions on Promoting the Third-Party Treatment of Environmental Pollution, which encourages and promotes the new pollution treatment model, where polluters entrust environmental services providers (ESPs) with certain payments stipulated in contracts [13]. This action indicates the significance attached to the third-party treatment model (TPTM) by the Chinese government and a starting point for its wide implementation across China.

In many developed countries, however, the model's effectiveness in curbing pollution has been quite satisfactory. Its success in China depends on the meaningful cooperation of multiple players in the model that has just been put into practice in the country [14,15]. Key players in the model include local governments, polluters, and ESPs. The outsourcing contracts between polluters and ESPs affect not only the polluters' outsourcing cost but also ESPs' payoffs and the effectiveness of treating pollution. Local governments, as environmental regulators, are responsible for monitoring this effectiveness. In case the standards are not met, local governments would impose penalties on ESPs and polluters. The behaviors and payoffs of the three players interact. Evidently, the game among the three players would determine whether the TPTM can effectively solve issues related to industrial pollution.

Recently, the evolutionary game framework has been increasingly applied to topics regarding the treatment of environmental pollution. Most studies addressed environmental pollution games between governments and polluters [16–19]. Others investigated whether the games among regions or states could lead to cooperation in treating environmental pollution [20–23]. In contrast, Jiang et al. (2019) [24] examined how the games among governments at various levels and enterprises affect the performance in environmental pollution treatment. A number of researchers introduced consumers into the games among governments and enterprises by employing the three-player evolutionary game model for governments, consumers, and enterprises to examine the effects of consumers' behaviors on environmental pollution [25–29]. Only a few researchers have addressed the TPTM in the area of environmental pollution by applying game theories. Among them, Xu et al. (2018) [30] and Zhou et al. (2019) [13] constructed an evolutionary game model that involved three players, including local governments, ESPs, and polluters, to study the development of the third-party treatment systems in China. They argued that local governments must adjust penalties on noncompliance dynamically, according to the development of the treatment systems. In addition, they found that fiscal subsidies granted to ESPs could improve the performance in environmental treatment. Even fewer researchers, also employing the evolutionary game model, examined the effects of a whistleblowing regime for environmental issues on the performance of environmental treatment [28].

The above literature review shows that only a few studies have investigated the TPTM in the evolutionary game framework. Only Xu et al. (2018) [30] and Zhou et al. (2019) [13] addressed the issues of environmental treatment by employing a three-player evolutionary game model by incorporating governments, polluters, and ESPs. Moreover, they focused on whether the governments have fulfilled their duties of supervision and whether polluters and ESPs have complied with relevant

regulations. In their studies, not much attention had been paid to how the outsourcing contracts between ESPs and polluters had been reached. Therefore, by building on their research results, this study made the following improvements by capturing the practices of third- party treatment of environmental issues. First, local governments in China may adopt the strategy of strict regulation or loose regulation in environmental supervision instead of regulating or not regulating. The strict and loose strategies are distinguished by the probabilities of being detected and punished by governments due to ESPs' unsatisfactory performance in treating pollution. Second, the responsibilities of the polluters and ESPs are also considered since the decisions about the outsourcing contracts between the polluters and ESPs can be incorporated into the model. With these two improvements, this study constructed an evolutionary game model for the three players to represent the treatment process under the TPTM. This approach is also the biggest difference between this study and previous studies.

2. Methods

2.1. Model Hypothesis

This study proposes the following hypotheses for building the three-player evolutionary game model involving local governments, polluters, and environmental services providers.

(1) Bounded rationality. It implies that players initially do not know the strategies at the Nash equilibrium of the three-player game. Therefore, they cannot adopt the corresponding best strategy for the Nash equilibrium to be reached at once. They can only choose any of the available strategies with a certain probability. By playing the game repeatedly, they continuously adjust the probability for each strategy until it converges to a stable Nash equilibrium strategy.

(2) Replication dynamics. Players of the game with bounded rationality adjust their strategies by using the replicator dynamics equation, which represents changes of the probability or frequency of a strategy being adopted by a player with a dynamic differential equation as below [31]:

$$F(x_v) = \frac{dx_v}{dt} = x_v[E(x_v) - \overline{E}]$$

where x_v denotes the probability of a player choosing strategy v, $E(x_v)$ is the expected payoff for the player with strategy v adopted, and $\overline{E}$ is the average payoff from adopting all the possible strategies.

(3) Hypotheses regarding the behaviors of local governments. Local governments, mostly responsible for regulating the performance of ESPs, are assumed to have two options: strict regulation or loose regulation. It is also assumed that the probability of local governments applying strict regulation is x $(0 \leq x \leq 1)$. With strict regulation, the probability of finding an unsatisfactory treatment performance is p^h, while that of loose regulation is $p^l(p^h > p^l)$. With strict regulation, the economic and time cost incurred by local governments is C_g^h, and the cost with loose regulation is $C_g^l(C_g^h > C_g^l)$. Meanwhile, strict regulation adopted by local governments would reduce economic output in the short term and result in cost C_g. However, satisfactory performance in treating pollution would improve the living environment. The welfare of residents would, thus, be increased by W_1. Moreover, rewards from the central government are W_2. When the performance is unsatisfactory, local governments impose a penalty *Pel* on polluters and ESPs.

(4) Hypotheses regarding the behaviors of polluters. Polluters entrust ESPs with treating pollution by outsourcing contracts that transfer the obligations of treating pollution to ESPs. There are mainly three issues to be agreed upon in the contracts: fees (M), the share of responsibilities (α), and liquidated damages (L). The fees (M) are to be paid by polluters to ESPs as compensation for treating pollution. However, ESPs are responsible for paying liquidated damages (L) to polluters in case the treatment performance is unsatisfactory. If local governments impose penalties for identified noncompliance, the penalties should be shared. Specifically, the penalty to be paid by polluters is $(1 - \alpha)Pel$, and that which is to be paid by ESPs is αPel. There are two types of contracts that can be awarded to ESPs by polluters. The first are the contracts with higher fees and a larger share of responsibilities (M^h, α^h).

That is, polluters pay higher fees to ESPs for ESPs to treat pollution satisfactorily. In case local governments impose penalties for unsatisfactory treatment, the ESPs pay a larger share of the penalties. The second type of contract are those with lower fees and a smaller share of responsibilities (M^l, α^l). That is, polluters pay low fees to ESPs. In case governments impose penalties for unsatisfactory treatment, the ESPs pay a smaller share of the penalties, where $M^h > M^l$, $\alpha^h > \alpha^l$. It is assumed that the probability of polluters choosing a high price contract (M^h, α^h) is y $(0 \leq y \leq 1)$. When ESPs conduct a satisfactory treatment, the polluters can also obtain payoff U for a successful treatment.

(5) Hypotheses related to the behavior of ESPs. ESPs are responsible for treating pollution after being entrusted by polluters and can choose from two options: treating pollution satisfactorily and unsatisfactorily. It is assumed that ESPs treat pollution satisfactorily at the probability of z $(0 \leq z \leq 1)$. It is also assumed that ESPs treat pollution satisfactorily at the cost of C_e^h and unsatisfactorily at the cost of C_e^l, where $C_e^h > C_e^l$.

Regarding the above hypotheses related to the behaviors of local governments, polluters, and ESPs, we have described the relevant parameters in Table 1.

Table 1. Model parameters and variable descriptions.

Player	Parameter	Description
Local Governments	p^h	The probability of local governments finding unsatisfactory treatment when the strategy of strict regulation is chosen.
Local Governments	p^l	The probability of local governments finding unsatisfactory treatment when the strategy of loose regulation is chosen.
Local Governments	C_g^h	The cost incurred by local governments when the strategy of strict regulation is chosen.
Local Governments	C_g^l	The cost incurred by local governments when the strategy of loose regulation is chosen.
Local Governments	C_g	Cost due to reduced economic output in the short term, given strict regulation adopted by local governments.
Local Governments	W_1	Increase in total social welfare from a good living environment, given satisfactory treatment.
Local Governments	Pel	Penalties imposed by governments on polluters and ESPs (environmental services providers) for unsatisfactory treatment.
Local Governments	W_2	Rewards from the central government for satisfactory treatment.
Polluters	M^h, α^h	Polluters pay high fees to ESPs, which assume a larger share of responsibilities when the treatment is unsatisfactory.
Polluters	M^l, α^l	Polluters pay low fees to ESPs, which assume a smaller share of responsibilities when the treatment is unsatisfactory.
Polluters	$(1-\alpha)Pel$	The penalties to be paid by polluters when the treatment is unsatisfactory, where $(1-\alpha)$ is the share of penalties to be paid by polluters.
Polluters	U	The payoff obtained by the polluters for satisfactory treatment.
Polluters	L	The liquidated damages paid by ESPs to polluters for unsatisfactory treatment.
ESPs	αPel	The penalties to be paid by ESPs when the treatment is unsatisfactory, where α is the share of penalties to be paid by ESPs.
ESPs	C_e^h	The cost incurred by ESPs in cases of satisfactory treatment.
ESPs	C_e^l	The cost incurred by ESPs in cases of unsatisfactory treatment.

2.2. Model Building

In the three-player game played by local governments, polluters, and ESPS, the probability of the local governments (a) choosing the strict regulation strategy is *x*; that of the polluters (b) choosing a high price contract is *y*, and that of the ESPs (c) choosing the strategy of treating pollution satisfactorily is *z*. The three players will adjust their probabilities continuously as the game is repeated. There are

eight decision combinations in the ultimate outcomes for each time the game is played (as shown in Table 2). Based on the above hypotheses of player behavior, it is possible to calculate the payoffs for the three players under different combinations of strategies, as shown in Table 3.

Table 2. The payoff matrix of the three-party game.

Local Governments: a		Strict Regulation (x)		Loose Regulation (1−x)	
ESPs: c		Satisfactory treatment (z)	Unsatisfactory treatment (1−z)	Satisfactory treatment (z)	Unsatisfactory treatment (1−z)
Polluters: b	High price contract (y)	(a1, b1, c1)	(a2, b2, c2)	(a3, b3, c3)	(a4, b4, c4)
	Low price contract (1−y)	(a5, b5, c5)	(a6, b6, c6)	(a7, b7, c7)	(a8, b8, c8)

Table 3. The payoff matrix of the three-party game (a). The payoff matrix of the three-party game (b).

(a)			
Local Governments: a		**Strict Regulation (x)**	
ESPs: c		Satisfactory treatment (z)	Unsatisfactory treatment (1−z)
Polluters: b	(M^h, α^h) (y)	$a_1 = W_1 + W_2 - C_g^h - C_g$ $b_1 = U - M^h$ $c_1 = M^h - C_e^h$	$a_2 = p^h Pel - C_g^h - C_g$ $b_2 = L - M^h - (1-\alpha^h)p^h Pel$ $c_2 = M^h - L - C_e^l - \alpha^h p^h Pel$
	(M^l, α^l) (1−y)	$a_5 = W_1 + W_2 - C_g^h - C_g$ $b_5 = U - M^l$ $c_5 = M^l - C_e^h$	$a_6 = p^h Pel - C_g^h - C_g$ $b_6 = L - M^l - (1-\alpha^l)p^h Pel$ $c_6 = M^l - L - C_e^l - \alpha^l p^h Pel$

(b)			
Local Governments: a		**Loose Regulation(1−x)**	
ESPs: c		Satisfactory treatment (z)	Unsatisfactory treatment (1−z)
Polluters: b	(M^h, α^h) (y)	$a_3 = W_1 + W_2 - C_g^l$ $b_3 = U - M^h$ $c_3 = M^h - C_e^h$	$a_4 = p^l Pel - C_g^l$ $b_4 = L - M^h - (1-\alpha^h)p^l Pel$ $c_4 = M^h - L - C_e^l - \alpha^h p^l Pel$
	(M^l, α^l) (1−y)	$a_7 = W_1 + W_2 - C_g^l$ $b_7 = U - M^l$ $c_7 = M^l - C_e^h$	$a_8 = p^l Pel - C_g^l$ $b_8 = L - M^l - (1-\alpha^l)p^l Pel$ $c_8 = M^l - L - C_e^l - \alpha^l p^l Pel$

3. Equilibrium Analysis

3.1. The Replicator Dynamics Equations of the Three-Game Players

3.1.1. The Replicator Dynamics Equation for Local Governments

Suppose that U_{X1} is the payoff expected by local governments when strict regulation is adopted, U_{X2} is the payoff expected by local governments when loose regulation is adopted, and U_X is the average payoff obtained by local governments, then U_{X1}, U_{X2}, and U_X can be expressed as follows:

$$U_{X1} = y \times z \times a_1 + y \times (1-z) \times a_2 + (1-y) \times z \times a_5 + (1-y) \times (1-z) \times a_6 \tag{1}$$

$$U_{X2} = y \times z \times a_3 + y \times (1-z) \times a_4 + (1-y) \times z \times a_7 + (1-y) \times (1-z) \times a_8 \tag{2}$$

$$U_X = x \times U_{X1} + (1-x) \times U_{X2} \tag{3}$$

Therefore, the replicator dynamics equation for local governments can be expressed as below:

$$
\begin{aligned}
F(x) &= \tfrac{dx}{dt} = x \times (U_{X1} - U_X) = x(1-x)(U_{X1} - U_{X2}) \\
&= x(1-x)[z(a_1 - a_3) + (1-z)(a_6 - a_8)] \\
&= x(1-x)[(1-z)(p^h - p^l)Pel + C_g^l - C_g^h + C_g]
\end{aligned}
\tag{4}
$$

3.1.2. The Replicator Dynamics Equation for Polluters

Suppose that U_{Y1} is the payoff expected by polluters in choosing high price contracts, U_{Y2} is the payoff expected by polluters in choosing low price contracts, and U_Y is the average payoff obtained by polluters, then U_{Y1}, U_{Y2}, and U_Y can be expressed as follows:

$$
U_{Y1} = x \times z \times b_1 + x \times (1-z) \times b_2 + (1-x) \times z \times b_3 + (1-x) \times (1-z) \times b_4
\tag{5}
$$

$$
U_{Y2} = x \times z \times b_5 + x \times (1-z) \times b_6 + (1-x) \times z \times b_7 + (1-x) \times (1-z) \times b_8
\tag{6}
$$

$$
U_Y = y \times U_{Y1} + (1-y) \times U_{Y2}
\tag{7}
$$

Therefore, the replicator dynamics equation for polluters can be expressed as below:

$$
\begin{aligned}
F(y) &= \tfrac{dy}{dt} = y \times (U_{Y1} - U_Y) = y(1-y)(U_{Y1} - U_{Y2}) \\
&= y(1-y)[x(1-z)(\alpha^h - \alpha^l)(p^h - p^l)Pel - z(\alpha^h - \alpha^l)p^l Pel + M^l - M^h + (\alpha^h - \alpha^l)p^l Pel]
\end{aligned}
\tag{8}
$$

3.1.3. The Replicator Dynamics Equation for ESPs

Suppose that U_{Z1} is the payoff expected by ESPs in choosing to treat pollution satisfactorily, U_{Z2} is the payoff expected by ESPs in choosing to treat pollution unsatisfactorily, and U_Z is the average payoff obtained by ESPs, then U_{Z1}, U_{Z2} and U_Z can be expressed as follows:

$$
U_{Z1} = x \times y \times c_1 + (1-x) \times y \times c_3 + x \times (1-y) \times c_5 + (1-x) \times (1-y) \times c_7
\tag{9}
$$

$$
U_{Z2} = x \times y \times c_2 + (1-x) \times y \times c_4 + x \times (1-y) \times c_6 + (1-x) \times (1-y) \times c_8
\tag{10}
$$

$$
U_Z = z \times U_{Z1} + (1-z)U_{Z2}
\tag{11}
$$

Therefore, the replicator dynamics equation for ESPs can be expressed as below:

$$
\begin{aligned}
F(z) &= \tfrac{dz}{dt} = z \times (U_{Z1} - U_Z) = z(1-z)(U_{Z1} - U_{Z2}) \\
&= z(1-z)[xy(\alpha^h - \alpha^l)(p^h - p^l)Pel + y(\alpha^h - \alpha^l)p^l Pel + x\alpha^l(p^h - p^l)Pel + L + C_e^l - C_e^h + \alpha^l p^l Pel]
\end{aligned}
\tag{12}
$$

3.2. Stability Analysis of the Evolutionary Game

In the three-dimensional dynamic evolutionary system comprised of the above three replicator dynamics equations, the probabilities of the three players using relevant strategies change over time. When $F(x) = 0, F(y) = 0, F(z) = 0$, it is possible to ascertain equilibrium points for the dynamic system. They are (0,0,0), (0,0,1), (0,1,0), (0,1,1), (1,0,0), (1,0,1), (1,1,0), (1,1,1), respectively. The unit cube constructed by the eight equilibrium points represent boundaries of evolution for the dynamic system. By analyzing the system's Jacobian matrix in terms of the sign of eigenvalues (assuming all eigenvalues are real), the stability for each of the equilibrium points can be obtained [32–34]. However, as the evolutionary system involves a number of variables, the calculation is complex by determining the Jacobian matrix for each of the equilibrium points and then judging the sign of eigenvalues. For simplicity, we analyze the sign and critical condition of the first derivative of the replicator dynamics equation for each of the variables at the equilibrium point separately, and then analyze the stability at each of the equilibrium points through digital simulation.

By differentiating the above three replicator dynamics equations, we get:

$$F'(x) = (1-2x)[(1-z)(p^h - p^l)Pel + C_g^l - C_g^h + C_g] \tag{13}$$

$$F'(y) = (1-2y)[x(1-z)(\alpha^h - \alpha^l)(p^h - p^l)Pel - z(\alpha^h - \alpha^l)p^l Pel + M^l - M^h + (\alpha^h - \alpha^l)p^l Pel] \tag{14}$$

$$F'(z) = (1-2z)[xy(\alpha^h - \alpha^l)(p^h - p^l)Pel + y(\alpha^h - \alpha^l)p^l Pel + x\alpha^l(p^h - p^l)Pel + L + C_e^l - C_e^h + \alpha^l p^l Pel] \tag{15}$$

The necessary condition for stable equilibrium points is F'(x) < 0, F'(y) < 0, and F'(z) < 0. The corresponding strategies (x^*, y^*, z^*), respectively, represent the ultimate stable strategies for the three players after playing the game repeatedly. The stable strategies also determine the question of whether the TPTM can effectively solve issues related to industrial pollution.

3.2.1. Stability Analysis of Environmental Regulation Strategies of Local Governments

According to Equation (4), when $(1-z)(p^h - p^l)Pel + C_g^l - C_g^h + C_g = 0$, then, $F(x) \equiv 0$, the expected payoff obtained by local governments from enforcing a strict regulation equals that from loose regulation, and the strict regulation at any probability x represents the best strategy. Nevertheless, it is not a stable strategy, as the condition will not hold for any variations.

When $(1-z)(p^h - p^l)Pel + C_g^l - C_g^h + C_g < 0$, then, $z > 1 - \frac{C_g^h - C_g - C_g^l}{(p^h - p^l)Pel}$. Given that $F(x) = 0$, two equilibrium points $x = 0, x = 1$ can be obtained. Moreover, $F'(x = 0) < 0$ and $F'(x = 1) > 0$. Then, the evolutionary phase diagram for regulatory strategies is as shown in Figure 1a. $x = 0$ is the stable equilibrium strategy; that is, the local governments will ultimately adopt loose regulation.
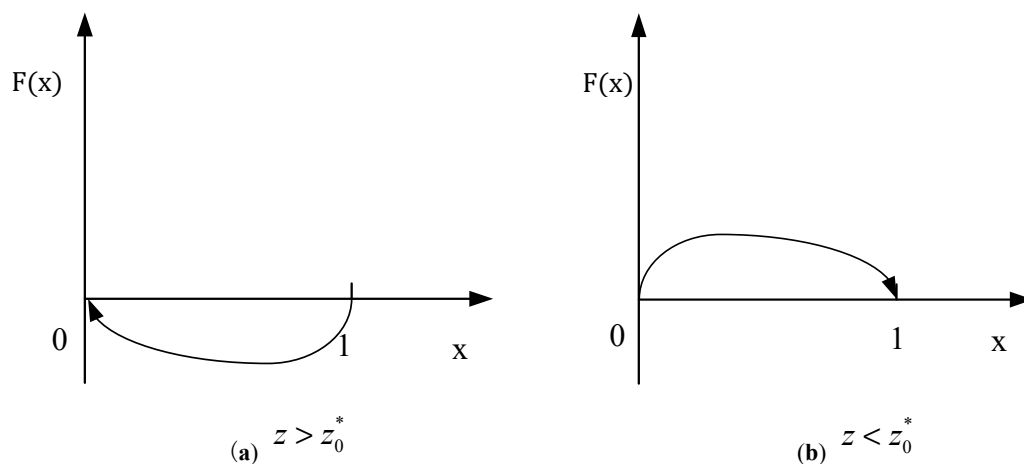
Figure 1. Phase diagram for replicator dynamics equation of local governments' regulatory strategies.

When $(1-z)(p^h - p^l)Pel + C_g^l - C_g^h + C_g > 0$, then, $z < 1 - \frac{C_g^h - C_g - C_g^l}{(p^h - p^l)Pel}$. Moreover, $F'(x = 0) > 0$ and $F'(x = 1) < 0$, then the evolutionary phase diagram for regulatory strategies of local governments can be as shown in Figure 1b. $x = 1$ is the stable equilibrium strategy; that is, the local governments will ultimately adopt strict regulation.

Therefore, when the probability of treating pollution satisfactorily by ESPs is smaller than a critical value (i.e., $z < z_0^*$, where $z_0^* = 1 - \frac{C_g^h + C_g - C_g^l}{(p^h - p^l)Pel}$), then the local governments will ultimately adopt a strict regulation. However, when the probability of treating pollution satisfactorily by ESPs is larger than a critical value (i.e., $z > z_0^*$), then the local governments will ultimately adopt loose regulation. The results show that whether local governments adopt strict regulation is only directly affected by the treatment performance of ESPs. It has no direct linkage to the strategies adopted by polluters.

3.2.2. Stability Analysis of Outsourcing Strategies of Polluters

According to Equation (8), we can get:

when $x(1-z)(\alpha^h - \alpha^l)(p^h - p^l)Pel - z(\alpha^h - \alpha^l)p^lPel + M^l - M^h + (\alpha^h - \alpha^l)p^lPel = 0$, then $F(y) \equiv 0$, therefore, polluters obtain the same payoff for both high and low price contracts, and polluters' choice at any probabilities y represents the best strategy.

When $x(1-z)(\alpha^h - \alpha^l)(p^h - p^l)Pel - z(\alpha^h - \alpha^l)p^lPel + M^l - M^h + (\alpha^h - \alpha^l)p^lPel < 0$, then, $x < \frac{z(\alpha^h - \alpha^l)p^lPel + (M^h - M^l) - (\alpha^h - \alpha^l)p^lPel}{(1-z)(\alpha^h - \alpha^l)(p^h - p^l)Pel - z(\alpha^h - \alpha^l)p^lPel} = x_1^*$. Setting $F(y) = 0$, two equilibrium points $y = 0, y = 1$ can be obtained, and $F'(y = 0) < 0, F'(y = 1) > 0$. Thus, the evolutionary phase diagram for outsourcing strategies is as shown in Figure 2a. $y = 0$ is the stable equilibrium strategy; that is, polluters will ultimately pay low price fees to ESPs for treating pollution. Therefore, when ESPs treat pollution unsatisfactorily, and local governments spot the noncompliance and impose penalties, ESPs are responsible for a smaller share of responsibilities.
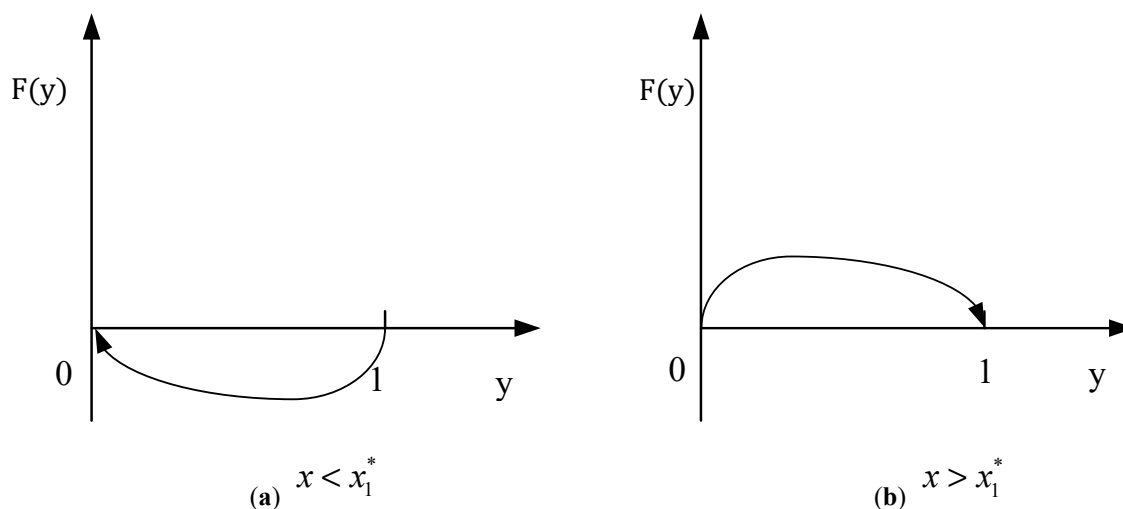

Figure 2. Phase diagram for replicator dynamics equation of outsourcing strategies of polluters.

When $x > x_1^*$, then $F'(y = 0) > 0$, and $F'(y = 1) < 0$. The evolutionary phase diagram for outsourcing strategies is as shown in Figure 2b. $y = 1$ is the stable equilibrium strategy; that is, the polluters will ultimately pay high price fees to ESPs for treating pollution. Therefore, when ESPs treat pollution unsatisfactorily, and local governments spot noncompliance and impose penalties, ESPs are responsible for a larger share of responsibilities.

The outsourcing strategies of polluters are related to the regulatory strategies of governments and the treatment strategies of ESPs. When the probability of local governments adopting strict regulation is lower than a critical value, polluters are speculative. They tend to pay low price fees to ESPs for saving treatment costs. Otherwise, they tend to pay high price fees to ESPs for treating pollution.

3.2.3. Stability Analysis of the Treatment Strategies of ESPs

According to Equation (12), when $x < \frac{p^l}{(p^h - p^l)} - \frac{L + C_e^h - C_e^l}{(p^h - p^l)Pel(y\alpha^h + (1-y)\alpha^l)} = x_2^*$, given that $F(z) = 0$, two equilibrium points can be obtained $z = 0, z = 1$, and when $F'(z = 0) < 0$, $F'(z = 1) > 0$, then the evolutionary phase diagram for the treatment strategies of ESPs is as shown in Figure 3a. $z = 0$ is the stable equilibrium strategy; that is, the ESPs will ultimately choose to treat pollution unsatisfactorily. When $x > x_2^*$, the evolutionary phase diagram for the treatment strategies of ESPs is as shown in Figure 3b. $z = 0$ is the stable equilibrium strategy; that is, the ESPs will ultimately choose to treat pollution satisfactorily.
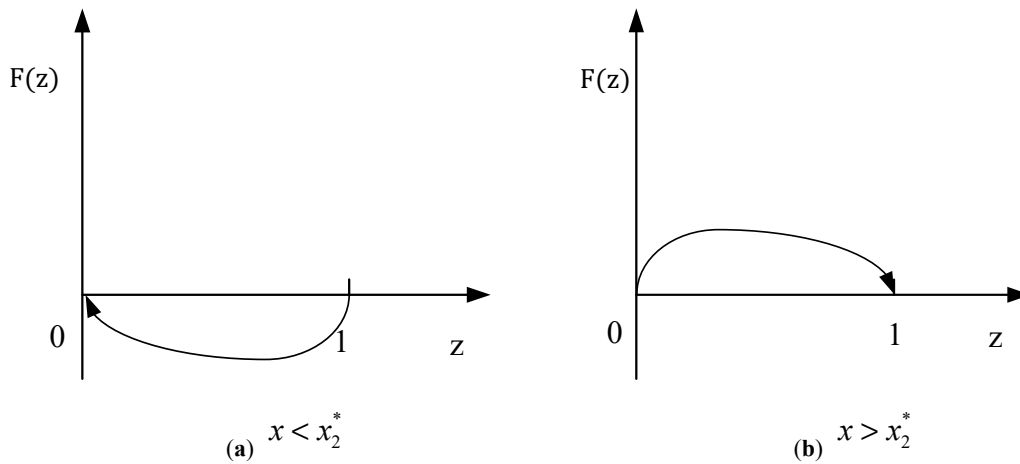
Figure 3. Phase diagram for replicator dynamics equation of the treatment strategies of ESPs.

The treatment strategies of ESPs are related to the regulation strategies of local governments and the outsourcing strategies of polluters. When the probability of local governments adopting strict regulation is lower than a critical value, ESPs are speculative. They believe that when they treat pollution unsatisfactorily, they can escape local governments' penalties for saving treatment costs. Otherwise, they tend to choose to treat pollution satisfactorily.

4. Simulations and Discussions

As shown by the analysis of the replicator dynamics equations for the three-player evolutionary game involving local governments, polluters, and ESPs, strategies of the three players (x, y, z) vary over time. Thus, to promote the TPTM's effectiveness, it is possible to control or adjust relevant parameters to drive the strategic choices of local governments and ESPs toward the direction expected by the general public. That is, local governments choose strict regulation, and ESPs choose to treat pollution satisfactorily (i.e., $x = 1, z = 1$). Based on replicator dynamics Equations (4), (8) and (12) for three-player decisions involving local governments, polluters, and ESPs, this study simulates, mostly by Python 3.4, the three-player game's evolutionary dynamics and the effects of changes in relevant parameters on the outcomes.

4.1. Evolution of Strategies of Local Governments, Polluters, and ESPs Under an Initial State

Setting (x_0, y_0, z_0) respectively denotes the probabilities of local governments choosing strict regulation, polluters choosing high price contracts, and ESPs choosing to treat pollution satisfactorily. Based on the values assigned to the relevant parameters in related studies [27,28], and considering the critical conditions determined by F'(x) = 0, F'(y) = 0, and F'(z) = 0, the following values are assigned to the relevant parameters in this study:

$$p^h = 0.8, \ p^l = 0.6, \ C_g^h = 5, C_g^l = 4, \ C_g = 2, \ W_1 = 15, \ Pel = 15, \ W_2 = 7, \ (M^h, \alpha^h) = (14, 0.9)$$
$$, \ (M^l, \alpha^l) = (11, 0.7), \ U = 10, \ L = 15, \ C_e^h = 9, \ C_e^l = 6$$

Moreover, assuming that players' initial strategies are $x_0 = 0.4, y_0 = 0.4, z_0 = 0.4$ respectively, with the Python simulation, we obtain the following equilibrium outcomes $(1, 0, 1)$ from the three-player game evolution (as shown in Figure 4).
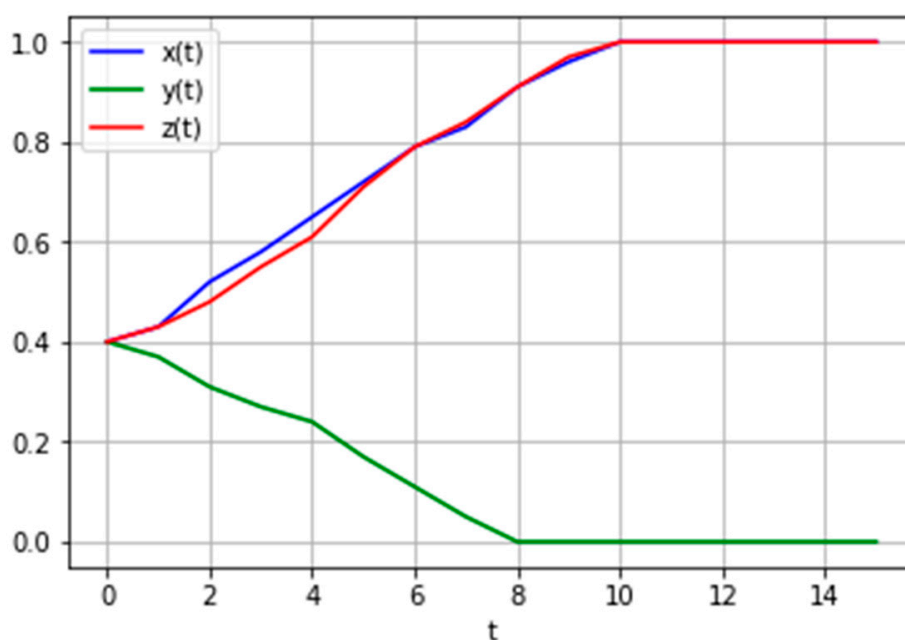
Figure 4. Outcomes from the three-player game evolution.

4.2. Effects of the Penalty Amounts Imposed by Local Governments on the Stable state of the Three-Player Game

From the stability analysis on three-player game equilibrium strategies in Section 3.2, it is evident that penalties imposed by local governments on ESPs and polluters affect the ultimate stable state of the three-player evolutionary game. When the probability of ESPs treating pollution satisfactorily is $z < z_0^*$, then $x \to 1$. Moreover, as $\frac{\partial z_0^*}{\partial Pel} > 0$, the larger the *Pel*, the larger the z_0^*. When the probability of local governments choosing strict regulation is $x > x_2^*$, then $z \to 1$. This situation indicates that the larger the penalty amount imposed by local governments for the unsatisfactory treatment of pollution, the stronger the motivation of local governments to obtain fiscal income through penalties, and the more likely local governments would adopt strict regulation, which further pushes ESPs to treat pollution satisfactorily.

By simulating three-player game evolution with different penalty amounts (as shown in Figure 5), the ultimate outcomes, as shown in Figure 5a–c, for smaller amounts are as follows. Local governments adopt loose regulation, ESPs choose to treat pollution unsatisfactorily, and polluters choose a high price contract to assume a smaller share of responsibilities for pollution. The ultimate outcomes, as shown in Figure 5d–f for a larger amount, are as follows. The local governments adopt strict regulations, ESPs choose to treat pollution satisfactorily, and polluters choose low price contracts to assume a larger share of responsibilities for pollution. Moreover, a larger penalty amount speeds up convergence in the three-player game.

Although a larger penalty amount imposed on noncompliance can motivate the pursuit of fiscal income by the local governments and promote strict regulation, such pursuit can also lead to abusive regulations. In other words, local governments may subject treatment performance to excessive scrutiny to increase fiscal income. Such practice distorts the behaviors of ESPs and polluters in treating pollution, thus leading to lower productivity and reduced overall economic output. Therefore, the increase in the penalty amount regarding noncompliance is constrained by economic loss.
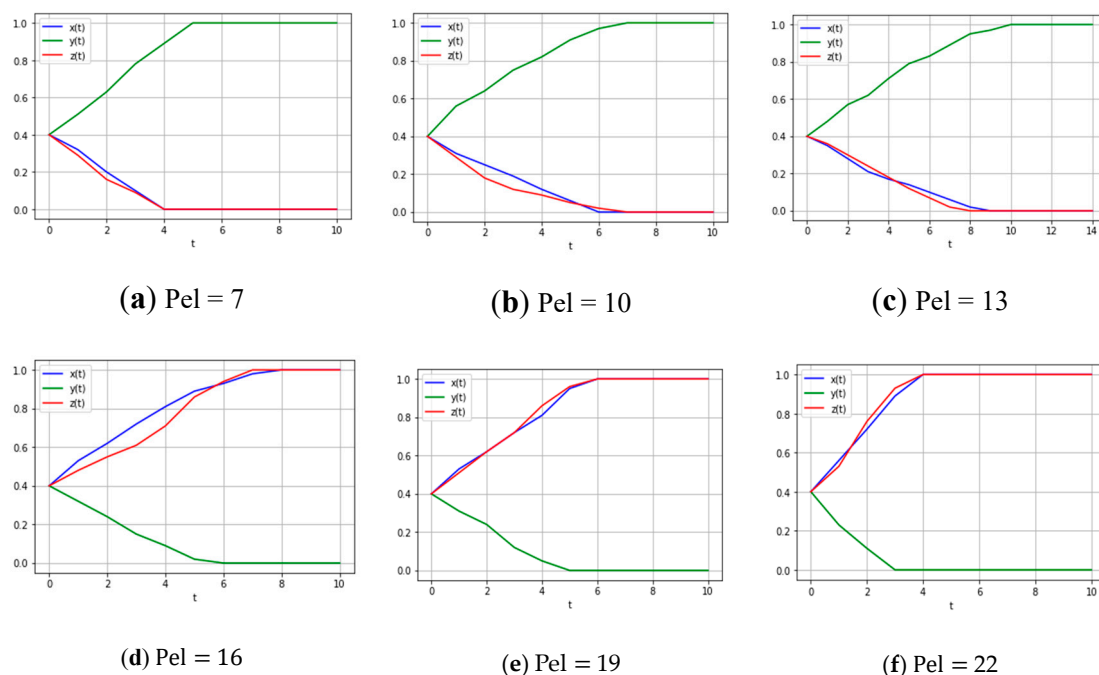
(a) Pel = 7

(b) Pel = 10

(c) Pel = 13

(d) Pel = 16

(e) Pel = 19

(f) Pel = 22

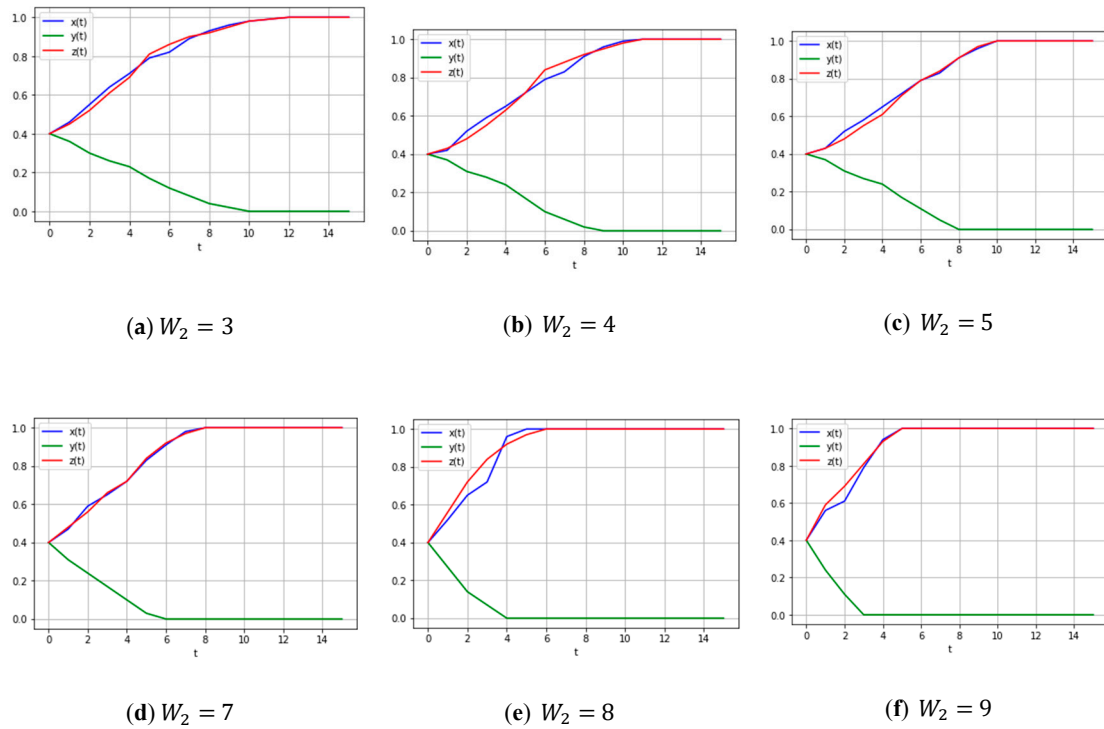**Figure 5.** Effects of different penalty amounts on the three-player evolutionary game.

4.3. Effects of the Amount of Environmental Awards from the Central Government to Local Levels on the Speed of Convergence of the Three-Player Game

According to the analysis on stable strategies for the three-player evolutionary game in Section 3.2, the critical values z_0^*, x_1^* and x_2^* do not relate to environmental awards W_2 from the central government to local levels. That is, the size of W_2 does not change the ultimate stable state of the three-player game. However, W_2 have effects on the convergence speed of the game. By simulating the three-player game evolution with different amounts of awards from the central government to local levels (as shown in Figure 6), we find that the speed of convergence increases with a higher award amount. With a larger award or penalty amount from the central government at the local levels, local governments have stronger motivation to adopt strict regulation on the treatment performance of ESPs to obtain awards or avoid penalties from the central government. When local governments adopt strict regulations, the unsatisfactory treatment of ESPs is more likely to be spotted. With higher expected penalty amounts for unsatisfactory treatment, ESPs will tend to choose the strategy of treating pollution satisfactorily while the best strategy for polluters is choosing the low-price contract.
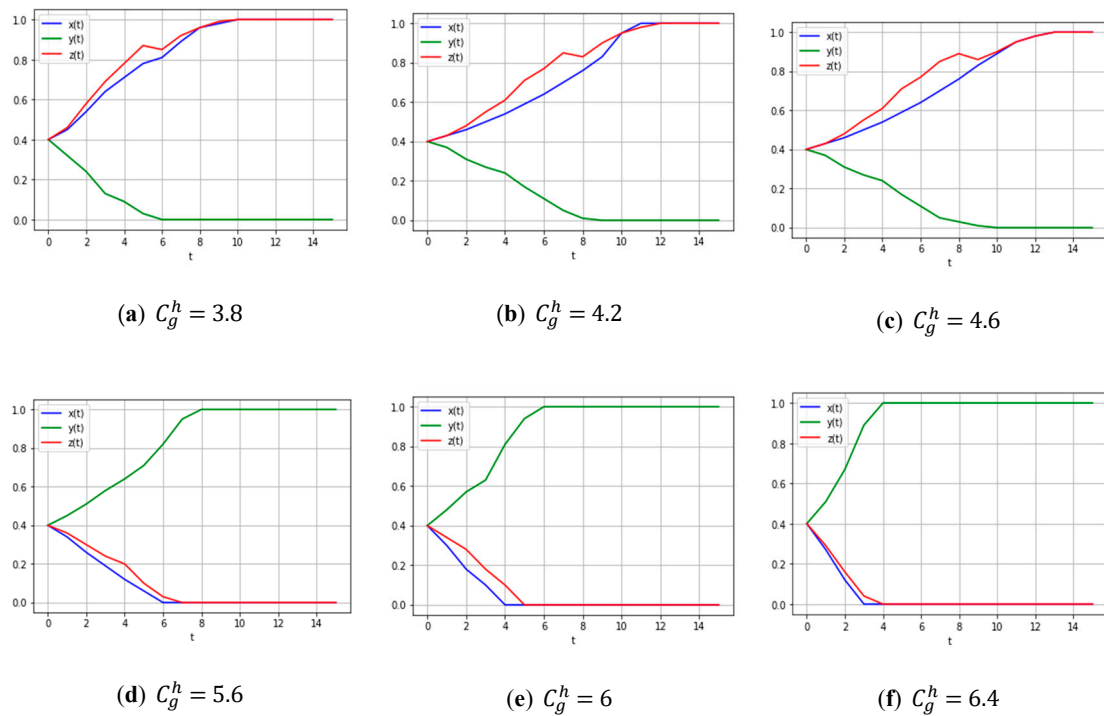
4.4. Effects of the Regulation Cost of Local Governments on the Stable State of the Three-Player Game

From the stability analysis on three-player game equilibrium strategies in Section 3.2, it is evident that the size of the critical value z_0^* is related to the regulation cost of local governments. Moreover, $\frac{\partial z_0^*}{\partial C_g^h} < 0$. Therefore, the higher the strict regulation cost C_g^h, the smaller the critical value z_0^*. It means governments are more likely to adopt strict regulation, while changes to z_0^* will lead to further changes to the critical values x_1^* and x_2^*. Simulating the three-player game evolution with different strict regulation costs C_g^h (as shown in Figure 7), we find that the three-player evolutionary game converges to the equilibrium state $(1, 0, 1)$, which is expected by the general public with a lower regulation cost. The lower the strict regulation cost, the higher the convergence speed. With a higher strict regulation cost, the three-player evolutionary game converges to the equilibrium state $(0, 1, 0)$, which is not expected by the general public. The higher the strict regulation cost, the higher the convergence speed. It demonstrates that lower strict regulation cost motivates local governments to adopt strict regulation, which, in turn, promotes ESPs to treat pollution satisfactorily to improve environmental

quality. The lower the strict regulation cost, the shorter the time needed to reach the equilibrium outcomes, thereby benefiting the rapid improvement of environmental quality.

(a) $W_2 = 3$ (b) $W_2 = 4$ (c) $W_2 = 5$

(d) $W_2 = 7$ (e) $W_2 = 8$ (f) $W_2 = 9$

Figure 6. Effects of different award amounts from the central government on the three-player evolutionary game.

(a) $C_g^h = 3.8$ (b) $C_g^h = 4.2$ (c) $C_g^h = 4.6$

(d) $C_g^h = 5.6$ (e) $C_g^h = 6$ (f) $C_g^h = 6.4$

Figure 7. Effects of different strict regulation costs incurred by local governments on the three-player evolutionary game.

5. Conclusions

At present, China has entered as a middle-income developing country. Environmental pollution has become an obstacle to further economic development; the third-party governance model of environmental pollution has become an important choice for the Chinese government. This study primarily investigates whether TPTM can effectively solve the issues regarding industrial pollution in China by constructing a three-player evolutionary game model involving local governments, polluters, and ESPs. The stability analysis on equilibrium states of the three-player evolutionary game shows that the game can converge to different equilibrium states under various critical conditions. It is possible to control or adjust relevant parameters to drive the behaviors of local governments and ESPs toward the direction that the general public expects. That is, local governments choose strict regulation, and ESPs choose to treat pollution satisfactorily. The above analysis is further verified with a numerical simulation test to illustrate the effects of different parameters on the convergence of the three-player evolutionary game. The following conclusions are reached in the verification process:

(1) A larger penalty amount can motivate local governments to enhance regulation and ESPs to choose to treat pollution satisfactorily. Moreover, a larger penalty amount also facilitates the convergence of the two players' behavior toward the above state. A larger penalty amount motivates local governments to adopt strict regulations to increase fiscal income. It also increases the expected noncompliance cost of ESPs. This result encourages ESPs to treat pollution satisfactorily, which is an outcome expected by the general public.

However, with a larger penalty amount, local governments may abuse regulation in the pursuit of fiscal incomes. Such practice distorts the behaviors of ESPs and polluters in treating pollution, thereby leading to lower productivity and reduced overall economic output. Therefore, local governments should develop clear and detailed criteria for imposing penalties to control the excessive regulation of local governments.

(2) The environmental awards from the central government do not affect the ultimate stable state of the three-player game; however, they affect the convergence speed. The awards are not a determining factor to the effectiveness of the TPTM but can speed up the evolution of the three-player game toward outcomes expected by the general public or shorten the time needed for the TPTM to reach the valid state.

(3) Regulation cost of local governments has substantial effects on whether the TPTM can effectively solve issues regarding industrial pollution. The lower regulation cost incurred by local governments means that, given a certain amount of the total cost, more resources can be directed to regulating the treatment process of ESPs and its outcomes. Meanwhile, the lower regulation cost can facilitate the emergence of the TPTM's effectiveness.

Based on the above conclusions, this study proposes the following recommendations for improving the effectiveness of the TPTM in China:

(1) Penalties on noncompliance should be increased further by the local governments, and rewards from the central government to local levels for satisfactory performance in treating pollution should also be increased. The promotional mechanisms for local government officials should evaluate their performance comprehensively by incorporating indicators in several dimensions (including the economic and environmental indicators) to motivate local governments to regulate pollution treatment strictly. Increasing environmental awards alone cannot effectively improve performance. The measure must be implemented together with other policies. While increasing environmental awards, imposing a larger penalty amount by the local governments on polluters can effectively improve the performance of the TPTM.

(2) A more robust regulatory system can reduce regulation costs and increase the probability of spotting pollution problems by local governments. Building on the existing regulatory system by introducing public whistleblowing mechanisms can engage private sectors. Specifically, the measures include leveraging big data systems and mobile network platforms for motivating the general public with appropriate economic awards to report noncompliance. They can lower local regulation costs of

governments, increase the efficiency in spotting pollution problems by the local governments, and push ESPs to solve issues related to industrial pollution effectively.

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