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The Impact and Internal Mechanism of Environmental Decentralization on Green Total Factor Production

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Abstract: Since the emergence of environmental federalism theory in the 1960s, the empirical research on it has been pursued by scholars, mainly focusing on whether a country's environmental regulation should be centralized or decentralized. For a long time, countries have been actively exploring and putting environmental governance systems into practice for themselves, especially at present, in the face of multiple constraints of resources, environment, sustainable development power and other factors. How to build an appropriate environmental governance system and promote the level of green development by encouraging enterprises' technological innovation is a practical problem to be solved urgently. Based on this, this paper constructs a new research framework of environmental decentralization—technological innovation—green total factor productivity (GTFP) and investigates the effect and mechanism of environmental decentralization on GTFP. The results show that environmental decentralization can reduce the quality of environmental information disclosure and inhibit the innovative output of enterprises, ultimately leading to the decrease of GTFP. Environmental decentralization has a spatial spillover effect on GTFP, which can promote GTFP in neighboring areas. This paper tries to enrich the research results of traditional environmental federalism theory, the "Porter Hypothesis", and growth pole theory, and it provides a solution to enterprises' financing constraint problem.

Keywords: environmental decentralization; green total factor production; technological innovation; environmental information disclosure quality; spatial spillover effect

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1. Introduction

Since the emergence of environmental federalism theory in the 1960s and 1970s, the empirical research on it has been sought after by the academic community, mainly focusing on whether a country's environmental regulation should be centralized or decentralized [1]. For a long time, around this issue of focus, countries have been actively exploring and practicing environmental governance systems applicable to themselves [2,3]. Especially at present, in the face of multiple constraints of resources, environment, sustainable development and other factors, how to build an appropriate environmental governance system and promote GTFP in a country by encouraging enterprises' technological innovation is a practical problem that needs to be solved urgently [4].

Based on the new classical economics theory "power decentralizing theory", it is suggested that the local government has larger discretion in environmental affairs management and will make environmental standards adapt to the actual situation in the region, which is good for the improvement of local GTFP [5,6]. This literature rarely explores the internal influence mechanism of environmental decentralization on GTFP, and could not explain the environmental problems occurred in most developing countries. For example, the decentralized environmental management system is utilized in China for a long time, but a various of environmental problems such as agricultural non-point source pollution in different provinces and water pollution in different rivers. Based on the "Porter Hypothesis" and from a dynamic perspective, "power centralization theory" suggested that enterprises are not always able to make optimal decisions.

Properly designed environmental regulation policies can stimulate enterprises to carry out technological innovation, promote the enterprise innovation compensation effect [7], improve the competitiveness of enterprises in the long run, boost technology diffusion within the industry, optimize the efficiency of industrial resource allocation, and thus achieve a "win-win" situation [8,9]. However, environmental decentralization will destroy properly designed environmental regulations that are not conducive to the improvement of GTFP, as well as hinder the process of green development [10–12]. These studies above ignore the differences in the effect of environmental regulation policies and fail to measure the real impact of environmental regulation on enterprises from the perspective of internal enterprises. Some other scholars have found that under the two opposite effects mentioned above, the real effect either presents a nonlinear relationship [13] or an insignificant relationship [14].

Similar to the free-riding of environmental regulation and transboundary pollution, environmental decentralization also has a spatial spillover effect. According to the growth pole theory, it is just an ideal for a country to achieve balanced development, which is impossible in reality [15,16]. Economic growth is usually transmitted from one or several "growth centers" to other sectors or regions gradually, and there will be a backwash effect and spread effect in this transition [17,18]. Few works have applied it to study the spatial spillover effect of environmental decentralization on GTFP. However, under the influence of these two opposite effects, only studying the impact of environmental decentralization on GTFP will not guarantee the scientificity and effectiveness of research conclusions and countermeasures.

Based on the traditional environmental federalism theory and the Porter Hypothesis, this paper investigates the effect and mechanism of environmental decentralization on GTFP. Compared with existing studies, the marginal contribution of this paper is as follows. First, a new framework consisting of environmental decentralization, technological innovation and GTFP is theoretically constructed to make up for the deficiency of the traditional analysis framework. Second, by analyzing the phenomenon of competition among regions for growth, the spatial spillover effect of environmental decentralization is explained, which makes the deduction and demonstration of the proposition more rigorous and the conclusion more reliable. Third, based on the theory of legality and stakeholder theory, the environmental information disclosure quality is used to measure the pressure enterprises are subjected to under environmental supervision. This is in order to reflect the implementation effect of environmental regulation policy tools, as well as to investigate the mechanism of environmental decentralization affecting the enterprise environmental information disclosure quality and then the enterprise's innovative output. The research on the influence mechanism of environmental decentralization on technological innovation is directed from the macro level to the micro level, which makes up the deficiency of existing research.

2. Methodology/Models

Based on the "Porter Hypothesis" and drawing on existing research results [19,20], this paper introduces environmental decentralization variables to build a model of environmental decentralization and enterprise innovative output. The reason for that is that under environmental decentralization, in order to gain an advantageous position in economic competition, each region will relax environmental regulations, resulting in the race to the bottom of environmental regulations. Based upon the analysis of the technological innovation path, this paper further studies the impact of environmental decentralization on the quality of enterprise environmental information disclosure, and then the impact of enterprise innovative output.

Hypothesis 1. *In the production process, an enterprise invests R units of variable production factors, produces* X_1 *unit products and causes* X_2 *unit pollution. Pollution can be controlled through technological innovation.*

Hypothesis 2. *Enterprises' technological innovation approaches include improving the production technology level or environmental protection technology level. The production technology level is measured by energy consumption per unit output T_1, and the environmental protection technology level is measured by energy consumption per unit for pollution discharge T_2. T_1X_1 represents the output energy consumption of an enterprise, T_2X_2 represents its pollution energy consumption, and their joint function of R can be expressed as*:

$$R = \varphi[f(T_1X_1, T_2X_2)] \tag{1}$$

In Equation (1), when the total inputs and pollution discharge remain unchanged, an increase in output means a decrease in energy consumption per unit output. Specifically, as T_1 decreases, the production technology level increases. When the total inputs and outputs remain unchanged, the reduction of pollution discharge means that the energy consumption per unit for pollution discharge decreases. Specifically, as T_2 increases, the environmental protection technology level increases.

Hypothesis 3. *Equation (1) is a second-order, continuous, homogeneous linear function, and $\varphi(f)$ is a homogeneous linear function. When $\varphi' > 0$, it represents that φ is the monotone increasing function of f. When $\varphi'' > 0$, it represents that φ is the function of diminishing returns to scale $\varphi(0) = 0$.*

According to Equation (1), the marginal output of X_1 and X_2 can be written as follows:

$$\frac{\partial X_1}{\partial R} = 1 \Big/ \left(\frac{\partial R}{\partial X_1}\right) = 1/\left(\varphi^1 f_1 X_1\right) \tag{2}$$

$$\frac{\partial(-X_2)}{\partial R} = -1 \Big/ \left(\frac{\partial R}{\partial X_2}\right) = -1/\left(\varphi' f_2 X_2\right) \tag{3}$$

The first derivative, $f_1 > 0$, represents that as T_1X_1 continually increases, the enterprise will invest more R. The second derivative, $f_{11} > 0$, represents that the function f is decreasing returns to scale. In addition, the first derivative, $f_2 < 0$, represents that the enterprise will reduce the input R with a continuous rise of T_2X_2. The second derivative, $f_{22} > 0$, means that the function f is diminishing returns to scale.

Hypothesis 4. *The technological progress of enterprises is endogenous and depends on the enterprises' total R&D investment, while it is allocated linearly for production technology and environmental technology innovation*:

$$\dot{X}_1 \Big/ X_1 = W_1(\alpha) W_2(Q/S) \tag{4}$$

$$\dot{X}_2 \Big/ X_2 = \alpha W_2(S) \tag{5}$$

Q represents the innovation output level and S represents the success rate of technological innovation, namely, Q/S represents the R&D input of enterprises and $W_2(Q/S)$ means technological progress brought by R&D input. $W_2(Q/S) \geq 0$ and $W_2'(Q/S) > 0$ show that the technological progress of the enterprise advances as the R&D investment increases. $W_2'(0) = 0$ indicates that the technological progress of enterprises is endogenous. α is the innovation possibility boundary, $\alpha \geq 0$, $W_1(\alpha) \leq 0$, $W_1'(\alpha) > 0$, indicating that with the rise of α, enterprises will have less R&D funds for technological progress in production. α_0 fits in $W_1(\alpha_0) = 0$.

Creating technology transformation curves (similar to the production possibility curve, given the allocation of R&D investment between production technology and environmental protection technology, if more funds are used to improve the level of production technology,

the funds used to improve the environmental protection technology will inevitably decrease) describes the linear distribution of innovation input between production technology and environmental protection technology, and the innovation input distribution rate can be obtained as γ:

$$\gamma = \frac{X_2}{X_1} d\left(\frac{X_2}{X_1}\right) \Big/ \left[\left(\frac{\partial X_2}{\partial R} \Big/ \frac{\partial X_1}{\partial R}\right) d\right] \left(\frac{\partial X_1}{\partial R} \Big/ \frac{\partial X_2}{\partial R}\right) \tag{6}$$

Through Equations (1)–(3), Equation (6) can be converted into:

$$\gamma = \frac{f_1 f_2}{f f_{12}} = \frac{f_{X_1} f_{X_2}}{f f_{X_1 X_2}} \tag{7}$$

γ is output emission elasticity, which is used to measure efficiency loss. That is, when $\gamma < 1$, enterprises tend to invest more money to improve the production technology level. When $\gamma = 1$, there is no difference in firms' preference for technological innovation. When $\gamma > 1$, enterprises will be more inclined to carry out environmental technology innovation. Similarly, the scale return of labor input $\delta = \varphi'' f / \varphi'$ can be obtained by taking the second derivative f. According to Hypothesis 3, φ'', f and φ' are all greater than zero, therefore $\delta > 0$.

3. Results

3.1. The Path Analysis of Enterprise Innovation

On the basis of the above discussion and referring to the existing literature [21], environmental variables (environmental information disclosure quality t and environmental decentralization l) are introduced to analyze the impact of environmental decentralization on enterprises' innovative output capacity. Accordingly, t/l represents the actual quality of enterprises' environmental information disclosure, and it measures the actual impact an enterprise suffered due to environmental regulations. $l > 1$ represents that environmental decentralization will reduce the quality of environmental information disclosure because under environmental decentralization, institutional supervision will be weakened to a certain extent, and enterprises' environmental information disclosure will face strong constraints. If the market price of the product X_1 is P, and the market price of the factor of production R is θ, then the enterprise profit function can be expressed as:

$$\pi = PX_1 - \theta R - (t/l)X_2 \tag{8}$$

Take the first-order derivative of Equation (8) for X_1 and X_2 respectively:

$$\frac{\partial \pi}{\partial X_1} = P - \theta \varphi' f_1(T_1 X_1, T_2 X_2) T_1 \tag{9}$$

$$\frac{\partial \pi}{\partial X_2} = -t/l - \theta \varphi' f_2(T_1 X_1, T_2 X_2) T_2 \tag{10}$$

According to the principle of profit maximization, Equations (9) and (10) can be transformed as:

$$\theta \varphi' f_1\left(T_1 \hat{X}_1, T_2 \hat{X}_2\right) = \frac{P}{T_1} \tag{11}$$

$$\theta \varphi' f_2\left(T_1 \hat{X}_1, T_2 \hat{X}_2\right) = \frac{t/l}{T_2} \tag{12}$$

where $\hat{X}_1$ and $\hat{X}_2$ are the output and the amount of pollution discharged when reaching profit maximization, respectively.

Take the first-order derivative of Equation (8) with respect to T_1 and T_2 and then substitute it into Equations (11) and (12):

$$\frac{\partial \pi}{\partial T_1} = -\theta \varphi' f_1 \left(T_1 \hat{X_1}, T_2 \hat{X_2} \right) \hat{X_1} = -\frac{P}{T_1} \hat{X_1} < 0 \tag{13}$$

$$\frac{\partial \pi}{\partial T_2} = -\theta \varphi' f_2 \left(T_1 \hat{X_1}, T_2 \hat{X_2} \right) \hat{X_2} = -\frac{t/l}{T_2} \hat{X_2} > 0 \tag{14}$$

It can be concluded that the profits of enterprises increase with the improvement of production technology and environmental protection technology, which is consistent with the existing research results. When product price P, environmental information disclosure quality t and environmental decentralization level l remain unchanged, the change of enterprise output X_1 and pollution discharge X_2 will change with the change of T_1 and T_2. Hence, we have that:

$$\frac{d\hat{X_1}}{dT} = \frac{\partial \hat{X_1}}{\partial T_1} \dot{T_1} + \frac{\partial \hat{X_1}}{\partial T_2} \dot{T_2} \tag{15}$$

Substituting Equations (11) and (12), as well as γ and δ, into Equation (15) yields:

$$\frac{\partial \hat{X_1}}{\partial T_1} = \left(\frac{-\hat{X_1}}{\varphi' T_1 \delta f} \right) \left[\delta \left(P\hat{X_1} - (t/l)\hat{X_2} \right) + P\hat{X_1} + \delta\gamma (t/l)\hat{X_2} \right] \tag{16}$$

$$\frac{\partial \hat{X_1}}{\partial T_2} = \left(\frac{\hat{X_1}}{T_2} \right) \left[\frac{(t/l)\hat{X_2}}{P\hat{X_1} - (t/l)\hat{X_2}} \right] (1 + \delta\gamma) \tag{17}$$

Based on the rational man hypothesis, we could have $P\hat{X_1} - (t/l)\hat{X_2} > 0$, and due to $\delta > 0$, it will be $\frac{\partial \hat{X_1}}{\partial T_1} < 0$, $\frac{\partial \hat{X_1}}{\partial T_2} > 0$. That is, with the improvement of production technology and environmental protection technology, the output level of enterprises will also increase. Similarly, we could have:

$$\frac{\partial \hat{X_2}}{\partial T_1} = \left(\frac{-\hat{X_2}}{\delta T_1 T_2} \right) \left[\frac{(t/l)\hat{X_1}}{P\hat{X_1} - (t/l)\hat{X_2}} \right] (1 + \delta\gamma) < 0 \tag{18}$$

$$\frac{\partial \hat{X_2}}{\partial T_2} = \left(\frac{\hat{X_2}}{T_2} \right) \left[\frac{P\hat{X_1}}{P\hat{X_1} - (t/l)\hat{X_2}} \right] \left[(\gamma - 1) + \left[\frac{(t/l)\hat{X_2}}{P\hat{X_1}} \right] (1 + 1/\delta) \right] > 0 \tag{19}$$

And when $\gamma \geq 1 - \left[\frac{(t/l)\hat{X_2}}{P\hat{X_1}} \right] (1 + 1/\delta)$, the improvement of enterprise production technology will promote the improvement of environmental protection technology.

To sum up, with the improvement of production technology, enterprise output and profits will increase. With the improvement of environmental protection technology, the amount of pollution discharged by enterprises will decrease. Furthermore, when the allocation rate of innovation input reaches a certain proportion, the improvement of production technology will promote the improvement of environmental protection technology. In other words, innovation performance is mainly reflected through the level of production technology and environmental protection technology when measuring the impact of innovation on economic and social development. Taking China as an example, five evaluation indexes are mainly set: the proportion of new product sales revenue in main business revenue, the proportion of high-tech product exports in goods exports, energy consumption per unit GDP, the main business revenue per capita, and the contribution rate of scientific and technological progress.

3.2. The Impact of Environmental Decentralization on Enterprise's Innovative Output

In order to investigate the impact of environmental decentralization on enterprise's innovative output, this paper further analyzes the change of the enterprise output emission ratio on the basis of the analysis of the enterprise's technological innovation path. Formula (6) is sorted out as follows:

$$\frac{d\left(\hat{X}_1 \Big/ \hat{X}_2\right) \Big/ dT}{\hat{X}_1 \Big/ \hat{X}_2} = \frac{d\left(\hat{T}_1 \Big/ \hat{T}_2\right) \Big/ dT}{\hat{T}_1 \Big/ \hat{T}_2}(\gamma - 1) \tag{20}$$

In addition, by combining Equations (4), (5), (11) and (12), the maximization function of innovation possibility boundary α and innovation output level Q can be expressed as:

$$\max_{\alpha,Q} \frac{\partial \pi}{\partial T_1}\dot{T}_1 + \frac{\partial \pi}{\partial T_2}\dot{T}_2 - c\frac{Q}{S} \tag{21}$$

where c represents the unit cost of innovation input. Substituting Equations (4), (5), (13) and (14) into Equation (21) yields:

$$\max_{\alpha,Q} \alpha W_2(Q/S)(t/l)\hat{X}_2 - W_1(\alpha)W_2(Q/S)P\hat{X}_1 - c\frac{Q}{S} \tag{22}$$

The derivative of Equation (22) on innovation possibility boundary α can be obtained after simplification

$$W_1'(\alpha) = \frac{tl\hat{X}_2}{P\hat{X}_1} \tag{23}$$

Taking the derivative of Equation (22) with respect to the innovation output level Q, and then it could be obtained after simplification as:

$$\frac{c}{W_2(Q/S)} = \hat{\alpha}(t/l)\hat{X}_2 - W_1'\left(\hat{\alpha}\right)P\hat{X}_1 \tag{24}$$

Since the innovation possibility boundary α is affected by the innovation input allocation rate γ, the change of innovation possibility boundary α over time T can be observed as:

$$\alpha^* = \frac{W_1'(\alpha)}{\alpha W_1''(\alpha)}(X_1^* - X_2^*) \tag{25}$$

Substituting Equation (20) into Equation (25) yields:

$$\alpha^* = \frac{W_1'(\alpha)}{\alpha W_1''(\alpha)}(T_2^* - T_1^*)(\gamma - 1) \tag{26}$$

Similarly, it can be obtained from Equation (24) as:

$$Q^* = \frac{W_2'(Q/S)Q}{W_2''(Q/S)} \frac{\alpha(t/l)\dot{X}_2 - W_1(\alpha)P\dot{X}_1}{\alpha(t/l)X_2 - W_1(\alpha)PX_1} \tag{27}$$

In other words, under the principle of profit maximization, enterprises will choose to increase technological innovation input when faced with government environmental regulations, and their innovative output capacity will increase accordingly. However, with the improvement of environmental decentralization, the quality of environmental information disclosure will decrease, which will inhibit the input of technological innovation. Thus, the innovative output capacity of enterprises will decrease. To sum up, environmental

decentralization will reduce the quality of environmental information disclosure and then inhibit enterprise innovative output. Taking the United States as an example, the public and various environmental stakeholders are important parts of the American environmental management system [22]. They review and supervise the environmental affairs of each state and report the problems found to the Environmental Protection Agency (EPA), which deals with them eventually. At the same time, the Council on Environmental Quality (CEQ) was established to collect environmental information, assess environmental quality, provide scientific and effective policy recommendations to the president and government agencies, and provide operational guidance on the implementation process in order to avoid the adverse impact of improper execution on enterprises.

3.3. The Impact of Environmental Decentralization on GTFP

Based on the above analysis, under environmental decentralization, each region will loosen environmental regulations, promote economic growth and inhibit enterprise innovative output. On this basis, this paper uses the measurement method of GTFP, proposed by the World Business Council for Sustainable Development (WBCSD), to investigate the impact of environmental decentralization on GTFP. According to the measurement method proposed by the WBCSD, GTFP can be expressed as:

$$GTFP = \frac{Y}{Y/T + W/T} \tag{28}$$

where $GTFP$ stands for the green total factor productivity measuring the green development level, Y is the value of a product or service measuring economic growth, T represents technology-level measuring enterprise innovative products, Y/T is total resource consumption, and W/T is total emission of pollution. Through Equation (28), economic growth (Y) can be expressed as

$$Y = \frac{W}{T/GTFP - 1} \tag{29}$$

According to the above analysis, environmental decentralization will promote economic growth and inhibit enterprise innovative output. Most existing research results believe that decentralization variables have a linear relationship with the influence of the above indicators [23]. In addition, because environmental decentralization in neighboring regions does not promote regional economic growth simply by affecting the production quantity or production technology, for the convenience of analysis, it is assumed that environmental decentralization in neighboring regions will only affect regional economic growth when measuring GTFP. Equation (28) can be further expressed as:

$$GTFP_i = \frac{Y_i^0 * l_i * l_j}{\frac{Y_i^0 * l_i * l_j}{T_i^0 / l_i} + \frac{W_i^0 * l_i}{T_i^0 / l_i}} \tag{30}$$

where $GTFP_i$ represents the green total factor productivity in region i, and l_i and l_j represent the level of environmental decentralization in region i and region j, respectively. Y_i^0 is the value of the initial product or service in region i, T_i^0 represents the initial technology level of region i, and W_i^0 is the degree of pollution caused by area i for the value of Y_i^0 unit of product or service produced. That is, $Y_i^0 * l_i * l_j$ is the value of actual products or services in region i, $\frac{Y_i^0 * l_i * l_j}{T_i^0 / l_i}$ is the actual resource consumption in region i, and $\frac{W_i^0 * l_i}{T_i^0 / l_i}$ is its actual pollution emission

Equation (30) could be simplified as:

$$GTFP_i = \frac{1}{1 + W_i^0 / Y_i^0} \frac{T_i^0}{l_i} \frac{1}{1 + 1/l_j} \tag{31}$$

According to Equation (31), $GTFP_i$ is directly proportional to the initial level of economic development (Y_i^0). The level of environmental decentralization (l_i) will suppress $GTFP_i$ by inhibiting enterprise innovative output (T_i^0/l_i), which is the influence mechanism of environmental decentralization on GTFP.

Combining Equation (29) and Equation (31) yields:

$$GTFP_i = \frac{GTFP_i^0}{l_i} \frac{1}{1+1/l_j} \tag{32}$$

According to Equation (32), $GTFP_i$ is directly proportional to the initial green total factor productivity ($GTFP_i^0$), and the local green total factor productivity ($GTFP_i$) is inversely proportional to the local level of environmental decentralization l_i and directly proportional to the level of environmental decentralization in neighboring regions (l_j), which is the influential effect of environmental decentralization on GTFP.

In other words, in the dynamic process of local economic development and daily environmental affairs management, there are mainly a "backwash effect" and a "spread effect" on the surrounding areas. The central government should take the initiative to carry out policy intervention, rather than passively waiting for the spread effect of growth poles to improve the economic development imbalance in its own country. This is mainly because as the growth pole plays its role, the backwash effect always precedes the spread effect. If there is no effective government intervention, the duration of the backwash effect will be prolonged, and the backwash effect will eventually be larger than the spread effect. Furthermore, it is in line with the trend of economic and social development to take into account the scarcity and limitation of resources, emphasize the important role of growth poles or growth points, and encourage the improvement of public services and technological innovation.

4. Discussions

Accordingly, under the analytical framework of environmental decentralization, technological innovation and GTFP (Figure 1), this section studies the effect and mechanism of environmental decentralization on GTFP. The specific research contents and purposes are as follows: Based on the "Porter Hypothesis", this paper studies the effect and mechanism of environmental decentralization on enterprises' innovative output, and it draws inference 1 and 2. Based on the theory of traditional environmental federalism and environmental game analysis between governments, this paper studies the effect and mechanism of environmental decentralization on GTFP, and it draws inference 3.

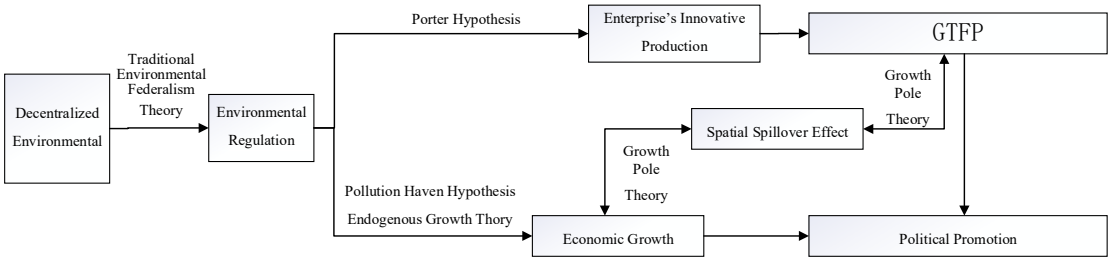

Figure 1. The analytical framework of environmental decentralization, technological innovation and GTFP.

From Section 3.2, we could have Inference 1: Environmental decentralization will inhibit enterprise innovative output.

Environmental regulation will promote the transformation of enterprises' environmental management from terminal governance to technological innovation. Although it will increase enterprises' environmental cost in this process, it will also stimulate an innovation compensation effect. When the environmental regulation is based on the market, it should

be reasonable and effective, and the innovation compensation effect will be higher than the environmental cost. Traditional environmental federalism theory holds that environmental decentralization will reduce the intensity of environmental regulation, and the reduction of environmental regulation intensity will inhibit enterprises' innovative output [24].

This paper argues that environmental decentralization will inhibit enterprises' innovative output from the following three aspects: inefficient production, information asymmetry and ineffective policy guidance. First, the inefficient production behavior of enterprises will be indulged. Environmental regulation will stimulate enterprises to carry out technological innovation, strengthen internal management, and improve inefficient production and polluting production behavior, while environmental decentralization will weaken this improvement effect. Second, information asymmetry leads to "government failure". Environmental decentralization will make the local government have too much power and intervene excessively, resulting in the problem of "government failure" and pushing the market to maintain low efficiency production. Third, the policy guidance will be ineffective. In the areas of implementing environment decentralization, the "innovation compensation effect" of environmental regulation will fail, and in the absence of policy guidance, the environmental cost saved by enterprises will not necessarily be used for technological innovation. To sum up, environmental decentralization will increase the difficulty of the environmental regulation design, and improperly designed environmental regulation will inhibit enterprises' innovative output.

From Sections 3.1 and 3.2, we could have Inference 2: Environmental decentralization will affect technological innovation by reducing the quality of enterprise environmental information disclosure.

According to the theory of legality and stakeholder theory, enterprises need to meet the information needs of government and other pressure groups. That is, by improving the quality of environmental information disclosure, they can win the recognition of their legitimacy from society and the public [25,26]. On this basis, the institutional theory is used to analyze the components of external pressure, and it holds that regulatory pressure restricts enterprises through formulating rules and standards, which has a certain mandatory effect. Economic competition motivates local governments to reduce environmental regulations, and the improvement of environmental decentralization reduces the intensity of environmental regulations, thus affecting the quality of enterprise environmental information disclosure. However, the degradation of the quality of environmental information disclosure will highlight the information asymmetry between enterprises and banks and other investment and financing institutions, which will bring great difficulties to enterprise financing [27,28]. The shortage of funds makes enterprises unable to carry out technological innovation.

In addition, with the aggravation of environmental problems, the green production and operation behavior of enterprises attract more attention from various stakeholders in society, and the appeal for environmental information disclosure becomes more frequent. At present, enterprises are mainly faced with policy-oriented institutional supervision, public-opinion-oriented social supervision and efficiency-oriented market regulation, prompting them to disclose environmental information. Among them, although the latter two have a great impact on enterprises' environmental information disclosure behavior, they are mostly enterprises' voluntary behaviors, and environmental decentralization has no impact on them. Moreover, policy-oriented institutional supervision takes laws and regulations as direct means to force enterprises with polluting production and operations to make relevant environmental information public and form hard constraints on enterprise environmental information disclosure. Under environmental decentralization, institutional supervision will be weakened to some extent, and the quality of enterprise environmental information disclosure will be reduced. Moreover, enterprises will be under less pressure from forced external environmental supervision, which will further reduce their willingness to improve polluting production and operation behaviors and reduce R&D investment to reduce costs.

From Section 3.3, we could have Inference 3: Environmental decentralization will not only inhibit GTFP, but also have spatial spillover effect, which will promote GTFP in neighboring areas.

Under environmental decentralization, the effect of environmental regulation on GTFP will be interfered with by environmental regulation policies in neighboring regions to a large extent. The implementation effect of environmental regulation policies is the result of a strategic game among policy makers in each region. From the perspective of regional economic competition, each region will consider the strategic response of neighboring regions when checking and balancing whether to issue an environmental regulation policy [29]. The objective function of decision making in each region is to pursue social welfare maximization in the region. As there is a highly positive correlation between GTFP and social welfare level, the maximization of GTFP can replace social welfare maximization.

For each region, there are two strategies to choose, namely, make the environmental regulation or not. The order of social welfare under different environmental strategies is: GTFP when there is no local regulation, but regulation in other regions > GTFP when there are regulations in both regions > GTFP when there are no regulations in both regions > GTFP when there is local regulation, but no regulation in other regions. The first part of the inequality above is the result of taking a free ride, that is, one region benefits from the unidirectional regulation of the neighboring region. The middle part of the inequality above is the result of environmental centralization, that is, unified environmental standards implementing in all regions of a country; thus, GTFP will increase in all regions. The last part of the inequality above is the result of being taken for a free ride, that is, unidirectional environmental regulation in one region that makes the neighboring regions enjoy the benefits of free riding.

As can be seen from the above inequality, when all regions implement environmental decentralization, in the one-off game, the dominant policy of all regions is not to carry out environmental regulation, which forms the "bottom-to-bottom competition" of environmental regulation among regions. If all regions adopt such strategies, the Nash equilibrium results in economic growth at the expense of the environment. However, environmental strategic behavior between regions is usually a long-term dynamic process; hence, "bottom-to-bottom competition" may not be the final result in the long run. When all regions implement environmental centralization, environmental regulation will be carried out. In the Nash equilibrium, the social welfare of all regions will be higher than that of environmental decentralization. In other words, the lack of environmental regulation or the incompatibility of low-standard environmental regulation with regional social welfare may support the transformation of the environmental management system from decentralization to centralization. Therefore, in the long-term dynamic game, environmental centralization will be implemented, environmental regulation will be carried out in neighboring areas, and GTFP will be improved. In addition, when environmental regulation is carried out in the local area, but not in the neighboring area, polluting enterprises in the local area will move to the neighboring area, thus improving the GTFP of the local area.

5. Conclusions and Implications

Based on the traditional environmental federalism theory and the Porter Hypothesis, this paper investigates the effect and mechanism of environmental decentralization on GTFP by constructing an analytical framework of environmental decentralization, technological innovation and GTFP. The main conclusions of this paper are as follows: (1) environmental decentralization will inhibit enterprises' innovative output; (2) environmental decentralization will affect enterprises' innovative output by reducing the quality of environmental information disclosure; (3) environmental decentralization will inhibit GTFP; and (4) environmental decentralization has a spatial spillover effect on GTFP, which could promote GTFP in neighboring areas.

Based on the above analysis and conclusions, this paper obtains the following policy implications:

First, ecological and environmental efficiency could be included in the regional performance appraisal system, and the new performance appraisal system could be further implemented to accelerate the transformation and upgrading of the economic development model and promote the construction of an ecological civilization. The government has faced a dilemma between economic growth and environmental protection for a long time. On the one hand, ecological environmental degradation is the result of extensive economic growth at the expense of the environment. On the other hand, ecological environment protection and improvement also require economic development as motivation and support. However, this does not mean that economic development and ecological protection in developing countries can follow the path of "pollution first, treatment later". Enterprises and local governments could take more active and effective measures, changing their view of protecting the environment from "remediation after the pollution" to "precaution before the pollution happens".

Second, local government's behavior should be standardized. It should strengthen effective oversight of environmental management and establish an environmental management system in which the government takes the lead, enterprises play the main role, and social organizations and the public participate. The root cause of "race to the bottom" is that local governments have too much discretionary power [30]. Without effective supervision, the efficiency of environmental management is bound to be reduced. Therefore, the central government should enhance efforts to protect the ecosystem, reform the ecological and environmental supervision system, improve the incentive mechanism for local governments to control pollution, improve the efficiency of environmental management, and guide local governments to compete rationally.

Third, the disclosure of environmental information is the key to solving environmental problems. The disclosure system for environmental information of enterprises should be improved and a long-term mechanism of green credit should be gradually established. With the introduction of Green New Deals in different countries, the number of relevant laws and regulations for environmental protection increases, and the industrial structure of various countries has also undergone major adjustment. Many industries with high pollution and energy consumption will gradually be phased out, and resource-saving and environment-friendly enterprises are thriving. Environmental information has become indispensable and important information for enterprises to engage in green and sustainable development operations, performance evaluation and investment decision making. Improving the environmental information disclosure system and establishing a long-term green credit mechanism may effectively improve the quality of environmental information disclosure, alleviate the problem of information asymmetry between enterprises and banks and other investment and financing institutions, lower the financing constraints of enterprises, and then use sufficient funds to carry out technological innovation and improve the environmental performance of enterprises driven by market profits.

Furthermore, we will combine with the development trend of relevant fields and continue to carry out research in the following aspects: First, economic competition is an important factor causing bottom-to-bottom competition of environmental regulations in a decentralized system. This paper fails to introduce economic growth into the model, which is not suitable for an analytical framework consisting of environmental decentralization, technological innovation and GTFP. Therefore, this paper will further build a theoretical model of environmental decentralization on economic growth and integrate it into the theoretical model of environmental decentralization and GTFP in order to make the propositional derivation and demonstration more rigorous and draw more reliable conclusions. Second, the measurement of GTFP has great regional differences. The selection of the non-expected output index should be updated at any time, along with the actual environmental situation of the measured region and the environmental policy of the central government.

Academia has not reached a consensus on the selection of a GTFP measurement model. This paper will conduct more valuable research on the above issues.

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