Environmental Regulations, Directed Technical Change and Vertical Division of Value Chain

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Abstract: This paper briefly reviews the economic literature on environmental regulation, technological innovation and vertical division of labor of value chain in the past decade. We first use a stylized growth model to analyze the channels and results of environmental regulations and the technological innovation they brought by. Then, we consider the impact of technological innovation brought by two forms of environmental regulation on the position of economic agents in the value chain. The results show that energy efficiency innovation brought by intensive environmental regulation has a more significant impact on economic performance, while product innovation brought by extended environmental regulation has a stronger promotion effect on the position of economic agents in the value chain. Available empirical evidence supports our results. Finally, we conclude with the goals that policies should nail in specific situations and the likely impact of different policies.

1 INTRODUCTION

How to deal with the increasing environmental concentration caused by the consumption of fossil fuels and take appropriate measures to ensure the efficiency of economic growth is one of the most serious challenges facing by the mankind today. And public regulations provide the necessary action target and organization frame to face and solve this challenge. Although a large number of studies focus on evaluating the implementation effect of public regulations, exploring the feasibility of developing alternative energy sources and the realization path of improving economic efficiency, all of the main policy analysis literature almost ignores the impact of environmental policies on economic efficiency. Existing evidence shows that strict environmental regulations tend to produce positive externalities, leading to higher economic efficiency, and economic subjects tend to be in a higher vertical division of labour in the Global Value Chain (GVC). On the other hand, the concentration of production factors in energy conservation and emission reduction may also change the impact path of technological innovation on economic performance, and form a resistance to the climb of the value chain of economic entities. What kind of environmental regulation can bring efficient technological innovation to economic subjects? Does such technological innovation have a similar effect on the embedment position of economic agents in the vertical division of labour in the GVC? This paper briefly reviews the economic research on these two topics, with a focus on the contributions of the last decade.

2 LITERATURE REVIEW

2.1 Environmental Regulations and Technological Innovation

Economic papers on environmental regulations and technological innovation can be traced back to the late 1980s and early 1990s, and the main issue is whether the former promotes the latter. Different schools hold different views on this. For example, the Neoclassical School believes that environmental regulation will increase the additional burden of enterprises not to use for production, which will at least lead to the regression of enterprises' production efficiency in the short term (Barbera, et al, 1990, Jorgenson, et al, 1990). In this regard, Poter and Van der Linde (Poter, Van, 1995) put forward a different point of view through case study. Appropriate

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environmental regulation can improve productivity through efficiency improvement, redistribution and innovation incentive, which is also known as the "Porter Hypothesis".

The issue of environmental regulations and technological innovation attracted wider attention for the first time at around 2008, mainly including environmental quality, economic models and technological innovation in the context of climate change (Maria et al, 2006, Bosetti, et al, 2008, Carraro, et al, 2009). These early studies generally argue that increased investment in technology R&D should be advocated in the context of climate change, and highlight the importance and feasibility of a low-carbon economy and cleaner production. This is because, as a result of climate policy implementation, especially when there is a weak substitutable relationship between energy and non-energy sectors, technological innovation will always be oriented towards energy knowledge, thus diluting the potential crowding out effect between the two sectors. The advance of this view lies in the ability to distinguish the energy and non-energy sectors, and then investigate the heterogeneity of the effects of technological innovation on the energy and non-energy sectors.

A second wave of research was revived in less than five years. This wave involves two distinct research paradigms. On the one hand, under the leadership of Acemoglu, endogenous technological changes in the growth model with environmental constraints have been preliminally investigated (Acemoglu, et al, 2012, Acemoglu, et al, 2014). This is the first theoretical study to emphasize the importance of technological change direction under environmental regulations: the best policy direction is to immediately transform endogenous technological progress into cleaner production knowledge and technology. Compared with the existing literature, this kind of research expands the understanding of technological innovation: for different sectors, technological innovation should be introduced differently to emphasize that the environmental regulations implemented by the economy have different policy objectives and therefore different policy effects. On the other hand, compared with technological innovation, a series of models developed around 2012 paid more attention to the impact of industrial structure on regional environmental quality (Whitmarsh, et al, 2011, Turnheim, et al, 2012). These studies suggest that the industrial structure or scale of a region (such as mainland China) will affect its total carbon emissions or carbon emission intensity; this effect may be achieved through indirect transmission mechanisms. Existing evidence shows that technological progress brought by environmental policies does not itself improve environmental quality, but achieves energy conservation and emission reduction through upgrading or optimization of industrial structure. These studies have established a goal for the implementation of public policies, that is, policies that focus on the regional industrial structure may bring about higher economic performance.

At the same time, some literature focused on the empirical evidence of the effect of environmental regulation on promoting technological level, and the results were often positive. Its core conclusion is that environmental regulation may lead to an increase in the proportion of innovation (R&D) expenditure (Testa, et al, 2011). In general, moderate environmental regulations can promote the progress of production technology. As a matter of fact, earlier studies on verification of Porter's hypothesis in China reached a similar point of view (Li, et al, 2010), but only reasonable environmental regulation can promote technological innovation of enterprises, and different environmental policies should be adopted for heterogeneous departments or enterprises. The contribution of this kind of research lies in affirms the difference between environmental regulations and emphasizes the applicability of environmental policies to economic subjects. In addition, the input of policies may not produce equal or higher returns, and economic entities need to bear the risk premium of the transformation of innovation achievements.

Finally, there has been a third wave of interest since 2017. Based on the fact of global environmental crisis and energy shortage, the aim is to explore the feasibility of energy transition and the long-term technical and economic characteristics of energy transition (Kittner, et al, 2017, Gielen, et al, 2019); It can be found that the research on environmental regulations and technological innovation has been gradually inclined to the performance evaluation in the field of energy. Literature shows that energy efficiency has the most obvious impact on environmental quality. Resource innovation and knowledge innovation are also important aspects of environmental innovation. At the same time, as new environmental and economic data have been generated by natural experiments on the implementation of environmental policies in various countries, more and more empirical evidence has been generated from the hypotheses and models emphasized in the early literature, further contributing to the emergence of more positive views on environmental policies (Shahbaz, et al, 2018).

Therefore, the main contribution of the recent literature is to consider the possibility of energy transition and energy efficiency as an approach, based on natural experimental data in various countries, and to demonstrate the economic and policy feasibility of this approach.

2.2 Literature Review of Global Value Chain

Since the study of Gereffi and Korzeniewicz (1994) in the 1990s, Global Value Chain, as an organized global division of labor, has attracted the attention of a wide range of disciplines. In such a division of labor system, developed economies, with their high production technology and diversified products, occupy a relatively high position in the GVC. Developing economies participate in the division of labor in the GVC, and attract the processing and transfer of intermediate products from developed economies by virtue of cheap low-skilled labor factors and environmental capital on the premise of relatively lack of production technology and physical capital. The relatively low-end position in the GVC creates opportunities for domestic economic growth.

From the perspective of resource endowment, developed economies have innate advantages in technological innovation. With relatively rich resources and experience, they can form scale effect of technological innovation and maintain their position and benefits in the division of labor in the global value chain (Brandt, Thun 2010). This innovation is mainly manifested in two aspects: Technological innovation of final products and intermediate products (Gereffi, 2014). In particular, emerging economic powers have huge final product and intermediate product markets, especially the differentiated demand of the final product market, which provides a huge resulting demand for the technological innovation of intermediate product production. After the innovation is completed and applied, it can compete in intermediate goods markets in developed economies. One of the manifestations of this phenomenon is that exports participating in the GVC will use more domestic intermediate products, which is reflected in the improvement of the embedding position of economies in the GVC (Zheng, Zheng 2020). Furthermore, strong innovation capability of intermediate products may even produce knowledge and technology spill over to developed economies, providing a reliable path for the climb of global value chain (Lu, Ng, 2012, Utar, TorresRuiz, 2013).

It can be seen that technological innovation in specific production links can change the division of labour status of economies in the global value chain, that is, realize the climb of the GVC. According to the existing literature, technological innovation caused by environmental regulation mainly involves energy utilization and clean production, which covers all links in the GVC from primary products, intermediate products to final products. Then, is the technological innovation caused by efficient environmental regulation homogeneous with the technological innovation that can promote the climb of value chain?

Therefore, a satisfactory framework for studying the embedment of environmental regulation, technological innovation and the position of the GVC should recognize the existence of environmental regulation with different objectives and technological innovation with different impact paths. It also includes the endogenous influence of technological innovation brought by environmental regulation on economic performance and the endogenous reaction of the embedment position of economic subject in the vertical division of labor of value chain on technological innovation. Specifically, what kind of environmental regulation can bring efficient technological innovation to economic subjects? What impact will such technological innovation have on the embedment position of economic agents in the GVC? We hope that a step can be taken towards this framework.

The rest of this paper will be arranged in the following patterns: in the third section, we set up an environmental regulation, technological innovation and economic performance benchmark growth model, the introduction of two dimensions of energy efficiency innovation and product innovation, to simulate the environmental regulation through technology innovation to affect the path of economic performance, and the efficient simulation results are analysed. The fourth section introduces the influence of two dimensions of technological innovation on the embedment position of economic subjects in the vertical division of GVC. The fifth section discusses the choice and direction of policy from the perspective of policy makers. Finally, the article will end in section 6.

3 A BENCHMARK GROWTH MODEL CONSIDERING ENVIRONMENTAL FACTORS

In this part, we propose a stylized model of endogenous growth; it will be used as a benchmark in the following analysis. On this basis, we consider the impact of the implementation of environmental regulations on economic performance, and the impact of the impact of the results of the model.

Our model depicts a universally representative economic agent whose economic performance is driven by and only by four factors: technological level, human capital, physical capital, and natural capital. We first describe the characteristics of the production sector and derive the analytic formula of endogenous economic performance as a function of environmental factors. Then we describe the characteristics of environmental regulation and turn environmental regulation into a function of economic performance. It is advisable to keep all the given values.

3.1 Four-factor Economic Growth Model

According to the adjusted Cobb-Douglas function, in each period, human capital (h_t), physical capital (k_t) and natural capital (e_t) are combined to produce economic performance (y_t) at a specific technological level (A_t). Among them, we define natural capital as the synthesis of net environmental factors that can be used by economic entities and affect economic performance, including environmental quality and natural resources, without considering the heterogeneity between the two. Therefore, the performance of the economic agent (y_t) is a function of the human capital (h_t), physical capital (k_t) and natural capital (e_t) it can obtain:

$$y_t = A_t {k_t}^{\alpha} {h_t}^{\beta} {e_t}^{1-\alpha-\beta} \quad (1)$$

Further, each element can be combined with different technical conditions, that is, the knowledge required to transform production technology into different elements, then economic performance can be expressed as a function of the product of each element and its knowledge:

$$y_t = A_{kt} {k_t}^{\alpha} \cdot A_{ht} {h_t}^{\beta} \cdot A_{et} {e_t}^{1-\alpha-\beta} \quad (2)$$

In the above formula, A_t is a scale parameter that changes with time and depends on the product of productivity of each single factor. It is assumed that the individual factors and their productivity are heterogeneous and completely irreplaceable to each other. $\alpha, \beta \in [0,1]$ represents the share of physical and human capital in the income of economic entities respectively and satisfy $\alpha + \beta \in [0,1]$.

We assume that physical capital is completely depreciated in a certain period, and human capital will lose its ability to contribute to economic performance in a certain period. From the perspective of potential investors, each economic entity has the risk premium of physical and human capital respectively, so the ratio of marginal return to risk premium constitutes the risk-free interest rate. The risk-free rate of physical capital follows the following formula:

$$R_{kt} \cdot \Phi_t = \alpha A_t {k_t}^{\alpha-1} {h_t}^{\beta} {e_t}^{1-\alpha-\beta} \quad (3)$$

Here R_{kt} is the risk-free interest rate of physical capital at time t, and Φ_t is equal to the risk premium of physical capital depreciation.

The utilization cost rate of natural capital per unit is given by the following formula:

$$c_t = A_t {k_t}^{\alpha} {h_t}^{\beta} {e_t}^{-\alpha-\beta} \quad (4)$$

Rearrange equation (3) and substitute it into equation (1), so that economic performance can be expressed as a function of natural capital and human capital:

$$y_t = \alpha^{\frac{1}{1-\alpha}} {A_t}^{\frac{1}{1-\alpha}} {R_k}^{\frac{\alpha}{\alpha-1}} {\Phi_t}^{\frac{\alpha}{\alpha-1}} h^{\frac{\beta}{1-\alpha}} {e_t}^{\frac{1-\alpha-\beta}{1-\alpha}} \quad (5)$$

Similar to equation (3), considering the risk premium caused by the elimination of human capital, take R_{ht} as the risk-free interest rate of human capital at time t and φ_t the risk premium of human capital depreciation, the following formula is given:

$$R_{ht} \cdot \varphi_t = \frac{\beta}{1-\alpha} \alpha^{\frac{1}{1-\alpha}} {A_t}^{\frac{1}{1-\alpha}} {R_k}^{\frac{\alpha}{\alpha-1}} {\Phi_t}^{\frac{\alpha}{\alpha-1}} {e_t}^{\frac{1-\alpha-\beta}{1-\alpha}} h^{\frac{\alpha+\beta-1}{1-\alpha}} \quad (6)$$

Rearrange equation (6) and substitute it into equation (5) so that economic performance can be expressed as a function of natural capital:

$$y_t = (\alpha^{\alpha} A_t)^{\frac{1}{1-\alpha-\beta}} \cdot \frac{\sqrt[\frac{\beta}{\alpha+\beta-1}]{\varphi_t \beta (1-\alpha) R_{ht}}}{R_{kt}^{\alpha} \cdot {\Phi_t}^{\alpha}} \cdot e_t \quad (7)$$

Clearly, economic performance depends linearly on the amount of natural capital per unit, increasing as production technology improves and decreasing as the risk premium increases.

Through equations (4) and (7), the utilization cost rate per unit of natural capital can also be expressed as an equation determined only by production technology and risk premium:

$$c_t = (\alpha^{\alpha} A_t)^{\frac{1}{1-\alpha-\beta}} \cdot \frac{\sqrt[\frac{\beta}{\alpha+\beta-1}]{\varphi_t \beta (1-\alpha) R_{ht}}}{R_{kt}^{\alpha} \cdot {\Phi_t}^{\alpha}} \quad (8)$$

The utilization cost rate of natural capital does not directly depend on the factor endowment of economic subjects. However, technological level can be regarded as positively correlated with natural capital. This is not inconsistent with the resource curse theory, because as explained above, the natural capital we consider is not exactly equivalent to the stock of natural resources, but the sum of environmental quality and natural resources that can be used by economic agents. This equation emphasizes the role of technological level on economic performance, which is consistent with Schumpeter's growth theory. Among them, the technological level is equal to the product of productivity of each single factor, which depends on the technological innovation ability of each factor. It should be noted that technological development may accelerate the depreciation of physical capital, but its impact on the renewal cycle of human capital is not directed which specifically depends on the culture and strategy of economic entities, will affect the risk premium and lead to changes in the use cost. This gives a cost-setting equation for natural capital:

$$y_t = C(e_t, X_t) \tag{9}$$

Here X_t is a set of characteristics that affect the production techniques and risks of economic agents. Based on the above analysis, we assume that there is $C(0, X_t) \geq 0, C'_{e_t} > 0$; with the second order condition $C''_{e_t e_t} < 0$; This means that our model is compatible with yield effects trait.

3.2 Internalization of Environmental Regulation: Product Innovation and Energy Efficiency Innovation

We now internalize the impact of environmental regulation. In our growth model, total factor productivity A_t is determined by the product of individual factor productivity. The implementation of environmental regulation shows that limited capital is invested into natural capital and inevitably brings technological innovation. The spillover effect of technological innovation is reflected in its impact on natural capital stock and factor productivity, without changing the stock of physical or human capital and factor productivity. Policy makers aim at maximizing economic utility and have no preference for any kind of capital.

There is a positive correlation between production technology and natural capital stock. Therefore, we assume that the single factor productivity A_{et} of natural capital is an increasing function of capital stock e_t, and the relationship between them is in accordance with the following equation:

$$A_{et} = \lambda^t A(e_t) \tag{10}$$

$\lambda > 1$ is a parameter that can capture the progress trend of economic subjects' r&d ability for new products, and $A(e_t)$ represents the arrangement and utilization efficiency of economic subjects' natural capital. Together they constitute natural capital single factor production technology. Thus, equation (7) can be rearranged as:

$$y_t = \alpha^{\frac{\alpha}{1-\alpha-\beta}} (A_{kt} \cdot A_{ht})^{\frac{1}{1-\alpha-\beta}} \cdot \frac{\sqrt[\frac{\beta}{\alpha+\beta-1}]{\varphi_t \beta(1-\alpha) R_{ht}}}{R_{kt}^{\alpha} \cdot \Phi_t{}^{\alpha}} \cdot [\lambda^t \cdot A(e_t)]^{\frac{1}{1-\alpha-\beta}} \cdot e_t \tag{11}$$

In this case, $\lambda^t \cdot A(e_t)$ as a single factor productivity, combined with natural capital e_t, has a nonlinear function relation with economic performance y_t.

We mentioned in this paper, on the corresponding natural capital factor productivity function, the environmental regulations, on the basis of the direction it brings, are divided into only two types: (i) extensive model of environmental regulation, can bring about product innovation, namely the economic entities can develop a product never produced before (increasing the value of λ); and (ii) intensive model of environmental regulation can bring energy efficiency innovation, that is, economic entities still continue to produce existing products, but can improve the arrangement and utilization efficiency of resources including energy, so that $A(e_t)$ can be improved.

It should be noted that energy efficiency innovation can improve the utilization efficiency of resources, which means that pollutant emissions will be correspondingly reduced and the relative stock of natural capital will be improved. It is reasonably assumed that the marginal improvement effect of energy efficiency innovation on natural capital stock conforms to the following formula:

$$e_i = E[e_t, A(e_t)] \tag{12}$$

Where, e_t represents the increment of natural capital brought by energy efficiency innovation; e_t and $A(e_t)$ represent the original capital stock and technology level respectively, and the first-order conditions $E(e_t, 0) > 0, E'_{A(e_t)} > 0$ are satisfied. This suggests that the increase of natural capital brought by energy efficiency innovation mainly depends on the original natural capital stock, and the original technology level also has a positive effect on the increase.

In the implementation of policies, limited policy funds will be directed to implement intensive or extensive environmental regulations. We assume that the same amount of funds can bring the same amount of policy effect, and then a certain amount of capital input will bring an increase of magnitude δ to the binary margin of technological innovation respectively. We consider the changes in economic performance brought by technological innovation: for product innovation, the following equation can be obtained:

$$y_{t\_ex} = [\alpha^{\alpha} A_{kt} A_{ht} A(e_t)]^{\frac{1}{1-\alpha-\beta}} \cdot \frac{\sqrt[\frac{\beta}{\alpha+\beta-1}]{\varphi_t \beta(1-\alpha) R_{ht}}}{R_{kt}^{\alpha} \cdot \Phi_t{}^{\alpha}} e_t(\delta+\lambda^t)^{\frac{1}{1-\alpha-\beta}} \quad (13)$$

For energy efficiency innovation, the following equation exists:

$$y_{t\_in} = (\alpha^{\alpha} A_{kt} A_{ht} \lambda^t)^{\frac{1}{1-\alpha-\beta}} \cdot \frac{\sqrt[\frac{\beta}{\alpha+\beta-1}]{\varphi_t \beta(1-\alpha) R_{ht}}}{R_{kt}^{\alpha} \cdot \Phi_t{}^{\alpha}} [\delta + A(e_t+e_i)]^{\frac{1}{1-\alpha-\beta}} (e_t + e_i) \quad (14)$$

Compare the impact of the binary margin of technological innovation on economic performance under the same investment scale, and rearrange the equation (11) and (12) to obtain the ratio of energy efficiency innovation to product innovation:

$$\frac{y_{t\_in}}{y_{t\_ex}} = \frac{[A(e_t+e_i)+\delta]^{\frac{1}{1-\alpha-\beta}}(e_t+e_i)\lambda^{\frac{t}{1-\alpha-\beta}}}{[A(e_t)]^{\frac{1}{1-\alpha-\beta}} e_t(\delta+\lambda^t)^{\frac{1}{1-\alpha-\beta}}} > 1 \quad (15)$$

This conclusion suggests that when policymakers plan to spend the same amount of capital, energy efficiency innovation brought about by intensive environmental regulations can have a stronger positive stimulus effect on the performance of economic agents. Therefore, the policy orientation we advocate is to transform endogenous technological progress into knowledge that can improve resource utilization efficiency. This policy conclusion is compatible with the results of Acemoglu et al. (Acemoglu, et al, 2012).

In our model, the creation of economic benefits does not depend on the stock of physical and human capital, but the stock of natural capital and the technical level of economic subjects can determine the impact scale of environmental policies on economic performance. At the same time, the implementation of policies can improve the utilization efficiency of natural capital by economic subjects, which constitutes the benefit equation of natural capital under the condition of whether to implement environmental policies or not. In the absence of environmental regulations, there are:

$$y_t = R_n(e_t, U_t) \quad (16)$$

In the implementation of environmental regulations, the revenue equation is:

$$y_t = R_i(e_t, U_t) \quad (17)$$

In this occasion, U_t is a set of characteristics that affect resource utilization and R&D innovation efficiency of economic subjects. According to our model and inference, when natural capital is zero, there is no economic output. After the implementation of environmental policies, natural capital can produce economic performance with higher efficiency. As a result, we get $R_n(0, U_t) = R_i(0, U_t) = 0, R'_{i\,e_t} > R'_{n\,e_t} > 0$. At the same time, based on the natural capital stock of energy efficiency innovation spillover effects, assuming that the second order condition $R''_{i\,e_t e_t} > 0, R''_{n\,e_t e_t} > 0$, which suggests that the stock of natural capital has a scale effect on the economy.

3.3 The Cost-revenue Analysis of Natural Capital

We now focus on the cost-revenue threshold in the use of natural capital. As the stock of natural capital in a region increases, the cost necessary to use natural capital changes monotonously with the benefits it brings, and the two can reach parity at some point (denoted by subscript q). Combining formula (7) and formula (14), it can be considered that the model has a unique non-zero critical value, under which $y_q = R(e_q) = C(e_q)$. Figure 1 provides a reasonable scenario that constitutes a unique threshold, in which we assume that natural capital always has an increasing unit return and a decreasing unit cost for economic performance. The relationship between natural capital and cost is identified by the cost setting equation, and the relationship between natural capital and income is expressed by the income setting equation.

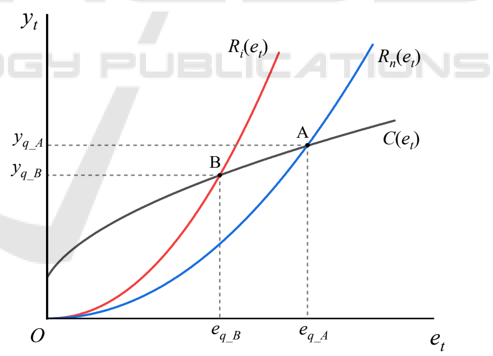

Figure 1: Cost-benefit Analysis of Natural Capital.

In the example in Fig. 1, there is a unique non-zero threshold for the costs and benefits of natural capital use, regardless of whether environmental regulations are enforced or not. Assuming that both A and B are dynamically stable, the equilibrium point A is the critical point at which economic subjects have incentive to use environmental capital to create output before implementing environmental regulation. Equilibrium point B is the critical point after the implementation of environmental regulations.

When $e_t \in [0, e_q)$, the economic subject will not engage in production because the cost of using natural capital is higher than the income it brings; when $e_t \in [e_q, e_{q\,max})$, the economic subject will use natural capital to produce and obtain benefits. Intensive, therefore, the implementation of the environmental regulation reduces the economic subject the threshold of the natural capital needed for production, can make more economic main body involved in the social production; for enterprises to participate in international trade, this change will affect them in the international division of labor in the product structure, cause they are vertical division of labor status changes in the global value chain.

4 GLOBAL VALUE CHAIN: DIRECTED TECHNICAL CHANGE AND CLIMBING CHANNEL

4.1 The Potential Result of Directed Technical Change

As explained in our empirical analysis, the influence path of the embedment of vertical division of labor position in response to technological progress needs to be distinguished. This is mainly based on the nature of energy efficiency innovation, product innovation and value chain respectively: product innovation brought by extensive environmental regulations is essentially the research and development of new products, which can create more possibilities for economic entities to embed in global value chain. Product R&D is a knowledge-intensive process. On the one hand, it may require the participation of industries at the high end of the value chain. On the other hand, there is a demand for its achievements to serve the high-end industries of the value chain by producing products with higher technology content to replace the original and low-technology products. The result of this process is that the status of economic subjects in GVC has been improved, that is, the value chain has climbed.

Consider the innovation in energy efficiency brought about by environmental regulation. On the one hand, the innovation process also needs the participation of high-end industries in the value chain; On the other hand, the reduction of energy consumption per unit caused by intensive environmental regulations indirectly brings higher natural capital stock to economic subjects, which means that the impact of innovation depends on the degree of dependence of GVC on natural capital. Under such an influence mechanism, the impact of technological innovation brought by two environmental regulations on the position of economic subjects in the global value chain is influenced by multiple factors. We wish to clarify this influence mechanism through theoretical analysis.

4.2 Influence Path

We construct a production model of economic agents in the global value chain division. Assume that the economic agent co-produces product y with other countries and the economic agent is not at the top end of the GVC. For any production link $i \in [0,1]$, the closer i is to 1, the closer the production link is to the top of the global value chain. The economic subject undertakes the production process of $[m,k]$; $m,k \in [0,1)$ in the global value chain.

According to the conclusion drawn in the fourth part of the paper, it is reasonable to assume that all economies and production links need only natural capital (E_i) and technological level (A_i); p and q represent the unit use price of natural capital and technology level respectively. Producing one unit of y requires e/i units of natural capital and ai units of technology. When energy efficiency innovation occurs, the stock of natural capital increases and the amount of natural capital required to produce a unit of product decreases. The unit price of natural capital is usually determined by its mining rate and social discount rate, which will not change in the short term. Therefore, the result of energy efficiency innovation will be shown as the reduction of parameter e. At the same time, when product innovation occurs, the unit use price of technology level will decrease in the short term, which is manifested as the decrease of q value.

In a perfectly competitive market, economic performance is approximately equal to its production cost. Therefore, when economic entities produce 1 unit of performance y, it can be expressed in the following formula:

$$y = \int_m^k \left(\frac{ep}{i} + aqi\right) di \tag{18}$$

Where, monomial ep/i constitutes the total cost of using natural capital E_i, and aqi constitutes the total cost of using technical level A_i. We respectively pay attention to the impact of economic performance, natural capital and production technology on the position of economic subjects in the value chain, and obtain:

$$\frac{\partial k}{\partial A_i} > \frac{\partial k}{\partial E_i} \tag{19}$$

This conclusion indicates that product innovation plays a higher role than energy efficiency innovation in promoting economic entities' position in the vertical division of value chain. In other words, product innovation will be more efficient for the promotion of economic subject's position in the value chain.

The influence path of product innovation can also be explained by additional influence mechanisms. The connotation of product innovation as defined by us is that economic subjects produce new products that have never been involved before under the stimulus of environmental policies. After the research and development results are applied, the original products will be completely eliminated, and eventually most of them will even be completely withdrawn from the market. In addition to our suggestion that innovation requires the participation of the higher end of the value chain, the results of innovation, namely the new products developed, also tend to have higher technological added value. The implementation of environmental policies is usually inclusive, which means that the technological innovation proposed by the policies is the choice of the vast majority of subjects. We assume that economic subjects do not need to bear the risk premium caused by innovation failure, and then the effect of policy implementation will be reflected in the improvement of the division of labor status of broad economic subjects or regions in the value chain.

According to our conclusion, if we simply consider from the perspective of efficiency, there is no environmental policy that can make economic subjects maximize their economic performance and maximize their position in the value chain. The maximization of one side's efficiency inevitably means the loss of the other side's efficiency. This means that policy makers need to make trade-offs between the two policies according to the reality of policy recipients.

4.3 Evidence

In terms of the research on product innovation and energy efficiency innovation, there are two papers that provided some of the more influential research (Pye, McKane, 2000, Gerstlberger, Knudsen, Stampe, 2013). Both papers limited the economic agent to the dimension of the firm, and examine the relationship between product innovation and energy efficiency, or synergies. Pye and McKane (2000) pointed out that energy efficiency may be a by-product of product innovation, and the product innovation can also arise as a by-product of energy efficiency improvement, and concluded that management must understand the costs and benefits associated with energy efficiency investments, regardless of the direction of this influence mechanism. Different from Pye and McKane, Gerstlberger et al. (Gerstlberger, et al, 2013) drew different conclusions after using data from a larger sample: Product innovation and energy efficiency in business operations are often separated, so business managers also need to make trade-offs in business strategies, depending on whether the performance of the business is more urgently needed, or whether it is to meet the needs of environmental friendliness. These analyses tell us that policy and strategy makers are often faced with the contradiction of promoting product innovation or energy efficiency innovation, and it is still worth exploring whether there are spillover effects between the two. However, in reality, there may exist public environmental policies that promote both product innovation and energy efficiency innovation. The implication for us is that a combination of environmental policies is recommended when policy funding constraints are not tight.

5 POLICY IMPLICATIONS

In our analysis, policy makers often face the dilemma of promoting product innovation or energy efficiency innovation, that is, whether to implement intensive or expansive environmental regulations. So, in the face of this dilemma, how should policymakers consider the direction of policy? Should their policy objectives be adjusted or maintained?

First, we need to consider why environmental policy needs to be anchored to targets for economic performance or product structure. According to environmental economics, the primary goal of environmental policy is not to achieve environmental friendliness, but to integrate the limited environmental resources, produce economic performance, and realize the maximization and sustainability of output efficiency. This means that the environmental policies implemented will rarely maintain the stock of natural capital at the expense of long-term economic growth. Therefore, both of the economic performance and product structure are factors that must be considered in the implementation of environmental policies.

Another reason for this dilemma is why an economic entity should care about its position in the vertical division of labour in the value chain. Higher vertical division of labour status usually means that the products produced by economic subjects contain higher added value; In international trade, each unit of product sold, high value-added products can bring higher profits than low value-added products, in other words, will affect the efficiency of economic subjects in international trade profit. If foreign trade is an important source for economic entities to obtain economic performance, it is necessary to pay attention to product structure and its position in vertical division of labour in the implementation of policies.

As we conclude in Section 5, when policy funds are abundant, the policy mix is usually the recommended course of action. However, if there are relatively strict capital constraints, such as in less developed economies or regions with high implementation costs, there is usually a choice of policy implementation. In this case, we suggest that the policy orientation of prioritizing economic performance should be considered. Economic subjects choose to improve the status of international division of labour in the hope of obtaining more efficient economic output. Strictly speaking, it still belongs to the path of pinning economic performance. If the policy has a high implementation cost, it is more efficient to implement intensive environmental regulations to drive energy efficiency innovation, thus obtaining a higher relative stock of natural capital and directly contributing to economic output.

In addition, both product innovation and energy efficiency innovation have positive effects on the performance of economic entities and their position in the vertical division of labour. This can also be proved by the theoretical model we have constructed. As for the promoting effect of product innovation on economic performance, formula (11)-(9) is considered to obtain:

$$y_{t\_ex}\text{-}y_t = \frac{e_t \cdot \sqrt[\frac{\beta}{\alpha+\beta\text{-}1}]{\varphi_t \beta(1\text{-}\alpha) R_{ht}}}{R_{kt}^{\alpha} \Phi_t{}^{\alpha} [\alpha^{\alpha} A_{kt} A_{ht} A(e_t)]^{\frac{1}{\alpha+\beta\text{-}1}}} \cdot [(\delta + \lambda^t)^{\frac{1}{1\text{-}\alpha\text{-}\beta}} \text{-} \lambda^{\frac{t}{1\text{-}\alpha\text{-}\beta}}] > 0 \quad (20)$$

The role of energy efficiency innovation on the position of economic subjects in the vertical division of labor in the value chain is as follows:

$$y = \int_m^k (\frac{ep}{i} + aqi) di, \frac{\partial k}{\partial E_i} < 0 \quad (21)$$

What we mainly evaluate in this paper is the effectiveness of the two innovation paths in promoting economic performance or division of labor status respectively. Product innovation can also improve the output performance of economic entities, and energy efficiency innovation can also have a positive impact on the position of economic entities in the vertical division of labor in the value chain. In this dimension, similar experience in policy practice can also be reasonably explained.

6 CONCLUSIONS

This paper briefly reviews the economic literature on environmental regulation, technological innovation and vertical division of labor of value chain in the past decade, with a focus on the role of technological innovation and directional technological change brought by environmental regulations on vertical division of value chain. Developing countries and development economists pay close attention to the transition from a single product exporter, a low value-added product exporter to a high value-added product producer. Through technological innovation, we can see that countries at the lower end of the value chain are able to transform their product mix, thus reducing economic inequality among the international community.

According to Porter's Hypothesis, environmental regulation can improve economic performance by promoting technological innovation, but the path behind this influence mode and the effect of the same influence path on the position of economic subjects in the value chain need to be further investigated. To test these two questions, we design two stylized growth models that are flexible enough to include the effects of environmental policies in different directions on economic performance and the location of vertical division of labor. We define intensive and extensive environmental regulations, which can bring energy efficiency innovation and product innovation to economic entities respectively. Our results show that intensive environmental regulations can bring more incremental performance to economic actors through energy efficiency innovation, while extensive environmental regulations can promote economic actors to climb up the value chain through product innovation. The existing literature provides empirical evidence for our conclusions, which indicates that our conclusions are basically compatible with the practical environmental policies.

What are we going next? As we suggest in this article, the policy mix is usually the recommended approach. However, when the implementation cost of combination policies is too high, we still suggest that intensive environmental regulations should be implemented to drive energy efficiency innovation, and the direct spillover effects of environmental regulations on economic performance should be prioritized to meet the needs of regional economic development in the short term.

Finally, it is worth noting that although we demonstrate the effects of product innovation and energy efficiency innovation on economic performance and vertical division of labor respectively, the fit between model and reality still needs further research. In particular, more empirical evidence is needed to verify our conclusion in the study of economic performance based on the differentiation of technological innovation, which may constitute the further improvement of the analytical framework of the new Schumpeter growth theory.

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