Frontiers in Business, Economics and Management
ISSN: 2766-824X | Vol. 7, No. 2, 2023

Research Status and Prospects of the Environmental Regulation' Impact on Green Innovation

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Abstract: The high-carbon and high-pollution industrial development path has caused serious damage to the global environment. Since the United Nations Conference on Environment and Development put forward the concept of "sustainable development" in 1978, governments of various countries have introduced various environmental protection laws and policies to guide the green transformation of industries and strengthen green innovation. Under the leadership of the "Porter Hypothesis", the academic circle has successively carried out various research on "the impact of environmental regulation on green innovation". This paper sorts out the existing research on environmental regulation on green innovation, analyzes and summarizes the status and deficiencies of current research, and puts forward prospects on this basis to provide a reference for follow-up research.

Keywords: Environmental Regulation, Green Innovation, Porter Hypothesis, Government Policy.

1. The Status Quo of the Global Environment and Environmental Regulations

Due to the impact of high carbon, high energy consumption, and high pollution industries, the harm of climate change to human beings has become beyond imagination in the past two decades. The sharpness of this change is often beyond the response of decision makers, and even subtly unnoticed by decision makers [1]. Human emergency management capabilities are often insufficient to deal with extreme hydrological events caused by climate change [2]. Climate change has also increased the scale of forest fires [3], increased the intensity of volcanic eruptions [4], increased the frequency of landslide disasters [5], and even affected human mental health [6].

To protect the environment, the United Nations Conference on Environment and Development formally proposed the concept of "sustainable development" in 1978. Subsequently, governments of various countries have successively issued various environmental protection laws and policies, trying to regulate the environment of the market, to achieve the goal of green and sustainable development. The United States passed the "Paris Agreement" in 2015. Although it once withdrew during the Trump presidency, after Biden was elected president, the United States became a party to the Paris Agreement again on February 19, 2021. In addition, state and local governments in the United States have taken various actions, such as regulating vehicle emissions, building construction codes, and energy consumption and emissions from power generation. The UK has also formulated a corresponding vision for emission reduction. As the host country of the United Nations Climate Change Conference (COP26) in 2021, the British government has formulated the "Climate Change Strategy 2021-2024" (Climate Change Strategy 2021-2024). France, Germany, Japan, South Korea, Russia, and many other countries have also formulated corresponding policies to deal with climate change according to their national conditions.

China's rapid development since the reform and opening-up has attracted worldwide attention. At present, China ranks second in the world in both economic and technological investment, and the total volume of trade in goods has leapt to the first in the world. However, behind this great development achievement, there is a relatively high environmental price. The extensive development model with high carbon, high pollution, high energy consumption and low efficiency is gradually eroding the "development dividend" released by the reform and opening-up. The environment is under load, and the lives and health of the people are also threatened.

To protect the lives and health of the people, ensure the sustainable development of the environment of China, fully implement the new development concept of Xi Jinping "Green mountains are golden mountains and silver mountains", and maintain the national ecological security, the CCP Central Committee and the State Council have successively launched many regulatory environmental policies. For example, "National Resource-Based Cities Sustainable Development Plan (2013-2020)", "Evaluation and Examination Measures for Ecological Civilization Construction Objectives", "Science and Technology Support Carbon Peak Carbon Neutral Implementation Plan (2022-2030)", etc. Local governments have also formulated environmental regulation policies of different sizes and in different forms according to local conditions. These measures have effectively restrained China's huge domestic market and high-carbon industries, and strengthened the willingness and determination of market players to carry out green innovation.

2. Definition and Connotation of Green Innovation

In 1994, Braun and Wield [7] defined green innovation for the first time, thinking that it is a general term for product improvement processes that minimize environmental pollution, material input, and energy use. Since then, scholars have discussed green innovation extensively. Rennings [8] pointed out that green innovation is new technology, new

product, new service and environmental protection process. Hellström [9] believes that green innovation is the whole process of applying the developed new product from the idea to the market. Dangelico and Pujari [10] believe that green innovation is an innovative activity that enables products with positive, sustainable or environmental attributes to minimize energy, reduce consumables and prevent pollution during the entire environmental production process. Sun and Razzaq [11] believe that green innovation is a type of technological innovation that emphasizes environmental friendliness, clean energy, ecological protection and response to climate change.

In fact, the essence of green innovation highlights the characteristics of environmental friendliness, resource conservation and pollution control. It has the same connotation as "eco-innovation", "environmentally friendly innovation" and "sustainable innovation", which are still popular in domestic and foreign research. Green innovation can improve corporate competitiveness, economic resilience, and environmental performance. Resource recycling, energy saving, pollution control, green product design, etc. can all be regarded as elements of green innovation.

3. Measuring Green Innovation

References are cited in the text just by square brackets [1]. (If square brackets are not available, slashes may be used instead, e.g. /2/.) Two or more references at a time may be put in one set of brackets [3, 4]. The references are to be numbered in the order in which they are cited in the text and are to be listed at the end of the contribution under a heading *References*, see our example below.

The main body of green innovation is often the enterprise. Therefore, green innovation data always come from the green innovation practice results of enterprises, especially green patent data, but different empirical studies have adopted different processing methods for green patent data. The research of Tan and Xu [12] used the number of green patents in the CNRDS database, and distinguished invention patents and utility model patents as substantive green innovations and strategic green innovations. Lin et al. [13] did not adopt utility model patents and design patents, but only considered invention patents, and to avoid the interference caused by high skewness, the natural logarithm is taken after adding 1 to the number of patent authorizations for green inventions, and then the processed value is used as a proxy variable for green innovation. Cai and Wang [14] used the method of adding the number of green invention patent applications and green utility model patent applications, then adding 1, and finally taking the natural logarithm. Lu and Zhu [15] adopted the method of taking the logarithm of the sum of green invention patents and green utility model patent applications as a variable representing green innovation. Li[16] considered that the number of green patents more reflects the green innovation ability of the current period, and at the same time considered the hysteresis of the impact of innovation activities and the autocorrelation of variables, set up a special formula $GTK_{i,t} = (1-\delta)GTK_{i,t-1} + PAT_{i,t}$. Among them, δ is the decay rate with a value of 0.1, which reflects the degree to which old knowledge is replaced by new knowledge. $PAT_{i,t}$ is the number of green patents, and $GTK_{i,t}$ represents the green knowledge stock in economy i in year t, and its initial value is set to $GTK_{i,t0} = PAT_{i,t0}/(g+\delta)$. δ is the average growth rate of the number of patents in 5 years between $t0$ and $t0+5$.

In addition, there are some studies that focus on the more microscopic individual level, and these studies often use Likert scale measurement. Jansen et al. [17] divided green innovation into exploratory green innovation and exploitative green innovation and set three topics to measure them. For exploratory green innovations, the topics set were "Frequently use new distribution channels for green products and services", "Frequently use the new opportunities in new markets of green products", and "Frequently seek out and reach out to new customers for green products and services in new markets"; For developmental green innovation, the topic set were "Frequently improve existing green products and services", "Enhancing economies of scale in existing green product markets", and "Continuously improving the efficiency of the supply of green products and services". Commonly used mature scales include Likert scales with different topics developed by Scott and Bruce [18], Chang[19], Pacheco et al.[20].

4. Impact of Environmental Regulation on Green Innovation

Green innovation is also a kind of innovation. According to the traditional hypothesis, environmental regulation will inevitably increase the compliance cost of the enterprise, thereby inhibiting the construction of new factories, reducing the profitability of the enterprise, and limiting the financial performance of the enterprise, which is unfavorable to innovation activities, i.e., it is inhibitory [21-23]. Since green innovation has double externalities, namely, knowledge spillover and environmental spillover, market allocation failure will inevitably occur. Currently, the government needs to use policy intervention to maximize the dividend of green innovation. Therefore, Porter proposed the famous "Porter Hypothesis". He believes that although environmental regulations will increase the compliance costs of enterprises, enterprises as key players in the market will be forced to innovate to meet the requirements of environmental regulations. The improvement of corporate performance brought about by this innovation can often cover or even exceed the compliance costs of the company. On the contrary, innovation will enhance the competitiveness of enterprises and promote the development of enterprises, and then realize the "win-win" of government environmental regulation and enterprise profitability [24]. Porter hypothesis can be divided into "Weak Porter hypothesis", "Strong Porter hypothesis" and "Narrow Porter hypothesis". Among them, the "Weak Porter Hypothesis" believes that environmental regulation can stimulate enterprises to innovate; "Strong Porter Hypothesis" believes that environmental regulation can not only stimulate corporate innovation, but also offset corporate compliance costs and enhance corporate competitiveness; "Narrow Porter Hypothesis" holds that flexible and moderate environmental regulation, especially some economic policies that the government can issue, can motivate enterprises to carry out innovative activities better than command-control environmental regulation. Porter hypothesis was subsequently extended and applied to meso- and macro-empirical studies, such as the study of the impact of environmental regulation on regional green innovation.

The Porter hypothesis has been validated in most empirical studies, but not supported in some studies. Saltari and Travaglini [25] found that the environmental policies aimed at incentivizing enterprises to invest in emission reductions

actually reduced the investment rate of enterprises in emission reductions. The increase of pollution tax will directly reduce the income of enterprises and lead to the reduction of enterprise investment, while the potential pollution cost borne by enterprises to carry out green innovation is too high, which will offset the benefits brought by government subsidies, thereby causing the reduction of enterprise investment. In addition, Kneller and Manderson [26] found that the increase in environmental R&D expenditures will reduce R&D expenditures in other fields, and this offset effect will even reduce the total R&D investment of enterprises. They believe that although environmental regulation does stimulate corporate innovation, it only transfers innovation resources from other fields to the field of environmental protection and has no special contribution to the total amount of corporate innovation. The total volume of innovation by firms has also failed to increase.

Although Porter hypothesis fails, this may be due to the "scale irreducibility" of economic and environmental issues [27], or it may be due to the failure of some enterprises to strictly implement environmental regulations. All in all, the conclusions of most studies can still satisfy Porter hypothesis, i.e., environmental regulation can promote green innovation.

5. Research Status and Insufficiency

Whether it is to test Porter hypothesis, or to explore new discoveries by jumping out of this hypothesis, the academic circle is still keen to study the impact of environmental regulation on green innovation. Zhang et al. [28] used survey data from 273 manufacturing companies in China to investigate the impact of command-control environmental regulation and market-based environmental regulation on green product innovation and green process innovation. The results show that both types of environmental regulations have a positive impact on green product innovation and green process innovation; Pang et al. [29] tried to investigate the quality of green innovation and analyzed the impact of environmental regulation on green innovation by using the Chinese patent census database and the panel data of industrial sectors in 30 provinces. The results show that the impact of environmental regulation on green innovation presents an inverted U relationship, and in the heterogeneity test, the impact of environmental regulation on green innovation in the central and western regions is not as significant as that in the southeastern region; According to the analysis results of the spatial error model, Fan et al. [30] found that there is a positive U-shaped relationship between environmental regulation and urban green innovation efficiency; Peng et al. [31] tried to distinguish the impact of different types of environmental regulation on different forms of green innovation, and built a theoretical framework of "environmental regulation-green innovation willingness-green innovation behavior" with green innovation willingness as an intermediary variable. The empirical results show that compared with incentive environmental regulation, control-command environmental regulation has a stronger impact on green innovation intention, and the impact of green innovation intention on green innovation behavior is very significant. The empirical results prove that environmental regulation can promote green innovation by enhancing the willingness of green innovation; Liu et al. [32] examined the impact of China's new environmental protection law on green innovation of listed companies in highly polluting industries. The results show that after the implementation of the new environmental protection law, enterprises tend to apply for more environmental patents, including utility model patents and invention patents, which proves that environmental regulation can promote green innovation. There are still many studies [33-39] on the impact of environmental regulation on green innovation.

Through the literature review of many related studies, it can be found that the research on the impact of environmental regulation on green innovation mainly has the following characteristics: (1) The independent variable representing "environmental regulation" is usually a dummy variable, or a proxy variable measured by policy strength. The variable that characterizes "green innovation" often uses the number of patents (grants or applications) in micro research, and green innovation efficiency or other proxy variables for measuring regional green innovation in macro research; (2) Most of the research objects are enterprises, and the survey data also come from enterprises, and there are relatively few regional macro studies; (3) Most of the publications come from Chinese scholars, and the data often come from secondary data such as Chinese listed companies or industrial enterprise databases; (4) The research results basically support the Porter hypothesis; (5) Regarding the relationship between environmental regulation and green innovation, most studies have proved that it has a linear promotion relationship, while some studies have proved that it presents a positive U-shaped or inverted U-shaped relationship, and a small number of studies have tested that it has a threshold effect ; (6) Empirical research accounts for the majority, most empirical research uses econometric tools such as spatial regression model and DID model, and a small part of empirical research uses management methods such as game theory. Research on theoretical derivation is relatively rare.

According to the induction of existing research, it is found that the existing research has the following deficiencies: (1) In micro research, the variable used to measure green innovation often uses the number of patents. In fact, patents do not represent the only achievements of innovative practice. Scientific and technological achievements, software works, governmental projects, enterprise projects, awards, etc. can all be regarded as the achievements of innovative practice. However, due to the lack of data, this part of the results cannot be included in the statistics of green innovation; On the other hand, in macro research, the measurement of regional or urban green innovation often requires the construction of an indicator system, and most of the indicators that constitute the indicator system are quoted from other people's research, and the selection of indicators is not scientific; (2) Most studies generally test the "Weak Porter Hypothesis", while the "Strong Porter Hypothesis" and "Narrow Porter Hypothesis" are rarely tested; (3) Most of the research objects are Chinese domestic enterprises or Chinese cities. This certainly shows that Chinese academic circles attach great importance to environmental regulation and green innovation, but it also shows that foreign research on the same level is very scarce, and research often lacks an international perspective.

6. Outlook

Based on the combing of existing literature, this paper summarizes the research status and shortcomings of environmental regulation on green innovation. In the future, we can start from the following paths to continue to enrich the relevant research content.

First, we can try to conduct long-term research and reduce

the use of existing second-hand data or patent data that has been used many times. We can try to obtain more data on green innovation of enterprises through long-term enterprise research, especially the data of small unlisted enterprises. Small enterprises are the majority group in the enterprise and have a strong representativeness. The patents, scientific and technological achievements, software works, projects, etc. related to green technology they own can undoubtedly represent the practical achievements of enterprises in green innovation. These data are more representative and authentic, can reduce the error of the research, and also make the research more "grounded".

Second, we can try to expand a research question horizontally. Using the obtained survey data, we can not only confirm the relatively simple "Weak Porter Hypothesis", but also continue to test the "Strong Porter Hypothesis" and "Narrow Porter Hypothesis" on this basis, making the content of the research more abundant.

Third, we can try to cooperate with foreign scholars, and try to obtain relevant foreign companies or data at the macro level, and then conduct exploratory research on some academic topics that are relatively risky (unpublishable if the attempt fails) but have deep digging value. It is possible to focus on the regional issues of China-foreign cooperation such as the "Belt and Road", look for more international topics and research hotspots, and focus on foreign companies or Chinese-funded companies abroad to make relevant research more diverse.

It is not enough to rely solely on the strength of the academic community, and more "government-industry-university/research institute" joint scientific research projects should be carried out. Since most of the environmental regulations are control-command environmental regulations, and the subject of implementation is the government, the government should play a leading role and provide convenience for scientific research from the following aspects:

First, innovate environmental regulation policies and provide a catalog of open policy lists. In most scenarios, environmental regulation has a positive impact on green innovation. Especially in terms of pollution control, the government should establish diversified environmental regulatory policies, and make these policies open to the public and achieve free access. These environmental regulatory policies should not be limited to the enterprise environmental protection director system, the enterprise environmental science and technology commissioner system, the community environmental protection supervisor system, the ecological compensation system, and the negotiation of pollution discharge restriction policies. In addition, environmental regulatory policies with economic incentives should also be disclosed in a timely manner, such as the amount, whereabouts, and audit status of special funds for green innovation, special funds for cleaner production, green subsidies for enterprises, incentive funds for green factories, incentive funds for green mines, and incentives for green construction sites, etc. Only by disclosing more environmental regulatory policies and providing practical and effective data can the quality of scientific research be improved, and the credibility of research be enhanced.

Second, promote the effectiveness of open environmental data and establish norms for open environmental data. In addition to obtaining data on environmental regulation and corporate green innovation, more environmental data are needed to conduct in-depth mechanism analysis and research, rather than processing statistical environmental data. These data can serve as mediators or moderator variables, contributing to dissecting the black box of environmental regulation. Therefore, local government departments at all levels should further classify environmental data under the guidance of environmental protection departments, give more accurate classifications to environment, resources, energy, and ecological data, and improve the ease of identification. The government should standardize and simplify the format, storage method, and use steps of data to enhance the actual use value of data. By sorting out environmental data, it can provide more convenience to the academic community and facilitate the study of more mechanism issues.

Third, improve the internal technical capabilities of government departments and establish a good sense of service. Just having massive amounts of data is not enough, it is also necessary to strengthen the talent allocation and capacity improvement of environmental data opening staff. On the one hand, the government should establish a sense of data openness that puts service first and takes the initiative for the staff and build a holistic view of environmental protection data development. Government staff must establish a strong sense of responsibility, uphold a good service attitude in the data opening work, and comprehensively promote the data opening process in the spirit of "opening and sharing". On the other hand, it is necessary to strengthen the construction of the talent team and regularly train the data opening staff. Training can enhance the environmental protection awareness and sense of responsibility of government employees, and can also improve their work skills, thereby reducing the sense of isolation for the public to share and use environmental data, improving the ability to identify and respond to data open risks, and improving the quality of environmental data. Only by improving the service quality and skills of government staff can the government better cooperate with the academic community and improve the quality of scientific research.

All in all, the influence of environmental regulation on green innovation is far from fading, and there are still many topics worthy of further exploration by the academic community. We look forward to more fruitful results in this field in the future, to make academic contributions to the sustainable development of human beings and environmental protection.

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