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Dynamic relationship among environmental regulation, technological innovation and energy efficiency based on large scale provincial panel data in China

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ABSTRACT

Based on the large scale provincial panel data on in China from 2006 to 2015, this paper uses the directed acyclic graph (DAG) and structure vector autoregrression (SVAR) to study the internal dynamic relationship among the environmental regulation, technological innovation and energy efficiency. The results of the DAG analysis confirm the existence of three conduct paths among environmental regulation, technological innovation and energy efficiency. First, the market incentive environmental regulation contributes directly to energy efficiency. Second, the market incentive environmental regulation drives the energy efficiency through technological innovation. Third, the command control environmental regulation contributes directly to energy efficiency. The results of forecast error variance decomposition based on SVAR model corroborate the view that the impacts of the command control environmental regulation and market incentive environmental regulation on energy efficiency have no obvious difference in the short term. In addition, with the extension of the forecast period, the promotion effect of the command control environmental regulation on energy efficiency gradually decreases, whereas the promotion effect of the market incentive environmental regulation on energy efficiency gradually increases. Technological innovation has a significant role in promoting energy efficiency both in the short and the long term. The changes in technological innovation are affected not only by itself, but also by the market incentive environmental regulation, whereas the command control environmental regulation has no obvious impact on technological innovation.

1. Introduction

Since the implementation of the reform and opening up policy, China's economy has realized rapid growth and achieved remarkable results. However, this rapid growth was anchored on the high pollution and high energy consumption. The fifth Plenary Session of the 18th Communist Party of China Central Committee proposed that “China will accelerate the construction of resource-saving and environment-friendly society”. This proposal was an affirmation of the decisions to implement the strategy of sustainable development and promote the harmonious development of humans and nature. A Strong environmental regulation is an important guarantee for the construction of a resource-saving and environment-friendly society. The reasonable design and effective implementation of the regulation tools can effectively control the energy consumption and improve the environment (Brunel and Levinson, 2016). Nevertheless, whether highly intensive environmental regulation can really contribute to the improvement of China's energy efficiency and environmental regulation could affect energy efficiency through technological innovation remain unknown. The investigation into the relationship among environmental regulation, technological innovation and energy efficiency can help in the formulation of an effective environmental regulation policy and improve the quality of environmental regulation policy. However, previous studies have discussed the relationship between the two variables of environmental regulation, technological innovation and energy efficiency independently. Few studies have placed environmental regulation, technological innovation and energy efficiency into the same framework of analysis, making it difficult to determine the relationship among the three factors. Therefore, we will study the relationship among environmental regulation, technological innovation and energy efficiency to provide the reference for setting a reasonable environmental regulation intensity for the promotion of technological innovation and energy efficiency to achieve energy-saving targets.

This study contributes to the literature in two ways. First, we divide environmental regulation into command control environmental regulation and market incentive environmental regulation, and use

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directed acyclic graph (DAG) methods to study the causal relationship among command control environmental regulation and market incentive environmental regulation, technological innovation, and energy efficiency under the same framework, and extract three conduct paths of these four variables. Second, we use Structure Vector Autoregression (SVAR) method to study the dynamic effect of command control environmental regulation and market incentive environmental regulation, technological innovation, and energy efficiency, and reveal the trajectories of the impact among these four variables in different sample periods.

2. Literature review

2.1. Literature review of the relationship between environmental regulation and technological innovation

In traditional economic theory, mutual inhibition between environmental regulation tools and technology innovation exists, and the main reason is that the implementation of environmental regulation will increase the cost of enterprise, and occupy the innovation resource of enterprise. Magat (1978) first affirmed that technological innovation is an important factor in solving the environmental protection and enterprise economic performance, and the technological innovation can not only reduce the cost of pollution control, but also improve production efficiency and profit margins through developing new products and improving the production process. In the 1990s, Porter and Vander Linde (1995) believed that appropriate environmental regulation can encourage enterprises to conduct more innovative activities and that these innovations will enhance the productivity of enterprises, thereby offsetting the costs of environmental protection and enhancing market profitability. Lanjouw and Mody (1996) investigated the relationship between environmental regulation and environmental technology invention in the United States, Japan and Germany. The results confirmed the positive correlation between pollution control expenditure and environmental patent quantity. The results further indicated that the number of environmental patent increased with the increase of government expenditure, but the effect of environmental regulation on technological innovation had a lag period of two years. Brunnermeier and Cohen (2003) used panel data to analyze empirically the relationship between environmental regulation and technological innovation of the 146 manufacturing industries in the United States from 1983 to 1992. The results indicated the existence of a positive correlation between pollution control cost and environmental patent. Innes and Carrionflores (2005) used the data of 127 manufacturing industries in the United States from 1989 to 2002 to examine the relationship between enterprises' pollution emissions and environmental protection technology patents. The results verified that the environmental regulation policy of the United States could encourage technical innovation of the regulated enterprises. With a newly created dataset of SO_2 and Nox regulations for coal-fired power plants and a patent-based measure of the technology frontier, Lovely and Popp (2011) confirmed that technological innovation by early adopters will influence the timing of new environmental regulation in non-innovating countries. Ma et al. (2011) classified environmental regulation tools as command control environmental regulation and market incentive environmental regulation, and empirically studied the influence of these two tools on technological innovation using the method of hierarchical regression. Their results indicated that command control environmental regulation did not have significant impact on technological innovation and that the market incentive environmental regulation had a significant positive impact on technological innovation. Sen (2015) used pollution tax as an index of environmental regulation and studied the relationship between environmental regulations and technological innovation by focusing on the automobile industry in a cross-country setting. The results validated that environmental regulation could not only improve the level of technological innovation but also reduce the environmental pollution. Debnath (2015) studied the impacts of environmental regulations on technological innovation in Japan and confirmed that environmental regulation had positive effect on technological innovation. C. Zhang et al. (2016) and P. Zhang et al. (2016) studied the influence of environmental regulation on enterprise technological innovation by the panel data of 30 provinces in China from 2003 to 2012. The results indicated that expenditure-style environmental regulation has an obvious crowding-out effect on enterprise technological innovation, and investment-style environmental regulation has incentive effects on technological innovation overall. Albrizio et al. (2017) found that a tightening of environmental policy is associated with a short-term increase in industry-level productivity growth in the most technologically advanced countries. Guo et al. (2017) used structural equation modeling approach to confirm that environmental regulation can significantly positively influence technological innovation.

2.2. Literature review of the relationship between environmental regulation and energy efficiency

Mandal (2010) used the data of India's cement industry to examine the effect of environmental regulation on energy efficiency, and determined that environmental regulation really could promote the increase of energy efficiency. Chen and Zhang (2012) empirically examined the effect of different environmental regulation tools on energy efficiency. The results indicated that discharge permit had positive effect on the enhancement of energy efficiency in the eastern region, and had negative effect in the central and western regions. These results further showed that environmental enforcement intensity had negative effect on the enhancement of energy efficiency in the western region and did not have significant effect in the eastern and central regions, and pollutant drainage fee had a negative effect on the enhancement of energy efficiency in the eastern region, while had a significant positive effect in the western and central regions. Bi et al. (2014) used the data on China's thermal power industry to analyze the effect of environmental regulation on energy efficiency, and determined that environmental regulation is conducive to promoting the energy efficiency of thermal power industry. Based on the survey of Danish enterprises, Dirckinck-Holmfeld (2015) studied the efficacy of environmental regulation on the enhancement of energy efficiency. The results confirmed that environmental licensing and ban framework of the Danish government were relatively vague, and could not provide the correct direction to promote energy efficiency. C. Zhang et al. (2016) and P. Zhang et al. (2016) analyzed the panel data of 30 provinces in China from 2000 to 2012 by using the super-efficiency DEA model. Empirical results showed that environmental regulation can significantly promote the total factor energy efficiency in China, which is an existing reversed transmission mechanism.

2.3. Literature review of the relationship between technological innovation and energy efficiency

Birol and Keppler (2000) pointed out that energy efficiency is the external manifestation of the production technology level, and the improvement of energy efficiency is the result of technological innovation. With the statistical data on China from 1978 to 2006, Tan and Zhang (2010) used a state space model to study the influence of technological innovation on energy efficiency and verified that technical progress had positive impact on energy efficiency. Xing (2014) used the grey correlation method to study the effect of technological innovation on energy efficiency, and the results verified the strong correlation between technological innovation and energy efficiency. Cagno et al. (2015) used the data of enterprises in Italy to study the effect of technological innovation on energy efficiency, and the result showed that technological innovation can effectively enhance energy efficiency of enterprises. Wei et al. (2016) studied the relationship between technology input-output and energy utilization efficiency in Shanghai over