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A study on evolution of energy intensity in China with heterogeneity and rebound effect

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ABSTRACT

Spatio-temporal heterogeneity and rebound effect are significant issues on evolution of energy intensity. This paper analyzed the local effect on the energy intensity evolution cross the thirty provinces of China from 1995 to 2011 applying the Geographically and Temporally Weighted Regression Model, calculated the rebound effect in both national and provincial levels during the same sample period above, and examined the effect of technological progress on energy intensity when there exists rebound effect. The results show that heterogeneity exists significantly in the evolution of China's energy intensity. On the point of view of the spatial and the temporal dimension, the identification of heterogeneity helps to comprehend the situation of the energy intensity which has been improved in higher degree during the period after 2000 than before, and more obviously in eastern region than central and western region. This paper also proves that the effect of technological progress on decreasing energy intensity is restricted because of the rebound effect. Therefore the spatio-temporal variation in the path of energy intensity's evolution should be fully considered, and corresponding policies are necessarily made to reduce rebound effect, which will lead to make the balanced development of energy consumption in different regions of China.

1. Introduction

Energy problems are concerned increasingly by the whole society when the contradiction between economic development and energy supplying gap becomes serious. Currently, decreasing the energy intensity to reduce energy consumption is an effective way to deal with energy issues. In order to effectively decrease the energy intensity, it is important to study the evolution of energy intensity in China.

Previous research focus on the issue that how the driving factors, such as technological progress, structural factors and institutional factors, affect the evolution of energy intensity [1–8]. However, the majority of these studies ignore the real fact that the regional and periodic unbalance of energy economy widely exists in China in the past several decades. Although some scholars study the spatial heterogeneity in different regions of China and temporal heterogeneity in different stages of Chinese economic development respectively [9,10], the spatial and temporal effect of these factors on energy intensity in the evolution haven't been studied comprehensively. If the spatio-temporal heterogeneity in the evolutionary process of the energy intensity is ignored, it is hard to reveal the fact of the energy intensity evolution in China.

Among these driving factors, the technological progress, which is important in the evolution of energy intensity, can decrease energy intensity to some extent. Many scholars regard it as a key factor in the evolution to increase the energy efficiency and decrease the energy intensity. However, it may produce *energy rebound effect*, which means technological progress, with energy efficiency improving, can promote economic growth, which leads to intense energy consumption. The concept of rebound effect stems from *Khazzoom-Brookes Postulate* [11]. In the next several decades, the definition is continuously developed by a number of researchers [12–16]. And many scholars have studied and calculated the energy rebound effect and found that the rebound effect exists significantly in China [17–22]. Also some researches focus on the heterogeneity in the rebound effect [23]. The rebound effect of energy consumption causes partially increasing of the energy savings, which directly weakens promoting effect that technological

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progress exerts on energy efficiency, and makes the relationship of technological progress and energy intensity become complicated. Thus if we want to study the evolution of the energy intensity comprehensively, the impact of rebound effect, especially on technological progress, couldn't be also neglected.

Different from previous studies, this paper will focus on the issues mentioned above, namely heterogeneity and rebound effect in energy intensity evolution. To begin with, we will try to reveal the spatio-temporal heterogeneity of the energy intensity evolution, in order to make a corresponding strategy about how to balance the regional development in energy economy in future. GTWR (Geographically and Temporally Weighted Regression) Model is a useful analytical framework to investigate the spatio-temporal heterogeneity and it is applied in this paper. And then, details on how the energy rebound effect exerts the influence on the evolution of energy intensity will be discussed to reveal how the energy rebound effect exerts an impact on the process of technological progress' improving energy intensity. Then some effective policies are given to relieve shock of the rebound effect. It is significant to make a contribution to saving energy, developing a low-carbon economy, and realizing the sustainable development of the Chinese economy.

The rest of the paper is organized as follows. The research methodology is developed and the dataset required is described in Section 2. The empirical results of GTWR model are provided and discussed in Section 3. The further discussion with rebound effect and some related analyses are displayed in Section 4. Section 5 provides some related policy implications followed, finally, by our conclusion.

2. Method and data

In Section 2.1, it is mainly to introduce the research method. In order to identify the spatio-temporal heterogeneity, an energy intensity evolutionary model based on GTWR model is developed in Section 2.1.1, and a calculating method of rebound effect is provided in Section 2.1.2 for making further discussion in Section 4. The descriptions of variables and data sources required in Section 2.1.1 and Section 2.1.2 are provided in Section 2.2.1 and Section 2.2.2 respectively.

2.1. Method

2.1.1. The energy intensity evolutionary GTWR model

The energy intensity is commonly measured by the ratio of energy consumption and economic output. Existing literature show that three major factors play key roles in the energy intensity's evolution.

(1) Technological progress: In a stable economic stage, technological progress is the most important factor in the evolution of the energy intensity [1]. Energy intensity can be decreased not only by improving the marginal productivity of elements, but also indirectly by improving the efficiency of energy configuration. But the relationship between technological progress and energy intensity is highly complex [11]. However some researchers denied the conclusion and proved that the technological progress does not decrease the energy intensity significantly, even negatively [2];

(2) Structural factors: On one hand, the optimization and restructuring of the industries can lead to the transformation from heavy industry to light industry, and it can significantly reduce energy intensity [3,4]; on the other hand, the energy consumption structure, with high consumption of coal, has greatly restricted the decline of China's energy intensity [5];

(3) Institutional factors: Institutional factors mainly include energy price and the foreign openness. In some energy-intensive industries of China, the energy price is one of the most important factors to regulate, as well as in the transitioning countries in the Central and Eastern European. The earlier the marketization of energy price is the higher regulating effect on energy efficiency [6]. Foreign Openness can introduce a number of enterprises which possess higher production efficiency, and then improve energy efficiency [7]. But there is also the transfer of polluting industries exerting environmental influence, causing an increasing effect on the energy intensity from the foreign investment [8].

Based on the existing literature, this paper selects the following five variables as the main driving factors affecting the energy intensity, including IS (industrial structure), TP (technological progress), EP (energy price), CS (energy consumption structure), OPEN (foreign openness). Based on the five factors selected, the Evolutionary Model of Energy Intensity can be constructed as follows:

$$EI = A(EP)^{\beta_2} \exp(\beta_3 IS + \beta_4 CS + \beta_5 OPEN + \mu) \tag{1}$$

where, A denotes the Technological Progress, and $A = e^{\beta_0 + \beta_1 TP}$. Then the linear logarithmic model is:

$$\ln EI_{it} = \beta_0 + \beta_1 TP_{it} + \beta_2 \ln EP_{it} + \beta_3 IS_{it} + \beta_4 CS_{it} + \beta_5 OPEN_{it} + \mu_{it} \tag{2}$$

While some researchers have proved that the driving effects of these factors vary across time and space. Fu X. et al. analyzed the dynamic development of energy efficiency, which illustrated the changing trend of energy efficiency [10]. Zhou J. analyzed the spatial variance of energy efficiency and the internal mechanism of the inter-province energy efficiency and his research indicates that spatial dependence and spatial heterogeneity, which caused by the energy development strategies put forward by government and the inter-province energy flowing, widely exist in the evolution of energy efficiency in China [9]. These researches also reflect the shortcoming that the traditional econometrics models only emphasize the averaging definition of the parameters, hardly reflecting the non-stationarity of the parameters across space and time [24,25]. However, the regional structure issues in the energy intensity's evolution cannot be reflected by the way in which only the temporal variation is considered, and the changing trend of decisive mechanism in the evolution of energy intensity cannot be revealed by the way in which the spatial variation is just considered. Only when the temporal and the spatial variation are both considered, which is called spatial-temporal heterogeneity, the evolution of energy intensity can be analyzed deeply and comprehensively.

Given the spatio-temporal correlation and nonstationarity, it is more close to the reality to take the spatial-temporal heterogeneity in the evolution of energy intensity into consideration. GTWR model is an effective method, which applies the coefficient-varying method to the panel data, to deal with the spatio-temporal heterogeneity [26]. So this method is used in this paper to obtain the empirical result.

GTWR Model, different from the traditional regression framework, is a method to estimate parameters locally, aiming to depict the spatio-temporal heterogeneity. This model allows the parameter estimates to vary across space and time, so it is likely to capture local effects $\beta_k(u_i,v_i,t_i)$ of the specific point (u_i,v_i,t_i). Based on the GTWR model, we can extend our model by allowing the parameters to be estimated locally and then the framework can be expressed as follows: