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The impacts of renewable energy and technological innovation on environment-energy-growth nexus: New evidence from a panel quantile regression

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ABSTRACT

To mitigate climate change, many studies have been conducted to identify the determinants of CO_2 emissions. However, a consensus has not been reached yet on the issue because past work has often not considered the unobserved individual heterogeneity across countries. Therefore, this study revisits the environment-energy-growth nexus by employing a panel quantile regression to incorporate the effects of renewable energy consumption and technological innovation within the research background of global 30 countries over the period 1980–2014. The advantage of this method is considering the distributional heterogeneity to provide a detailed description of linkage between the CO_2 emissions and driving factors at different emissions levels. The results show that the effects of determinants on CO_2 emissions are heterogeneous. For high-emissions countries, the function of renewable energy consumption is limited in reducing CO_2 emissions due to the smaller proportion of renewable energy use. Moreover, technological innovation greatly affects countries with relatively higher CO_2 emissions. Therefore, one option is to financially support and apply technological innovations to generate renewable energy at lower costs as well as increase energy efficiency. Moreover, transforming the economic growth mode is helpful to transfer from non-renewable to renewable sources of energy to meet energy demand.

1. Introduction

With rapid economic development and technological progress, the demand for energy in developed and developing countries has increased. Although energy consumption can lead to economic growth, it is the principal reason for environmental degradation [1]. Over the past few decade, environmental pollution has become one of the greatest global issues because of large increases in greenhouse gas (GHG) emissions [2]. With the development of industry, GHG emissions, carbon dioxide (CO_2) emissions in particular, have sharply increased [3]. Moreover, the IPCC (2007) predicted that energy-related CO_2 emissions in 2030 will have increased by 40–110%. Therefore, it is necessary to investigate the energy consumption-related factors that influence changes in CO_2 emissions to realize energy-saving emission reduction and achieve low carbon economy development.

Regarding the main factors driving CO_2 emissions, the majority of studies have focused on economic growth and aggregate energy consumption. However, according to [4] and [5], aggregate energy consumption and economic growth alone may fail to explain changes in CO_2 emissions. In fact, in order to attain sustainable economic development, countries have turned their attention to the development and utilization of renewable energy. We will rely on renewable energy in the future [6]. In 2014, renewable energy accounted for 19.2% of global final energy consumption. The International Energy Agency (IEA) predicted that renewable energy will be the fastest growing component of global energy demand. For example, renewable energy technologies are the fastest growing sources of electricity in the US. Furthermore, environmentalist [7,8] have increased interest in the distribution of renewable energy resources in the power system because renewable energy is a virtually carbon-free energy source that can serve as a potential solution to climate change problems. However, according to [9], a much smaller part of work in the literature

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Nomenclature

Abbreviation

CO_2	Total carbon dioxide emissions
NRE	Non-renewable energy consumption
RE	Renewable energy consumption
PGDP	Real per capita gross domestic product
TECH	Technological innovation
FDI	Foreign direct investment
NRE	International Energy Agency
FINA	Financial development
POP	Population size

Symbols

L	Natural logarithms

investigated the linkage between economic growth and energy consumption by energy source (i.e., renewable energy consumption and non-renewable energy consumption). Therefore, we need to pay attention to the impact of renewable energy consumption on CO_2 emissions.

Because technological innovation is crucial in improving energy efficiency [10–12], it is a factor worthy of our attention when we explore the determinants of CO_2 emissions. High technology enables the economy to produce a level of output consuming a lower level of energy [13]. Moreover, technological innovation could lead to quicker adoption of renewable energy to meet energy demands and change the energy consumption structure. Even though previous researchers have extensively analyzed the relationship between disaggregated energy consumption, CO_2 emissions and economic growth, they did not include the effect of technological innovation in the environment-energy-growth nexus. Therefore, this paper discusses the influence of technological innovation on CO_2 emissions to expand the research target.

In terms of research method, most of the existing literature [14–19] adopted conventional panel estimation techniques that failed to consider unobserved individual and distributional heterogeneities across countries in the panel. In addition, some studies rely on a multivariate framework without including some control variables which lead to the omitted variables bias.[1] As a result, existing studies did not come to the consensus conclusion concerning the effects of driving factors on CO_2 emissions. To fill these gaps, we examine the determinants of CO_2 emissions using panel quantile regression, adding relevant variables as control variables.

This paper makes several contributions to the existing literature. First, as shown in Table 1 in the appendix section, most existing studies used aggregate energy consumption as variable in their models and thus failed to estimate the effects of energy consumption by source. Instead, we include renewable and non-renewable energy sources separately in this models, and as such, it provides us some new finding about their disaggregated impacts on CO_2 emissions. Second, it employs the panel quantile regression method to empirically investigate the influence of driving factors on CO_2 emissions at different levels of CO_2 emissions in global 30 countries, which could provide more complete results compared to conventional panel regression and demonstrate the possible heterogeneity. Third, in order to avoid the omitted-variable bias faced by previous studies, several related control variables are included in our model. Indeed, against the background of an apparent lack of consensus in the literature on the environment-energy-growth nexus issue, the results of this study could provide scientific information for policy-makers to target policies to meet the CO_2 emissions level of a specific country rather than on the average of the entire group.

The outline of this paper is organized as follows: Section 2 reviews the related literature on the environment-energy-growth issues. Section 3 explores the panel quantile regression model and data, and Section 4 presents the results and a detailed discussion. The last section concludes the paper and presents related policy implications.

2. Literature review

There are three main research groups studying the environment-energy-growth nexus in the environmental economics literature. First, scholars ([20–24]) focuses on examining the validity of the Environmental Kuznets Curve (EKC) hypothesis. In fact, in the most EKC framework, one limitation of this group is that they identified the relation between environment and income in a bivariate framework and hence suffers from omitted variable bias [25–29]. Therefore, in order to circumvent omitted variable bias in EKC framework [30–32], introduced energy consumption into the link between CO_2 emissions and economic growth (Appendix Table 1) and found that the environmental EKC hypothesis was invalid. Some scholars [25,33–36] confirmed the existence of U-shaped relationship between CO_2 emissions and economic growth by building on the environmental Kuznets curve (EKC) framework. While there was also some evidence that the EKC hypothesis was an N-shaped relationship [37]. Indeed, existing studies also failed to find evidence of a consensus conclusion about the effects of economic growth on CO_2 emissions.

Actually, the influence of energy consumption in CO_2 emissions is also controversial. Some scholars concluded that total energy consumption has a positive effect on CO_2 emissions [25,32,38–40]. Some researchers [25,32] thought that there existed bidirectional causality between CO_2 emissions and economic growth. While, according to [39,41], there was unidirectional causality from energy consumption to CO_2 emissions. Some results of Granger causality tests indicated the existence of a positive causality from CO_2 emissions to energy consumption [6].

Second, the majority of the environment-energy-growth nexus comes from aggregate energy consumption and conventional fossil energy consumption. Indeed, a much smaller body of work in the literature discussed the relationships between non-renewable energy consumption, renewable energy use, economic growth and CO_2 emissions (Appendix Table 2). All previous studies showed that the non-renewable energy consumption stimulates the CO_2 emissions, but the findings varied regarding the effects of renewable energy consumption.

Renewable energy consumption has contributed to CO_2 emissions reduction and improvement in technical and economic efficiency [42] [43].concluded the unidirectional causality exists between renewable energy use and economic growth. While, some researchers [44,45] revealed a bidirectional causality between them. And, some scholars [18,23,24,46–48] found that renewable energy mitigated CO_2 emissions. While [15,49,50], supported the renewable energy consumption has positive effect on CO_2 emissions. In addition [51], thought that GDP and renewable energy consumption contributed to CO_2 for lower threshold, while renewable energy use mitigated CO_2 for upper threshold. In conclude, empirical findings regarding the nexus of economic

[1] Omitted variables bias occurs when some variables are correlated with the dependent variable and one or more other independent variables but they are omitted in a regression model.