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How effective are energy efficiency and renewable energy in curbing CO_2 emissions in the long run? A heterogeneous panel data analysis

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ABSTRACT

Energy efficiency and renewable energy are considered to be two indispensable solutions to control GHG (greenhouse gas) emissions. Moreover, industrialization is at the center of discussions on the roles of countries to reduce CO_2 emissions. However, the literature is underprovided to understand the long run contribution of energy efficiency, renewable energy and industrial composition in reducing GHG emissions at the macro level. In this study, we differentiate the effects of economic activity, energy efficiency, economic structure and use of renewable energy resources on CO_2 emissions. We develop energy efficiency indices for thirty six countries for the period of 1971–2009 and use a CCE (common correlated effects) estimator model that is consistent under heterogeneity and cross-sectional dependence. We find a positive significant effect of energy efficiency on CO_2 emissions in the long-run. Similarly, substituting renewable energy for non-renewable energy reduces CO_2 emissions in the long-run. Our results ensure widely discussed roles of energy efficiency and renewable energy in curbing CO_2 emissions. Furthermore, the scale of economic activity measured by real income and industrialization have significant positive effect on CO_2 emissions.

1. Introduction

The relationship between CO_2 emissions and economic activity is important in understanding global climate change and controlling GHG (greenhouse gas) emissions . This relationship is widely explored through the EKC (Environmental Kuznets Curve) hypothesis, and granger causality and panel cointegration analyses on the factors affecting CO_2 emissions in the literature. Dinda (2004) [13] and Al-mulali (2012) [2] provide extensive reviews on EKC, and granger causality and panel cointegration analyses, respectively. While the literature is extensive, energy efficiency and renewable energy, which are considered to be two indispensable solutions to control GHG (greenhouse gas) emissions, have not been studied as the factors affecting CO_2 emissions. In addition to energy efficiency and renewable energy, industrialization is also at the center of discussions on the roles of countries to reduce CO_2 emissions. The net effects of these factors can be best observed over a longer time horizon. Therefore, we investigate the long-run equilibrium relationship between these factors and CO_2 emissions.

We separate economic activity into its components: scale (scale is sometimes called economic activity), energy efficiency, economic structure and the use of renewable energy resources. The scale component captures the effect of increases in GDP (gross domestic product) on CO_2 emissions keeping economic structure and efficiency constant. Economic structure confines the effects of shifts to the agriculture, manufacturing and service sectors. Countries may experience structural changes from pollution-intensive low value added manufacturing sectors to low polluting high value added service sectors. The effect of technology on CO_2 emissions is embodied in energy efficiency. As countries grow, they obtain more resources that enable the production of energy efficient products. Greater energy efficiency in turn enables higher income with lower CO_2 emissions. In the paper, we develop a comprehensive and reliable measure of energy efficiency for each country to study its effect on emissions and to investigate the potential of energy efficiency policies to reduce emissions. The strategies in use to reduce CO_2 emissions suggest that the substitution of renewable energy resources for non-renewable resources is a well-established way to reduce emissions, especially the replacement of fossil fuels. While policy makers suggests energy efficiency measures and the use of renewable energy sources along with other CO_2 emissions tax or trading schemes, the literature lacks empirical studies investigating

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the relationship between energy efficiency and renewable consumption and CO_2 emissions using current time series econometrics methods with actual data. Therefore, our model specifically captures the effects of energy efficiency via a comprehensive and reliable measure and the substitution of renewable energy resources for non-renewable sources on CO_2 emissions enabling us to fill this gap in the literature and to provide empirical evidence on the roles of renewable energy and energy efficiency in reducing CO_2. To our knowledge, no studies have investigated the effects of aforementioned economic activities on CO_2 emissions across countries and over time.

Finally, we employ the factor decomposition analysis with the most advanced panel data methodology available, the CCE (common correlated effects) estimation model of Pesaran (2006) [32] to investigate the role of energy efficiency and renewable energy in curbing CO_2 emissions for 36 countries for the period 1971–2009. The superiority of the CCE approach arises from the fact that it can handle heterogeneity and both weak and strong forms of cross-section dependence. Furthermore, the country-specific effects and the heterogeneous trend components absorb the effects of any time-invariant or time-varying omitted variables, thereby eliminating omitted variable bias.

The rest of the paper is organized into four sections. Section 2 provides a review of the relevant literature. The data are described, variables are constructed and the estimation methodology is introduced in section 3. Section 4 presents the results. Finally, we provide some concluding remarks in section 5.

2. Literature review

The literature on the relationship between economic growth and environmental pollution has two main components, the first focusing on economic growth and environmental pollution (the economic growth-environmental pollution nexus), and the second concentrating on economic growth and energy consumption (economic growth-energy consumption nexus). A voluminous EKC and Granger causality literature with a bivariate framework has emerged in studies of both nexuses [1,3,35,37].

2.1. Economic growth-environmental pollution nexus

The studies in the first part of the literature investigate the relationship between economic growth and environmental pollution using income and CO_2 emissions, the main source of the GHG effect. Within the first nexus, the increasing number of EKC studies has motivated the development of two other subsets of studies on the causal relationship between CO_2 emissions and income and on the estimation methodologies used to understand this relationship.

In the EKC portion of the literature, a large number of empirical studies focus on the shape of the EKC for single countries or groups of countries. These studies' findings regarding the relationship between CO_2 emissions and GDP (gross domestic product) vary from study to study. While some studies verify the inverted-U shape of the EKC, others find different curve shapes. Based on an extensive review of the literature, Jaunky (2011) [19] discloses that empirical evidence on the existence of the EKC has always been mixed and conflicting. Jaunky (2011) [19] specifically emphasizes that the implementation of renewable energy resources should accompany direct measures curbing CO_2 emissions.

Similarly, Piaggio and Padilla (2012) [34] study the relationship between CO_2 emissions and economic activity for 31 countries for the period from 1950 to 2006 using a co-integration analysis. They suggest considering the differences among countries in the relationship between CO_2 emissions and economic activity to avoid faulty estimations and conclusions. They state that differences would depend on the real determinants of the relationship, which would be shaped by energy and environmental policies. As inferred by Piaggio and Padilla (2012) [34] and Jaunky (2011) [19]; our model captures the effects of these policies by including energy efficiency and renewable energy resources in reference to non-renewable resources in a multivariate setting.

Facilitated by EKC studies, studies focusing on the causality between CO_2 emissions and income investigate the existence and the direction of the relationship. Similar to the EKC research, the empirical evidence for the causal relationship differs from study to study. These puzzling results on EKC and the causal relationship between CO_2 emissions and GDP have motivated researchers to scrutinize the econometric techniques employed in the relevant literature. Methodological studies have been carried out to test the validity of the econometric models, tools and functional forms [39,40]. As the estimation and methodology subset of the literature expands with the desire to eliminate estimation problems and find appropriate robust techniques, the literature also values studies that extend the findings of existing studies by implementing new econometric techniques developed by Pesaran (2006) [32] for the panel data [6,38].

2.2. Economic growth-energy consumption nexus

The second part of the literature, the economic growth-energy consumption, extensively studies the causal relationship between energy consumption and GDP. Ozturk (2010) [26] provides a comprehensive review of the literature and concludes that there are conflicting results on the existence and the direction of this causality. Different data sets, country characteristics, variables used and econometric methodologies are listed as the main reasons for these conflicting results. Ozturk (2010) [26] suggests that researchers working in this area should employ new approaches and perspectives rather than simply analyzing different countries and different time intervals using the same models and methods.

Although many studies focus on bivariate models of energy and output, a few studies include a third variable such as urbanization, employment, energy prices, capital or labor in addition to energy and output (e.g. Refs. [14], [21,23,26,38]). Among these studies, Lee and Chang (2008) [21] touch on the importance of energy efficiency in reducing GHG emissions, however, they do not directly study the relationship between energy efficiency and GHG emissions. They argue that governments in Asian countries should aim to implement energy efficient industrial processes to better control GHG emissions. Given the importance of energy efficiency emphasized in the literature, we incorporate energy efficiency in our model to see its impact on CO_2 emissions.

Energy intensity is one of the components derived from CO_2 emissions. Although Wing (2008) [41] only studies a single county, this work is of interest because it focuses on energy intensity in the U.S. at an aggregate level and the multiple factors behind it over the period from 1958 to 2000. Specific attention is devoted to technical change and industry composition. Wing (2008) [41] finds that changes in industrial composition and disembodied technological progress are the main sources of the decline in the energy intensity. Input substitution due to changes in the relative prices of inputs has only transitory impact. Similarly, Sadorsky's (2014) [38] work on the effect of urbanization on CO_2 emissions is also of interest since it captures the effect of technology through energy intensity in emerging economies. Sadorsky (2014) [38] stresses the role of reduction in energy intensity in reducing CO_2 emissions in emerging countries where population and affluence are likely to rise.

The other important factor affecting CO_2 emissions is industrialization or changes in the composition of a country's economic activities. Although Cherniwchan (2012) [9] does not focus on CO_2,