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The causal relationship between renewable electricity generation and GDP growth: A study of energy sources ☆

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ABSTRACT

This paper examines the causal relationship between economic growth and electricity generation from renewable sources (biomass, geothermal, hydroelectric, solar, waste, and wind) across 20 OECD countries over 1990 to 2008. The results from a commonly used panel error correction model find (a) a bidirectional relationship between aggregate renewable generation and real GDP, (b) biomass, hydroelectricity, waste, and wind energy exhibit a positive long-run relationship with GDP, (c) hydroelectricity and waste generation exhibit a short-run positive bidirectional relationship with GDP growth, and (d) biomass, hydroelectric, and waste electricity generation have the largest impact on real GDP in the long-run. We extend the analysis to consider the possibility of structural breaks and cross-sectional dependence. Accounting for cross-sectional dependence, we find that in the short-run, increases in biomass and waste generation negatively affect GDP, while aggregate renewable and hydroelectricity increase GDP. Energy conservation policies will positively impact GDP, if the policies cause decreases in biomass or waste energy but increase hydroelectricity and wind energy.

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1. Introduction

As energy costs have risen, more scrutiny has been placed on the potential negative consequences of expanded energy use; however, a reduction in energy usage could have unintended consequences for economic growth. In order to determine the impact of energy use on economic growth, a plethora of literature has looked at the relationship between energy consumption and economic growth. Payne (2010b) provides an extensive overview of this literature, examining 101 studies over the period 1978 to 2008, but no clear consensus has been found on the causal nature of this relationship.[1]

From this literature, a much smaller body of work has emerged examining a possible relationship between renewable energy and economic growth. Empirical evidence on the relationship is mixed. Several studies find a bidirectional relationship between renewable energy consumption and economic growth (Apergis and Payne, 2010a,b, 2011a,b,d, 2012a,b; Apergis et al., 2010). Sadorsky (2009, 2009b) reports no evidence of a bidirectional relationship in the short-run but finds a relationship in the long run from real GDP to renewable energy consumption. Menegaki (2011) fails to find a bidirectional relationship, examining 27 European countries. Payne (2009, 2012) also fails to find

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[1] Four primary econometric approaches are used to analyze the causal relationship: Granger–Sims causality testing, Engle–Granger/Johanssen–Juselius cointegration and error-correction modeling, Toda–Yamamoto long-run causality testing, and panel cointegration error correction modeling. Of the studies examined, 23.1% showed unidirectional causality from energy consumption to GDP growth, 19.5% found causality from GDP growth to energy consumption, 28.2% show a bidirectional relationship, and 29.2% show no relationship.

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evidence of causality in the US. Examining energy use by sector, Bowden and Payne (2010) find only unidirectional causality from renewable energy consumption to real GDP, similar to Pirlogea and Cicea (2012) who reports that Romanian renewable energy consumption Granger-causes output.

Furthermore, the role of individual sources is important given countries' current challenges in determining the optimal mix of energy. Almost no published research exists on the nexus between individual sources of renewable energy and GDP growth. Payne (2011) examines the relationship between biomass consumption and GDP in the US, and finds a positive unidirectional relationship from biomass to GDP. Ewing et al. (2008) analyze the impact of industrial production and employment on hydroelectricity, solar, wind, wood, and waste energy.

This paper seeks to contribute to the literature on the nexus between renewable energy and GDP growth by examining individual renewable sources, including biomass, geothermal, hydroelectric, solar, waste, and wind. Using electricity generation data on 20 OECD countries from 1990 to 2008, we implement a panel error correction model (ECM) to analyze the causal relationship between real GDP and each individual renewable energy source. Following Apergis and Payne (2012b), we utilize a production model framework accounting for capital and labor. The results find evidence of a bidirectional short-run relationship between aggregate renewable electricity generation and GDP. We further test for structural breaks in the data and examine the possibility of cross-sectional dependence (CSD). Extending the panel ECM to control for CSD, we find that renewable energy positively impacts GDP, but changes in GDP negatively impacts renewable energy. We implement a similar analysis for each individual source of energy, but an analysis of the interactions between sources is beyond the scope of this paper.

Our results contribute to the literature in several important ways. First, we add to the energy-growth literature by making a distinction between electricity generation, electricity consumption, and energy consumption.[2] We examine renewable electricity generation measured in MWh rather than energy consumption, because consumption refers to energy delivered to end-use sectors, and because consumption may or may not include wind and hydroelectric power depending on the data source and their measurement unit of energy. Electricity generation also differs from electricity consumption by measuring the firm's production rather than the end user's consumption. Examining electricity generation, allows us to disaggregate the data by energy source, and still follow the production framework model. The production model allows us to overcome some omitted variable bias while avoiding using ad hoc control variables. Including capital and labor in the analysis is common in the energy-economic growth and renewable energy-economic growth literature (Payne, 2010a,b).

We extend the renewable energy-growth literature by examining individual sources of energy. Biomass, hydroelectricity, waste, and wind energy sources exhibit a positive long-run equilibrium relationship with GDP growth. In the short-run, hydroelectricity exhibits the largest positive Granger-causing impact on GDP growth; and GDP growth has the largest positive impact on biomass, solar, and waste energy.

We further extend the analysis to examine the possibility of structural breaks and account for CSD. The results highlight the importance of controlling for CSD. While the estimates for biomass, geothermal, and solar are similar to the previous results, the results for aggregate renewable, hydroelectricity, waste, and wind change. The estimates from the CSD corrected panel ECM find that in the short-run, waste energy has a negative impact on GDP growth, and hydroelectricity has a positive impact. GDP growth still exhibits a positive impact on biomass and waste energy, but a negative impact on hydroelectricity. Wind exhibits a positive bidirectional relationship with GDP. Finally, geothermal exhibits a negative bidirectional relationship with GDP and solar shows a unidirectional relationship from GDP to solar energy.

The results highlight the need to distinguish between renewable sources. Biomass and waste generation are important drivers in the renewable energy–GDP relationship, but the environmental impacts between sources vary. For example, biomass and waste generation emit CO_2, nitrogen, and sulfur into the atmosphere, despite being labeled as net neutral CO_2 emitters.[3] According to the EPA, US renewables averaged 1.22 lbs of SO_2 per MWh and 0.06 lbs of NO_x per MWh despite hydroelectricity, solar, and wind emitting negligible amounts of either. Comparatively, biomass and waste generation emit more carbon than solar, wind, and geothermal generation. Table 1 compares the average annual CO_2 emissions of US power plants by primary fuel sources, including natural gas, geothermal generation, the four largest biomass fuel sources, and three types of coal generation. The average power plant emissions are reported in lbs per MWh, and demonstrate that CO_2 may increase as biomass generation increases, depending on the type of biomass used and the source replaced. Municipal solid waste (MSW) averaged 2993 lbs of CO_2 per MWh, emitting more CO_2 than natural gas, subbituminous coal, and lignite coal. If MSW energy replaces coal, lignite, or subbituminous coal, CO_2 emissions would increase.[4]

The remainder of the paper is organized as follows: Section 2 presents the unit root test results, examines cointegration between the variables from a production model framework, and provides estimates from a fully modified OLS model to examine the long-run relationship between renewable energy and GDP. Section 3 presents the results of a panel ECM for aggregate renewable electricity generation to test for a causal relationship between renewable energy and GDP. We then implement the same econometric model to analyze individual sources of electricity generation. Section 4 extends the previous analysis by examining the data for structural breaks and CSD. We then implement the panel ECM controlling for CSD to analyze the individual sources. Section 5 concludes with a discussion of policy implications.

2. Data, unit roots, and tests for cointegration

Data were collected from the International Energy Agency's dataset on world renewable and waste energy statistics. We examine gross electricity production (GWh) by energy source for 20 countries from 1990 to 2008.[5] Real GDP, gross fixed capital formation, and size of the labor force were collected from the OECD.

Renewable electricity generation includes biomass, hydroelectric, geothermal, solar, waste, and wind. Table 2 presents the average annual growth rate in generation for each country. Only six countries utilize geothermal and solar energy over the entire time period considered. Most countries utilize biomass, hydro, and waste energy, with biomass and waste energy contributing to most of the renewable energy growth. When utilized, wind and solar energy exhibit the largest growth rates. Comparing the GDP growth rate to the growth in renewable energy, no discernible trend appears. The top 5 countries in aggregate renewable energy growth, Denmark, Netherlands, Belgium, Portugal, and Germany, are ranked 7th, 11th, 5th, 16th, and 3rd in terms of real GDP growth.

[2] Several studies have examined the electricity consumption–GDP relationship (Apergis and Payne, 2011; Ozturk, 2010; Payne, 2010).

[3] Net neutral carbon emitters release CO_2 as part of the natural carbon cycle of the earth. Biomass products extract CO_2 from the air as they grow, and release CO_2 when burned.

[4] Biomass includes solid biofuels, biogasoline, biodiesels, biogases, and other liquid biofuels. Municipal waste is defined as waste collected from the residential, commercial and public service sectors, used for the production of heat and power in a central location. We examine only the renewable fraction of municipal waste.

[5] Countries included: Australia, Austria, Belgium, Canada, Denmark, France, Germany, Iceland, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, and United States.

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