Energy Policy 61 (2013) 793–801

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

The causal relationship between energy resources and economic growth in Brazil

Hsiao-Tien Pao [a,*], Hsin-Chia Fu [b]

[a] Department of Management Science, National Chiao Tung University, Taiwan, ROC
[b] College of Engineering, Huaqiao University, Quanzhou, China

HIGHLIGHTS

- We model three kinds of clean energy and non-clean energy consumption and real *GDP*.
- There is fossil fuel consumption–economic growth bidirectional causality.
- There is new renewables consumption–economic growth bidirectional causality.
- There is nuclear energy consumption–economic growth bidirectional causality.
- Substitutability exists for new renewables–fossil fuel or new renewables–nuclear.

ARTICLE INFO

Article history:
Received 7 April 2012
Accepted 23 June 2013
Available online 19 July 2013

Keywords:
Renewable
Nuclear
Granger causality

ABSTRACT

This study investigates the causal relationship between clean and non-clean energy consumption and economic growth in Brazil over the period of 1980–2009. Clean energy consumption at aggregated level of total renewable energy consumption and disaggregated levels of hydroelectric, new renewables, and nuclear energy consumption are tested within a production function framework. A cointegration test reveals a long-term equilibrium relationship between real output, capital, labor, and renewable and non-renewable energy consumption at aggregated level, and a long-term equilibrium relationship between real output, capital, labor, and hydroelectric/new renewables/nuclear and fossil fuel energy consumption at disaggregated level. The capital, labor, and new renewables elasticities of real output are positive and statistically significant, other energy consumption item's elasticities are insignificant. The results from error correction model reveal the interdependencies between new renewables, nuclear, fossil fuel, and total non-renewable energy consumption and economic growth, the unidirectional causality from hydroelectric/total renewable consumption to economic growth, the substitutability between new renewables and fossil fuel consumption, and the substitutability between new renewables and nuclear energy consumption. Additionally, nuclear and new renewables energy consumption responds to bring the system back to equilibrium. Overall, aggregated analysis may obscure the relationship between different types of clean energy consumption and economic growth.

1. Introduction

According to the 2010 International Energy Outlook released by the US Energy Information Administration (EIA), worldwide renewable energy consumption has been increasing at a rate of 2.6% per year. In 2008, approximately 19% of the global energy consumption was from renewable sources, 13% of which was from traditional biomass (mainly used for heating), 3.2% from hydroelectricity, and the remaining 2.7% from rapidly growing 'new renewables' (e.g., small hydro, modern biomass, wind, solar, geothermal, and biofuels). Renewable energy power generation makes approximately 18% of the global electricity, with 15% from hydropower and 3% from other new renewable energy sources. 'New renewables' technologies are befitting for local electricity generation in rural and remote areas, where the transportation costs for crude oil or natural gas and the transmission costs of electricity are often prohibitively high. Globally, 3 million households are estimated to receive power from small solar PV systems. Micro-hydropower systems configured into village-scale or county-scale mini-grids are emerging in many areas. More than 30 million rural households use family-sized biogas digesters for lighting and cooking. Biomass cookstoves have been used by 160 million households (Wikipedia, 2011). In addition, expected increases in oil prices, increased awareness of the environmental

* Corresponding author. Tel.: +886 3 5131578; fax: +886 3 5710102.
E-mail addresses: htpao@mail.nctu.edu.tw, htpao123@gmail.com (H.-T. Pao).

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http://dx.doi.org/10.1016/j.enpol.2013.06.113

damage caused by fossil fuel consumptions, and government incentives for new renewables energy development will continue to foster the global usage of new renewables energy. These 'new renewables' can provide approximately 6% of worldwide electricity by 2030.

Although environmentalists have warned that catastrophic climate change is a real and imminent danger, we still need a large-scale source of around-the-clock electricity to meet our energy needs. Nuclear energy can generate electricity with no carbon dioxide or other greenhouse gas emissions, and it is the only effective option in order to supply the large demand for clean electricity on a global scale. Currently, nuclear power plants supply approximately 6% of the global energy and 14% of the global electricity needs. Nuclear power and new renewables will be urgently needed as partners if the world's enormous demand for clean energy is to be met (World Nuclear Association (WNA), 2011). The use of new renewable energy and nuclear energy is critical to the development of global clean energy economy in the future, due to the continuous depletion of reserve of earth's fossil fuel as well as global warming.

The topic of causal relationship between energy consumption and economic growth has been well-studied in energy economics literature such as Ozturk (2010) and Payne (2010a, 2010b). However, the empirical results may be varied and even conflicted, due to the difference in country′ characteristic, time period, econometric methodology, or proxy variables for energy consumption and income. The causality between energy consumption and economic growth in different directions may have different policy implications. Under the assumption of positive correlation between energy consumption and economic growth, the presence of unidirectional causality from energy consumption to economic growth or bidirectional causality between them would suggest that energy conservation policies that reduce energy consumption may lead to decline in economic growth. In contrast, unidirectional causality from economic growth to energy consumption or no causality in either direction suggests that energy conservation policies will have little or no impact on economic growth (Apergis and Payne, 2013).

Among the literature of energy consumption and economic growth nexus, some studies also examined the relationships between different types of clean energy consumption (renewable or nuclear) and economic growth (Pao and Fu, 2013). Recent researches by Apergis and Payne (2011b, 2011c) focus on the link between both renewable and non-renewable energy consumption and economic growth for sustainable economic development. This paper extends recent works on the energy consumption–growth nexus to analyze the relationships between both the clean and non-clean energy consumption and economic growth in sustainable countries such as Brazil. Brazil is one of the fastest-growing major economies in the world, with an annual growth rate of *GDP* of approximately 5%, and is expected to become one of the world's top five economies in the future. In the past 2 decades, Brazil has achieved a development model that combines social inclusion with sustained economic growth and balanced use of natural resources. This model can maintain high levels of renewable energy to stimulate economic growth and lift millions of people out of poverty, while protecting the country's forests and biodiversity (Secretariat of Social Communication (SECOM), 2012). According to the 2009 EIA, Brazil's renewable energy consumption reached 97% of its total domestic electricity generation, and the growth rate of different types of energy consumption are varies. During the 1980–2009 period, new renewable energy consumption (i.e., non-hydroelectric renewable energy consumption, *NHREC*) with a very high annual average growth rate of 8.72% accounted for 2.89% of the total renewable energy consumption (*TREC*), while hydroelectric energy consumption (*HEC*) with an annual average growth rate of 3.66% accounted for 97.11% of *TREC*. Additionally, nuclear energy consumption (*NUCEC*), with the highest annual average growth rate of 19.65%, accounted for 1.20% of the total non-renewable energy consumption (*TNREC*), while fossil fuel consumption (*FFC*) with the lowest annual average growth rate of 2.85% accounted for 96.67% of *TNREC*. Currently, Brazil is one of the world's cleanest energy matrices. A country with high growth rate or high proportion of clean energy consumption may imply an interdependent relationship between economic growth and clean energy consumption or substitutability between the clean and non-clean energy sources to achieve sustainable economy.

Due to the greatly different growth rates of the various types of energy sources, this study focuses on the disaggregated analysis of the causal relationship between clean energy (hydroelectric, new renewables, and nuclear) consumption and economic growth in Brazil over the period of 1980–2009 since aggregated analysis may well mask the differential impact of hydroelectric, new renewables, and nuclear energy consumption on economic growth. The results are compared with the aggregated analysis of the causal relationship between total renewable energy consumption and economic growth. The simultaneous use of clean and non-clean energy consumption in the production function framework intends to distinguish the relative influence of each type on economic growth and to analyze the substitutability between the different types of energy sources. The neo-classical one-sector aggregated production model is adopted where capital, labor, clean energy consumption, and non-clean energy consumption are treated as separate inputs. Within this framework, a vector error-correction model (VECM) is employed to test for multivariate cointegration and Granger causality.

This study is organized as follows. Section 2 provides a brief literature review. Section 3 describes the analytical model and econometric methodology. Section 4 presents relevant energy and economic data and also presents the cointegration and Granger causality results. Section 5 presents the conclusions.

2. Literature review

Since the dawn of the 21st century, the relationships between non-renewable, renewable, or nuclear energy consumption and economic growth have been researched upon (Payne, 2010a, 2010b). Common methodologies include the forecast error variance decomposition analysis model, the bivariate error correction model, the Toda–Yamamoto procedure within a production function framework, and the multivariate error correction model within a production function framework. Using a generalized forecast error variance decomposition analysis, Sari and Soytas (2004) found that different energy consumption items have different effects on real output, where lignite, waste, oil, and hydraulic power are the top four alternative energy sources in Turkey. For the US, Ewing et al. (2007) found that coal, natural gas, and fossil fuel energy sources unexpectedly have the largest impacts on the variation of real output, while several renewable energy sources also exhibit considerable impacts. Using a bivariate panel error correction model, Sadorsky (2009) presented evidence of bidirectional causality between non-hydroelectric renewable energy consumption and economic growth for a panel of 18 emerging economies. Using the Toda–Yamamoto procedure within a production function framework for analyzing data of the US, Payne (2009) found no evidence of a causal relationship between total renewable and non-renewable energy consumption and real *GDP*; Payne (2011b) provided a disaggregated analysis of the causal relationship between fossil fuel (coal, natural gas, and petroleum) consumption and real *GDP*, and their results showed