Applied Energy 213 (2018) 208–218

Contents lists available at ScienceDirect

Applied Energy

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

GDP and energy consumption: A panel analysis of the US

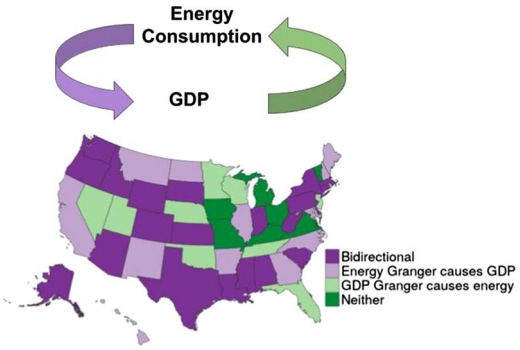
Brinda Mahalingam*, Wafa Hakim Orman

Department of Accounting, Finance, and Economics, College of Business, University of Alabama in Huntsville, 301 Sparkman Drive, Huntsville, AL 35899, USA

HIGHLIGHTS

- Granger causality tests performed for GDP and energy consumption (EC) in US states.
- Panel Granger causality is tested for the US and for regions within the US.
- Wide variation between US states and regions.
- Including capital and labor changes direction of Granger causality in 35/50 states.
- Energy conservation policy design should accommodate within-country variation.

GRAPHICAL ABSTRACT



ARTICLE INFO

Keywords:
Granger causality
Panel cointegration
Energy consumption
GDP
Panel unit roots

ABSTRACT

Does energy consumption lead to economic growth or does economic growth cause energy consumption? Arguments can be made either way and empirical studies have been inconclusive. Most of the existing studies relating Gross Domestic Product (GDP) and Energy Consumption (EC) use countries as the unit of observation which complicates the interpretation and generalization of results because countries differ greatly in their stage of economic development, culture, technology and so forth. This study focuses on states within the U.S.A. which avoids many of these complications. Specifically, the relationship between state energy consumption and state GDP for the country is analyzed. Empirical results using panel cointegration and panel causality tests which allows for heterogeneity and structural breaks are applied to the country as a whole and regions within the country. There are significant regional differences within the U.S. especially for two regions; in the Rocky mountain region energy consumption Granger causes state GDP and in the Southwest it is opposite, GDP Granger causes energy consumption. The full results suggest that federal energy policy needs to be flexible to be most beneficial to the different regions.

1. Introduction

With fluctuating fossil fuel prices, a growing renewable energy sector, and instability in policies relating to conservation and environmental regulations and trade, the energy sector is likely to remain volatile for the foreseeable future. What sort of impact might this have on our continued economic growth? The relationship between economic growth and energy consumption continues to be of critical interest and has been analyzed by researchers for the past few decades. There is little consensus on whether energy conservation impedes growth or contributes to economic growth. Al-mulali et al. [1] describe four outcomes from a review of the literature. The results fall into four commonly used broad categories: (i) *Energy conservation hypothesis*: Energy consumption 'causes' GDP or energy consumption drives

* Corresponding author at: University of Alabama in Huntsville, 301 Sparkman Drive, Huntsville, AL 35899, USA.
E-mail addresses: brinda.mahalingam@uah.edu (B. Mahalingam), wafa.orman@uah.edu (W.H. Orman).

https://doi.org/10.1016/j.apenergy.2018.01.036
Received 14 September 2017; Received in revised form 20 December 2017; Accepted 11 January 2018

Table 1
Summary of literature on US regarding energy consumption and economic growth.

Authors	Years covered	Causality tests	Major findings
Kraft and Kraft [4]	1946–1974	Granger causality tests	Growth to EC
Akarca and Long [33]	1950–1970	Sim's technique	Neutrality
Eden and Hwang [34]	1947–1979	Sim's technique	Neutrality
Abosedra and Baghestani [35]	1947–1987	Cointegration and Granger Causality	Growth to EC
Eden and Jin [36]	1974–1990	Cointegration and Granger Causality	Neutrality
Stern [37]	1947–1990	MVAR model	EC to growth
Cheng [38]	1947–1990	Cointegration and Granger Causality	Neutrality
Stern [5]	1948–1994	Cointegration and Granger Causality	EC to growth
Soytas et al. [39]	1972–2004	GMM	Neutrality
Ewing et al. [40]	2001–2005	VAR and forecast error variance decomposition	Growth to EC
Sari et al. [41]	2001–2005	ARDL bounds testing approach	GDP to REC
Payne [42]	1949–2006	Toda Yamamoto Procedure	Neutrality
Bowden and Payne [43]	1949–2006	Toda Yamamoto Procedure	EC to growth
Menyah and Wolde-Rufael [44]	1960–2007	Toda Yamamoto causality test	Neutrality (NEC to GDP)
Payne and Taylor [45]	1957–2006	Toda Yamamoto Procedure	Neutrality (NEC to GDP)
Fallahi [46]	1960–2005	Markov switching VAR models Ganger cuasality	Bidirectional
Yildrim et al. [47]	1949–2010	Toda Yamamoto Procedure	No causality (REC to GDP)
Aslan et al. [48]	1973 q1-2013q2	Wavelet analysis and Granger cuasality	Growth to EC
Carmona et al. [49]	1973 q1-2015q2	Hatemi and Toda Yamamoto Procedure	Growth to EC
Tiwari [50]	1973–2011	Hatemi	Asymmetric with different sources

Note: REC is renewable energy consumption and NEC is Nuclear energy consumption.

economic growth. (ii) *Growth hypothesis*: GDP causes energy consumption or economic growth drives energy consumption (iii) *Feedback hypothesis*: Bidirectional, whereby causation runs both ways between GDP and energy consumption (iv) *Neutrality hypothesis*: GDP and energy consumption are independent.

Granger causality or "Granger predictability" as Stock and Watson [2] label it, is when one of the variables, say GDP, can be used to predict another variable, energy consumption, then GDP "Granger Causes" energy consumption. The test was developed by Granger [3] in his seminal paper where he defines causality and feedback and even provides a testable model. A seminal paper on the United States by Kraft and Kraft [4] found a causal relationship that ran from income to energy, later, Stern [5] found that it ran from energy to income.

Since then, panel data studies encompassing several countries have become popular among Granger causality studies, as they increase power and reliability of the results. Al-mulali et al. [1], Ozturk [6], Tiba and Omri, [7] and Omri [8] provide an exhaustive list of studies and present the results of energy GDP causality research in the past few decades. Trying to find a pattern, researchers have tried grouping different countries, for example, Akkemik and Goksal [9], compare developed and developing countries. Chang et al. [10] groups countries in a region (Asia) and Costantini and Martini [11] compare OECD and non OECD countries.

Studies that focus on the U.S. yield results inconsistent results. A few studies have focused on only the US but have studied the country as a whole. Other studies have included the US as part of a panel of countries. A summary of past studies for the U.S. is presented in Table 1.

The US is a diverse country with some states producing and consuming fossil fuel energy to feed their industries while other states surge forward in production and consumption of renewable energy. Parts of the country are driven by agricultural products and others by manufacturing. For instance, the U.S. Energy Information Administration[1] (EIA) reported that Texas consumed 13% of the total U.S. energy consumption in 2015 and California ranked second in energy use. While Texas consumed 13 quadrillion Btu, Vermont consumer only 132 trillion Btu. EIA also reports that the "top10 states exceeded the combined energy use of the other 41 states (including D.C.)" Fig. 1 showing energy consumption and real GDP by state reveals that there are significant differences in energy consumption between the states. Louisiana's per capita energy consumption ranks the highest and New York ranks the lowest. It is important to understand and address these differences so that policies that are implemented do not impede economic growth and hamper the overall development of the country.

This paper is the first to disaggregate the data for the U.S. in order to highlight the differences between states on the nature of the causal relationship between GDP and energy consumption. This allows for profound regional differences that exist within the US is recognized. The unique contributions of this paper are highlighted below:

First, two models are estimated. The first model estimates the relationship between energy consumption and real GDP and the second includes capital and labor as inputs along with energy consumption. Since the relationship between energy consumption and GDP may well be related to labor-capital substitution or augmentation, the second model accounts for some potential omitted variable bias.

Second, Granger causality for each state is determined separately using the Toda-Yamamoto [12] procedure for both models, after testing all the variables for unit roots. Results show that including capital and labor in the model frequently alters the nature of Granger causality in many states.

Third, panel data techniques are utilized to model the relationship between energy consumption and GDP while accounting for cross-sectional dependence, heterogeneous coefficients, and structural breaks.

Fourth, short run causality is estimated using the Canning and Pedroni [13] approach which allows for heterogeneity in the long run and is robust when cross sectional dependence exists. This approach is employed to test for panel causality. Pesaran's [14] common mean group estimator which allows for cross sectional dependence is used to obtain the sign of causal direction and estimate elasticities.

Fifth, the states are grouped into Bureau of Labor Statistics (BLS) regions, which categorizes states that are geographically contiguous and share some vital economic characteristics. This gives a broader perspective of the relationship between energy consumption and growth.

There have been only two other studies that have examined the relationship between energy consumption and income within a country. Akkemik et al. [15] examine Granger causality between energy consumption and income at the provincial level in China. Herrerias et al. [16], study the short and long run causality for the provinces in China using techniques such as panel cointegration and the Canning and Pedroni [13] approach to long run causality. This study is the first to do so for the United States.

[1] https://www.eia.gov/todayinenergy/detail.php?id = 32,312.