Journal of Business Research 69 (2016) 2271–2276

Contents lists available at ScienceDirect

Journal of Business Research

Causal complexity of economic development by energy consumption☆

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ARTICLE INFO

Article history:
Received 1 September 2015
Received in revised form 1 October 2015
Accepted 1 November 2015
Available online 29 December 2015

Keywords:
Causal complexities
Causal recipes
FsQCA
Industrialized economies

ABSTRACT

This study intends to explore the associations between the energy consumption relevant antecedents and economic development by using fuzzy set/Qualitative Comparative Analysis (fsQCA). FsQCA yields the causal recipes (causal combinations) for the outcome, GDP. The energy relevant data are from the U.S. Energy Information Administration and economic relevant data are from the International Monetary Fund. The analysis results provide two groups of causal recipes: One group explains the conditions for knowledge-intensive industrialized economies and the other explains those conditions for traditional industrialized economies. Both groups lead to high GDP. The results illustrate that only one equation may be insufficient to describe the associations between the energy consumption relevant antecedents and the economic development. This study also applies multivariate regression analysis (MRA) for similar analysis. The results report that not every variable of each individual year is significant, thus reflecting the problem of MRA.

1. Introduction

For the past decades, the global energy consumption is constantly increasing. Taking into account the scarcity of energy resources, the threat of the greenhouse effect on one hand, and the economic development on the other hand, scholars are very eager to explore the relationships between energy consumption and economic development (Acaravci & Ozturk, 2010; Warr & Ayres, 2010).

Energy consumption encompasses fossil fuels, nuclear, and renewable energy. Fossil fuels are coal, petroleum, and natural gas, which are the main sources of greenhouse gas emissions. Renewable energy encompasses the wind and solar energy, biomass, geothermal, hydropower, etc., in other words, clean energy. Global status reports of various years show that total energy consumption is consistently increasing from 2006 to 2012 within an interval of every two years (REN21, 2007, 2010, 2012, 2014). Hence, this study aims to identify the causal complexity among renewable energy consumption, non-renewable energy consumption, and economic development through the observations of OECD countries and Taiwan.

Complex causality draws growing research attention (Schneider & Eggert, 2014). Fuzzy set/qualitative comparative analysis (fsQCA) focuses on asymmetric relationships to find conditions that are sufficient to cause an outcome (Woodside, 2013). FsQCA estimates the quality of outcome explanation by using alternative configurative models (Woodside et al., 2011), and differs from conventional statistical methods in aspects such as set-theoretic versus correlational connections, calibration versus measurement, configurational conditions versus independent variables, and causal complexity analysis versus net effects analysis (Ragin, 2008).

Previous relevant studies focus on the statistical relationships between a small number of antecedents and outcome, which may not be able to reflect the true causes and associations (Komal & Abbas, 2015; Jorgenson et al., 2014; Saboori et al., 2014). Instead, this study uses fsQCA to show the causal recipes (combinations of more antecedents) between energy consumption and economic development. Different causal recipes contribute to the high economic development. Also, this study conducts MRA analysis with the same data to estimate the relationship between economic growth and energy consumptions in comparison with the fsQCA results. Section 2 presents a literature review and proposes propositions. Section 3 introduces fsQCA and antecedents. Section 4 lists the common annual causal recipes with their implications and the MRA results. Section 5 concludes this study.

2. Propositions

Lee (2006) studies the relationship between energy consumption and income for 11 developed countries. Sari and Soytas (2006) find energy to be an important factor of output in six developing countries. Ozturk (2010) provides a literature survey on energy-growth nexus through gathering numerous references. Mahadevan and Asafu-Adjaye (2007) examine the relationship between energy consumption and GDP growth by a panel error correction model for twenty net energy importers and exporters over the period from 1971 to 2002.

☆ The authors thank Alicia Mas-Tur, University of Valencia, and Domingo Ribeiro Soriano, University of Valencia for their suggestions on revising this article. The authors acknowledge and are grateful for the financial support from the Ministry of Science and Technology, Taiwan, ROC under grant NSC 102-2410-H-035-041-MY2.

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http://dx.doi.org/10.1016/j.jbusres.2015.12.041
0148-2963/

The empirical results of these studies suggest that energy consumption has a significant positive effect on real GDP in both developed and developing countries.

Tugcu et al. (2012) examine the relationship between renewable energy consumption and non-renewable energy consumption and real GDP for G7 countries, Canada, France, Italy, Germany, England and Japan over the period from 1980 to 2009. The results show that both renewable and non-renewable energy consumption have a significant positive effect on real GDP. Omri (2013) shows a significant positive relationship from energy consumption to CO_2 emission. Therefore, CO_2 emission always goes with non-renewable energy consumption.

In addition to energy consumption, previous studies point out two other primary factors: capital and labor. Apergis and Payne (2009) conduct a research for eleven countries of the Commonwealth of independent States over the period from 1991 to 2005. The empirical results show that energy consumption, real capital, and labor force have a significant positive effect on real GDP. Apergis and Payne (2010) examine a panel with 25 of OECD countries over the period from 1985 to 2005. The results reveal a positive relationship between renewable energy consumption and real GDP. The capital and labor also have a significant positive effect on economy development. Apergis and Payne (2012) examine 80 countries in a panel over the period from 1990 to 2007. The results show significant positive causalities among renewable energy consumption, non-renewable energy consumption, real capital, labor force, and real GDP. Salim et al. (2014) analyze OECD countries over the period from 1980 to 2011. The results show a significant relationship among non-renewable energy consumption, real capital, and GDP growth. However, Wolde-Rufael (2009) studies seven African countries over the period from 1971 to 2004. The results suggest that energy's contribution to real GDP is relatively low compared to the capital stock and labor.

Menegaki (2011) examines the causal relationship between renewable energy consumption and economic growth for twenty-seven European countries over the period from 1997 to 2007 and finds that renewable energy consumption, CO_2 emission, and employment rate have a significant positive effect on real GDP. Omri (2013) conducts a study on the nexus among energy consumption, economic growth and CO_2 emission for 14 Middle East and North Africa countries over the period from 1990 to 2011. The results show that energy consumption has a significant positive relation to real GDP per capita for ten countries out of fourteen, whereas CO_2 emissions have a significant negative relation to real GDP per capita for all countries. Real capital is significantly positive to real GDP, whereas labor is significantly negative.

Following the literature review, this study presents the following propositions:

Proposition 1. *High non-renewable energy consumption and high CO_2 emission countries are high economy development countries.*

Proposition 2. *High renewable energy consumption countries are high economy development countries.*

Proposition 3. *High non-renewable energy consumption and high CO_2 emission countries with high capital and high labor force are high economy development countries.*

Proposition 4. *Low non-renewable energy consumption and low CO_2 emission countries with low labor force are high economy development countries.*

3. Research method

3.1. FsQCA

FsQCA is a method that applies Boolean algebra and fuzzy set theory to identify the causal complexities of a specific phenomenon in terms of set relations. FsQCA calibrates the original data into fuzzy set degree through the specification of the three qualitative breakpoints: full membership, full non-membership, and maximum ambiguity (Ragin, 2008). This study applies three-level scale for calibration: values exceeding 95% as full membership, values less than 5% as full non-membership, and 50% as the crossover point for the degree of "more in" or "more out" the set.

In fsQCA, the result comes up with an outcome that constitutes a subset of antecedents. The configurational statement appears as follows with consistency and coverage (Huarng, 2015):

$$X_1 * \sim X_2 \rightarrow Y$$

where Y is the specific outcome; X_1 and X_2 are the causal conditions, namely antecedents. The sign * represents "logical and," whereas ~ represents "not". The above equation represents that $X_1 * \sim X_2$, a causal recipe, is a sufficient condition of the outcome, Y.

Various causal recipes can lead to the same outcome. Sometimes, different combinations of antecedents may appear contradictory to each other. But this situation demonstrates that fsQCA can capture all possible combinations from the data. And this is also what the conventional MRA lacks.

After the assessment, fsQCA signifies the reliability depending on two indexes, consistency and coverage. The consistency index is analogous to significance and the coverage index is analogous to coefficient of determination, R^2 (Woodside, 2013). Consistency is informative with the score above or equal to 0.75 (Ragin, 2008). The measurement of consistency is equal to:

$$\text{Consistency}(X_i \le Y_i) = \Sigma[\min(X_i, Y_i)]/\Sigma(X_i).$$

Coverage determines the degree of a subset (X_i) addressing the outcome (Y_i). The measurement of fuzzy set coverage is:

$$\text{Coverage}(X_i \le Y_i) = \Sigma[\min(X_i, Y_i)]/\Sigma(Y_i).$$

3.2. Antecedents and outcome

This study conducts cross-sectional analysis over the period from year 1980 to 2011 for Taiwan and 24 of Organization Economic Cooperation and Development (OECD) countries (excluding Chile, Czech Republic, Estonia, Hungary, Israel, Mexico, Poland, Slovak Republic, Slovenia, and Turkey for the lack of partial data.)

Following the previous studies, this study uses real GDP per capita (realgdp) as the outcome; and renewable energy consumption (rec), non-renewable energy consumption (nonrec), carbon dioxide emission (co2), real gross fixed capital formation per capita (realcap), and labor force (labor) as the antecedents.

The outcome, realgdp, is in constant 2010 US dollars. Following Sadorsky (2009), rec is in quadrillion British thermal unit (Btu) as electricity consumption relevant to hydroelectric power, geothermal, solar, wind, and wood and waste electric power consumption. Antecedent nonrec is in quadrillion Btu, representing the amount subtracting renewable electricity consumption from total primary energy consumption, whereas the measurement of the sum of energy consumption includes renewable electricity consumption and others relevant to coal, petroleum, natural gas, and nuclear. Antecedent co2 in quadrillion Btu serves as the environmental variable. Antecedent realcap is in constant 2010 US dollars as a proxy for capital. Finally, labor is in millions people.