Energy Economics 39 (2013) 108–121

Contents lists available at SciVerse ScienceDirect

Energy Economics

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

Energy consumption and real GDP in G-7: Multi-horizon causality testing in the presence of capital stock

Paraskevi K. Salamaliki, Ioannis A. Venetis *

University of Patras, Department of Economics, University Campus, Rio, 26504, Greece

ARTICLE INFO

Article history:
Received 24 July 2012
Received in revised form 19 April 2013
Accepted 20 April 2013
Available online 30 April 2013

JEL classification:
Q43
C32

Keywords:
Energy consumption
Real GDP
Capital stock
Structural breaks
Multiple horizon causality

ABSTRACT

This paper applies two recent time series methods to re-examine the causal relationship among energy consumption, real GDP and capital stock in G-7 countries. These methods, the Dufour et al. [2006, Journal of Econometrics, 132:337–362] multiple horizon causality testing and the Hill [2007, Journal of Applied Econometrics, 22:747–765] sequential causality testing allow to test for (non)causality in a multivariate framework and can further reveal the time profile of causal effects, the presence of causation delays and the direct or indirect nature of the causal effects. Given the trending nature of the time series employed, we further take into account the presence of structural breaks in the form of trend changes. Our empirical results show that multi-horizon causality testing does uncover crucial information with respect to the dynamic interaction among energy consumption, real GDP and capital stock, while structural breaks do exist and appear to be critical for causality inference. In regard to causality direction, we find that real GDP dominates in anticipating energy consumption in G-7 countries.

1. Introduction

The potential causal relationship between energy consumption and economic growth, along with the policy implications that accrue from such a relation, has been under theoretical and empirical scrutiny at least since the earlier oil shocks of the 1970s. Kraft and Kraft (1978) are the first who examined the relation between income and energy consumption in the U.S. The literature has grown substantially thereafter, while the convention of the Kyoto Protocol on 2005 renewed attention of applied researchers, leading to a large amount of empirical work during the 2000s. In particular, research interest is focused on whether energy conservation policies, i.e. constraints regarding the use of energy, can be implemented in developed or developing countries without producing adverse effects on economic growth.

Payne (2010) and Ozturk (2010) provide extensive surveys of the empirical literature regarding causality between energy consumption and economic growth. Most of these studies use the Granger (1969)[1] concept of causality to examine the relationship between energy consumption and economic growth, addressing the question of how useful the variables are in forecasting each other or whether energy consumption takes precedence over growth and vice versa. The vector autoregression (VAR) framework developed by Sims (1972, 1980) and the corresponding VAR-based causality tests have been the dominant method of causality testing between the two variables in many empirical studies.

The role of energy in the performance of the economy has been a contradictable topic in the literature. On the one hand, conventional neo-classical growth theory models output processes in terms of the basic production factors (i.e. inputs), namely capital and labor. Growth is thus attributed to capital stock, labor and a residual with the latter being referred as the “Solow” residual that represents unexplained growth. As a result, little or even no attention is paid on energy use and its role in the production process and the determination of real GDP, suggesting neutrality of energy to growth.

On the other hand, there is the ecological and biophysical view which models growth from a thermodynamic perspective (Cleveland et al., 1984). The production of goods is now straightly related to the use and the availability of energy, which is considered as the primary factor of production. Thus, a country's economic performance depends on energy consumption and it will be affected by constraints to energy consumption. Stern (1993, 2000) also underlines the essential role of energy in the U.S. macroeconomy, while Hudson and Jorgenson (1974), Griffin and Gregory (1976) and Berndt and Wood (1979) constitute earlier studies that attempted

* Corresponding author. Tel.: +30 2610969964.
E-mail addresses: salamp@upatras.gr (P.K. Salamaliki), ivenetis@upatras.gr (I.A. Venetis).
URL: http://application.econ.upatras.gr/en/node/130 (I.A. Venetis).

[1] The original definition of Granger (1969) refers to the predictability of a variable $X(t)$ from its own past, the past of another variable $Y(t)$, and possibly a vector $Z(t)$ of auxiliary variables, *one-step ahead*.

0140-9883/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.eneco.2013.04.010

to include energy along with capital and labor in the traditional production process.

Beaudreau (1995, 2005) points out the engineering approach to output processes which considers production or output growth under absence of energy impossible, while Pokrovski (2003), based on the perceived substitution between energy from external sources and labor in technological processes, proposes that since energy-driven equipment works in the place of manual labor and acquires all the properties of a production input, then production of output can be determined by three inputs, i.e. energy, capital stock and labor and energy is considered as a value-creating production factor.

Despite the large number of existing studies in the field of energy consumption-real GDP nexus, empirical analysis has yielded mixed results regarding the role of energy in achieving economic growth.[2] Hence, a consensus on the causal relation between energy consumption and real output in the U.S. or elsewhere has not been reached. Conflicting results among countries should not be unexpected given that different countries have different energy consumption patterns and various sources of energy, structural, institutional and political differences and exhibit different developing stages, thus the role of energy on growth cannot be identical across countries (Masih and Masih, 1997; Yuan et al., 2008). Yet, as Zachariadis (2007) points out, there have been differences in results for the same countries and sample periods or similar datasets. The adoption of different econometric/causality methods or definitional specifications of variables are considered as important factors for this fact.

As regards the causality test methods, the models employed in the literature vary, while some or all models may be misspecified so that they are not able to uncover all plausible causal relationships between energy consumption and real GDP. For example, causality from energy consumption to real GDP might occur in a nonlinear[3] way rather than the linear way implied from the linear conditional mean models mostly used in the applied literature. In addition, causality effects might arise via conditional volatility or at different frequencies rather than the aggregated used in many studies.

An important issue pertains with the number of variables included in the time series causality framework. Most studies in the literature have used the bivariate approach to examine the causal relationship between energy consumption and economic growth. The bivariate setting has become very popular in analyzing Granger-causality relationships, as one-step ahead causation implies h-step ahead causation (direct causality) between the two variables of interest.[4] More precisely, it has been seen that if one variable is Granger non-causal for another, second variable at forecast horizon $h = 1$ (one-step ahead), it will also be Granger non-causal for the second variable at higher forecast horizons, $h > 1$ (Granger, 1980; Pierce, 1975).

However, Lütkepohl (1982) emphasizes the omitted variable(s) problem related to the bivariate approach, which can lead to erroneous conclusions with respect to causality inference. For example, Granger causality in a bivariate system may be observed due to a relevant omitted variable, while Granger non-causality may result from neglected variables, i.e. the absence of relevant useful information from the model. Based on this fact, Lütkepohl (1982) stresses the use of multivariate models in order to examine and characterize causality relations between two variables of interest, as higher dimensional time series models can provide additional information on multiple causal channels among the system variables, that could remain hidden or lead to spurious correlations in the bivariate framework.

Therefore, the use of multivariate models can help so that useful information is not omitted, while it further allows for the presence of causal chains among the system variables. Specifically, while one-step ahead non-causation implies h-step ahead non-causation in the bivariate setting, yet this result does not necessarily hold in a multivariate framework in which more than the two variables of direct interest are included (Dufour and Renault, 1998; Lütkepohl, 1993). In contrast, the presence of additional variables can induce indirect causality results at higher forecast horizons, revealing nuanced details on multiple-horizon causation which would be collapsed out in a bivariate model.

Stern (1993, 2000) underlines the possible existence of substitution or complementarity relationships between energy and other inputs (capital, labor) which could remain hidden in the bivariate context, implying no causality from energy to GDP. A multivariate and therefore multi-horizon approach would help to reveal such relationships and causality from energy to real GDP might be observed. Based on this aspect and on the production function framework illustrated above, some recent studies employ trivariate or multivariate models by including capital and/or labor when testing for causality between energy consumption and real GDP. Yet, these studies constitute a small proportion in the energy consumption-real GDP literature, while Payne (2010) and Ozturk (2010) clearly underline the necessity of the adaptation of multivariate frameworks in future research.

More important, all existing studies employ methods that only test for the presence of direct causality between energy consumption and real GDP. Thus, although they may avoid the problem of omitted variables by including additional, relevant variables in the model, they cannot capture all possible causal links (indirect causality) that, as explained above, can show up at higher forecast horizons. A useful extension on this direction would be a concept of causality that encompasses both direct and indirect Granger causality and can ensure that all possible combinations are analyzed through the characterization of (non)causality at all forecast horizons.

We contribute to the energy consumption-real GDP causality literature in several aspects. First, we re-examine the causal relationship between energy consumption and real GDP for the G-7 countries in an aggregate production function framework, by including capital and employment as in Ghali and El-Sakka (2004), Sari and Soytas (2007), Lee et al. (2008), Yuan et al. (2008) and Lee and Chien (2010). Moreover, following Lee et al. (2008) and Lee and Chien (2010) we consider variables in per capita form dividing by labor. Thus, a trivariate model of energy consumption, real GDP and capital stock, all variables expressed in per capita units, is adopted in our analysis.

Second, we employ two recent time series causality methods, the Dufour et al. (2006) statistical procedure for testing non-causality at different horizons and the Hill (2007) efficient tests of long-run causation in trivariate VAR systems. These methods use the Dufour and Renault (1998) notion of causality, which is an extension of the original definition of Granger (1969) causality and is based on linear predictability at higher forecast horizons. They are empirically attractive because they reduce, for horizons greater than one (higher horizons), the increasing complexity of nonlinear non-causality parametric restrictions in VAR models to linear. These methods will allow us to investigate the dynamic interaction among energy consumption, real GDP and capital stock and can help us to provide additional information on both the time profile of causal effects and their direct or (possible) indirect nature.

As Lütkepohl (1993) and Dufour and Renault (1998) point out, for multivariate models in which a vector of auxiliary variables Z is used in addition to the variables of interest X and Y, it is possible that Y does not cause X one-step ahead, but can still help to predict X several periods ahead. Assume that one of the variables of primary interest,

[2] Several empirical studies formulate four testable hypotheses to explain the direction of causality between energy consumption and real GDP. These are termed as the growth, conservation, feedback and neutrality hypothesis. For further discussion, see Squalli (2007), Payne (2010) and Ozturk (2010).

[3] See e.g. Hu and Lin (2008), Lee and Chang (2007), Chiou-Wei et al. (2008), Huang et al. (2008).

[4] Moreover, as Zachariadis (2007) points out, bivariate models can be very useful in cases that handle countries with scarce data, for which additional time series on factors of production (e.g. capital stock, employment) are hardly available.