Applied Energy 142 (2015) 44–55

Contents lists available at ScienceDirect

Applied Energy

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

Revisiting energy consumption and GDP causality: Importance of *a priori* hypothesis testing, disaggregated data, and heterogeneous panels

Brantley Liddle [a,b,*], Sidney Lung [c]

[a] *Centre for Strategic Economic Studies, Victoria University, Melbourne, Australia*
[b] *Asia-Pacific Energy Research Centre, Tokyo, Japan*
[c] *School of Economics and Finance, Victoria University, Melbourne, Australia*

HIGHLIGHTS

- Panel long-run Granger-causality performed on end-use disaggregated energy and GDP.
- Panels vary by geography, income, and relative energy intensity.
- Results of reduced-form supply and demand models are highly consistent across panels.
- Income causes per capita residential electricity consumption in all panels.
- Income causes per capita motor gasoline consumption in all panels.

ARTICLE INFO

Article history:
Received 24 July 2014
Received in revised form 30 October 2014
Accepted 21 December 2014
Available online 12 January 2015

Keywords:
Energy consumption
Economic growth
Panel Granger causality
Heterogeneous panels
Developed and developing countries
Cross-sectional dependence

ABSTRACT

This paper disaggregates energy consumption and GDP data according to end-use to analyze a broad number of developed and developing countries grouped in panels by similar characteristics. Panel long-run causality is assessed with a relatively under-utilized approach recommend by Canning and Pedroni (2008) [1]. We examine (i) reduced form production function models for both the industry and service/commercial sectors, where aggregate energy consumption is expected to cause aggregate output; and (ii) reduced form demand models, where income is expected to cause (separately) per capita residential electricity consumption and per capita gasoline consumption. We uncover for 12 different panels a set of super-consistent causality findings across two demand models that income "Granger-causes" per capita consumption. By contrast, the results from the production function models suggest that a different modeling framework is required to glean new, useful insights.

1. Introduction

Economic growth and energy consumption have been highly correlated historically. This correlation coupled with concerns over energy consumption's environmental costs (e.g., carbon emissions) and security issues (e.g., foreign supply dependence and nuclear technology proliferation) has helped to spur an extensive and exponentially growing literature that uses statistical techniques based on [2,3] to reveal the causal direction (often called Granger-causality)[1] of the energy consumption-economic growth relationship. A survey by Payne [4] listed 101 such energy-GDP causality papers, the first of which was published in 1978 (only 10 published prior to 1990); over half the papers listed were published since 2005.[2] Those over-100 previous studies, surveyed in [4] and covering every country with available data, have uncovered the full spectrum of possible causality results (bi-directional causality, noncausality, and both types of uni-directional causality). Indeed, the consensus of several critical literature reviews is that the literature focusing on the temporal causality between energy consumption and economic growth has produced neither robust conclusions nor convincing rationale [4–8].

We propose to contribute to this vast literature by (the surprisingly novel idea of) analyzing data that is disaggregated according

* Corresponding author at: Asia-Pacific Energy Research Centre, Inui Bldg., Kachidoki 11F, 1-13-1 Kachidoki, Chou-ku, Tokyo 104-0054, Japan.
E-mail address: btliddle@alum.mit.edu (B. Liddle).

[1] A variable, y, is said to be "Granger-caused" by another variable, x, if x helps in the prediction of y. Thus, Granger causality measures precedence and information content, but does not by itself prove causality (that y is the effect or result of x), any more than any statistical test can prove causality.

[2] A simple search on Science Direct using the key words "energy panel causality" and "cointegration" locates an additional 801 journal articles published from 2010 (search conducted October 29, 2014).

http://dx.doi.org/10.1016/j.apenergy.2014.12.036
0306-2619/

to end-use in such a way that economic theory can be used to predict causality *a priori*—as such our paper provides a critique of the energy-GDP causality literature. We analyze (i) a reduced form bi-variate production function model for both the industry and service/commercial sectors (considering aggregate energy and output), and (ii) a reduced form bi-variate demand model considering income (per capita GDP) and, separately, per capita residential electricity consumption and (from the road sector) per capita gasoline consumption. In addition, by employing panel methods, we consider a large number of both developing and developed countries, which we analyze according to geography, development levels, and energy intensity. Lastly, we (i) employ pre-testing methods that are robust to heterogeneity and cross-sectional dependence (as well as structural breaks); (ii) analyze long-run panel causality using the Canning and Pedroni [1] method, which allows for heterogeneity among the causality relationships; and then (iii) estimate long-run elasticities with a heterogeneous panel estimator that is robust to cross-sectional dependence.

2. Energy and GDP data disaggregation motivated by economic theory

Among the most common reasons for the lack of consensus/disparate results are omitted variables (i.e., bi-variate versus multivariate analyses) and choice of econometric methods—e.g., not considering cointegration [4]. In this paper, we offer an additional reason for the lack of consensus: the common practice of causality testing in the absence of *a priori* theory/model.

The energy-GDP causality literature has characterized the four possible causality results as four different "hypotheses" [7]. Those four result possibilities are: (i) the so-called neutrality hypothesis or the finding of no causality; (ii) the so-called conservation hypothesis or the finding of uni-directional causality running from economic growth to energy consumption; (iii) the so-called growth hypothesis or the finding of uni-directional causality running from energy consumption to economic growth; and (iv) the so-called feedback hypothesis or the finding of bi-directional causality.

Unfortunately, none of these four so-called hypotheses enables predictions: there is no way to know which of the four causality findings will be true for a particular country or group of countries without first performing the test (rather than hypotheses, these findings are really *ex post* descriptive categories). Indeed, since energy is a production input *and* a final consumption good, one might expect nearly all countries would be characterized by the feedback "hypothesis" (i.e., bi-directional energy-GDP causality); but again, no such consistent finding has emerged [4,7]. Likewise, if a test produces a result different from previous ones, there is no way of knowing—in the absence of *a priori* theory—whether that test has uncovered new evidence or whether the unusual result is simply a manifestation of one of the several causes of the literature's disparate results that were mentioned above.

If, however, both energy and GDP were *disaggregated* in a way that made studying causality between them more meaningful, then neo-classical theory could provide guidance on the causality relationships *a priori*. For example, *aggregate* industry energy consumption—as an input to production—would be expected to cause (along with other production factors like capital and labor) *aggregate* industry output. One would expect a positive relationship between energy consumption and output (i.e., more energy consumed leads to greater output and *vice versa*) in a production function framework.

A few single-country studies (e.g., [9–12]) have estimated sectoral-level production functions similar to Eq. (1):

$$\ln(VA)_{it} = \alpha_i + \gamma_t + \beta_1 \ln(En)_{it} + \beta_2 \ln(L)_{it} + \beta_3 \ln(K)_{it} + e_{it} \tag{1}$$

where *VA* is value added or output, *En* is energy consumption, *L* is labor, and *K* is capital stock (ideally all variables would be in sector-based aggregates).

The challenge for researchers in applying this type of causality model to panel data is that time series data for value added, physical capital, and labor employed at the ISIC two-digit classification level (e.g., for nonmetallic minerals, chemicals, etc.) is available for only a few OECD countries (in databases like the OECD's Structural Analysis Database).[3] Indeed, the only such sector-based, production function, panel study, Liddle [13], considered panels of only six to 12 OECD countries. Hence, since we are interested in considering panels of (a large number of) developed and developing countries, we examine the following "reduced form" production function for industry and service/commercial sectors:

$$\ln(VA)_{it} = \alpha_i + \gamma_t + \beta_{1i} \ln(En)_{it} + e_{it} \tag{2}$$

Similarly, one could employ a demand-model framework in which income (or GDP per capita) would be expected to cause normal consumption goods like energy consumption (per capita) in personal transport and the residential sector. Such a demand model could include the price of that energy as well as the price from a competing energy source. Again, one would expect a positive, causal relationship between income (GDP per capita) and per capita energy consumption (higher income leads to higher energy consumption and *vice versa*).

Several single-country studies focusing on either residential energy/electricity or gasoline consumption (e.g., [14–17]) have analyzed a demand model similar to Eq. (3):

$$\ln(Epc)_{it} = \alpha_i + \gamma_t + \beta_1 \ln(GDPpc)_{it} + \beta_2 \ln(Epr)_{it} + e_{it} \tag{3}$$

where *Epc* is energy consumption per capita, *GDPpc* is GDP per capita or income, and *Epr* is the real energy price.

Researchers interested in applying this type of demand causality model to panels also are challenged by a lack of data availability—the IEA has time series, price data for only OECD countries, and that data begins only in 1978 and is missing observations for several of those countries. For example, Narayan et al. [18], who considered the residential electricity consumption demand, studied the G-7 countries, and Liddle [19], who focused on gasoline demand, analyzed 14 OECD countries. So again, to increase the scope of countries considered we examine a "reduced form" model to analyze residential electricity and motor gasoline demand:

$$\ln(Epc)_{it} = \alpha_i + \gamma_t + \beta_{1i} \ln(GDPpc)_{it} + e_{it} \tag{4}$$

3. Brief additional literature review and this paper's contribution

A few previous studies have analyzed similar reduced form, bi-variate production function and demand models. Both Liddle [20] and Zachariadis [21] looked individually (using time series methods) at a number of developed countries (18 OECD and G-7 countries, respectively). Both of those papers uncovered substantial heterogeneity as well as several economically implausible causality results. For example, [20] found industry output "caused" energy consumption for the UK, while [21] found that same direction of causality for Canada, Germany, and the UK (depending on the causality method used). Also, per capita road and residential energy consumption "caused" per capita GDP for Spain [20], and residential energy consumption "caused" income in Japan and France [21].

[3] At the less disaggregated level of industry and service sectors (i.e., ISIC one-digit classification level), one can construct time series of labor employed (from World Bank data) for most OECD countries and about a dozen non-OECD countries; however, to our knowledge the corresponding physical capital data series are not available.