Energy Economics 34 (2012) 865–873

Contents lists available at SciVerse ScienceDirect

Energy Economics

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

Energy consumption-GDP nexus: Heterogeneous panel causality analysis

K. Ali Akkemik [a,*], Koray Göksal [b,1]

[a] Kadir Has University, Department of Economics, Cibali, Istanbul, 34083, Turkey
[b] Yildirim Beyazit University, Department of Economics, Cinnah Cad., No. 16, Kavaklıdere, Ankara, Turkey

ARTICLE INFO

Article history:
Received 9 February 2011
Received in revised form 30 March 2012
Accepted 1 April 2012
Available online 16 April 2012

JEL classification:
C22
C23
Q49

Keywords:
Energy
Granger causality
Heterogenous panel

ABSTRACT

Existing studies examining the Granger causality relationship between energy consumption and GDP use a panel of countries but implicitly assume that the panels are homogeneous. This paper extends the Granger causality relationship between energy consumption and GDP by taking into account panel heterogeneity. For this purpose, we use a large panel of 79 countries for the period 1980–2007. Specifically, we examine four different causal relationships: homogeneous non-causality, homogeneous causality, heterogeneous non-causality, and heterogeneous causality. The results show that roughly seven-tenths of the countries exhibit bi-directional Granger causality, two-tenths exhibit no Granger causality, and one-tenths exhibit uni-directional Granger causality.

1. Introduction

Energy consumption is assumed to increase with higher level of development due to increased living standards. According to the World Bank's World Development Indicators database, measured in constant 2000 US dollars, world GDP grew on average by 4.7% per annum from 1980 to 2007. During the same period, world total energy consumption, measured in tons of oil equivalent, grew on average by 2.4% per annum. Average annual growth rate of energy consumption varied largely across different regions for the stated period. For instance, it was 8.0% for the developing countries in the Asia-Pacific region, 11.0% for the Middle East and North Africa, 1.3% for OECD, and 1.0% for the Euro area. The former two are rapidly growing regions with average annual GDP growth rates exceeding both over 6% for 1980–2007 while the latter two have mature economies with relatively slower growth rates averaging 3–4% for the same period.

The causal relationship between energy consumption and GDP has been subject to a number of studies since the seminal work by Kraft and Kraft (1978). A review of literature on the causal relationship between energy consumption and income is not aimed here since compact reviews are available elsewhere (e.g., Chontanawat et al., 2006; Huang et al., 2008). A list of selected studies with respective country and period coverage along with main findings is presented in Table 1. Most of these studies employed homogeneous panel Granger causality, error correction model, cointegration, vector autoregression, and panel data analysis. In the 47 studies listed in Table 1, there are 11 cases of no causality, 16 cases of bi-directional causality, and differing causality and cointegration relationships between energy consumption and GDP in others. The conclusions about causality do not lead to a general conclusion. This is due to differences in the methods applied and coverage of times and economies that differ from one study to the other.

Studies finding causality that runs from energy consumption to GDP generally argue against policies aiming reductions in energy consumption due to the negative effect on GDP. The causal relationship running from GDP to energy consumption, on the other hand, implies that higher economic growth leads to an increase in energy use. In those studies where no causal relationship between energy consumption and income exists, economic growth and energy policies are deemed independent of each other. Finally, if there is a causal relationship running in both ways, energy use and GDP are interdependent.

In search for more generalized results for causality between energy consumption and income, researchers use panel data by combining cross-sections (countries) for limited time periods. In such studies, typically dynamic panel Granger causality is employed. However, these studies fail to check whether the panels are homogenous. An important shortcoming of the stated studies is that the Granger causality methodology is based on the implicit assumption that the panel data is of a homogenous nature. Even so, the results for causality, even for the same economies and similar periods, are conflicting and contradictory. Therefore, it is difficult to reach a conclusion about the causal relationship

* Corresponding author. Tel.: +90 212 5336532 1609; fax: +90 212 5336515.
E-mail addresses: ali.akkemik@khas.edu.tr (K.A. Akkemik), kgoksal@ybu.edu.tr (K. Göksal).
[1] Tel.: +90 312 4667533 3543.

0140-9883/$ – see front matter
doi:10.1016/j.eneco.2012.04.002

Table 1
Review of selected literature on the causality between energy (E) and income (Y).

Study	Country	Period	Results
Kraft and Kraft (1978)	US	1947–1974	Causality exists.
Akarca and Long (1980)	US	1947–1972	No causality
Yu and Hwang (1984)	US	1947–1979	No causality
Yu and Choi (1985)	Poland, UK, US	1950–1976	Y ↔ E
	Korea		Y → E
	Philippines		E → Y
Erol and Yu (1987)	Canada, France, UK	1950–1982	No causality
	Italy, Japan		Y → E
	Germany		E → Y
Nachane et al. (1988)	16 countries	1950–1985	Y ↔ E
Hwang and Gum (1992)	Taiwan		Y ↔ E
Yu and Jin (1992)	US	1974–1990	No causality
Stern (1993)	US	1947–1990	E → Y
Ebohon (1996)	Nigeria, Tanzania	1960–1984	Y ↔ E
Masih and Masih (1996)	Malaysia, Philippines, Singapore	1955–1991	No cointegration
	India		E → Y
	Indonesia		Y → E
	Pakistan		Y ↔ E
Cheng and Lai (1997)	Taiwan	1955–1993	Y → E
Glasure and Lee (1997)	Korea	1961–1990	No causality
	Singapore		E → Y
Masih and Masih (1998)	Sri Lanka, Thailand		E → Y
Cheng (1999)	India	1952–1995	Y → E
Asafu-Adjaye (2000)	Philippines, Thailand	1971–1995	Y ↔ E
	India, Indonesia, Turkey		E → Y
Stern (2000)	US		E → Y
Yang (2000)	Taiwan	1954–1997	No causality
Aqeel and Butt (2001)	Pakistan	1955–1996	Y → E
Ghosh (2002)	India	1950–1997	Y → E
Soytas and Sari (2003)	Argentina	1950–1994	Y ↔ E
	Italy, Korea		Y → E
	France, Germany, Japan, Turkey		E → Y
Altinay and Karagol (2004)	Turkey	1950–2000	No causality
Ghali and El-Sakka (2004)	Canada	1961–1997	Y ↔ E
Jumbe (2004)	Malawi	1970–1999	Y → E
Morimoto and Hope (2004)	Sri Lanka	1960–1998	E → Y
Oh and Lee (2004)	Korea	1981–2000	No short-run causality
Paul and Bhattacharya (2004)	India	1950–1996	Y ↔ E
Shiu and Lam (2004)	China	1971–2000	E → Y
Lee (2005)	18 developing countries	1975–2001	E → Y
Lee and Chang (2005)	Taiwan	1954–2003	E → Y
Wolde-Rufael (2005)	19 countries in Africa	1971–2000	Cointegration in 10 countries
Lee (2006)	Germany, UK		No causality
	Sweden, US		Y ↔ E
	Belgium, Canada, Netherlands, Switzerland		E → Y
	France, Italy, Japan		Y → E
Al-Iriani (2006)	Gulf countries		Y → E
Yoo (2006)	Malaysia, Singapore	1971–2002	Y ↔ E
	Indonesia, Thailand		Y → E
Halicioglu (2007)	Turkey	1968–2005	Y → E
He et al. (2007)	China (Beijing)	1978–2006	Y ↔ E
Lee and Chang (2007)	12 developed countries		Y ↔ E
	28 developing countries		Y → E
Lise and van Montfort (2007)	Turkey	1970–2003	Cointegration
Mehrara (2007)	11 oil-exporting countries	1971–2002	Y → E
Mozumder and Marathe (2007)	Bangladesh		Y → E
Akinlo (2008)	Sudan, Zimbabwe		Y → E
	Gambia, Ghana, Senegal		Y ↔ E
	Cameroon, Cote d'Ivoire, Kenya, Nigeria, Togo		No causality
Ashgar (2008)	Bangladesh, Nepal, Pakistan	1971–2003	Y → E
Dhungel (2008)	Nepal	1980–2004	Y ↔ E
Huang et al. (2008)	Low-income countries	1972–2002	No causality
	Middle-income countries		Y → E
	High-income countries		Y affects E negatively
Lee and Chang (2008)	16 Asian countries	1971–2002	Long-run: E → Y
Apergis and Payne (2010a)	9 Latin American countries	1980–2005	Cointegration, E → Y
Costantini and Martini (2010)	71 countries	1978–2005	Different causality relations
Kahsai et al. (2010)	19 African countries	1980–2005	Y ↔ E

Note: E → Y denotes Granger causality running from energy consumption to GDP. Y → E denotes Granger causality running from GDP to energy consumption. E ↔ Y denotes bi-directional Granger causality between GDP and energy consumption.

between energy consumption and income. If the panel is heterogenous when Granger causality assumes a homogeneous panel, then there is a heterogeneity bias (Pesaran and Smith, 1995). Hurlin and Venet (2001) offer a method to test homogeneous causality against heterogenous causality. This method has been employed in other panel causality studies to examine the causal relationships between exports and economic growth (He and Zhang, 2010) and between carbon emissions and economic growth (Maddison and Rehdanz, 2008) among others. Only one paper, Al-Iriani (2006) has dealt with the issue of panel heterogeneity in examining the causal relationship between energy consumption and income for 11 Gulf countries. Al Iriani uses heterogenous panel cointegration developed by Pedroni (2004) and finds evidence for the existence of a long-run relationship. He then proceeds to Granger causality techniques developed by Holtz-Eakin et al. (1988). He finds evidence for unidirectional causality from GDP to energy consumption.

In this paper, we examine Granger causality between energy consumption and GDP for a panel made up of 79 countries for the period 1980–2007. For 17 former transition economies, due to lack of reliable data for the pre-1990 period, the period of analysis restricted to 1990–2007. This paper contributes to the literature about the causal relationship between energy consumption and income by extending the panel Granger causality techniques beyond those currently available. In our panel Granger causality exercise, we take into account the potential heterogeneity of the countries in the sample. To this end, we use the method for panel data Granger causality with fixed coefficients proposed by Hurlin and Venet (2001). We first test for homogeneous (non)causality and then if the test fails we test for heterogenous (non)causality in our heterogenous panel.

The rest of the paper is organized as follows. Data construction and data sources are explained in Section 2. Section 3 sets out the method of analysis and the testing procedure. The results are presented in Section 4. Finally, the fifth section concludes.

2. Data

For the analysis, we gathered data on real GDP, energy use, capital input, and labor input for the period 1980–2007. Real GDP and labor data are obtained from World Development Indicators (WDI) database published by the World Bank. Real GDP data measured in constant 2000 US dollars. WDI data are based on the national accounts database of the World Bank and OECD National Accounts data. Labor refers to the working age population, defined as the number of people between age 15 and 60. Final energy use is measured in tons of oil equivalent and are obtained from International Energy Agency statistics database.

Capital data are not readily available in official statistics. Nehru and Dhareshwar (1995) estimated capital stock data using the perpetual inventory method for a large number of countries for the period 1950–1990. It is possible to extend their capital stock data by using the perpetual inventory method.[2] However, Sari and Soytas (2007) warned that the use of capital stock series estimated with the perpetual inventory method is problematic since the variance in capital stock computed using this method is correlated with the change in investment.[3] Following their suggestion, we use gross fixed capital formation data obtained from WDI database. All data are expressed in natural logarithms.

Our database includes 79 countries. We categorized countries into groups to examine whether there are any structural differences. The country groups of significance are listed as Asia (11 countries), Developed Countries (25 countries), European Union (15 countries, i.e., EU-15), Developing Countries (37 countries), and Transition Economies (17 countries). In total, data are available for the period 1980–2007 for 62 countries but data for 17 transition economies (i.e., former Soviet republics including Russia and former command economies in Central and Eastern Europe) are available only for the period 1990–2007. A list of these countries is presented in Table 2. Descriptive statistics of the data are presented in Table 3.

Table 2
List of countries.

Area	Countries
Developing countries	Algeria, Argentina, Bangladesh, Bolivia, Brazil, Cameroon, Chile, China, Colombia, Costa Rica, Cote d'Ivoire, Dominican Republic, Ecuador, Egypt, El Salvador, Guatemala, Honduras, India, Indonesia, Iran, Kenya, Malaysia, Mexico, Morocco, Mozambique, Nicaragua, Pakistan, Panama, Paraguay, Peru, Philippines, Senegal, South Africa, Thailand, Tunisia, Turkey, Uruguay
Developed countries	Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Singapore, Spain, Sweden, Switzerland, UK, USA
Asia	Bangladesh, China, India, Japan, Indonesia, Korea, Malaysia, Pakistan, Philippines, Singapore, Thailand
EU	Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, UK
Transition economies	Belarus, Bulgaria, Czech Republic, Estonia, Hungary, Kazakhstan, Kyrgyzstan, Latvia, Macedonia, Moldova, Poland, Romania, Russia, Slovenia, Tajikistan, Ukraine, Uzbekistan

3. Methodology

In panel data causality analysis, choosing the appropriate technique is an important theoretical and empirical issue. The conventional Granger causality is not reliable for panel data due to variations across the cross-sections, i.e. heterogeneity. Erdil and Yetkiner (2005) categorized recently developed panel causality techniques taking into account the heterogeneity issue into two broad categories. On the one

Table 3
Descriptive statistics.

	Mean	Median	Minimum	Maximum	Standard deviation
All countries					
lnK	23.480	23.629	19.466	28.462	1.877
lnE	17.046	16.990	14.133	21.573	1.678
lnY	25.040	25.118	21.350	30.072	1.811
lnL	15.871	15.684	11.759	20.466	1.552
Asia					
lnK	24.453	24.077	21.581	27.896	1.531
lnE	18.187	17.944	15.451	21.394	1.415
lnY	25.777	25.382	23.741	29.280	1.437
lnL	17.508	17.406	13.926	20.466	1.570
EU					
lnK	24.565	24.417	21.075	26.749	1.261
lnE	17.645	17.660	14.834	19.706	1.244
lnY	26.156	25.981	22.752	28.358	1.285
lnL	15.565	15.355	11.924	17.559	1.353
Developed countries					
lnK	24.654	24.534	20.683	28.462	1.590
lnE	17.740	17.646	14.219	21.573	1.546
lnY	26.198	26.042	22.364	30.072	1.605
lnL	15.600	15.355	11.759	18.873	1.585
Developing countries					
lnK	22.681	22.590	19.466	27.654	1.622
lnE	16.576	16.259	14.133	21.394	1.599
lnY	24.258	24.216	21.350	28.530	1.497
lnL	16.054	15.875	13.376	20.466	1.502
Transition economies					
lnK	21.949	21.998	18.210	26.228	1.665
lnE	11.128	10.625	7.709	17.947	3.193
lnY	23.434	23.459	20.389	26.733	1.548
lnL	15.257	15.254	13.375	18.156	1.258

[2] In the perpetual inventory method, capital stock is calculated using the formula $K_{t+1} = K_t(1-\delta) + I_t$, where K refers capital stock, δ refers to depreciation rate (which is assumed to be constant in most studies), and I refers to gross fixed capital formation (investment).

[3] Gross fixed capital formation is preferred to gross capital stock estimates in recent supply-side energy-income causality studies, e.g., Apergis and Payne (2010b).

hand, Holtz-Eakin et al. (1988) and their followers (e.g., Nair-Reichert and Weinhold, 2001; Weinhold, 1996) take the autoregressive coefficients and slope coefficients in panel VAR model as variable. On the other hand, Hurlin and Venet (2001) propose a method by taking the autoregressive coefficients and slope coefficients as constant. The main criterion of selection between the two approaches is the time span. If the time span is short, the second method is advised. Our data cover the period 1980–2007 and therefore the second approach is more appropriate.

We attempt to study the causal relationship between logged values of energy consumption (E) and real GDP (Y) using multivariate dynamic panel Granger causality method with fixed coefficients proposed by Hurlin and Venet (2001). It is now widely accepted that bivariate causality analysis examining the energy–income nexus lead to spurious causal relationship. Therefore it is necessary, at the outset, to address how we deal with a possible flaw observed in bivariate panel causality studies, the omitted variable bias. Omitted variable bias arises when some other explanatory variables which are actually correlated with the dependent variable is omitted from the regression. In this case, the covariance between the explanatory variables and the error term from the true regression will not be equal to zero. In most papers, instrumental variables are added to the regression to tackle this issue. However, empirically it is difficult find appropriate instruments. We choose to derive from a theoretical model rather than discretionary selection of control variables. Therefore, we adopt the widely-used production function approach which states that real GDP is a function of capital (lnK), labor (lnL), and energy (lnE), all in natural logarithms. In the causality regressions we employ the variables lnK and lnL as the control variables. By adding these two variables we account for the causality relations between the dependent variables of interest (lnE or lnY) and lnK and lnL that are hidden in the bivariate causality analysis. For instance, as shown by Stern (1993), changing energy consumption may result in more use of capital and labor which substitute energy. We believe that the multivariate causality analysis better reflects the causality from energy to GDP or the other way around by taking into account the causality relationships involving capital and labor as well. In addition, in this paper we employ the heterogeneous fixed effects dynamic panel data estimation technique as presented in Hurlin and Venet (2001). In this technique, fixed effects that do not vary in time are controlled for, and the lags of dependent variables are included in the regression.

To test for causality in heterogeneous panels, we use the following model for the causality from GDP to energy consumption[4]:

$$ln\,E_{i,t} = \sum_{j=1}^{n} \gamma^{j} ln\,E_{i,t-j} + \sum_{j=1}^{n} \beta_i^{j} ln\,Y_{i,t-j} + u_{i,t}, \qquad u_{i,t} = \alpha_i + \epsilon_{i,t}$$

Likewise, to test for the causal relationship running from energy consumption to GDP, we use the following model:

$$ln\,Y_{i,t} = \sum_{j=1}^{n} \gamma^{j} ln\,Y_{i,t-j} + \sum_{j=1}^{n} \beta_i^{j} ln\,E_{i,t-j} + u_{i,t}, \qquad u_{i,t} = \alpha_i + \epsilon_{i,t}$$

Here i refers to individual countries, t denotes time, and j is the number of lags. α, β, and γ are parameters to be estimated. lnK and lnL also enter the regression as exogenous variables.

In this section we abstain from technical details of the analysis and leave it to Appendix A. We provide a brief overview of the methodology here. Hurlin and Venet (2001) present four types of causality relationships that may emerge from panel data:(i) homogenous causality (HC), (ii) homogenous non-causality (HNC), (iii) heterogeneous causality (HEC), and (iv) heterogeneous non-causality (HENC). In the conventional Granger causality studies regarding energy and income, heterogeneity of the countries or regions included in the panel are overlooked and any causal relationship found is viewed as homogenous causality. We are especially concerned with heterogeneous non-causality case where there is at least one country in the panel for which no causality relationship exists.

To test for the above four types of causality, we follow the procedure in Hurlin and Venet (2001) which is explained in detail in Appendix A. The computation of the test statistics used in testing the four causality hypotheses are also explained in Appendix A.[5] These statistics are compared with the critical F statistics. The analytical procedure can be summarized as follows. We first test HNC against the alternative hypothesis. In this test, the null hypothesis states that there is no causal relationship for any of the countries in the panel. If the HNC hypothesis is not rejected, we conclude that there is no causal relationship at all for any country in the panel. If the HNC hypothesis is rejected, this is an evidence of the existence of a causal relationship. However, this relationship can be of either homogenous or heterogenous type. We then test the HC hypothesis. If the HC hypothesis is accepted, we conclude that the panel homogenously exhibits a causal relationship between energy and income. Most causality studies assume the existence of this type of a causal relationship. However, if the HC hypothesis is rejected, a heterogeneous group of countries may exhibit causality. As a consequence, the HENC hypothesis is tested for all countries in the panel to find the countries which account for the causality in the panel. If the HENC hypothesis is not rejected for a specific country or a subset of countries in the panel, we conclude that this country or subset of countries do not yield any causal relationship. If the HENC hypothesis is rejected, then HEC applies, i.e., there is a causal relationship for all countries despite cross-country heterogeneity in the panel.[6]

4. Empirical results

Prior to the Granger causality tests, we search for the existence of unit roots for two series, logged energy consumption, lnE, and logged real GDP, lnY. The conventional augmented Dickey-Fuller (ADF) tests for detecting unit root are known tobe weak hypothesis testing of stationarity for panel data. Therefore, we use two other more powerful unit root tests that are used widely for panel data, based on Levin et al. (2002) and Im et al. (2003). We abbreviate the former as LLC and the latter as IPS. While the LLC test assumes common unit root for all panel members, the IPS test allows for individual unit roots for panel members. Panel unit root test results are shown in Table 4. The results of the LLC test lead us to accept the existence of unit root at levels while the IPS test results rejects the null hypothesis of non-stationarity of both series at levels. The results also demonstrate evidence for the stationarity of the first differences of both series. It is shown in Baltagi (2005: 245) that the IPS test is more powerful than the LLC test. In addition, the IPS test uses unit root tests separately for individual cross-sections. We adhere to the stronger IPS test results and conclude that both series are stationary.

In choosing the optimal lag order, we employ widely-used vector autoregressive (VAR) lag length selection criteria, namely Akaike, Schwarz, and Hannan–Quinn information criteria. For this purpose, we run a vector autoregressive model with lnE and lnY as endogenous variables and lnK and lnL as exogenous variables. In most VAR regressions, Schwarz and Hannan–Quinn information criteria indicate two lags while Akaike information criterion indicates larger but various lag lengths. In all cases except Asia, we choose two lags (and four for Asia) as the appropriate lag length based on Schwarz and Hannan–Quinn criteria. All causality equations are estimated using fixed

[4] This section is heavily based on Hurlin and Venet (2001).

[5] In each hypothesis, we run the specified regressions and save the sum of squared residuals to be used in computing the test statistics. These statistics are then compared with the relevant F statistics to observe the significance at the 1, 5, and 10 levels.

[6] The analyses were conducted using Eviews v. 6.

Table 4
Unit root tests.

	Level		First difference	
	lnY	lnE	lnY	lnE
LLC (common unit root)	−0.497	1.671	−14.971***	−20.220
IPS (individual unit root)	−3.569***	−4.977***	−19.849***	−26.699***

Note: *** significant at 1% level, ** significant at 5% level, * significant at 10% level.

effects since Hurlin and Venet (2001) report that for T sufficiently large (larger than 30) dynamic panel bias is negligibly small. The standard errors of the regressions are corrected for heteroscedasticity using period seemingly unrelated regression method. Critical values for F tests are based on F distribution with $(Nn, NT-N(1+n)-n)$ degrees of freedom (Hurlin and Venet, 2001).

4.1. Results for causality running from GDP to energy consumption

The results for the tests of homogeneous non-causality (HNC) and homogeneous causality (HC) from GDP to energy consumption are presented in Table 5. The HNC hypothesis is rejected for all country groups at 1% level except for the EU, where it is rejected only at 10%. The fourth column of Table 5 shows that there is no homogeneous causality (HC) from GDP to energy for all country sub-samples other than the EU. Subsequently, we conclude that panel heterogeneity holds for all sub-samples but not for the EU, for which we find homogenous causality from GDP to energy.

In the next step, we test the HENC hypothesis. 66 out of 79 countries exhibit heterogeneous causality (HEC) from GDP to energy. Eight developing countries, three transition countries, and two developed countries exhibit heterogeneous non-casuality (HENC). For Asia, the HENC hypothesis is rejected at 5% level while it is rejected only at 10% for Developed Countries. Therefore, we can conclude that there is Granger causality for Asian and developed country sub-samples though weakly for the latter. On the other hand, the HENC hypothesis is not rejected for Developing Countries and Transition Economies. For these two sub-samples, GDP does not Granger cause energy consumption.

Overall, our results suggest there is some evidence for the causal relationship from GDP to energy consumption and it is heterogeneous across countries. Among the country subsamples, homogeneous causality relationship holds only for the EU. On the other hand, homogeneous causality does not hold for Developed Countries, of which the EU is a subset. An important finding of this paper is that the causality relationship between GDP and energy consumption (in this case from the former to the latter) is highly heterogenous. A good case in point is the EU and developed country subsamples. Homogeneity of the panel including 15 EU countries becomes irrelevant when the panel is extended to include 10 more developed countries such as Australia, Japan, the US, etc. This finding provides evidence for the importance of panel heterogeneity since individual predictors for the causality relationships are different across panel members. This finding points to divergent results in causality studies listed in Table 1. In other words, the cross-sectional heterogeneity of the panel is an important determinant of the causality relationship because the causality relationship may hold only for a sub-group of countries in the panel (Table 6).

Table 5
Tests of homogeneous non-causality (HNC) and homogeneous causality (HC) (causality running from GDP to energy consumption).

	Lags	F_{HNC}	F_{HC}
All countries	2	1.672***	1.623***
Asia	4	1.934***	1.841***
Developed countries	2	1.666***	1.625***
Developing countries	2	1.697***	1.601***
EU	2	1.427*	1.329
Transition economies	2	2.635***	2.540***

Note: *** significant at 1% level, ** significant at 5% level, * significant at 10% level.

4.2. Results for causality running from energy consumption to GDP

The results of HNC and HC tests for the causal relationship running from energy consumption to GDP are presented in the second column of Table 7. The results are qualitatively the same as those for the reverse causality relationship explained in the previous subsection. The HNC hypothesis is rejected for all sub-samples at 1% level except for the EU where it is rejected at 5%. We show in the third column of Table 7 that the HC hypothesis is rejected as well. Consequently, we look at causality relationships at the individual country level by using the HENC hypothesis. For the EU, we conclude that there is homogenous causality between GDP and energy consumption.

The results of HENC tests by countries are presented in Table 8. 63 countries exhibit Granger causality running from energy consumption to GDP. 16 countries, including nine developing countries (Costa Rica, Cote d'Ivoire, Dominican Republic, Ecuador, Egypt, India, Malaysia, Panama, and Senegal), one transition economy (Hungary), and six developed countries (Belgium, Denmark, France, Italy, Sweden, and Switzerland) exhibit HENC. The results in Table 9 confirm that the HENC hypothesis is rejected for the HENC sub-samples.

After examining the causality from energy consumption to GDP, again we find that the causality relationship between GDP and energy consumption is highly heterogenous as in the case of the causality relationship in the opposite direction. Causality relationship is not homogeneous across subsamples except the EU as in the previous case. This finding provides another evidence for the heterogeneity of the causal relationship within the panels.

5. Conclusions

In this paper, we build on previous research about the causality relationship between energy consumption and GDP in panel data and extend Granger causality by taking into consideration panel heterogeneity. Our panel consists of 79 countries for the period 1980–2007. In previous studies, an implicit assumption behind the Granger causality relationship was the homogeneity of the panel. The contribution of this paper to the literature is the application of a more advanced Granger causality technique for fixed coefficient panels developed by Hurlin and Venet (2001).

Most of the previous panel causality studies implicitly assumed panel homogeneity. We show that panel heterogeneity is common and an important issue. We demonstrate that the causality relationships between energy consumption and GDP, in both directions, are of a highly heterogenous nature. Therefore, an important conclusion of this paper is that panel heterogeneity needs to be tested when searching for causality between energy consumption and income. This applies not only to cross-country studies, but also to causality studies conducted across different regions within a country. In this study, homogenous causality relationship is found only for the panel made up of EU-15 countries. Once the heterogeneity of the causal relationship is confirmed for the panel, it may then be necessary to derive different policy recommendations for the panel members rather than formulating a policy that applies to all panel members.

Despite the diversity in the causality relationships across country subsamples, the key results of this paper carry important policy implications. Due to the heterogeneity in the causal relationships, we take individual country perspective rather than the aggregated country groups while devising policy recommendations. Panel causality tests show that bidirectional causality is observed in seven-tenths of the countries (57 out of 79) in the sample. Unidirectional causality is observed in about one-tenths (7 out of 79) and no causality in two-tenths (15 out of 79). We conclude for the 57 countries exhibiting bidirectional causality that there is an interaction between energy

Table 6
Results of heterogeneous non-causality tests (causality running from GDP to energy consumption).

Result: HENC		Result: HEC	
Developing countries			
Argentina	0.231	Algeria	4.760**
Colombia	0.557	Bangladesh	27.977***
Costa Rica	1.935	Bolivia	12.075***
Cote d'Ivoire	3.173	Brazil	4.679**
Dominican Republic	1.965	Cameroon	4.742**
Ecuador	0.278	Chile	3.719**
Malaysia	1.470	China	17.195***
Paraguay	2.803	Egypt	15.270***
		El Salvador	4.355**
		Guatemala	21.354***
		Honduras	39.760***
		India	20.111***
		Indonesia	11.459***
		Iran	7.579***
		Kenya	25.842***
		Mexico	12.895***
		Morocco	9.988***
		Mozambique	4.823**
		Nicaragua	7.048***
		Pakistan	19.487***
		Panama	13.026***
		Peru	41.182***
		Philippines	34.415***
		Senegal	10.195***
		South Africa	5.711***
		Thailand	15.968***
		Tunisia	14.269***
		Turkey	11.983***
		Uruguay	7.048***
Developed countries			
Denmark	2.250	Australia	3.751**
Switzerland	0.212	Austria	14.829***
		Belgium	4.627**
		Canada	7.718***
		Finland	5.081**
		France	11.563***
		Germany	7.072***
		Greece	7.037***
		Iceland	22.770***
		Ireland	13.026***
		Italy	17.835***
		Japan	6.189***
		Korea	7.159***
		Luxembourg	10.453***
		Netherlands	3.695**
		New Zealand	17.632***
		Norway	8.259***
		Portugal	8.989***
		Singapore	5.783***
		Spain	10.711***
		Sweden	4.025**
		UK	11.240***
		USA	12.486***
Asia			
Malaysia	1.470	Bangladesh	27.977***
		China	17.195***
		India	20.111***
		Indonesia	11.458***
		Japan	6.189***
		Korea	7.159***
		Pakistan	19.487***
		Philippines	34.415***
		Singapore	5.783***
		Thailand	15.968***
Transition economies			
Kyrgyzstan	1.926	Belarus	21.003***
Poland	0.871	Bulgaria	130.670***
Slovenia	1.085	Czech Republic	7.068***
		Estonia	18.409***
		Hungary	19.766***
		Kazakhstan	9.325***
		Latvia	15.553***
		Macedonia	6.191***
		Moldova	77.717***
		Romania	42.959***
		Russia	18.516***
		Tajikistan	90.570***
		Ukraine	127.500***
		Uzbekistan	32.978***

Note: *** significant at 1% level, ** significant at 5% level.

consumption and economic growth, i.e. the so-called "feed-back hypothesis," which implies that energy serves as an engine of growth and energy consumption is also determined by the scale of economic activities. These countries are composed of 19 developed countries and 38 developing and transition countries. The share of countries with bidirectional causality is around seven-tenths in both developed and developing/transition countries subsamples. This result is contrary to the unidirectional causality found in most bi-variate cross-country causality studies (e.g., Lee and Chang, 2008; Mehrara, 2007). We believe that omission of factors that may impact on the causality relationship between energy consumption and energy may explain part of this difference in results. The interaction between energy and capital and labor is important in this respect.[7] Among the countries in this category, the rapid growth of China drives attention to the availability of energy resources and energy demand in the world. On the other hand, the world's leading energy producing and resource-rich countries (e.g. Brazil, Indonesia, Mexico, Russia, and the US) as well as the world's leading energy-consuming countries (e.g., China, Germany, Japan, Russia, the UK, and the US) exhibit bidirectional causality. This paper finds evidence for the importance of energy for economic growth in these countries and the energy sectors play an important role in sustaining economic growth, even when the contribution of capital and labor are also taken into consideration.

There is unidirectional causality from GDP to energy in nine countries (Belgium, Egypt, France, Hungary, India, Italy, Panama, Senegal, and Sweden) and from energy to GDP for six countries (Argentina, Colombia, Kyrgyzstan, Paraguay, Poland, and Slovenia). In the case of causality from GDP to energy consumption, countries in this group include four developed economies including France and Italy and a large developing country, India. Given that these countries are resource-constrained, energy efficiency and energy-saving policies should be of importance for policymakers in these countries. To give a case in point, the rapid growth of India especially poses important challenges for energy demand in the world. In the case of causality from energy consumption to GDP, the six economies in this category are developing Latin American or transition economies. In these economies, energy-saving policies or large increases in world energy prices are expected to hamper economic growth because the reduction in energy consumption via energy conservation leads to lower economic growth. Subsequently, environmental consequences of dependence on energy to grow need to be addressed since fossil fuels such as coal and oil are the major sources of energy. A possible solution is to put in place relevant policies to enhance energy efficiency in these countries. Although this comes with a cost, as Belke et al. (2010) argued for 25 OECD countries, energy policies designed to reduce greenhouse emissions should shift their focus on alternative energy sources and this may rather promote economic development.

There is no Granger causality in either direction in seven countries (Costa Rica, Cote d'Ivoire, Denmark, Dominican Republic, Ecuador, Malaysia, and Switzerland). In these countries, energy policies and economic growth are independent from each other and energy-

[7] Apergis and Payne (2010a) argued for Latin American countries that energy consumption impacted positively on capital and therefore on economic growth.

Table 7
Tests of homogeneous non-causality (HNC) and homogeneous causality (HNC) (causality running from energy consumption to GDP).

	Lags	F_{HNC}	F_{HC}
All countries	2	2.008***	1.671***
Asia	4	2.656***	1.896***
Developed countries	2	1.830***	1.725***
Developing countries	2	2.159***	1.626***
EU	2	1.584**	1.402
Transition economies	2	26.162***	3.733***

Note: *** significant at 1% level, ** significant at 5% level, * significant at 10% level.

Table 8
Results of heterogeneous non-causality tests (causality running from energy consumption to GDP).

Result: HENC		Result: HEC	
Developing countries			
Costa Rica	2.407	Algeria	7.370***
Cote d'Ivoire	2.432	Argentina	6.769***
Dominican Republic	2.973	Bangladesh	6.896***
Ecuador	0.427	Bolivia	11.684***
Egypt	1.745	Brazil	3.823**
India	3.279	Cameroon	13.016***
Malaysia	1.451	Chile	40.268***
Panama	2.794	China	5.958***
Senegal	3.129	Colombia	5.838***
		El Salvador	13.752***
		Guatemala	33.117***
		Honduras	15.583***
		Indonesia	6.691***
		Iran	4.926**
		Kenya	30.500***
		Mexico	17.276***
		Morocco	5.195**
		Mozambique	4.652**
		Nicaragua	18.717***
		Pakistan	26.835***
		Paraguay	12.432***
		Peru	58.028***
		Philippines	16.380***
		South Africa	23.239***
		Thailand	17.125***
		Tunisia	9.724***
		Turkey	7.798***
		Uruguay	11.137***
Developed countries			
Belgium	0.853	Australia	6.426***
Denmark	2.207	Austria	8.614***
France	1.533	Canada	3.550**
Italy	1.190	Finland	5.554***
Sweden	2.018	Germany	9.030***
Switzerland	0.334	Greece	7.784***
		Iceland	21.597***
		Ireland	31.902***
		Japan	4.777**
		Korea	8.790***
		Luxembourg	12.484***
		Netherlands	4.694**
		New Zealand	18.717***
		Norway	7.358***
		Portugal	9.849***
		Singapore	12.335***
		Spain	6.980***
		UK	18.319***
		USA	73.690***
Asia			
India	3.279	Bangladesh	6.896***
Malaysia	1.451	China	5.958***
		Indonesia	6.691***
		Japan	4.777**
		Korea	8.790***
		Pakistan	26.835***
		Philippines	16.380***
		Singapore	12.335***

Table 8 (*continued*)

Result: HENC		Result: HEC	
		Thailand	17.125***
Transition economies			
Hungary	3.088	Belarus	9.055***
		Bulgaria	89.666***
		Czech Republic	6.358***
		Estonia	11.010***
		Kazakhstan	9.688***
		Kyrgyzstan	9.525***
		Latvia	9.477***
		Macedonia	13.714***
		Moldova	20.126***
		Poland	22.215***
		Romania	219.104***
		Russia	76.849***
		Slovenia	10.008***
		Tajikistan	245.764***
		Ukraine	76.652***
		Uzbekistan	27.563***

Note: *** significant at 1% level, ** significant at 5% level.

saving policies should have a neutral effect on economic growth. These countries do not seem to share a common characteristic in terms of energy policies and environmental protection.

The findings of the paper can be enriched in the future by focusing on different sources of energy. The current study has a macro perspective. A more disaggregated sectoral analysis may have significant policy implications as well. Future line of research should emphasize these two points.

Appendix A. Heterogenous panel causality analysis

The regression equation for causality from GDP to energy consumption is as follows:

$$ln\,E_{i,t} = \sum_{j=1}^{n} \gamma^j ln\,E_{i,t-j} + \sum_{j=1}^{n} \beta_i^j ln\,Y_{i,t-j} + u_{i,t}, \qquad u_{i,t} = \alpha_i + \epsilon_{i,t} \tag{1}$$

The regression equation for causality from energy consumption to GDP is then as follows:

$$ln\,Y_{i,t} = \sum_{j=1}^{n} \gamma^j ln\,Y_{i,t-j} + \sum_{j=1}^{n} \beta_i^j ln\,E_{i,t-j} + u_{i,t}, \qquad u_{i,t} = \alpha_i + \epsilon_{i,t} \tag{2}$$

In these equations the subscripts i, t, and j refer to individual countries, time, and the number of lags, respectively. α, β, and γ are regression parameters. The variables E and Y are both expressed in natural logarithm, which is denoted by ln. lnE and lnY are stationary variables and the autoregressive coefficients γ^j and the slope coefficients β_i^j are assumed to be constant over the period of analysis. In addition, γ^j are identical across cross-sections and β_i^j are allowed to vary across cross-sections. lnK and lnL are added in the regressions as exogenous variables.

Hurlin and Venet (2001) makes the following assumptions about the error term $\epsilon_{i,\,t}$:

(i) For each cross-section unit i, individual residuals $\epsilon_{i,\,t}$ are independently and normally distributed with $E(\epsilon_{i,\,t})=0$ and finite heterogeneous variances $E(\epsilon_{i,\,t}^2)=\sigma_{i,\,t}^2$.
(ii) Individual residuals are independently distributed across groups, i.e., for all $i \neq j$ and for all time periods t and s, $E(\epsilon_{i,\,t}, \epsilon_{j,\,s})=0$.
(iii) lnE and lnY are covariance stationary.

Next, we define the best linear predictor of $lnE_{i,\,t}$, i.e., $E\left(ln\,E_{i,t}\middle|\,\widetilde{lnE}_{i,t},\ \widetilde{lnY}_{i,t}\right)$, given the past values of $lnE_{i,\,t}$, i.e., $\widetilde{lnE}_{i,t} = (lnE_{i,-p}, \ldots lnE_{i,0}, \ldots$

Table 9
Tests of heterogeneous non-causality (HENC).

	$lnY \rightarrow lnE$	$lnE \rightarrow lnY$
	F_{HENC}	F_{HENC}
Asia	4.345**	4.818**
Developed countries	3.200*	15.786***
Developing countries	2.235	7.347***
Transition economies	2.241	39.119***

Note: 1. *** significant at 1% level, ** significant at 5% level, * significant at 10% level.
2. E → Y denotes Granger causality running from energy consumption to GDP. Y $K_{t+1} = K_t(1-\delta) + I_t$ E denotes Granger causality running from GDP to energy consumption.

$lnE_{i,t-1}$), and the past values of $lnY_{i,\ t}$, i.e., $\widetilde{lnY}_{i,t} = (lnY_{i,-p}, \ldots lnY_{i,0}, \ldots lnY_{i,t-1})$.

Testing for homogenous non-causality (HNC) means testing the hypothesis that there are no individual causality relationships:

$$\text{For all } i, E\left(lnE_{i,t} \middle| \widetilde{lnE}_{i,t}, \alpha_i\right) = E\left(lnE_{i,t} \middle| \widetilde{lnE}_{i,t}, \widetilde{lnY}_{i,t}, \alpha_i\right) \tag{3}$$

The null hypothesis (H_0) and the alternative hypothesis (H_a) for HNC are:

$$\begin{aligned} &H_0 : \beta_i^j = 0 \text{ for all } i \in [1, N] \text{ and for all } j \in [1, n] \\ &H_a : \exists (i, j) \middle| \beta_i^j \neq 0 \end{aligned} \tag{4}$$

The F statistic for the HNC test is calculated as follows:

$$F_{HNC} = \frac{(RSS_2 - RSS_1)/Nn}{RSS_1/[NT - N(1+n) - n]} \tag{5}$$

where RSS_2 is the sum of squared residuals obtained under H_0 and RSS_1 is that obtained under the unrestricted model shown by Eq. (1). T is the number of periods, N is the number of cross-sections (countries), and n is the number of lags. If we fail to reject the HNC hypothesis, we conclude that there is no Granger causality from lnY to lnE (or the other way around if we consider Eq. (2)). Then, the causality examination procedure stops at this point. If we reject the HNC hypothesis, we then proceed to test the homogeneous causality hypothesis.

Testing for homogenous causality (HC) means testing the hypothesis that there are individual causality relationships:

$$\text{For all } i, E\left(lnE_{i,t} \middle| \widetilde{lnE}_{i,t}, \alpha_i\right) \neq E\left(lnE_{i,t} \middle| \widetilde{lnE}_{i,t}, \widetilde{lnY}_{i,t}, \alpha_i\right) \tag{6}$$

The null hypothesis (H_0) and the alternative hypothesis (H_a) for HC are:

$$\begin{aligned} &H_0 : \beta_i^j = \beta^j \text{ for all } i \in [1, N] \text{ and for all } j \in [1, n] \\ &H_a : \exists j \in [1, n] \text{ and} \exists (i, k) \in [1, N] \middle| \beta_i^j = \beta_k^j \end{aligned} \tag{7}$$

The F statistic for the HC test is calculated as follows:

$$F_{HC} = \frac{(RSS_3 - RSS_1)/(N-1)n}{RSS_1/[NT - N(1+2n) + n]} \tag{8}$$

where RSS_3 is the sum of squared residuals obtained when the homogeneity restriction is imposed for each lag j of the coefficients associated to the variable $lnY_{i,\ t-j}$. If we do not reject the HC hypothesis, there is a Granger causality from lnE to lnY and it is valid for all countries in the panel. Then, the causality examination procedure stops. If we reject the HC hypothesis, it means that the causality relationship does not hold for at least one country in the panel and we then proceed to test the heterogeneous non-causality hypothesis.

Testing for heterogenous non-causality (HENC) means testing the hypothesis that there is at least one and at most $N-1$ equalities as follows:

$$\text{For all } i, \exists i \in [1, N], E\left(lnE_{i,t} \middle| \widetilde{lnE}_{i,t}, \alpha_i\right) \neq E\left(lnE_{i,t} \middle| \widetilde{lnE}_{i,t}, \widetilde{lnY}_{i,t}, \alpha_i\right) \tag{9}$$

The null hypothesis (H_0) and the alternative hypothesis (H_a) for HENC are:

$$\begin{aligned} &H_0 : \exists i \in [1, N] \text{ and for all } j \in [1, n], \beta_i^j = 0 \\ &H_a : \text{For all } i \in [1, N], \exists j \in [1, n] \middle| \beta_i^j \neq 0 \end{aligned} \tag{10}$$

The F statistic for the HENC test is calculated in two steps as follows: First, we test the hypothesis $\beta_i^j = 0$ for all $j \in [1, n]$ and compute the following set of F statistics:

$$F_{HENC}^i = \frac{\left(RSS_{2,i} - RSS_1\right)/n}{RSS_1/[NT - N(1+2n) + n]} \tag{11}$$

where $RSS_{2,\ i}$ is the sum of squared residuals obtained from Eq. (1) when the homogeneity restriction $\beta_i^j = 0$ is imposed for all i and for all $j \in [1, n]$. In this test the n coefficients attached to the variable $lnY_{i,\ t-j}$ are all equal to 0, i.e., they are excluded from Eq. (1). The n tests allow for testing individuals that exhibit no causality relationships. The second step of the F test is a test of the joint hypothesis that there is no causality relationship for a subgroup of cross-sections. Denoting the subgroup that exhibits causal relationships as I_c and that does not as I_{nc}, the following model is run for all time periods $t \in [1, T]$:

$$\begin{aligned} &lnE_{i,t} = \sum_{j=1}^{n} \gamma_i^j lnE_{i,t-j} + \sum_{j=1}^{n} \beta_i^j lnY_{i,t-j} + u_{i,t} \\ &u_{i,t} = \alpha_i + \epsilon_{i,t} \quad \text{with} \begin{cases} \beta_i^j \neq 0, & i \in I_c \\ \beta_i^j = 0, & i \in I_{nc} \end{cases} \end{aligned} \tag{12}$$

Denoting the dimensions of I_c and I_{nc} respectively as N_c and N_{nc}, the F statistic is then calculated as follows:

$$F_{HENC} = \frac{(RSS_4 - RSS_1)/N_{nc} n}{RSS_1/[NT - N(1+n) - N_c n]} \tag{13}$$

where RSS_4 is the sum of squared residuals obtained when the restriction $\beta_i^j = 0$ is imposed for all $i \in I_{nc}$.

If we fail to reject the HENC hypothesis, there is Granger causality from lnE to lnY only for a sub-sample of countries. Testing for heterogenous causality (HEC) means testing that there is at least one individual causality relationship and at most the number of cross-section units, N, and also that individual predictors shown below are heterogeneous:

$$\begin{aligned} &\exists i \in [1, N], E\left(lnE_{i,t} \middle| \widetilde{lnE}_{i,t}, \alpha_i\right) \neq E\left(lnE_{i,t} \middle| \widetilde{lnE}_{i,t}, \widetilde{lnY}_{i,t}, \alpha_i\right) \\ &\exists (i, k) \in [1, N], E\left(lnE_{i,t} \middle| \widetilde{lnE}_{i,t}, \widetilde{lnY}_{i,t}, \alpha_i\right) \neq E\left(lnE_{k,t} \middle| \widetilde{lnE}_{k,t}, \widetilde{lnY}_{k,t}, \alpha_k\right) \end{aligned} \tag{14}$$

Hurlin and Venet (2001) also extend these tests to instantaneous homogeneous/heterogeneous causality/non-causality tests as well. Since we are interested in a long-run relationship based on the past values of the variables at hand, we do not run such tests. The test statistics for all these null hypotheses are available in Hurlin and Venet (2001).

References

Akarca, A.T., Long, T.V., 1980. On the relationship between energy and GDP: a reexamination. J. Energy Dev. 5, 326–331.
Akinlo, A.E., 2008. Energy consumption and economic growth: evidence from 11 Sub-Sahara African countries. Energy Econ. 30, 2391–2400.
Al-Iriani, M.A., 2006. Energy-GDP relationship revisited: an example from GCC countries using panel causality. Energy Policy 34, 3342–3350.

Altinay, G., Karagol, E., 2004. Structural break, unit root, and the causality between energy consumption and GDP In Turkey. Energy Econ. 26, 985–994.
Apergis, N., Payne, J.E., 2010a. Renewable energy consumption and economic growth: evidence from a panel of OECD countries. Energy Policy 38, 656–660.
Apergis, N., Payne, J.E., 2010b. Energy consumption and growth in South America: Evidence from a panel error correction model. Energy Econ. 32, 1421–1426.
Aqeel, A., Butt, M.S., 2001. The relationship between energy consumption and economic growth in Pakistan. Asia Pac. Dev. J. 8, 101–110.
Asafu-Adjaye, J., 2000. The relationship between energy consumption, energy prices and economic growth: time series evidence from Asian developing countries. Energy Econ. 22, 615–625.
Ashgar, Z., 2008. Energy-GDP relationship: a causal analysis for the five countries of South Asia. Appl. Econ. Int. Dev. 8, 167–180.
Baltagi, B.H., 2005. Econometric Analysis of Panel Data, third ed. John Wiley and Sons.
Belke, A., Dreger, C., de Haan, F., 2010. Energy consumption and economic growth: New insights into the cointegration relationship. Discussion Paper No. 1017. Deutsches Institut für Wirtschaftsforschung, DIW, Berlin.
Cheng, B.S., 1999. Causality between energy consumption and economic growth in India: an application of cointegration and error-correction modeling. Indian Econ. Rev. 34, 39–49.
Cheng, B.S., Lai, T.W., 1997. An investigation of co-integration and causality between energy consumption and economic activity in Taiwan. Energy Econ. 19, 435–444.
Chontanawat, J., Hunt, L.C., Peirse, R., 2006. Causality between energy consumption and GDP: Evidence from 30 OECD and 78 non-OECD countries. Surrey Energy Economics Discussion Paper No. 113. Surrey Energy Economics Center, Department of Economics, University of Surrey, UK.
Costantini, V., Martini, C., 2010. The causality between energy consumption and economic growth: a multi-sectoral analysis using non-stationary cointegrated panel data. Energy Econ. 32, 591–603.
Dhungel, K.R., 2008. A causal relationship between energy consumption and economic growth in Nepal. Asia Pac. Dev. J. 15, 137–150.
Ebohon, O.J., 1996. Energy, economic growth and causality in developing countries: a case study of Tanzania and Nigeria. Energy Policy 24, 447–453.
Erdil, E., Yetkiner, I.H., 2005. A Panel Data Approach for Income-Health Causality. In: Yfantopoulos, J.N. (Ed.), The Economics of Health Reforms. ATINER, pp. 701–724.
Erol, U., Yu, E.S.H., 1987. On the causal relationship between energy and income for industrialized countries. J. Energy Dev. 13, 113–122.
Ghali, K.H., El-Sakka, M.I.T., 2004. Energy use and output growth in Canada: a multivariate cointegration analysis. Energy Econ. 26, 225–238.
Ghosh, S., 2002. Electricity consumption and economic growth in India. Energy Policy 30, 125–129.
Glasure, Y.U., Lee, A.R., 1997. Cointegration, error-correction, and the relationship between GDP and electricity: the case of South Korea and Singapore. Resour. Energy Econ. 20, 17–25.
Halicioglu, F., 2007. Residential electricity demand dynamics in Turkey. Energy Econ. 29 (2), 199–210.
He, D., Zhang, W., 2010. How dependent is the Chinese economy on exports and in what sense has its growth been export-led? J. Asian Econ. 21, 87–104.
He, Y.X., Li, D.Z., Li, Y., 2007. Research on the cointegration relationship on energy consumption and economic growth in Beijing. WSEAS Trans. Environ. Dev. 9 (3), 165–170.
Holtz-Eakin, D., Newey, W., Rosen, H., 1988. Estimating vector autoregressions with panel data. Econometrica 56, 1371–1395.
Huang, B.N., Hwang, M.J., Yang, C.W., 2008. Does more energy consumption bolster economic growth? An application of the nonlinear threshold regression model. Energy Policy 36, 755–767.
Hurlin, C., Venet, B., 2001. Granger Causality Tests in Panel Data Models with Fixed Coefficients. Eurisco Working Paper No. 2001–09. University of Paris-Dauphine.
Hwang, D.B.K., Gum, B., 1992. The causal relationship between energy and GDP: the case of Taiwan. J. Energy Dev. 12, 219–226.
Im, K.S., Pesaran, M.H., Shin, Y., 2003. Testing for unit roots in heterogeneous panels. J. Econom. 115, 53–74.
Jumbe, C., 2004. Cointegration and causality between electricity consumption and GDP: empirical evidence from Malawi. Energy Econ. 26, 61–68.
Kahsai, M.S., Nondo, C., Schaeffer, P.V., Gebremedhin, T.G., 2010. Does Level of Income Matter in the Energy Consumption and GDP Nexus: Evidence from Sub-Saharan African Countries. Research Paper No. 2010–7. West Virginia University Resgional Research Institute.
Kraft, J., Kraft, A., 1978. On the relationship between energy and GNP. J. Energy Dev. 3, 401–403.
Lee, C.C., 2005. Energy consumption and GDP in developing countries: a cointegrated panel analysis. Energy Econ. 27, 415–427.
Lee, C.C., 2006. The causality relationship between energy consumption and GDP in G-11 countries revisited. Energy Policy 34, 1086–1093.
Lee, C.C., Chang, C.P., 2005. Structural breaks, energy consumption, and economic growth revisited: evidence from Taiwan. Energy Econ. 27, 857–872.
Lee, C.C., Chang, C.P., 2007. Energy consumption and GDP revisited: a panel analysis of developed and developing countries. Energy Econ. 29, 1206–1223.
Lee, C.C., Chang, C.P., 2008. Energy consumption and economic growth in Asian economies: a more comprehensive analysis using panel data. Resour. Energy Econ. 30, 50–65.
Levin, A., Lin, C.F., Chu, C.S.J., 2002. Unit root tests in panel data: asymptotic and finite-sample properties. J. Econom. 108, 1–24.
Lise, W., van Montfort, K., 2007. Energy consumption and GDP in Turkey: is there a co-integration relationship? Energy Econ. 29, 116–1178.
Maddison, D., Rehdanz, K., 2008. Carbon Emissions and Economic Growth: Homogeneous Causality in Heterogeneous Panels. Working Paper No. 1437. Kiel Institute for the World Economy, Kiel.
Masih, A.M.M., Masih, R., 1996. Energy consumption, real income and temporal causality: results from a multi-country study based on cointegration and error-correction modeling techniques. Energy Econ. 18, 165–183.
Masih, A.M.M., Masih, R., 1998. A multivariate cointegrated modeling approach in testing temporal causality between energy consumption, real income and prices with an application to two Asian LDCs. Appl. Econ. 30, 1287–1298.
Mehrara, M., 2007. Energy consumption and economic growth: the case of oil exporting countries. Energy Policy 35, 2939–2945.
Morimoto, R., Hope, C., 2004. The impact of electricity supply on economic growth in Sri Lanka. Energy Econ. 26, 77–85.
Mozumder, P., Marathe, A., 2007. Causality relationship between electricity consumption and GDP in Bangladesh. Energy Policy 35, 395–402.
Nachane, D.M., Nadkarni, N.M., Karnik, A.V., 1988. Co-integration and causality testing of the energy GDP relationship: a cross-country study. Appl. Econ. 20, 1511–1531.
Nair-Reichert, U., Weinhold, D., 2001. Causality tests for cross-country panels: a new look at FDI and economic growth in developing countries. Oxf. Bull. Econ. Stat. 63, 153–171.
Nehru, V., Dhareshwar, A., 1995. A new database on physical capital stock: sources, methodology and results. World Bank. Available online, http://go.worldbank.org/SSDYULZHZ0 (accessed Oct 26, 2011).
Oh, W., Lee, K., 2004. Energy consumption and economic growth in Korea: testing the causality relation. J. Policy Model. 26, 973–981.
Paul, S., Bhattacharya, R.N., 2004. Causality between energy consumption and economic growth in India: a note on conflicting results. Energy Econ. 26, 977–983.
Pedroni, P., 2004. Panel cointegration: asymptotic and finite sample properties of pooled time series with an application to the PPP hypothesis – new results. Econom. Theory 20, 597–627.
Pesaran, M.H., Smith, R., 1995. Estimating long-run relationships from dynamic heterogeneous panels. J. Econom. 68, 79–113.
Sari, R., Soytas, U., 2007. The growth of income and energy consumption in six developing countries. Energy Policy 35, 889–898.
Shiu, A., Lam, P., 2004. Electricity consumption and economic growth in China. Energy Policy 32, 47–54.
Soytas, U., Sari, R., 2003. Energy consumption and GDP: causality relationship in G-7 countries and emerging markets. Energy Econ. 25, 33–37.
Stern, D.I., 1993. Energy and economic growth in the U.S.A. Energy Econ. 15, 137–150.
Stern, D.J., 2000. Multivariate cointegration analysis of the role of energy in the U.S. macroeconomy. Energy Econ. 22, 267–283.
Weinhold, D., 1996. Investment, growth and causality testing in panels. Econ. Previs. 126, 163–175.
Wolde-Rufael, Y., 2005. Energy demand and economic growth: the African experience. J. Policy Model. 27, 891–903.
Yang, H.Y., 2000. A note on the causal relationship between energy and GDP in Taiwan. Energy Econ. 22, 309–317.
Yoo, S.H., 2006. The causal relationship between electricity consumption and economic growth in the ASEAN countries. Energy Policy 34, 3573–3582.
Yu, S.H., Choi, J.Y., 1985. The causal relationship between energy and GNP: an international comparison. J. Energy Dev. 10, 249–272.
Yu, E.S.H., Hwang, B.K., 1984. The relationship between energy and GNP: further results. Energy Econ. 6, 186–190.
Yu, S.H., Jin, J.C., 1992. Cointegration tests of energy consumption, income and employment. Resour. Energy 14, 259–266.