Energy Consumption and Real Income: A Panel Cointegration Multi-country Study

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Abstract
The direction of the causality between energy consumption and income is an important issue in the fields of energy economics, economic growth, and policies toward energy use. The seminal work on the relations between energy consumption and aggregate income is Kraft and Kraft (1978). An extensive literature has followed on, including Akarca and Long (1980), Yu and Choi (1985), Erol and Yu (1988), Abosedra and Baghestani (1991), Hwang and Gum (1992), Masih and Masih (1996, 1997), Lee (2005), Soytas and Sari (2003), and Joyeux and Ripple (2007). The findings of these papers, and others, provide anything but consensus on either the existence of relations or direction of causality between the variables.

The work in this paper extends this research by analysing the cointegrating and causal relations between income and three energy consumption series based on panel data and the latest panel methodologies. These relations are analysed for the 30 OECD countries and 26 non-OECD countries. The results support a finding of causality flowing from income to energy consumption for developed and developing economies, alike.

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1. **Introduction**

The direction of the causality between energy consumption and income is an important issue for energy economics, economic growth, and policies toward energy use. The motivation for examining the relations between income and energy consumption first arose in the 1970s when developed countries first proposed significant energy conservation programs. The underlying question then was to determine whether energy consumption caused economic activity (as measured by income) or vice versa. If energy consumption caused economic activity, conservation programs would be expected to limit economic activity and the level of income that may be attained. Policy proposals to reduce CO_2 emissions by reducing energy consumption raise the same questions that motivated the earlier research. It is therefore useful to extend the previous research employing the latest analytical tools on updated and broader data sets so that we may better understand these relations and the potential impact of proposed policies.

The seminal work in the area of the relations between energy consumption and income is Kraft and Kraft (1978), but it and nearly all of the research that has followed has lacked discussion of the underlying economic theory relating these variables. Kraft and Kraft (1978) introduce their work with the following:

"According to a current view, there is a constant and unchanging relationship between gross energy consumption and gross national product (GNP). A logical corollary is that energy conservation is an unacceptable policy option since it would adversely influence

economic activity. This implies that the direction of causality runs from energy to GNP as well as the other way around."

The source of the "current view" is never identified, and no theoretical model is specified for the relations between the variables. However, with the exception of the last seven words of the above quote, the implication is that the model underlying the "current view" was a production function model.

A general production function model relates economic activity (measured by output or income) to a set of economic variables with, at least, an implicit direction of causality flowing from these variables to economic activity. For example, the following general linear form is typical:

$$\gamma = \beta_0 + \sum_{i=1}^{n} \beta_i x_i$$

where γ is economic activity, and the x_is represent the causal (explanatory) economic variables.[1] One of the x_is may be a measure of energy input, such as energy consumption, and economic theory posits a positive relation between the variables.

Kraft and Kraft's (1978) last seven words above, ("…as well as the other way around"), suggest an alternative theoretical linkage. The obvious alternative theory is based on

[1] If we are assessing a cross section of countries these elements of the equation will be vectors of data inclusive of all countries being analyzed.

consumption or demand models. A general energy consumption/demand model relates consumption of energy to a set of economic variables with, at least, an implicit direction of causality flowing from these variables to energy consumption. A general linear example is as follows:

$$\xi = \beta_0 + \sum_{i=1}^{n} \beta_i x_i$$

where ξ is energy consumption, and the x_is represent the causal (explanatory) economic variables. One of the x_is will be a measure of economic activity (such as income); consistent with economic theory, income is expected to have a positive influence on consumption/demand of energy (in other words, energy is viewed as a normal good).

However, those last seven words also throw open the question of the potential for ambiguity in the direction of causality, and indeed they suggest an expectation of causality feedback. Once we raise the question of direction of causality between economic activity and any of the economic variables, we are suggesting a divergence from such fundamental uni-directional models, and we introduce the potential for some "traditional" economic variables to be at least partly caused by economic activity rather than the cause of economic activity.

The income-energy consumption literature presents a divergence from the empirical economic growth literature,[2] since the primary thread running through the literature since Kraft and Kraft (1978) is the question of whether or not energy consumption (however defined) causes income (however defined) or vice versa. Indeed, one interpretation of this body of research is of a search for a clear indication, from the data, of which theory actually applies. A finding of uni-directional causality from energy consumption to income implies a production model. If, on the other hand, the finding is of uni-directional causality running from income to energy consumption, the appropriate model is a consumption or demand model. For either of these conclusions to hold the estimated parameters must be statistically significant and have the correct theoretical sign.

Alternatively, if the finding is of feedback causality between the variables, a multi-equation system should be developed to capture the complete set of effects in the relations between the variables; a single-equation model will be inappropriate given the bi-directional causality. Our analyses address these questions, and they are informed by the energy-consumption-income literature and the theory and empirics on economic growth, production, consumption, and demand. Our hypothesis is that income causes energy consumption, and our results generally support this hypothesis.

In addition to providing insights into the applicable economic theory, this paper contributes to the literature by extending the analysis to more countries and additional

[2] Most of the empirical economic growth literature tends to only introduce energy-related variables as having an influence on growth when the country in question is a producer, and often exporter, of the energy. This may be seen, for example, in Sala-I-Martin (1997) and Sala-I-Martin, Doppelhofer, and Miller (2004).

measures of energy consumption, and by increasing the explanatory power of the relevant causality tests of these relations by employing panel data techniques.

We extend the analysis to all thirty OECD countries and twenty six non-OECD countries. Rather than combining these into a single panel of fifty six, we accept the likelihood of significant differences between the two groups and analyze them separately. This approach provides a basis for comparison between developed and developing countries, and with previous research.

After establishing the panel unit root and cointegration characteristics of data series, we examine the causality relations between PPP-adjusted GDP (PPP-GDP) and three measures of energy consumption: residential electricity consumption, total electricity consumption, and total energy consumption.

For the sample period 1973-2007, we find short-run causality (tested against a null of Homogeneous Non Causality, HNC) flowing from PPP-GDP to residential electricity, total electricity, and total energy for the OECD panel. We also find long run causality flowing from PPP-GDP to total energy and residential electricity.

Over the same period for the full twenty-six country non-OECD panel, we are able to reject the null of HNC and find short-run causality flowing from PPP-GDP to residential electricity and total electricity, but not for total energy. However, when we exclude seven countries that exhibit large breaks in their total energy series, we find short-run causality

(i.e., reject the HNC null) flowing from PPP-GDP to all three energy measures. For both groups of non-OECD countries, we also have short-run causality from total electricity to PPP-GDP, and we find long run causality from PPP-GDP to residential electricity and total energy.

In section two, the paper presents a brief review of the literature. Section three discusses the data, while section four presents the methodology employed in this paper. Section five presents the empirical results, and section six concludes.

2. Energy and income literature

The seminal paper inquiring into the relations between energy consumption and aggregate income is Kraft and Kraft (1978). The focus of their paper, and much of the energy-income research that followed, is an attempt to determine the direction of causality between these two economic variables. Their primary finding was that causality was unidirectional running from GNP to energy, suggesting that energy conservation programs would not adversely affect economic activity.

An extensive literature has followed. These include Akarca and Long (1980)[3], Yu and Choi (1985), Erol and Yu (1988), Abosedra and Baghestani (1991), Hwang and Gum (1992), Yu and Jin (1992), Masih and Masih (1996, 1997), and Soytas and Sari (2003). The findings of these papers, and others, provide anything but consensus. Indeed, Akarca and Long (1980) declare that the Kraft and Kraft (1978) results are spurious, based on a finding of no causal relations in either direction, by changing the time period by just two years; a reduction, eliminating 1973 and 1974 data, which may introduce a structural shift into the series. This result suggested neutrality between GNP and energy consumption. While the result raised questions about the analysis conducted by Kraft and Kraft (1978), it was still consistent with the overall conclusion that conservation programs would not be expected to negatively impact on the level of economic activity.

The mixed results have been attributed to different methods, different series, and different time periods. The mixed, and sometimes inconsistent, results extend to attempts to address questions related to the relevance of the production versus demand model specification. Oh and Lee (2004a, 2004b) investigate the relations between energy and income for Korea, while also modelling capital and labor and price effects; Oh and Lee (2004b) address the relevance of demand versus production, while Oh and Lee (2004a) employ a production-type specification. In terms of short- and long-run causality Oh and

[3] Akarca and Long (1980) inadvertently introduces what may be viewed as an element of confusion into this thread of the literature. While Kraft and Kraft (1978) couch their interpretation in terms of the relations between energy consumption and economic *activity*, Akarca and Long (1980) couch theirs in terms of energy consumption and economic *growth*, even while employing the same GNP measure of the level of economic activity. The usage of the phrase economic growth when evaluating economic activity permeates the economics literature (e.g., Frankel and Romer,1999), but it nonetheless may lead to misunderstanding without explicit clarification. We thank an anonymous referee for pointing out that without clarification such phrasing may be misinterpreted to imply a relation between energy consumption and the economic *growth rate*. Our analysis follows that of Kraft and Kraft (1978), and indeed that of Akarca and Long (1980), where our focus is on economic activity and not on economic growth rates.

Lee (2004b) finds no difference between their demand and production specifications, finding no short-run causality between energy and economic activity, and unidirectional causality flowing from GDP to energy. On the other hand, Oh and Lee (2004a) find long-run bidirectional causality and short-run unidirectional causality flowing from energy to GDP. While the inconsistency may be due to changes in the time period (although they overlap), data frequency, and estimation technique, it does suggest that shifting to a multivariate environment including prices, capital, and labor may not necessarily be the solution to ambiguous results in this literature.

Our paper extends a relatively new literature employing panel data techniques with the aim of increasing the explanatory power of the tests run on relatively short time series available for the relevant economic variables. Even here, however, we find mixed results regarding directions of causality. Lee (2005) examines the panel cointegration and causality relations between GDP and energy consumption for eighteen developing countries for the period 1975-2001. Employing a model that included a variable for gross capital stock, Lee (2005) finds evidence for long- and short-run uni-directional causality flowing from energy consumption to GDP.

Joyeux and Ripple (2007) examine the panel cointegration relations between PPP-GDP and three measures of energy consumption for the period 1971-2001, with a focus on the relations between PPP-GDP and residential electricity consumption. They find no evidence of cointegration between the three pairings of PPP-GDP and each of their three

energy consumption variables. The Joyeux and Ripple (2007) results differ with those of Lee (2005) even though six of their seven countries are included in Lee's eighteen.

The current paper also arrives at different panel cointegration results than does Joyeux and Ripple (2007), as well as differing from Lee (2005). Lee (2005) is based on annual data drawn from *World Development Indicators*, so the differences may be the result of different variables being specified. However, the differences with Joyeux and Ripple (2007) raise questions about the underlying data and its evolution. Both data sets are drawn from the International Energy Agency (IEA) online database, with the current paper including the seven countries from their earlier paper but with a longer series as the result of extensions of the IEA data. One possible cause for the differences are changes in the measures of some energy series dealing with non-commercial energy sources and an apparent change in PPP-GDP series beyond a simple change of base year. One possible additional reason for the difference in results may be attributed to the time period employed by Joyeux and Ripple (2007). As noted later in this paper, including observations for the period prior to the first oil shock may introduce a structural change into the analysis that significantly alters the results. While beyond the scope of this paper, we are investigating the causes of these differences in results.

Al-Iriani (2006) applies panel analyses to the income and energy consumption relations for the Gulf Cooperation Council countries for the period 1971-2002; this brings major energy (oil) exporting countries into the mix of countries covered by this line of research. Al-Iriani finds cointegration and unidirectional causality, but in this case it flows from

GDP to energy consumption. This paper seems to come full circle, albeit with different techniques, data, and time period, back to the conclusions of Kraft and Kraft (1978) whereby conservation programs, and likely those aimed at reducing CO_2 emissions, are not expected to infringe upon economic activity.

A recent example of a study that specifies a theoretical model for the relations between energy and income is Lee and Chang (2007). They report results for estimations based on both single and two-sector growth models for Taiwan, estimated as both linear and non-linear (threshold) specifications. They report statistical significance for energy consumption's effect on income, but they provide no tests for direction of causality. However, their specification effectively restricts, a priori, the causal influence to flow from energy to income.

Our paper extends this earlier research by adding to the countries analysed, employing current techniques, and examining causal relations with an eye to revealing the relevant underlying theories. Our intension is to further enhance the explanatory power of the direction of causality test by both significantly expanding the number of countries employed in the cross section and by employing all of the currently available time series.

3. Data

The data employed in our analyses are from the IEA's internet data service. The data available through the data service are more complete than found in the hardcopy volumes of IEA Energy Statistics and Balances, for both OECD and Non-OECD countries. The

IEA data series typically provide for consistency across time and countries and hence provide a very suitable basis for analyzing multi-country relations via panel techniques.

The variables employed for the central questions addressed in this paper are total electricity consumption, residential electricity consumption, total energy consumption, PPP-GDP, and population. The three energy variables provide the basis for three distinct sets of specifications, examining alternative directions of causality and thus alternative economic theories, relating energy consumption to a measure of income/economic activity, represented herein by PPP-GDP. Residential electricity consumption, total energy consumption, total electricity consumption and PPP-GDP are converted to per capita and the logarithms are taken.

The electricity consumption series are measured in gigawatt hours (GWh), while the total energy consumption series are measured in thousands of tonnes of oil equivalents (ktoe). The GDP series are PPP adjusted and in 2000 U.S. dollars. The twenty six non-OECD countries included are Argentina, Bangladesh, Brazil, Cameroon, Chile, China, Chinese Taipei, Ecuador, Egypt, India, Indonesia, Islamic Republic of Iran, Kenya, Kuwait, Malaysia, Mozambique, Myanmar, Nigeria, Pakistan, Philippines, Saudi Arabia, Singapore, Sudan, Thailand, Venezuela, Vietnam. The sample period is 1971 through 2007 for most of the countries[4]. The thirty OECD countries are Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, Netherlands, New

[4] There are missing observations for the following countries: China (1971-78), Malaysia (1971-72), Philippines (1971-74), Saudi Arabia (1971-82), Vietnam (1971-79).

Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States. The sample period is 1960 through 2007 for most of the countries[5].

4. Methodology

In this paper, we pool cross-section and time series data to study relations between income and different measures of energy consumption. Before we conduct tests of cointegration between those variables, it is necessary to perform unit root tests. Unit root and cointegration tests in the time series dimension suffer of low power and/or size distortion. The addition of the cross-sectional dimension, however, brings an improvement to the power of unit root and cointegration tests by acting as repeated draws from the same distribution.

We also test for short-run and long-run bi-variate causality between PPP-GDP and the electricity/energy variables. The use of a panel data methodology in this context improves the power of non-causality tests applied to time series. It also allows us to consider a heterogeneous model to test the non-causality hypothesis; it is therefore possible to test the relations between PPP-GDP and the electricity/energy variables without considering the same dynamic model for all the countries in the sample.

We use the approach presented in Hurlin (2004, 2005 and 2008) and Hurlin and Venet (2008) for the short-run causality test. Their approach is essentially to test for causality

[5] There are missing observations for the following countries: Czech Republic (1960-70), Denmark (1960-72), Hungary (1960-64), Korea (1960-70), Mexico (1960-70), Slovak Republic (1960-70).

within a stationary VAR framework with fixed coefficients. Hurlin (2005, 2008) proposes a simple test of the Homogenous Non Causality (HNC) hypothesis. Under the null hypothesis, there are no causal relations for all the units of the panel. He specifies the alternative as the Heterogenous Non Causality (HENC) hypothesis. Under the null or the alternative, the unconstrained parameters and the dynamics may be different from one cross-section unit to another.

To study long-run causality, we initially test for cointegration and then estimate the implied single Error Correction equations using the pooled mean group estimators (PMGE) proposed by Pesaran *et al.* (1996) and Pesaran *et al.* (1999).

4.1 Panel Unit Root Tests

We consider four panel unit root tests: the Im, Pesaran and Shin (2003) (IPS), Maddala and Wu (1999), Pesaran (2007) and Choi (2006) tests. The first two tests assume cross-sectional independence. This assumption is likely to be violated for the income variable. It has also been found by Banerjee, Cockerill and Russell (2001) and O'Connell (1998) that these tests have poor size properties and have a tendency to over-reject the null of a unit root if the cross-sectional independence assumption does not hold. Pesaran (2007) and Choi (2006) relax this assumption.

Im, Pesaran and Shin (2003) tests are conducted using the following model:

$$\Delta y_{i,t} = \alpha_i + \delta_i t + \theta_t + \rho_i y_{i,t-1} + \sum_{L=1}^{p_i} \gamma_{iL} \Delta y_{it-L} + \varsigma_{i,t} \qquad (1)$$

where i = 1,…,N denotes countries, t =1,…,T denotes time. The ζ_{it} errors are also assumed to be autocorrelated with different serial correlation and variance properties across the cross-section units, but they are independent across the units of the sample.

They test the null that each series in the panel has a unit root for all cross-section units against the alternative that at least one of the series is stationary.

H_0: $\rho_i = 0$ for all i; H_1 : $\rho_i < 0$ for $i = 1, 2, ..., N_1$, $\rho_i = 0$ $i = N_1+1, N_1+2,..., N$

The Im, Pesaran and Shin (2003) test used in this study is the adjusted average of the ADF individual unit root test statistics. They tabulate the statistics for three specifications of the deterministic terms in (1). The IPS statistic is asymptotically $N(0,1)$, as T and N go to infinity, when N/T go to k (a positive finite constant), and when the $lim(N_1/N) = \lambda_1$, $0 < \lambda_1 \leq 1$. Breitung (2000) shows that the power of the IPS tests is sensitive to the specification of the deterministic terms.

Maddala and Wu (1999) proposed a Fisher-type test which combines the p-values from unit root tests for each cross-section i:

$$P = -2\sum_{i=1}^{N} \ln p_i \qquad (2)$$

P has a χ^2 distribution with $2N$ degrees of freedom as $T_i \to \infty$ for finite N. This test also has the benefit of not requiring a balanced panel.

Karlson and Lothgren (2000) note that for large *T*, and if a few cross-section units are stationary, there is a risk that the whole panel will be modelled as stationary because of the high power of both panel unit root tests. For small *T*, on the other hand, there is a risk that the whole panel may be modelled as non stationary. This is due to the relatively low power of the tests if the proportion of stationary series in the panel is large. They conclude that "…a careful joint analysis of both the individual and the panel unit root tests results are called for to fully assess the stationary properties of the panel data."

Choi (2006) develops unit root tests for cross-sectionally correlated panels. He utilizes a two-way error-component model which imposes the same pair-wise error covariances across the different cross-section units. These tests are obtained by combining p-values from Dickey-Fuller-GLS tests computed for each of the individual units after elimination of the deterministic trend components and cross-sectional correlations. These tests have a standard normal asymptotic distribution.

Pesaran (2007) augments the standard DF (or ADF) regressions with the cross-section averages of lagged levels and first-differences of the individual series. The panel unit root tests are based on the simple averages of the individual cross-sectionally augmented ADF statistics. A truncated version of the test is also considered where the individual cross-sectionally augmented ADF statistics are truncated to avoid undue influences of extreme outcomes when T is small. The average of the cross-sectionally augmented ADF statistics (alternatively truncated cross-sectionally augmented ADF statistics) is called a cross-sectionally augmented IPS test or CIPS (alternatively CIPS*).

Panel unit root tests in the presence of multiple structural breaks are also included in our analysis. Carrion et al. (2005) propose a test statistic for the null hypothesis of panel stationarity in the presence of multiple structural breaks. Each country in the panel can have a different number of breaks occurring at different dates. The breaks can shift the mean and/or the trend of the individual time series. Their procedure is based on the generalization of the Kwiatovski et al. (1992), KPSS, univariate tests developed by Hadri (2000). Although the statistic has a standard normal distribution, the authors recommend computing the bootstrap distribution to account for cross-section dependence. Finally, it should be emphasised that the empirical power of the test can be expected to be low for small T (below 100).

4.2 Panel Cointegration Tests

As is the case for unit root tests, cointegration panel tests can be expected to have higher power than the corresponding time series tests. The tests applied in this analysis are single equation tests developed by Pedroni (1997, 2004). Pedroni (1997, 2004) develop tests for the null of no cointegration in the bivariate case. Pedroni (1999) generalizes these tests to the multivariate case.

Pedroni (1999) uses the following model:

$$y_{it} = \alpha_i + \delta_i t + \beta_{1i} x_{1it} + \ldots + \beta_{Ki} x_{Kit} + e_{it} \qquad (3)$$

where there are K regressors, which are allowed to be endogenous.

The tests for the null of no cointegration are based on testing whether the error process, e_{it}, is stationary. This is achieved by testing whether $\rho_i = 1$ in:

$$\hat{e}_{it} = \rho_i \hat{e}_{it-1} + v_{it} \tag{4}$$

Pedroni (1999, 2004) presents seven tests which are divided into two groups. The four test statistics in the first group, the panel cointegration statistics, are based on pooling along the within-dimension. The alternative hypothesis for these tests is that $\rho_i = \rho < 1$. The three test statistics in the second group, the group mean cointegration statistics, are based on pooling along the between-dimension. The alternative hypothesis for these tests is that $\rho_i < 1$ for all *i*. These tests are less restrictive since they allow for heterogeneity across countries.

For both groups, Pedroni constructs two non parametric and one parametric test statistics that take autocorrelation into consideration:

i. A Phillips-Perron (1988) (PP) type *rho* statistic;
ii. A Phillips-Perron (1988) (PP) type t-statistic;
iii. A Dickey-Fuller (1979) (ADF) type t-statistic (these tests are analogous to the LLC and IPS tests in the unit root case).

He also develops a non parametric panel variance ratio test statistic. These seven test statistics can be rescaled so that they are distributed as standard normal. Under the alternative of cointegration, the panel variance statistic diverges to plus infinity whereas the other six test statistics diverge to minus infinity. Consequently, for the panel variance

test, the right tail of the standard normal distribution is used to reject the null of no cointegration, and for the other six tests the left tail is used.

In practice it is possible for different tests to give contradicting conclusions. Choosing which test is more appropriate is not easy. The group mean tests particular strength is that they are less restrictive. Regarding the best way to correct for autocorrelation, non parametric tests are likely to be more robust to outliers but have poor size properties and tend to over-reject the null when it is true. The ADF-type tests have better power if the errors follow an autoregressive process (Harris and Sollis (2003)).

Pedroni (2004) examines the small sample power properties of his seven test statistics. He finds that the size distortion is small and the power is high for $T>100$. For smaller T, he shows that the group ADF test has the best power properties followed by the panel ADF test; the panel variance test and group *rho* test perform poorly.

Pedroni (1997, 2004) recommends subtracting out common time effect to capture certain forms of cross-sectional dependency. Such a procedure has the added advantage that it will also subtract out the effects of homogenous structural breaks. We therefore subtract commontime effects when performing the cointegration tests mentioned above. We also complement the Pedroni's (2004) tests with Westerlund's (2006) cointegration tests in the presence of multiple structural breaks. Westerlund (2006) presents a Lagrange multiplier (LM) test for the null hypothesis of cointegration in the presence of multiple structural breaks. It allows for endogenous regressors, serial correlation and heterogeneous breaks

in both the level and trend of a cointegrated panel regression. The distribution of the LM statistic is asymptotically normally distributed. The test is a test of the null hypothesis of cointegration for all countries against the alternative of no cointegration for at least one country.

4.3 Causality Tests

Following Hurlin (2008), we consider two covariance stationary variables, denoted by *x* and *y*, observed on T periods and on N cross-section units. We also make the assumption that the data generating process is a VAR model:

$$y_{it} = \alpha_i + \sum_{k=1}^{p} \gamma_i^{(k)} y_{it-k} + \sum_{k=1}^{p} \beta_i^{(k)} x_{it-k} + \varepsilon_{it} \tag{5}$$

The individual effects α_i are assumed to be fixed. Pooled estimation without heterogenous intercepts leads to a bias in the estimated slope coefficients. Hurlin (2008) points out that this could lead to misleading causality test results. Starting values for y_{it} and x_{it} are assumed to be observed. $\gamma_i^{(k)}$ and $\beta_i^{(k)}$ may differ across cross-section units. For each cross-section unit the error terms ε_{it} are assumed to be $i.i.d.$ $\left(0, \sigma_i^2\right)$ and independently distributed across units.

Hurlin (2008) proposes a test for HNC:

$$H_0 : \beta_i = 0 \quad \forall i = 1, ..., N \tag{6}$$

where $\beta_i = \left(\beta_i^{(1)}, ..., \beta_i^{(p)}\right)'$. Under the alternative hypothesis, there is causality from *x* to *y* for at least one cross-section unit.

$$H_1 : \beta_i = 0 \quad \forall i = 1, ..., N_1$$
$$\beta_i \neq 0 \quad \forall i = N_1 + 1, N_1 + 2, ..., N \tag{7}$$

where N_1 is unknown and $N_1 < N$.

His test for Granger non causality is similar to the Im, Pesaran and Shin (2003) test for unit root. The test statistic is computed as the cross-sectional average of individual Wald statistics defined to test the Granger non causality hypothesis for each country. If the error terms are cross-sectionally independent, the average statistic sequentially converges under the HNC hypothesis, when *T* tends to infinity first and then *N* tends to infinity, to a normal distribution. A standardized statistic is proposed based on the exact moments of the asymptotic moments of the individual Wald statistics. This is the $Z_{N,T}^{HNC}$ statistic. If it is larger in absolute value than the corresponding normal critical value for a given level of significance, the homogeneous non causality (HNC) hypothesis is rejected.

If the null is not rejected the variable *x* does not Granger cause the variable *y* for all the countries of the panel. If the HNC is rejected and if $N_1 = 0$, *x* Granger causes *y* for all the countries of the panel: in this case we get a homogenous result as far as causality is concerned. If the HNC is rejected and $N_1 > 0$, then the causality relations are heterogeneous.

It should be emphasized that the tests above require the series to be stationary and therefore cannot be applied to cointegrated I(1) series. In this case, the causal relations must be identified as in Toda and Phillips (1993). There does not exist, at this point in time, a generalization of the Toda and Phillips approach to a panel model. For the

variables found to be I(1) we apply the Hurlin (2008) test after first differencing the series. For cointegrated I(1) variables we also use the PMGE method to estimate the single error correction equations. The PMGE approach restricts the long-run coefficients to be equal across the countries (they are pooled), while the short-run coefficients are estimated individually and then averaged. The estimates are based on the application of the maximum likelihood approach and a Newton-Raphson algorithm to the following specification:

$$\Delta y_{it} = \phi_i \left(y_{it-1} \right) + \beta_i^{'} X_{it} + \sum_{j=1}^{p-1} \lambda_{ij} \Delta \left(y_{it-j} \right) + \sum_{j=0}^{q-1} \mu_{ij} \Delta X_{it-j} + \eta_i + \varepsilon_{it} \qquad (8)$$

for each country *i*, where ε_{it} is the disturbance term and X_{it} designates the vector of the explanatory variables, which can themselves be endogenous. If the roots of this equation lie outside the unit circle, then the model is error-correcting (ϕ_i <0) and there exists long-run relations between the dependent variable and its determinants defined by

$$y_{it} = -\left(\beta_i^{'} / \phi_i \right) X_{it} + \nu_{it} \qquad (9)$$

The long-run coefficients are equal to $\alpha_i = -\left(\beta_i^{'} / \phi_i \right)$; the long-run homogeneity hypothesis is thus characterized by $\alpha = \alpha_i$ for every country *i*. The long-run causality test from *X* to *y* therefore reduces to testing whether $\phi = \phi_i$ is significantly negative. Additionally, we calculate the mean group estimator (MGE), which is an average of both the short- and long-run coefficients. We test for long-run homogeneity using a joint Hausman test based on the null hypothesis of equivalence between the PMGE and MGE

estimators[6]. If the long-run coefficients are homogenous, then the MGE estimates are consistent and efficient (this is labelled as the h-test in the tables).

5. Results

The methodology described in the previous section is applied to study the relations between per capita PPP-GDP and each of three energy series: per capita residential electricity consumption, per capita total electricity consumption, and per capita total energy. All variables are in logs.

5.1 Unit Root Tests

The panel unit root tests are displayed in Tables 1 and 2, where we report test results organized by OECD and non-OECD grouping and alternative sample periods. The panel unit root test results provide strong evidence of panel unit roots for the PPP-GDP, residential electricity, total electricity and total energy variables (per capita), i.e. the series are all I(1). In Appendix A results from panel unit root tests in the presence of multiple structural breaks using Carrion *et al.* (2005) approach are presented (Table A-1). Results are unchanged when using the standard normal distribution critical values. We cannot reject the null of stationarity for PPP-GDP in the case of non OECD countries when bootstrapped critical values are used. Given the low power of the test when T is small (<100) we assume in the what follows that PPP-GDP is also $I(1)$.

5.2 Cointegration Tests

[6] See Pesaran et al. (1996).

The next step in our analysis is the panel cointegration testing. Summaries for the cointegration findings are reported in Tables 3-5, designating the variable pairs by independence and dependence, whether cointegration is found, and which table reports the relevant test statistics. The Pedroni (1999, 2004) panel cointegration test statistics are displayed in Tables 6-11. The tests are performed twice. Once with the dependent variable being PPP-GDP, then with the dependent variable chosen to be one of the energy related consumption variables. This is necessary to lay the foundations for testing alternative directions of long-run causality. When evaluating the results it will be useful to recall that for smaller *T* the group ADF test has the best power properties followed by the panel ADF test; and that the panel variance test and group *rho* test tend to perform poorly. Moreover, since the panel cointegration analysis incorporates a battery of tests, if only one of them is found to be significant, unless it is the group ADF test, we conclude that there is insufficient evidence to support a finding of cointegration.

We find that there is no cointegration for the OECD countries between PPP-GDP and any of the three energy consumption variables in either direction for the sample period 1960 to 2007. However, if we restrict the sample period to that following the first oil shock (1973 to 2007), we find cointegration between total energy and PPP-GDP and between residential electricity and PPP-GDP when PPP-GDP is the independent variable.[7]

[7] Note that, when PPP-GDP is the independent variable, we evaluate the PPP-GDP and residential electricity tests as providing weak evidence in favour of cointegration because in this case the group ADF statistic is significant. This test statistic has been shown to have the best power properties among the six statistics.

The results are quite different for the non-OECD countries. For the full 26-country panel and the full sample from 1971 to 2007, we find cointegration between PPP-GDP and residential electricity and between PPP-GDP and total electricity when PPP-GDP is the dependent variable. And we also find cointegration between PPP-GDP and residential electricity and between PPP-GDP and total energy when PPP-GDP is the independent variable. When we use the truncated sample, for the post oil-shock period, from 1973 to 2007, we find no cointegration between PPP-GDP and any of the energy consumption series when PPP-GDP is the dependent variable. The pattern of cointegration for relations with PPP-GDP as the independent variable is unaltered by the shortening of the series.

As noted above, seven of the twenty six non-OECD countries have large breaks in their total energy consumption series. When we exclude these countries,[8] Cameroon, India, Kenya, Mozambique, Nigeria, Sudan, Vietnam, we find no cointegration for either sample period when PPP-GDP is the dependent variable. When PPP-GDP is the independent variable, we find strong evidence of cointegration between PPP-GDP and residential electricity and between PPP-GDP and total energy, for either sample period.

The failure to find cointegration in some cases could be due to the presence of structural breaks between 1973 and 2007. Energy markets experienced changes over this period such as the collapse of the energy prices in the early 1980s, due in part to over-reaching by OPEC, the increased uncertainty that followed Desert Storm in 1991 and the international military return to Iraq in 2002, and the significant growth in energy demand

[8] Restriction to the 19-country subset is also supported by the Hausman tests, reported below, for poolability, at least for the relations between PPP-GDP and total energy. The poolability of the full 26-country group is rejected, but it is not rejected for the 19-country subset.

from China and India beginning in the early 2000s. Moreover, the uncertainty brought to the market by unclear policies regarding how and if carbon emissions are to be priced and the non-market-based decisions to significantly increase the role of renewable in the energy mix, with the aim to reduce demand for fossil fuels, led to apparent under-investment in productive capacity that may have affected the supply-side of the energy markets. We therefore examine both groups allowing for the influences of structural breaks.

The results of panel cointegration tests in the presence of multiple structural breaks are presented in Table A-2 in Appendix A for the 1973-2007 sample period. For the OECD countries no cointegration is found between any of the pairs. This test cannot be applied on unbalanced panels and therefore only 22 countries could be considered initially among the non-OECD countries. The null of cointegration for all countries is rejected at the 1% significance level for all pairs except: when PPP-GDP is the dependent variable we reject the null at 5%, but not 1%, between PPP-GDP and residential electricity; and when PPP-GDP is the independent variable we reject the null at 5%, but not 1%, between PPP-GDP and all three energy consumption measures. There is no evidence that the failure to find cointegration in some cases is due to the presence of structural breaks between 1973 and 2007. Westerlund (2006) points out, however, that his test presents serious size distortions when T is less than 100. Since we have corrected for common time effects when performing the Pedroni tests we proceed assuming the results from these tests are more reliable than the Westerlund's test even in the presence of structural breaks.

Our results indicate sensitivity to the sample period in a manner somewhat reminiscent of the findings of Akarca and Long (1980), albeit in reverse. Akarca and Long (1980) found different results than Kraft and Kraft (1978) when they restricted the series to observations ending in 1972; thus truncating the series to include only observations from prior to the first oil shock. Our results differ when we restrict the sample period to begin with 1973 (thus excluding observations from prior to the first oil shock), for either OECD or non-OECD countries. The effect is obviously strongest for the OECD countries, since we find no cointegration when we include observations from prior to the first oil shock, but we do find strong and multiple instances of cointegration for the truncated sample period. This influence also carries over to our causality results.

5.3 Causality Tests

We next examine the short-run and long-run causality relations.

5.3.1 Short-run Causality Tests

We apply the Hurlin (2008) tests to the first differences of our variables since they were found to be I(1). We report a summary of the short-run causality results in Table 12, organized by directional pairings of the series, country groupings, and identification of the relevant tables for inspection of the test statistics. Results of the short-run causality tests are displayed in Tables 13. We only present the results for the period following the first oil shock (1973 to 2007), since this period will be more relevant for current policy considerations; results for the full sample can be obtained from the authors upon request.

For the OECD countries, we reject the null of HNC from PPP-GDP to residential electricity, total electricity and total energy, and there are no feedback effects. That is, there is uni-directional causality from income to each of the three energy consumption series.

For the full 26 non-OECD countries, we reject the null of HNC from PPP-GDP to residential electricity and to total electricity, but not to total energy. We find feedback from total electricity to PPP-GDP. When we exclude the seven countries as earlier, we find short-run causality from PPP-GDP to each of the three energy consumption variables, with feedback only for total electricity.

We turn next to the long-run causality results.

5.3.2 Long-run Causality Tests

Long-run causality will not hold in cases where cointegration does not exist. Therefore, we estimate the cointegrating relations using both the PMGE and MGE methodologies only for the cases where we found statistical evidence for cointegration.

When interpreting the long-run causality test results, a significant error correction coefficient implies that long-run causality flows from the explanatory variable to the dependent variable in the pairing. The long-run coefficients may be evaluated as elasticities since the variables have been transformed into natural logs. The summaries in Tables 14 report long-run causality results by direction between variable pairs and

indicate the tables for the relevant test statistics. Furthermore, the long-run coefficient estimates and causality test statistics are presented in Tables 15 to 17.

OECD countries

We do not estimate any cointegrating relations for the 1960 to 2007 sample period, and hence no long-run causality tests, since we found no cointegration for this period.

The 1973 to 2007 period, however, produces interesting results. We estimate two error correction equations, one for total energy as the dependent variable and one with residential electricity as the dependent variable. The Hausman h-test fails to reject poolability for the residential electricity equation, so the PMGE estimates will provide more efficient coefficient estimates than will the MGE. The PMGE estimate of the error correction coefficient (which may be interpreted as the speed of adjustment by the dependent variable to deviations from long-run equilibrium) is statistically significant. We can therefore conclude that there is long-run causality from PPP-GDP to residential electricity. The estimate of -0.229 for the error correction coefficient implies that 22.9 percent of a deviation from long-run equilibrium will be eliminated in one period through changes in the dependent variable. For the total energy equation the Hausman test rejects poolability. The PMGE estimates in that instance might not provide more efficient estimates than the MGE estimates.

The long-run coefficients may be interpreted as long-run elasticities, so we are also interested in their relation to unitary elasticity. The PMGE estimate of the long-run

income elasticity for total energy consumption is 1.08, as reported in Table 15. The estimate is not significantly different from 1.0,[9] so we may conclude that unitary long-run income elasticity characterized total energy consumption for the OECD as a group over the period 1973-2007. This result does not hold for the MGE estimate.

Non-OECD countries: All 26 countries

The long-run estimates for the full set of 26 non-OECD countries are reported in Table 16. We estimate cointegrating relations for residential electricity and total energy with PPP-GDP as the explanatory variable. The estimated error correction coefficient (-0.226) for the relations between PPP-GDP and residential electricity is significant and the PMGE long-run coefficient estimate is 0.557 and highly significant. We may again conclude that long-run causality flows from income to energy consumption. The long-run income elasticity estimate is significantly different from, and less than, 1.0 (the *t* statistic equals -8.95), so we can conclude that residential electricity consumption was inelastic for the 26 non-OECD countries for this period.

For the total energy and PPP-GDP pair the long-run coefficient estimate is very small, 0.123, and barely significant. This may reflect the large breaks in the total energy consumption series for the seven countries identified earlier. We therefore rely on the 19-country non-OECD grouping for an interpretation of this pairing.

Non-OECD countries: 19 countries

[9] The *t* statistic for the hypothesis of $\hat{\beta}$ = 1 is calculated as $(\hat{\beta}-1)/S.E.$ and is 1.734.

The long-run estimates for the sub-set of 19 non-OECD countries are reported in Table 17. As was the case for the larger non-OECD sample, we estimate cointegrating relations for residential electricity and total energy with PPP-GDP as the explanatory variable. The Hausman h-test cannot reject poolability for the 19-country subset, so the PMGE estimates will be examined.

The long-run coefficient estimate when residential electricity is the dependent variable is significant and equal to 0.563, and the speed of adjustment is highly significant and equal to -0.245. The speed of adjustment and income elasticity estimates for the group of 19 countries are similar in magnitude to that for the group of 26 countries.

The long-run coefficient estimate when total energy is the dependent variable is highly significant and equal to 0.853, and the error correction coefficient is significant and equal to -0.154. This implies causality flowing from income to energy consumption, but the estimated speed of adjustment is very slow, with only 15 percent of a deviation from long-run equilibrium being eliminated in one period. The estimated income elasticity, while substantially larger than that for residential electricity for this group, is significantly different from 1.0 (the *t* statistic equals -2.59), so we may conclude that total energy consumption for the sub-set of 19 non-OECD countries was income inelastic over the 1973-2007 period.

OECD and non-OECD comparison

The relations between PPP-GDP and total energy consumption were estimated for the 30 OECD and 19 non-OECD countries. The OECD countries exhibit unitary income elasticity, over the sample period, while the total energy consumption of the non-OECD countries is found to be income inelastic. The income inelastic character of total energy may be reflecting the significantly income inelastic character of residential electricity consumption (a subset of total energy), and this behaviour may be due to the tendency for this energy source to be subsidized in developing countries. The very slow speed of adjustment to disequilibrium in the non-OECD countries may also be due to government interference, and it may be linked to significant energy use in export sectors of these developing countries.

For the relations between PPP-GDP and residential electricity the income elasticities and speeds of adjustment are quite similar for the OECD and non-OECD countries.

6. Conclusion

We examine the causal relations between income and three measures of energy consumption for all 30 OECD and a set of 26 non-OECD countries. We employ the latest panel cointegration methodologies, which allow us to address heterogeneity issues and apply these to a grouping of all OECD countries and non-OECD countries.

Our paper contributes to the research in this area in four ways. First, we extend the use of panel data analysis and techniques beyond that currently found in the literature. These techniques increase the power of the causality tests that are necessary to evaluate the

economic implications of various policies for addressing both energy conservation and emissions reductions. Our second contribution is to expand the range of energy consumption variables evaluated. Our measures of energy consumption add breadth to those found in prior research in this area, ranging from a household-level measure of electricity consumption to a measure of aggregate energy consumption for the entire country.

The overall conclusion gained is that for both the short-run and the long-run causality flows predominantly from income to energy consumption, but within this general finding there are differences between the OECD and non-OECD countries in this study. This suggests that different energy policies may be appropriate depending upon the stage of development of the countries in question.

Our results generally support the findings of the original Kraft and Kraft (1978) paper. Where causality is shown to exist it tends to flow from income (PPP-GDP) to the energy consumption measure of interest. As such, our third contribution is to shed light on the relevant economic theory to employ when modelling income-energy consumption relations. The results suggest that when modelling these relations they will best be specified and interpreted as a consumption/demand model.

Our fourth contribution stems from the observation that our results also provide additional evidence supporting earlier findings that the first oil shock may have introduced a structural shift in the relations between energy consumption and economic

activity. Strikingly different results occur in our analyses depending on the inclusion or exclusion of observations from prior to this shock; producing effectively a reversal of the "test" employed by the Akarca-Long (1980) analysis of the original Kraft-Kraft (1978) paper. Thus, for meaningful and useful policy prescriptions to be developed either the pre-shock period should be ignored or the nature of the structural shift should be explicitly addressed and handled carefully.

Finally, our results suggest that neither energy conservation programs nor plans to constrain CO_2 emissions by reducing use of fossil fuels should have a negative effect on economic activity, whether in developed or developing countries. It is also worth noting that this conclusion holds even where no causality is found, since the lack of causality implies that any of the policies aimed at energy consumption will have at worst a neutral effect on income.

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Table 1: Panel unit root tests

OECD Countries

(1960-2007)

	IPS-ADF[(1)]			Maddala and Wu [(2)]		
	Level c,t	1st diff c	concl	Level c,t	1st diff c	concl
PPP GDP	0.683	-20.065*	I(1)	61.144	527.826*	I(1)
Residential Electricity	0.442	-23.364*	I(1)	65.078	369.254*	I(1)
Total Electricity	-1.786	-23.847*	I(1)	66.793	385.181*	I(1)
Total Energy	-3.623*	-25.237*	I(0)	69.996	521.120*	I(1)

(1973-2007)

	IPS-ADF[(1)]			Maddala and Wu [(2)]		
	Level c,t	1st diff c	concl	Level c,t	1st diff c	concl
PPP GDP	-0.723	-19.075*	I(1)	61.515	437.875*	I(1)
Residential Electricity	-1.951	-17.385*	I(1)	73.512	403.851*	I(1)
Total Electricity	-0.827	-20.150*	I(1)	72.264	464.275*	I(1)
Total Energy	-3.532*	-22.892*	I(0)	65.696	539.585*	I(1)

Non OECD Countries

(1971-2007)

	IPS-ADF [(1)]			Maddala and Wu [(2)]		
	Level c,t	1st diff c	concl	Level c,t	1st diff c	concl
PPP GDP	-1.070	-19.202*	I(1)	49.847	399.693*	I(1)
Residential Electricity	-1.887	-21.945*	I(1)	51.452	382.640*	I(1)
Total Electricity	0.844	-18.231*	I(1)	65.125	388.857*	I(1)
Total Energy	-2.779*	-26.942*	I(0)	65.776	481.816*	I(1)

Notes:

(1) All tests statistics are asymptotically distributed as N(0,1). * Rejects at 5% level. All tests are one-sided tests, thus values of the test statistic in the left tail of the standard normal distribution are evidence for rejection of the null of a unit root. Exact 5% critical values for the IPS tests are -1.82 without trend and -2.45 with trend (obtained from IPS (2003) Table 2 with N = 25 and T = 30).

(2) The statistic is distributed asymptotically as chi-square with 2N degrees of freedom, where N is the number of cross countries in the panel (26 for non OECD countries and 30 for OECD countries). The null hypothesis of a unit root is rejected for large values of the chi-square statistic. * Rejects at 5% level.

c and c,t indicate that a constant term and a constant term plus a trend components are included in the regression.

Table 2: Panel unit root tests for cross-sectionally dependent variables

OECD Countries (1973-2007)

		Choi[(1)]				Pesaran (2007)[(2)]		
		Level c,t	1st diff c	concl		Level c,t	1st diff c	concl
PPP GDP	P_m	-1.657	12.511*	I(1)	CIPS*	-1.831	-3.296*	I(1)
	Z	4.718	-8.725*	I(1)				
	L*	5.947	-9.493*	I(1)				
Residential Electricity	P_m	0.026	11.448*	I(1)	CIPS*	-1.730	-3.737*	I(1)
	Z	1.127	-8.365*	I(1)				
	L*	1.708	-8.870*	I(1)				
Total Electricity	P_m	-1.033	11.227*	I(1)	CIPS*	-1.795	-3.738*	I(1)
	Z	2.448	-8.287*	I(1)				
	L*	3.149	-8.804*	I(1)				
Total Energy	P_m	-0.015	15.086*	I(1)	CIPS*	-1.693	-3.831*	I(1)
	Z	0.935	-10.016*	I(1)				
	L*	1.350	-11.060*	I(1)				

Non OECD Countries (1973-2007)

		Choi[(1)]				Pesaran (2007)[(2)]		
		Level c,t	1st diff c	concl		Level c,t	1st diff c	concl
PPP GDP	P_m	-0.846	9.115*	I(1)	CIPS*	-1.761	-3.505*	I(1)
	Z	1.546	-7.485*	I(1)				
	L*	1.988	-7.504*	I(1)				
1983-2007 Residential Electricity	P_m	0.287	3.980*	I(1)	CIPS*	-1.384	-3.009*	I(1)
	Z	4.373	-3.335*	I(1)				
	L*	5.477	-3.407*	I(1)				
Total Electricity	P_m	2.276	7.614*	I(1)	CIPS*	-1.436	-3.490*	I(1)
	Z	0.839	-5.997*	I(1)				
	L*	1.022	-6.260*	I(1)				
Total E nergy	P_m	0.284	13.715*	I(1)	CIPS*	-2.551	-3.933*	I(1)
	Z	-1.057	-9.684*	I(1)				
	L*	-1.063	-10.238*	I(1)				

Notes:

(1) All the statistics are distributed as standard normal asymptotically. The null hypothesis of a unit root is rejected for large positive values of the P_m statistic, while it is rejected for large negative values of the other two statistics. Accordingly, at the 5% level, we conclude as follows:

$$\text{no unit root if } \begin{cases} P_m > +1.64 \\ Z < -1.64 \\ L^* < -1.64 \end{cases}$$

(2) * Rejects at 5% level. All tests are one-sided tests, thus values of the test statistic to the left tail of the critical values are evidence for rejection of the null of a unit root. Exact 5% critical values for the CIPS* tests are with trend and intercept -2.72 (T=30 and N=20), -2.66 (T=30, N=30) and with intercept only -2.20 (T=30, N=20), -2.15 (T=30, N=30) (obtained from Tables IIb-IIc in Pesaran (2007)). For this test, there is no unit root if the test statistic is less than the critical value.

Table 3: Cointegration Summary - OECD countries

Variables (Independent→Dependent)	Cointegration (**Y**/N)	Test Statistics Table
1960 - 2007		
All pairings	N	Tables 6 & 7
1973 - 2007		
Res Elec→PPP-GDP	N	Table 8
Tot Elec→PPP-GDP	N	
Tot Engy→PPP-GDP	N	
PPP-GDP→Res Elec	**Y (weak)**	Table 9
PPP-GDP→Tot Elec	N	
PPP-GDP→Tot Engy	**Y**	

Table 4: Cointegration Summary – Non-OECD: 26 countries

Variables (Independent→Dependent)	Cointegration (**Y**/N)	Test Statistics Table
1971 - 2007		
Res Elec→PPP-GDP	**Y**	Table 6
Tot Elec→PPP-GDP	**Y**	
Tot Engy→PPP-GDP	N	
PPP-GDP→Res Elec	**Y**	Table 7
PPP-GDP→Tot Elec	N	
PPP-GDP→Tot Engy	**Y**	
1973 – 2007		
Res Elec→PPP-GDP	N	Table 8
Tot Elec→PPP-GDP	N	
Tot Engy→PPP-GDP	N	
PPP-GDP→Res Elec	**Y**	Table 9
PPP-GDP→Tot Elec	N	
PPP-GDP→Tot Engy	**Y**	

Table 5: Cointegration Summary – Non-OECD: 19 countries
(excluding Cameroon, India, Kenya, Mozambique, Nigeria, Sudan, Vietnam)

Variables (Independent→Dependent)	Cointegration (**Y**/N)	Test Statistics Table
1971 - 2007		
Res Elec→PPP-GDP	N	Table 10
Tot Elec→PPP-GDP	N	
Tot Energy→PPP-GDP	N	
PPP-GDP→Res Elec	**Y**	Table 11
PPP-GDP→Tot Elec	N	
PPP-GDP→Tot Energy	**Y**	
1973 – 2007		
Res Elec→PPP-GDP	N	Table 10
Tot Elec→PPP-GDP	N	
Tot Energy→PPP-GDP	N	
PPP-GDP→Res Elec	**Y**	Table 11
PPP-GDP→Tot Elec	N	
PPP-GDP→Tot Energy	**Y**	

Table 6: Panel Cointegration Tests: PPP-GDP dependent variable

OECD Countries[(1)] (1960-2007)			
	PPP-GDP and Residential Electricity	PPP-GDP and Total Electricity	PPP-GDP and Total Energy
panel v-stat	0.148	-0.943	-0.371
panel rho-stat	1.553	1.243	1.911
panel pp-stat	1.336	0.443	2.056
panel adf-stat	0.850	1.421	1.636
group rho-stat	2.417	2.417	3.083
group pp-stat	1.808	1.348	3.153
group adf-stat	0.893	1.665	3.224
Non OECD Countries[(1)] (1971-2007)			
	PPP-GDP and Residential Electricity	PPP-GDP and Total Electricity	PPP-GDP and Total Energy
panel v-stat	2.102*	1.177	0.940
panel rho-stat	-0.236	-0.454	0.593
panel pp-stat	-1.642	-2.221*	-0.830
panel adf-stat	-1.871*	-2.669*	-0.677
group rho-stat	0.541	0.959	1.581
group pp-stat	-1.438	-1.630	-0.373
group adf-stat	-2.449*	-2.713*	-0.386

Notes:

(1) All tests statistics are asymptotically distributed as N(0,1). * Rejects the null of no cointegration at 5% level. All tests are one-sided tests: for the panel variance test the right tail of the standard normal distribution is used to reject the null of no cointegration and for the other six tests the left tail is used.

(2) An intercept and a trend were included in the cointegrating regression.

Table 7: Panel Cointegration Tests: PPP-GDP independent variable

OECD Countries[(1)] (1960-2007)			
	PPP-GDP and Residential Electricity	PPP-GDP and Total Electricity	PPP-GDP and Total Energy
panel v-stat	-0.308	-0.027	0.183
panel rho-stat	1.157	0.484	-0.301
panel pp-stat	-0.263	-1.297	-1.996*
panel adf-stat	0.376	-0.595	-1.878*
group rho-stat	2.157	0.184	0.582
group pp-stat	0.386	-1.956	-1.392
group adf-stat	0.194	-1.579	-1.248
Non OECD Countries[(1)] (1971-2007)			
	PPP-GDP and Residential Electricity	PPP-GDP and Total Electricity	PPP-GDP and Total Energy
panel v-stat	1.488	-0.086	0.553
panel rho-stat	-1.280	1.073	-1.427
panel pp-stat	-2.793*	0.242	-2.619*
panel adf-stat	-2.741*	-0.345	-2.321*
group rho-stat	-0.077	1.886	0.051
group pp-stat	-2.385*	0.733	-1.963*
group adf-stat	-2.572*	-0.167	-2.094*

Notes:

(1) All tests statistics are asymptotically distributed as N(0,1). * Rejects the null of no cointegration at 5% level. All tests are one-sided tests: for the panel variance test the right tail of the standard normal distribution is used to reject the null of no cointegration and for the other six tests the left tail is used.

(2) An intercept and a trend were included in the cointegrating regression.

Table 8: Panel Cointegration Tests: PPP-GDP dependent variable

OECD Countries[(1)] (1973-2007)			
	PPP-GDP and Residential Electricity	PPP-GDP and Total Electricity	PPP-GDP and Total Energy
panel v-stat	-0.589	-0.816	-0.220
panel rho-stat	2.074	2.263	1.963
panel pp-stat	1.819	1.615	1.728
panel adf-stat	-0.477	0.303	0.857
group rho-stat	2.993	2.916	2.473
group pp-stat	2.482	2.000	1.750
group adf-stat	-0.071	0.139	0.546
Non OECD Countries[(1)] (1973-2007)			
	PPP-GDP and Residential Electricity	PPP-GDP and Total Electricity	PPP-GDP and Total Energy
panel v-stat	2.034*	1.556	1.037
panel rho-stat	0.565	0.371	1.174
panel pp-stat	-0.565	-0.691	0.148
panel adf-stat	-0.404	-1.085	-0.625
group rho-stat	1.346	1.565	2.277
group pp-stat	-0.288	-0.106	0.967
group adf-stat	-1.142	-1.368	-0.614

Notes:

(1) All tests statistics are asymptotically distributed as N(0,1). * Rejects the null of no cointegration at 5% level. All tests are one-sided tests: for the panel variance test the right tail of the standard normal distribution is used to reject the null of no cointegration and for the other six tests the left tail is used.

(2) An intercept and a trend were included in the cointegrating regression.

Table 9: Panel Cointegration Tests: PPP-GDP independent variable

OECD Countries[(1)] (1973-2007)			
	PPP-GDP and Residential Electricity	PPP-GDP and Total Electricity	PPP-GDP and Total Energy
panel v-stat	1.734*	1.853*	2.300*
panel rho-stat	1.160	0.792	-1.816*
panel pp-stat	-0.500	-1.124	-3.836*
panel adf-stat	-1.074	-1.003	-2.845*
group rho-stat	1.883	1.486	-0.838
group pp-stat	-0.622	-0.619	-3.763*
group adf-stat	-2.266*	0.681	-3.108*
Non OECD Countries[(1)] (1973-2007)			
	PPP-GDP and Residential Electricity	PPP-GDP and Total Electricity	PPP-GDP and Total Energy
panel v-stat	1.668*	-0.255	0.739
panel rho-stat	-1.292	0.981	-1.805*
panel pp-stat	-2.649*	-0.094	-3.228*
panel adf-stat	-2.408*	-1.050	-2.785*
group rho-stat	0.143	2.201	0.041
group pp-stat	-1.943*	0.886	-2.303*
group adf-stat	-2.252*	-0.362	-2.213*

Notes:

(1) All tests statistics are asymptotically distributed as N(0,1). * Rejects the null of no cointegration at 5% level. All tests are one-sided tests: for the panel variance test the right tail of the standard normal distribution is used to reject the null of no cointegration and for the other six tests the left tail is used.

(2) An intercept and a trend were included in the cointegrating regression.

Table 10: Panel Cointegration Tests: PPP-GDP dependent variable

(19 countries excluding Cameroon, India, Kenya, Mozambique, Nigeria, Sudan, Vietnam)

Non OECD Countries (1971-2007) [(1)]			
	PPP-GDP and Residential Electricity	PPP-GDP and Total Electricity	PPP-GDP and Total Energy
panel v-stat	1.547	1.272	1.408
panel rho-stat	0.892	-0.052	-0.551
panel pp-stat	0.079	-1.282	-1.932*
panel adf-stat	0.616	-0.595	-1.136
group rho-stat	1.290	1.180	0.678
group pp-stat	-0.071	-0.642	-1.342
group adf-stat	-0.253	-0.870	-0.862
Non OECD Countries (1973-2007) [(1)]			
	PPP-GDP and Residential Electricity	PPP-GDP and Total Electricity	PPP-GDP and Total Energy
panel v-stat	1.080	1.306	1.227
panel rho-stat	1.502	0.952	0.218
panel pp-stat	0.933	0.441	-0.541
panel adf-stat	0.597	0.788	-1.242
group rho-stat	1.982	1.945	1.388
group pp-stat	1.037	1.032	0.167
group adf-stat	-0.312	0.357	-0.902

Notes:

(1) All tests statistics are asymptotically distributed as N(0,1). * Rejects the null of no cointegration at 5% level. All tests are one-sided tests: for the panel variance test the right tail of the standard normal distribution is used to reject the null of no cointegration and for the other six tests the left tail is used.

(2) An intercept and a trend were included in the cointegrating regression.

Table 11: Panel Cointegration Tests: PPP-GDP independent variable

(19 countries excluding Cameroon, India, Kenya, Mozambique, Nigeria, Sudan, Vietnam)

Non OECD Countries (1971-2007) (1)			
	PPP-GDP and Residential Electricity	PPP-GDP and Total Electricity	PPP-GDP and Total Energy
panel v-stat	1.381	-0.660	0.369
panel rho-stat	-0.944	1.838	-0.568
panel pp-stat	-2.410*	1.277	-2.042*
panel adf-stat	-2.173*	0.703	-1.110
group rho-stat	-0.042	2.232	0.131
group pp-stat	-2.569*	1.386	-1.901*
group adf-stat	-2.044*	0.716	-2.246*
Non OECD Countries (1973-2007) (1)			
	PPP-GDP and Residential Electricity	PPP-GDP and Total Electricity	PPP-GDP and Total Energy
panel v-stat	1.697*	-0.876	0.629
panel rho-stat	-1.168	1.844	-0.452
panel pp-stat	-2.542*	0.822	-1.740*
panel adf-stat	-2.632*	-0.356	-2.159*
group rho-stat	-0.199	2.751	0.514
group pp-stat	-2.457*	1.520	-1.280
group adf-stat	-2.460*	-0.042	-3.038*

Notes:

(1) All tests statistics are asymptotically distributed as N(0,1). * Rejects the null of no cointegration at 5% level. All tests are one-sided tests: for the panel variance test the right tail of the standard normal distribution is used to reject the null of no cointegration and for the other six tests the left tail is used.

(2) An intercept and a trend were included in the cointegrating regression.

Table 12: Short-run Causality Summary – 1973 – 2007

Variable causality (From→To)	Short-run Causality (**Y**/N)	Test Statistics Table
OECD countries		
Res Elec→PPP-GDP	N	Table 13
Tot Elec→PPP-GDP	N	
Tot Engy→PPP-GDP	N	
PPP-GDP→Res Elec	**Y**	
PPP-GDP→Tot Elec	**Y**	
PPP-GDP→Tot Engy	**Y**	
Non-OECD: 26 countries		
Res Elec→PPP-GDP	N	Table 13
Tot Elec→PPP-GDP	**Y**	
Tot Engy→PPP-GDP	N	
PPP-GDP→Res Elec	**Y**	
PPP-GDP→Tot Elec	**Y**	
PPP-GDP→Tot Engy	N	
Non-OECD: 19 countries		
Res Elec→PPP-GDP	N	Table 13
Tot Elec→PPP-GDP	**Y**	
Tot Engy→PPP-GDP	N	
PPP-GDP→Res Elec	**Y**	
PPP-GDP→Tot Elec	**Y**	
PPP-GDP→Tot Engy	**Y**	

Table 13: Panel short-run causality tests

OECD Countries (1973-2007)

To		Causality from			
		PPP-GDP	Residential Electricity	Total Electricity	Total Energy
PPP-GDP	Z		-0.504	-0.404	-0.121
	p-value		0.615	0.686	0.903
Residential Electricity	Z	3.999*			
	p-value	0.000			
Total Electricity	Z	2.327*			
	p-value	0.020			
Total energy	Z	2.694*			
	p-value	0.007			

26 Non OECD Countries (1973-2007)

To		Causality from			
		PPP-GDP	Residential Electricity	Total Electricity	Total Energy
PPP-GDP	Z		-0.378	3.377*	-1.427
	p-value		0.706	0.000	0.154
Residential Electricity	Z	4.505*			
	p-value	0.000			
Total Electricity	Z	2.432*			
	p-value	0.015			
Total energy	Z	1.660			
	p-value	0.097			

(1) For all tests three lags were used. All tests statistics are asymptotically distributed as N(0,1). The Z test is a two-sided test. * Rejects the null of homogenous non causality at 5% level.

19 Non OECD Countries (1973-2007)

To		Causality from			
		PPP-GDP	Residential Electricity	Total Electricity	Total Energy
PPP-GDP	Z		0.342	3.939*	-0.704
	p-value		0.732	0.000	0.482
Residential Electricity 2 lags	Z	4.186*			
	p-value	0.000			
Total Electricity	Z	3.200*			
	p-value	0.001			
Total energy	Z	2.334*			
	p-value	0.020			

(1) For all tests three lags were used. All tests statistics are asymptotically distributed as N(0,1). The Z test is a two-sided test. * Rejects the null of homogenous non causality at 5% level.

Table 14: Long-run Causality Summary - 1973 – 2007

Variable causality (From→To)	Long-run Causality (**Y**/N)	Test Statistics Table
OECD countries		
PPP-GDP→Res Elec	**Y**	Table 15
PPP-GDP→Tot Engy	**Y**	Table 15
Non-OECD: 26 countries		
PPP-GDP→Res Elec	**Y**	Table 16
PPP-GDP→Tot Engy	**Y**	Table 16
Non-OECD: 19 countries		
PPP-GDP→Res Elec	**Y**	Table 17
PPP-GDP→Tot Engy	**Y**	Table 17

Table 15: Pooled Mean Group Estimates
OECD Countries (1973-2007)

		Explanatory Variable	
		PPP-GDP	
Dependent Variable	Estimator	Long-run coefficient	Error correction coefficient
Residential Electricity	PMGE	0.424 [5.739]	-0.229 [-7.855]
	MGE	-0.155 [-0.261]	-0.286 [-9.536]
	h test p-value	0.97 0.32	
Total Energy	PMGE	1.080 [23.410]	-0.315 [-6.201]
	MGE	0.645 [3.702]	-0.430 [-8.245]
	h test p-value	6.70* 0.01	

t-statistics in brackets. h-test is the Hausman poolability test.
* indicates that the Hausman test rejected poolability.

Table 16: Pooled Mean Group Estimates
26 Non OECD Countries (1973-2007)

		Explanatory Variable	
		PPP-GDP	
Dependent Variable	Estimator	Long-run coefficient	Error correction coefficient
Residential Electricity	PMGE	0.557	-0.226
		[11.257]	[-4.556]
	MGE	0.647	-0.323
		[2.731]	[-7.053]
	h test	0.15	
	p-value	0.70	
Total Energy	PMGE	0.123	-0.330
		[1.807]	[-8.442]
	MGE	0.323	-0.369
		[1.336]	[-9.014]
	h test	0.74	
	p-value	0.39	

t-statistics in brackets. h-test is the Hausman poolability test.
* indicates that the Hausman test rejected poolability.

Table 17: Pooled Mean Group Estimates
19 Non OECD Countries (1973-2007)
(excluding Cameroon, India, Kenya, Mozambique, Nigeria, Sudan, Vietnam)

		Explanatory Variable	
		PPP-GDP	
Dependent Variable	Estimator	Long-run coefficient	Error correction coefficient
Residential Electricity	PMGE	0.563	-0.245
		[12.645]	[-5.124]
	MGE	0.741	-0.332
		[1.728]	[-6.888]
	h test	0.17	
	p-value	0.68	
Total Energy	PMGE	0.853	-0.154
		[15.016]	[-5.061]
	MGE	0.823	-0.227
		[3.851]	[-6.238]
	h test	0.02	
	p-value	0.89	

t-statistics in brackets. h-test is the Hausman poolability test.

Appendix A

Table A-1: Unit Root Panel Data Tests in the Presence of Multiple Breaks

	Breaks (homogeneous) Test statistic (p-value) [5% Bootstrap critical values]	Breaks (heterogeneous) Test statistic (p-value) [5% Bootstrap critical values]
OECD Countries (1973-2007)		
PPP GDP	9.870 (0.000) [13.492]	25.985 (0.000) [21.182]
Residential Electricity	23.130 (0.000) [16.993]	36.088 (0.000) [33.467]
Total Electricity	24.796 (0.000) [16.183]	47.298 (0.000) [42.044]
Total Energy	13.555 (0.000) [11.955]	27.538 (0.000) [25.050]
Non OECD Countries (1973-2007)		
PPP GDP	10.950 (0.000) [20.524]	31.051 (0.000) [41.127]
Residential Electricity 1983-2007	31.951 (0.000) [43.039]	82.426 (0.000) [175.306]
Total Electricity	16.154 (0.000) [17.202]	35.222 (0.000) [38.674]
Total Energy	10.374 (0.000) [20.628]	40.806 (0.000) [46.039]
Non OECD 19 Countries (1973-2007)		
PPP GDP	14.339 (0.000) [40.294]	21.933 (0.000) [69.221]
Residential Electricity 1983-2007	26.521 (0.000) [15.186]	83.589 (0.000) [56.882]
Total Electricity	8.109 (0.000) [10.217]	30.005 (0.000) [28.217]
Total Energy	7.551 (0.000) [19.510]	42.775 (0.000) [41.000]

The number of breaks has been estimated using the LWZ (Liu et al. (1997)) criteria allowing for a maximum of 5 breaks. The long-run variance is estimated using the Bartlett kernel with automatic spectral window bandwidth selection as in Andrews (1991). The critical values are obtained from bootstrap distribution based on 2000 replications. The null is stationarity.

Table A-2: Panel Cointegration Tests in the Presence of Multiple Structural Breaks

OECD Countries[1] (1973-2007)			
	PPP-GDP and Residential Electricity	PPP-GDP and Total Electricity	PPP-GDP and Total Energy
PPP-GDP dependent variable	4.859**	4.891**	5.417**
PPP-GDP independent variable	4.834**	4.633**	3.738**
Non OECD Countries[1] 22 countries[3] (1973-2007)			
	PPP-GDP and Residential Electricity	PPP-GDP and Total Electricity	PPP-GDP and Total Energy
PPP-GDP dependent variable	3.318**	3.295**	3.348**
PPP-GDP independent variable	3.701**	4.234**	3.464**
Non OECD Countries[1] 16 countries[4] (1973-2007)			
	PPP-GDP and Residential Electricity	PPP-GDP and Total Electricity	PPP-GDP and Total Energy
PPP-GDP dependent variable	2.317*	3.110**	3.221**
PPP-GDP independent variable	2.915**	2.427*	2.412*

Notes:

(1) All tests statistics are asymptotically distributed as N(0,1). * Rejects the null of cointegration at 5% level; ** Rejects the null of cointegration at 1% level.

(2) An intercept was included in the cointegrating regression and only breaks in levels are considered. Results for breaks in levels and trends all show a very strong rejection of the null of cointegration.

(3) This test does not allow for unbalanced panels and therefore China, Philippines, Saudi Arabia and Vietnam had to be excluded.

(4) Excluding China, Philippines, Saudi Arabia, Vietnam, Cameroon, India, Kenya, Mozambique, Nigeria, and Sudan.