Hydroelectricity Consumption and Economic Growth Nexus: Evidence from a Panel of Ten Largest Hydroelectricity Consumers[#]

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Abstract

This paper explores the long-run and causal relationships between hydroelectricity consumption and economic growth for a panel of the 10 largest hydroelectricity consuming countries over the period 1965 to 2012. The countries include Brazil, Canada, China, France, India, Japan, Norway, Sweden, Turkey and the U.S.A. Using the Bai and Perron (2003) tests for cointegration, the results indicate that real GDP per capita and hydroelectricity consumption per capita appear to be cointegrated around a broken intercept. Granger causality results from a nonlinear panel smooth transition vector error correction model suggest different results depending on the regimes, which we identified based on structural break tests. The test identified three breaks at 1988, 2000 and 2009. For the pre-1988 period, there is evidence of unidirectional causality running from real GDP per capita to hydroelectricity per capita in both the short- and long-run. Over the post-1988 period, there exists evidence of bidirectional causality between hydroelectricity energy consumption per capita and real GDP per capita in both the short- and the long-run. The results imply the existence of a feedback hypothesis with both hydroelectricity consumption and growth promoting each other in more recent periods, as the importance of hydroelectricity as a renewable energy, has become more prominent.

Keywords: Economic growth, Granger causality, Hydroelectricity, Panel cointegration, 10 largest hydroelectricity consumers.

JEL Codes: C33, Q25, Q42, Q43.

[#] We would like to thank two anonymous referees for many helpful comments. However, any remaining errors are solely ours.

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1. Introduction

A number of studies have analyzed the causal relationship between renewable energy consumption and economic growth across different countries or sets of countries (Abakah, 1993; Apergis and Payne, 2010a, 2010b, 2011a, 2011b, 2012 and 2014; Halkos and Tzeremes, 2014; among others). There is also a growing literature on the causal relationship between renewable energy consumption and economic growth. Most of these studies use aggregate energy sources (with the exceptions of Abakah, 1993; Ohlers and Fetters, 2014; Ziramba, 2013; Halkos and Tzeremes, 2014). With the world facing global warming, mainly as a result of the consumption of fossil fuels, it might be important to consider hydroelectricity which is non-polluting. The role of hydroelectricity on agricultural production and hence, the GDP growth is undeniable, as have been described in detail in Valipour (2014a, b; 2015a, b) and Valipour et al., (2015). There is a growing literature on energy intensity and carbon emissions. Such studies include Bentzen (2004), Jin (2007), Sorrell and Dimitropoulos (2008), Zhang (2003), Zhang and Zhaohua (2014), Zhaohua, Yin, Zhang, and Zhang (2012), Zhaohua, Zeng, Wei, and Zhang (2012), Zhaohua, Feng, and Zhang (2014, Zhaohua, Milin, and Wang (2014), Zhaohua, Wang, Yin (2015), Zhaohua, and Chao (2015), Zhaohua, and Yang (2015), Zhaohua and Chao (2015), among others. The role of individual sources of renewable energy is important, given countries' challenges in determining the optimal mix of energy.

The goal of this paper is to assess the causal relationships between hydroelectricity consumption and economic growth in a panel of the 10 largest consumers of hydroelectricity. The empirical analysis employs annual data spanning the period 1965 to 2012. The countries include Brazil, Canada, China, France, India, Japan, Norway, Sweden, Turkey and the U.S.A. Note that, Venezuela is also a very prominent user of hydroelectricity (2.1 percent of world share, BP's Statistical Review of World Energy, 2013) and ranks in the top 10 countries, however, due to the lack of data on per capita real GDP going as far back as 1965, we had to exclude it from the analysis. The ten countries included in the analysis covers 67.4 percent of world hydroelectricity consumption, with China coming in first with 27.4 percent and Turkey with 1.0 percent of world share (BP's Statistical Review of World Energy, 2013). Canada, Brazil and the U.S. follows China with 9.8 percent, 9.5 percent and 6.7 percent of world share (BP's

Statistical Review of World Energy, 2013). Given these figures, and the lack of per capita real GDP data for Venezuela, the choice of the ten countries were quite obvious in our analysis. This paper contributes to the literature on the nexus between renewable energy consumption and economic growth by examining a particular energy source, hydroelectricity. Also note that, among these ten countries four of them are in the world's top five polluting countries. Of all ten sample countries, only Sweden is among the leading countries in the use of renewable energies. The use of hydroelectricity is important as it reduced carbon emissions.

This study is among a few studies, third to be precise, that make use of a nonlinear panel smooth transition vector error correction model to study the relationship between energy consumption and growth. The other two studies by Omay and Kan (2010) and Apergis and Payne (2012) have looked at aggregate energy and aggregate renewable energy respectively. However, none of the studies dealing with hydroelectricity (as will be seen from the literature review below), have used nonlinear panel smooth transition vector error correction model. While aggregate energy analyses are helpful, but these studies cannot be necessarily used for energy sector-specific analysis, since policy recommendations for aggregate energy could possibly not hold for a specific-type of energy in question, which in our case is hydroelectricity. The importance of hydroelectricity on the growth process via agricultural output has already been discussed above, and given that we show nonlinearity and structural breaks in the relationship exists between the two variables (growth and hydroelectricity in the empirical segment), makes our analysis even more important, since using linear frameworks (as utilized in the hydroelectricity literature) are likely to provide incorrect results and policy conclusions due to model-misspecifcation.

The remainder of the paper is organized as follows: the next section gives the testable hypotheses in the energy consumption-economic growth relationship and an overview of the empirical literature on the nexus between renewable and non-renewable energy consumption and economic growth. Section 3 outlines the data employed in this study. Section 4 outlines the empirical analysis and the obtained results. The econometric methodologies which are employed in this study are also discussed in the same section.

Section 5 presents the panel Granger causality test results. Finally, section 6 provides concluding remarks.

2. Energy consumption – growth hypotheses and literature overview

The relationship between energy consumption and economic growth can be classified into four testable hypotheses: growth, conservation, feedback, and neutrality (Apergis and Payne, 2010a). The growth hypothesis suggests that energy consumption contributes to economic growth, both directly and indirectly, as a complement to other inputs in the production process. Support for this hypothesis requires unidirectional causality from energy consumption to income. The conservation hypothesis states that energy conservation policies that curtail energy consumption would not adversely affect real income. Unidirectional causality running from income to energy consumption provides support for this hypothesis. The feedback hypothesis argues that energy consumption and income are interdependent and complimentary to each other. Support for this hypothesis requires the presence of bi-directional causality between the two variables under consideration. Finally, the neutrality hypothesis implies that energy consumption has a minor role in the determination of real income (Payne, 2008). This hypothesis is supported in the case where there is no Granger-causality between energy consumption and economic growth.

Numerous studies have examined the causal dynamics between renewable energy consumption and economic growth. Empirical evidence has been rather mixed (Payne, 2008).Unlike most studies, Ohlers and Fetters (2014) examine the causal relationship between renewable electricity generation and economic growth. One of the earliest studies to assess the causal relationship betwwen hydroelectricity consumption and economic growth has been that by Abakah (1993). The author assesses the relationship between economic growth and three sources of energy- charcoal, petroleum and hydroelectricity in Ghana over the period 1976 to 1990. The results indicate a significant negative correlation for charcoal and positive correlation with respect to the consumption of hydroelectricity and petroleum.

Apergis and Payne (2010a) examine the causal relationship between renewable energy consumption and economic growth for thirteen countries within Eurasia over the period 1992 to 2007. They use a multivariate panel data framework which includes such variables such as real gross domestic product (GDP), renewable energy consumption, real gross fixed capital formation and labour force. Their panel cointegration test reveals a long-run equilibrium relationship among these variables. They also find bidirectional causality between renewable energy consumption and economic growth in both the short- and the long-run. Thus, their results lend support for the feedback hypothesis in the panel of countries.

In another study on a panel of 20 OECD countries, Apergis and Payne (2010b) examine the relationship between renewable energy consumption and economic growth spanning the period 1985 to 2005. Capital and labour are included as control variables in the multivariate framework. They use the Im et al. (2003) unit root test and they find that all variables to be integrated of order one. Theyalso employ the heterogeneous panel cointegration test advanced by Pedroni (1999, 2004) to examine the long-run relationship among the variables across the panel of countries. Their findings document a long-run equilibrium relationship, while their Granger causality test results indicate the presence of bidirectional causality between renewable energy consumption and economic growth.

Apergis, Payne, Menyah and Wolde-Rufael (2010) examine the causal relationship between carbon emissions, nuclear energy consumption, renewable energy consumption and economic growth in a panel of 19 developed and developing countries over the period 1984 to 2007. They employ several panel unit root tests and conclude that all the variables are integrated of order one. The Larson et al. (2001) cointegration test is employed, whilethe panel rank test results reject the null hypothesis of no cointegration. Their long-run estimates indicate that there is a statistically significant positive relationship between carbon emissions and renewable energy consumption. Their panel Granger causality test results suggest that renewable energy consumption does not contribute to emissions reductions, whilethey indicate the presence of bidirectional causality between renewable energy consumption and economic growth.

Using data on a panel of six Central American countries, Apergis and Payne (2011a) examine the relationship between renewable energy consumption and economic growth over the period 1980 to 2006. Again, capital and labour are included as explicit control variables. Various panel unit root tests are employed and there is overwhelming evidence in support of panel unit roots in the variables. Their panel cointegration results indicate that the null hypothesis of no cointegration was rejected at the 1 percent significance level, while there exists bidirectional causality between renewable energy consumption and economic growth in both the short- and the long-run.

Apergis and Payne (2011b) examine the relationship between renewable and non-renewable electricity consumption and economic growth for a panel of 16 emerging economies over the period 1990 and 2007. They employ a multivariate framework which includes capital and labour as control variables. Several panel unit root test are employed and the results illustrate the presence of unit roots across all variables. Panel cointegration test results indicate that the null hypothesis of no cointegration is rejected. Their results from the panel error correction model reveal unidirectional causality from economic growth to renewable energy consumption in the short-run and bidirectional causality in the long-run.

Apergis and Payne (2012) also examine the relationship between renewable and non-renewable energy consumption and economic growth for a panel of 80 countries within a multivariate framework over the period 1990 to 2007. They include the four variables, i.e. real GDP, capital, labour and renewable or non-renewable energy consumption. Their panel cointegration test results suggest a long-run equilibrium relationship among the variables, while Granger causality results highlight the presence of bidirectional causality between renewable and non-renewable energy consumption and economic growth in both the short- and the long-run. They also find evidence of substitutability between the two energy sources, which is indicated by the presence of short-run bidirectional causality.

Apergis and Payne (2014) examine the determinants of renewable energy consumption for a panel of seven Central American countries over the period 1980 to 2010. They include such variables as real GDP per capita, carbon emissions per capita, coal and oil prices in their analysis. They specify and estimate a demand model, while they use several panel unit root tests to assess the time series properties of the data involved. Their results indicate that the variables are integrated of order one, whiletheir panel cointegration results indicate a long-run relationship among the variables. Finally, Granger causality results from the non-linear panel smooth transition vector error correction model suggest the presence of short- and long-run bidirectional causality between renewable energy consumption and real GDP.

Tugcu, Ozturk and Aslan (2012) examine the long-run causal relationship between renewable and non-renewable energy consumption in the G7 countries over the period 1980 to 2009. They use an individual country analysis approach, whilethey estimate the classical and augmented Cobb-Douglas production function. In the classical specification, output is a function of physical capital, labour force and energy consumption. The production function is then augmented through the addition of both the research and development expenses and human capital. They use the bounds test approach to cointegration to test for the long-run relationship among the variables. Their causality results document the presence of bidirectional causality between both forms of energy consumption and economic growth. The augmented production function specification generated mixed causality results for each country.

Ohlers and Fetters (2014) examine the causal relationship between electricity generation from various forms of renewable energy (i.e., biomass, geothermal, hydroelectricity, solar, waste, and wind) and economic growth in a panel of 20 OECD countries over the period 1990 to 2008. They employ a production function framework which expresses output as a function of capital, labour, renewable and non-renewable energy generation. They use six different panel unit root tests to ascertain the panel time series properties of the data. Their results suggest that all the variables are integrated of order one. They employ Pedroni (1999, 2004)'s panel cointegration methodological approach and their results display a cointegrating relationship among the variables under consideration. Their Granger causality test results indicate that hydroelectricity exhibits a short-run positive bidirectional relationship with GDP growth, while hydroelectricity is among the energy sources with the largest long-run impact on real GDP.

Sebri and Ben-Salha (2014) explore the causal relationship between economic growth and renewable energy consumption in the BRICS countries over the period 1971 to 2010. Individual country analysis is carried out within a multivariate framework which includes both carbon emissions and trade openness. They employ the autoregressive distributed lag approach to cointegration and they provide evidence of a long-run relationship among the variables. Their short-run Granger causality results indicate that there exists bidirectional causality between economic growth and renewable energy consumption (except for the case of Brazil). Their long-run Granger causality results suggest bidirectional causality (except for the case of India).

Halkos and Tzeremes (2014) use non-parametric methodological approaches to examine the relationship between electricity consumption from renewable sources and GDP in a sample of 36 countries. They examine a number of renewable energy sources, including, wind, geothermal, solar biomass, and waste. When they analyse the entire sample of countries, their results reveal an increasing relationship up to a certain level of GDP. When countries are grouped into sub-samples, based on the level of their economic development, the results change significantly. For emerging and developing countries, the relationship appears to be highly non-linear, whilefor the case of developed countries, the results also reveal an increasing non-linear relationship.

In a study on three African countries, Ziramba (2014) examines the presence of causal relationship between hydroelectricity consumption and economic growth within a multivariate framework over the period 1980 to 2009. The sample countries are Algeria, Egypt, and South Africa. The author uses the Granger causality test developed by Toda and Yamamoto (1995) and he provides evidencein favour of the neutrality hypothesis for Egypt, of the feedback hypothesis in Algeria, and of the conservation hypothesis in South Africa.

Sebri (2015) makes use of a meta-analysis approach to synthesize the empirical literature on the subject of renewable energy consumption and economic growth nexus. The study finds out why different studies on the energy consumption-economic growth nexus provide support for different hypotheses. Their empirical results reveal that the variations in the supported hypotheses is due to a number of characteristics, including estimation methodologies employed, as well as the level of development of the country on which a study is conducted.

Omri, Mabrouk and Sassi-Tmar (2015) investigate the causal relationship between nuclear and renewable energy consumption and economic growth in a panel of 17 developed and developing countries. They employ an augmented Cobb-Douglas production function in a dynamic simultaneous equation approach where both energy consumption and economic growth are treated as endogenous variables. Their Granger causality results illustrate the presence of unidirectional causality running from renewable enrgy consumption to economic growth in five of the countries under study; unidirectional causality from economic growth to renewable energy consumption in three of the countries considered; and bidirectional causality in six of the countries under investigation. There is no evidence of causality between renewable enrgy consumption and economic growth in three of the countries under consideration.

As can be seen from the discussion of the literature review, the studies have primarily concentrated on renewable energy in aggregate, but not necessarily the importance of hydroelectricity. With hydroelectricity being the leading source of renewable energy in the world, accounting for 19 percent of global power generation in 2013 (BP's Statistical Review of World Energy, 2013), it makes complete sense to look at the importance of hydroelectricity's influence on growth on its own rather than reneable energy in aggregate. In addition, it is also observed that results are sensitive to countries of choice, sample period and the methodology. This implies that the analysis of the relationship between energy consumption, in particular renewable energy, and hydroelectricity in our case, must be be based on updated data on a regular basis. The fact that the results tend to vary over time could also be a result of structural breaks and regime changes, and hence, requires one to first analyse the break dates in this relationship and conduct the analysis over sub-samples, and also requires one to account for nonlinearity to accommodate for the fact that the relationship can vary across the phases of the economy, that is whether it is in expansion or recession.

3. **Data**

Annual data for the largest 10 hydroelectricity consumers (i.e., Brazil, Canada, China, France, India, Japan, Norway, Sweden, Turkey and the U.S.)[1] are obtained, spanning the period 1965 to 2012 for the following two variables: real GDP per capita (Y) and total hydroelectricity consumption per capita, defined in kilowatt hours (HY). Note that the start and end dates are purely driven by data-availability. We obtain data on real GDP percapita and population fromWorld Bank's World Development Indicators database, while hydroelectricity consumption is derived from BP's Statistical Review of

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[1] As obtained from BP's Statistical Review of World Energy, 2013.

World Energy, 2013. We derive per capita hydroelectricity consumption, by dividing total hydroelectricity consumption by the population figures.The natural logarithms of thesevariables are used in the analysis and denoted by lower case letters, i.e., y and hy.

4. **Empirical analysis**

The empirical analysis is making use of a number of advanced panel estimation methodological approaches that have been used extensively in the empirical energy literature. Nevertheless, for the same testing procedures, more alternative methodologies have been used, but in the majority of these cases the results came out to be tantamount.

We begin the analysis by examining the presence of cross-sectional dependence. Panel unit root tests of the first-generation can lead to spurious results (because of size distortions), if significant degrees of positive residual cross-section dependence exist and are ignored. Consequently, the implementation of second-generation panel unit root tests is desirable only when it has been established that the panel is subject to a significant degree of residual cross-section dependence. In the cases where cross-section dependence is not sufficiently high, a loss of power might result if second-generation panel unit root tests that allow for cross-section dependence are employed. Therefore, before selecting the appropriate panel unit root test, it is crucial to provide some evidence on the degree of residual cross-section dependence.

The cross-sectional dependence (CD) statistic by Pesaran (2004) is based on a simple average of all pair-wise correlation coefficients of the OLS residuals obtained from standard augmented Dickey-Fuller regressions for each variable in the panel. Under the null hypothesis of cross-sectional independence, the CD test statistic follows asymptotically a two-tailed standard normal distribution. The results uniformly reject the null hypothesis of cross-section independence at one percent level of significance, providing evidence of cross-sectional dependence in the data.

Two second-generation panel unit root tests are employed to determine the degree of integration in the respective variables. The Pesaran (2007) panel unit root test does not require the estimation of factor loading to eliminate cross-sectional dependence. Specifically, the usual ADF regression is augmented to include the lagged cross-sectional mean and its first difference to capture the cross-sectional dependence that arises through a single-factor model. The null hypothesis is a unit root for the Pesaran (2007) test. The bootstrap panel unit root tests by Smith et al. (2004) utilize a sieve sampling scheme to account for both the time series and cross-sectional dependence in the data throughbootstrap blocks. All four tests by Smith et al. (2004) are constructed with a unit root under the null hypothesis and heterogeneous autoregressive roots under the alternative hypothesis. The results of these panel unit root tests are reported in Table 1. The results associated with the Pesaran (2007) methodological approach indicate the acceptance of the null hypothesis, i.e. the presence of a unit root, in the levels of the variables under study and the rejection of the unit root hypothesis only after first differencing these variables. Similarly, the results in relevance to the Smith et al. (2004) methodological approach also illustrate the acceptance of the unit root hypothesis in the levels across all relevant variables, and the rejection of the hypothesis in terms of first differenced variables. Overall, the empirical findings out of the panel unit root tests provide solid evidence that the variables under consideration by the empirical analysis should enter the modelling process as in first differences.

Table 1. Panel Unit Root Tests

Variable	**Pesaran CIPS**	**Pesaran CIPS***	**Smith et al. t-test**	**Smith et al. LM-test**	**Smith et al. max-test**	**Smith et al. min-test**
hy	-1.15	-1.19	-1.32	4.12	-1.21	1.32
Δhy	-6.72[a]	-6.25[a]	-6.53[a]	29.38[a]	-6.72[a]	6.81[a]
y	-1.36	-1.23	-1.26	4.21	-1.15	1.22
Δy	-7.92[a]	-7.21[a]	-6.38[a]	30.93[a]	-8.24[a]	7.25[a]

Notes: Δ denotes first differences. A constant is included in the Pesaran (2007) tests. Rejection of the null hypothesis indicates stationarity in at least one country. CIPS* = truncated CIPS test. "a" denotes rejection of the null hypothesis. Both a constant and a time trend are included in the Smith et al. (2004) tests. Rejection of the null hypothesis indicates stationarity in at least one country. For both tests the results are reported at lag = 3. The null hypothesis is that of a unit root.

Next, we employ a panel unit root test which allowa for endogenously determined structural breaks: the LM(λ) test of Carrion-i-Silvestre et al. (2005).The Carrion-i-Silvestre et al. (2005) test allows for an unknown number of breaks in the level of each series, while its null hypothesis is stationarity. Table 2 shows that the Carrion-i-Silvestre et al. (2005) test rejects the null hypothesis of stationarity in levels at the 1% significance level; however, with the variables in first-differences, it fails to reject the null hypothesis.

Therefore, the empirical findings indicate that therespective variables are integrated of order one with a structural breakoccurring in either in 1988 or in 2000 or in 2009.

Table 2. Panel unit root tests with breaks

Variables	Carrion-i-Silvestre et al. (LM(λ))	Break locations
hy	26.81*	1988-2000-2009
Δhy	1.37	
y	31.25*	2000
Δy	1.36	

Notes: The null of the LM(λ) test implies stationarity, while we use a trimming parameter of 0.1 T. The test is computed using the Bartlett kernel. All bandwidths and lag lengths are chosen according to 4(T/100)2/9. The critical value for the LM(λ) test at the 1% significance level is 10.63. * denotes statistrical significance at 1%.

The breaks locations are linked to policies in specific countriesto promote renewable energy (including hydroelectric sources) as well as the construction of damsin specific countries. For instance, inthe case of the U.S., in 2000 various innovations at the state level, such as the introduction of renewableportfolio standards that required utilities to generate, orpurchase, minimum levels of renewable energy were adopted (Lean and Smyth, 2013) or in the case of China, in the 2000s the completion of Three Gorges in 2009 and of Xiluodu in 2009 occurred. In the case of Brazila potential break in 1988 could have occurred, associated with the completion of Tucurui.

Given that there are structural breaks, then testing for the presence of cointegration without explicitly considering the presence of structural shifts generates invalid findings. Therefore, we make use of the approach recommended by Bai and Perron (2003). The Bai and Perron (2003) tests for cointegration are reported in Table 3. The findings illustrate that the two variables under consideration variables appear to be cointegrated around a broken intercept, given that the bootstrapped p-value denotes the acceptance of the null hypothesis of the presence of cointegration.

Table 3. Panel cointegration tests (the Bai–Perron procedure)

Statistic	Bootstrapped p-value
12.374	0.47

Notes: The Bai and Perron (2003) procedure tests the null hypothesis of cointegration. The p-value is based on the bootstrapped distribution. The number of lags in the sieve approximation is five with 1000 bootstrap replications.

In the following step, the empirical analysis carries out the estimation of the long-run cointegration vector using the fully modified OLS (FMOLS) approach for heterogeneous cointegrated panels (Pedroni, 1999, 2001). The results of the FMOLS estimates are reported in Table 4 which shows that real GDPper capitahas a positive and statistically significant impact on hydroelectricity energy consumption per capita. More specifically, the results highlight that a 1% increase in real GDP per capita increases hydroelectricity energy consumption per capita by 0.526%;

Table 4. FMOLS long-run panel estimates: $hy_{it} = \alpha_{ij} + \beta_1 y_{it} + \varepsilon_{it}$

Variables	Coefficient estimate	Bootstrapped p-value
y	0.526*	0.003

Notes: * denotes 1% significance. The p-values are based on the bootstrappeddistribution. The number of bootstrap replications is 1000.

5. Panel Granger causality results

Given the presence of a long-run relationship, we next estimate a non-linear panel smooth transition vector error correction model which takes into consideration that not only the adjustment to the long-run equilibrium,but also the dynamic relationship between the two variables might be non-linear. Following Gonzalez et al. (2005) and

Omay and Kan (2010), we introduce the following panel smooth transition vector error correction model:

$$\Delta hy_{it} = a_1 + b_1EC_{i(t-1)} + \sum_{j=1}^{p_1} d_{11j}\Delta hy_{i(t-j)} + \sum_{j=1}^{p_2} d_{12j}\Delta y_{i(t-j)} + G(s_{it}; \gamma, c)\ [\beta_{11}EC_{i(t-1)} + \sum_{j=1}^{p_3} \varphi_{11j}\Delta hy_{i(t-j)} + \sum_{j=1}^{p_4} \varphi_{12j}\Delta y_{i(t-j)}] + \mu_{1it} \quad (1)$$

$$\Delta y_{it} = a_2 + b_2EC_{i(t-1)} + \sum_{j=1}^{p_5} d_{21j}\Delta hy_{i(t-j)} + \sum_{j=1}^{p_6} d_{22j}\Delta y_{i(t-j)} + G(s_{it}; \gamma, c)\ [\beta_{21}EC_{i(t-1)} + \sum_{j=1}^{p_7} \varphi_{21j}\Delta hy_{i(t-j)} + \sum_{j=1}^{p_8} \varphi_{22j}\Delta y_{i(t-j)}] + \mu_{2it} \quad (2)$$

where, for i = 1,…,N and t = 1,…,T where N and T denote the cross-sectionand time dimensions of the panel, respectively; a represents fixed individual effects; EC is the error correction term from the cointegration vector; and μ is the error term assumed to be a martingale difference with respect to the history of the vector of variables with mean zeroand variance, σ_i^2. To address regime-shifts in the short- and long-run, Gonzalez et al. (2005) and Omay and Kan (2010) consider the employment of the following logistic transition function:

$$G(s_{it}; \gamma, c) = [1 + \exp(-\gamma \prod_{j=1}^{m} (s_{it} - c_j))]^{-1}$$

with $\gamma>0$ and $c_m \geq \ldots \geq c_1 \geq c_0$, where $c = (c_1,\ldots,c_m)'$ is anm-dimensional vector of location parameters and the slope parameter,γ, denotes the transition smoothness parameter between regimes. Given the regime-dependent dynamics between the two variables, we follow Li (2006) by conducting the Granger causality tests separately for each regime: pre-1988 and post-1988 periods; pre-2000 and post-2000 periods; and, pre-2009 and post-2009 periods. The null hypotheses of no Granger-causality can be formulated for hydroelectricity energy consumption per capita (i.e. Eq. (1)) for the pre-the event and post-the event periods as follows: (1) real GDP per capitadoes not Granger cause hydroelectricity energy consumption per capita for the pre-event period in the short-run, H_0: $d_{12} = 0$; (2) real GDP per capita does not Granger cause hydroelectricity energy consumptionper capita for the pre-event period in the long-run, H_0: $b_1 = 0$ and/or $b_1 = d_{12}= 0$; (3) real GDP per capita does not Granger cause hydroelectricity energy consumption per capita for the post-event period in the short-run, H_0: $d_{12} = \varphi_{12}= 0$; and (4) real GDP per capita does not Granger cause hydroelectricity energy consumption per capita forthe post-event period in the long-run, H_0: $b_1 = \beta_{11} = 0$ and/or $b_1 =\beta_{11} = d_{12} = \varphi_{12}= 0$. Similarly, the short- and long-run null hypotheses of the absence of Granger-causality can be readily applied to the second equation specified in the panel smooth transition vector error correction model (Eq. (2)). Panels A, B, C, D, E and F of Table 5 report the results of the regime-wise Granger-causality tests.

Table 5. Regime-wise Granger-causality tests

Dependent variable	Sources of causation		
	Short-run		Long-run
	Δhy	Δy	EC
Panel A: pre-1988 period			
Δhy	---	35.64*	-0.237*
		[0.00]	[0.00]
Δy	1.51	---	-0.052
	[0.29]		[0.21]

Panel B: post-1988 period			
Δhy	---	42.19*	-0.264*
		[0.00]	[0.00]
Δy	19.26*	---	-0.117*
	[0.00]		[0.00]
Panel C: pre-2000 period			
Δhy	---	39.12*	-0.218*
		[0.00]	[0.00]
Δy	23.08*	---	-0.185*
	[0.00]		[0.00]
Panel D: post-2000 period			
Δhy	---	49.73*	-0.292*
		[0.00]	[0.00]
Δy	24.35*	---	-0.148*
	[0.00]		[0.00]
Panel E: pre-2009 period			
Δhy	---	53.07*	-0.268*
		[0.00]	[0.00]
Δy	28.15*	---	-0.166*
	[0.00]		[0.00]
Panel F: post-2009 period			
Δhy	---	61.42*	-0.298*
		[0.00]	[0.00]
Δy	27.14*	---	-0.177*
	[0.00]		[0.00]

Notes: Partial F-statistics are reported with respect to short-run changes in the independent variables. EC represents the respective error correction term. Probability values are in brackets and are reported underneath the corresponding partial F-statistic. Significance level: * (1%).

For the pre-1988 period, as shown in Panel A, the short-run causality results reveal that there exists a unidirectional causality running from real GDP per capita to hydroelectricity per capita between the variables specified in Eqs. (1)-(2), because the Wald test over the first-regime period is less than its critical value, supporting the null hypothesis of non-significance effect, while over the second-regime period, the Wald F-tests reject the null of non-significant effects across both variables in relevance. Similar results are holding in the long-run. For the post-1988 period, as shown in Panel B, the short-run causality tests yield different results relative to the pre-1988 period. In particular, with respect to the short-run causality results, bidirectional causality exists now between hydroelectricity energy consumption per capita and real GDPper capita. The long-run causality results mimic the short-run results in terms of the presence of bidirectional causality. These findings seem to strongly support the two different stages of the relationship between the considered variables has undertaken over the two-regime periods. More specifically, prior to the time threshold point, it was the growth process of the relevant countries that was driving the development of hydroelectricity consumption which obviously was on a very primitive level. However, the growth process reached a critical point that managed to advance any type of technology and capacity in relevance to hydroelectricity investments so as they managed to start substantially contributing to further economic growth. As a result, better technological achievements, as well as further revenues for R&D developments, associated with potential reduced costs of the use of hydroelectricity consumption, seem to have been the primary drivers for boosting economic growth.

The results with respect to the two remaining breaks, i.e. 2000 and 2009, not only provide supportive evidence for the presence of bidirectional causality between hydroelectricity energy consumption and economic growth, but also they look stronger, indicating the increasing role of hydroelectricity energy sources to sustain economic production, and therefore, economic growth. These new findings seem to corroborate those derived above and in relevance to the first break, thus, expemplyfying the dynamics associated with how self-sustained the hydroelectricity power can feed in higher levels of economic growth.

Finally, the regime change in the PSTRVEC model is governed by the transition function defined in equation (3). Now, with respect to the three regimes identified above, this part of the analysis considers and reports the estimates of the variables of interest, i.e. γ that determines the speed of transition between the two in relevance regimes, and c that determines the midpoint of the transition. The results are reported in Table 6. They highlight that the estimated value of c is 0.00016, 0.00042 and 0.00037 for the 1988, 2000 and 2009 break points, respectively, which are all very close to zero, thus, providing support to the argument that the regimes in the PSTRVEC model considered, correspond to negative and positive values of the GDP growth rate, i.e., recessionary and expansionary regimes. Additionally, the corresponding values of γ take on the values of -2.315, -2.559 and -2.186, indicating a relatively high speed of adjustment between the two business regimes, with the highest speed being associated with the regime-2000.

Table 6. Estimated parameters of the transition function

Parameter	Regime: 1988	2000	2009
c	0.00016	0.00042	0.00037
	[0.01]	[0.00]	[0.00]
γ	-2.315	-2.559	-2.186
	[0.00]	[0.00]	[0.01]

Notes: Figures in brackets denote p-values.

6. **Concluding remarks and policy implications**

The objective of this paper was to test the long-run causal relationships between economic growth and hydroelectricity consumption in a panel of the 10 largest hydroelectricity consuming countries over the period 1965 to 2012.This was achieved by undertaking the analysis within a bivariate framework involving real GDP per capita and hydroelectricity consumption per capita. We first checked for cross-sectional dependence in each of the variables in the panel before checking for panel unit root. Having detected evidence of cross-sectional dependence, we used two second-generation panel unit root tests to determine the degree of integration in the respective variables. The results provided supportive evidence for the presence of a unit root acrossboth variables under investigation.

Having detected panel unit roots in the series, we then employed the fully modified OLS (FMOLS) approach for heterogeneous cointegrated panels. The results displayed that real GDP per capita had a positive and statistically significant impact on hydroelectricity energy consumption per capita with an elasticity of 0.526. Finally, we estimated a non-linear panel smooth transition vector error correction model. For the pre-1988 period, there was evidence of unidirectional causality running from real GDP per capita to hydroelectricity per capita in both the short- and the long-run. Over the post-1988 period, there was evidence of bidirectional causality between hydroelectricity energy consumption per capita and real GDP per capita in both the short- and the long-run. The results with respect to the two remaining breaks, i.e. 2000 and 2009, not only provided supportive evidence for the presence of bidirectional causality between hydroelectricity energy consumption and economic growth, but also they looked stronger, indicating the increasing role of hydroelectricity energy sources to sustain economic production, and therefore, economic growth.

The main policy implications from our study can be presented as follows. First, the presence of bidirectional causality in the post 1988 period provides support for the feedback hypothesis whereby hydroelectricity consumption and economic growth are interdependent. Within the panel of countries examined, the interdependence between hydroelectricity consumption and economic growth suggests that energy policies designed to increase the production and consumption of hydroelectricity will have a positive impact on economic growth, all other things being equal. Policy makers should therefore encourage efforts to promote hydroelectricity production and consumption in these countries. They must introduce appropriate incentive mechanisms for the development and market accessibility of hydroelectricity. Such incentives could include hydroelectricity production tax rebates and or subsidies; Rebates for the installation of hydro energy systems. Such developments compete with fossil fuel based energy sources and will curtail the long-run environmental degradation associated with carbon emissions.

Finally, potential venues for future research will be to expand the empirical analysis to include a larger number of countries, regardless of their current hydroelectricity energy consumption levels. In case similar results are obtained, even similar to those over the first-regime period, that could be a motivation for them to keep investing and using hydroelectricity consumption that will boost their economic growth, unless of course, geographic reason are preventing them from doing so.

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