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Short- and long-run causality between energy consumption and economic growth: Evidence across regions in China

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HIGHLIGHTS

- We investigate the relationship between energy and economic growth across Chinese regions.
- We examine short- and long-run causality.
- We use panel cointegration techniques.
- We find that causality runs in the long-run from economic growth to energy consumption from 1999 to 2009.
- We conclude that policies for conserving energy can be adopted without interrupting the path of growth.

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ABSTRACT

The relationship between energy consumption and economic growth has created a large body of research in the energy-economics literature. In this paper, we investigate such a relation in the case of Chinese regions from 1995 to 2009. The majority of previous studies have ignored the regional dimension and the cross-sectional dependence of provinces. Besides, different energy policies adopted by the government have influenced energy intensity over time, showing improvement in the 1990s and deterioration from 2000 onwards. Thus, it is necessary to examine these two periods separately. Moreover, a detailed disaggregation of total energy consumption into electricity, coal, coke, and crude oil consumption and its linkage with economic growth may provide new insights for the design of energy policy across Chinese regions. We use panel techniques to test the direction of the causality in the long- and short-run between these different types of energy consumption and economic growth. Our results are mixed from 1995 to 2009 due the aforementioned break around 1999. However, in all cases our estimations provide empirical evidence that from 1999 to 2009 there is unidirectional causation from economic growth to energy consumption in the long-run. Therefore, energy-saving policies can be adopted without interrupting the path of growth.

1. Introduction

The reduction of greenhouse gas emissions is one of the most important concerns across countries. However, there is little consensus among developed economies on the way to meet international commitments until developing countries such as India and China commit themselves to alleviate climate change [1]. This is relevant due to the rising importance of these countries in the contribution to global warming given their fast economic growth and increasing demand for energy resources. As is well-known one way to reduce emissions is to cut energy consumption. However, in the case of developing countries this aim is conditioned by economic development. Often these economies face the dilemma of promoting energy-saving measures at the expense of economic growth. Thus, an essential empirical investigation is whether energy consumption is a consequence or a cause of economic growth. Conclusions of such analysis are relevant not only for the design of energy policies to mitigate global warming, but also to link these policies with economic development and the welfare of the whole population. In addition, investigating the direction of the causality between energy consumption and economic growth may help to clarify the economic model that prevails in this relationship. In other words, whether energy consumption is seen as an input – and in this case, energy influences economic growth – and therefore a production model is supported by the data, or by contrast

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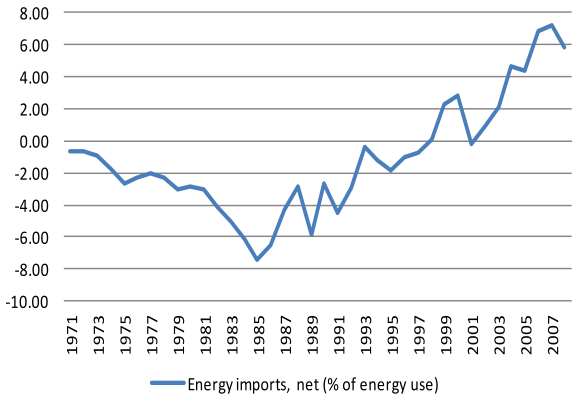

Fig. 1. Energy imports, China. *Source*: World Bank and own elaboration.

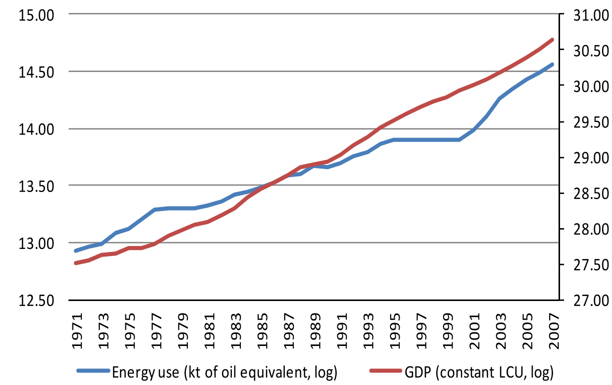

Fig. 2. Energy use (right) and GDP (left). *Source*: World Bank and own elaboration.

is considered a good – and economic growth causes energy consumption following a demand model.

Among developing countries, China is probably one of the most interesting cases for several reasons. First, the Chinese economy has undergone an exceptional performance over the past three decades switching from a central planned to a more market-oriented economy. Besides, by the year 2009 this country became the most important consumer and producer of energy in the world overtaking the United States. However, even the largest power producer, China, was pursed to participate in the international market to import energy from the mid-1990s onwards as seen in Fig. 1. Given its sheer size, any domestic shock not only affects its economy, but also international markets. The Chinese government, aware of how essential is energy consumption for its economy and of its role in generating environmental damage, established in the mid-nineties a series of measures to cut energy consumption. As shown in Fig. 2, energy consumption remained steady between 1995 and 2000, leading to physical shortages of electricity in the first half of the 2000s [2].[1] Energy consumption increased rapidly thereafter. The current trend of China in terms of increasing energy consumption and carbon dioxide emissions, growing on average around 10% per year, makes necessary corrective actions to protect the environment. The Eleventh Five-year plan aimed at achieving energy and environmental goals, but such targets were not met.

Analyzing the economy as a whole may provide interesting insights on the current debate concerning the relationship between energy consumption and economic growth. However, this economy has singular characteristics that makes imperative to investigate that nexus across regions. First, preferential policies have encouraged economic growth in coastal areas at the expense of the central and western ones, creating a significant unbalanced growth with a high degree of inequalities.[2]

In addition, energy resources are unevenly distributed across the vast territory. Coal, the most important source of energy, is mainly produced in Shanxi and Inner Mongolia, while the generation of electricity is located in the South, Sichuan and its neighbors, and crude oil is mainly concentrated in the North-Western provinces. This dispersion of energy resources forced the government to put as first priority the guarantee of energy supply to meet a growing demand for energy, especially in the Eastern regions that require large amounts of energy linked to economic growth. In a second stage, the increasing level of pollution in both producing and consuming regions and the growing demand for energy have revealed that active environmental policies also need to be implemented. Thus, the agglomeration of economic activities around the coast and the unbalanced growth between regions with this marked heterogeneity justify the need to analyze the causal relationship between energy consumption and growth at the regional level. Although we do not have enough time series observations to study each region individually or to break up our regional panel in sub panels, we use panel techniques, which allow as much heterogeneity as possible. Longer time series would be necessary to establish the target of regional energy conservation for environment protection or promotion of regional development.

To the best of our knowledge the majority of previous works examine the causal relationship at the national level, generating biases through aggregation and yielding contradictory results ([7,8]). Only a few studies investigate this issue across Chinese regions following [9]s lead work. Thus, over the 1985–2008 period [10] find bidirectional causality between coal consumption and GDP growth, while, by using panel cointegration techniques, [11] document a bidirectional causal relationship between energy consumption and economic growth from 1995 to 2007, and [12] apply short-run panel causality tests to study the relationship between energy consumption and GDP over the 1986–2008 period. This paper is based on the same approach but differs from the previous ones in many significant ways.

First, we use panel cointegration techniques to study the Chinese regions. We consider that this methodology is appropriate since as pointed out by [13] short-time spans will weaken the power of unit root, cointegration and causality tests in time series data, thereby giving rise to distorted and mixed results. The use of panel data with a higher number of observations may overcome this problem, see [14]. Besides, previous work assumes that cross-sectional units are independently distributed. This assumption is rather restrictive and is likely to be violated for the GDP variable in regional panels. Following [15,16], we relax this hypothesis by the introduction of the cross-sectional dependence across different regions in China, when unit root and cointegration tests are carried out respectively. This provides more reliable tests on the nature of the relationship between energy consumption and economic growth.

Second, we follow Canning and Pedroni's approach [17] to test for long-run causation in a cointegrated panel framework. Their test gives information about the incidence of a long-run effect rather than just about whether there is at least one such long-run causality in at least one region. It also allows for heterogeneity of the dynamic models for all the regions in the sample. This is important since, as pointed out in the introduction, the regions included in our study are very diverse. Furthermore, we estimate the long-run elasticities using group-mean Panel Dynamic Ordinary Least Squares (Panel DOLS) proposed by [18].

Third, we test the short-run causality in the panel following [19], which takes into account the heterogeneity of the causal relationships and the heterogeneity of the data generating process.

[1] See [3,4].
[2] See [5,6].

Table 1
Panel unit root tests, sample period 1995–2009 *p*-values.

Levels	With constant and trend					
	Total energy	Electricity	Coal	Crude oil	Coke	PC-GDP
IPS-ADF	0.11	0.40	0.38	0.36	0.99	1.00
Maddala and Wu						
ADF version	0.05	0.05	0.08	0.36	0.99	0.84
PP version	0.06	0.06	0.08	0.38	0.99	0.84
Pesaran (2007)						
CIPS	0.09	0.17	0.01	0.97	0.16	0.70
CIPS*	0.09	0.17	0.09	0.97	0.16	0.80
Choi (2006)						
Pm	0.63	0.33	0.33	0.95	0.97	0.11
Inv. Normal(Z)	0.20	0.04	0.13	0.90	0.77	0.01
Logit (L*)	0.22	0.05	0.17	0.94	0.75	0.02
1st Difference$^{(5)}$	With constant					
IPS-ADF	0.00	0.00	0.00	0.00	0.00	0.003
Maddala and Wu						
ADF version	0.00	0.00	0.00	0.00	0.00	0.01
PP version	0.00	0.00	0.00	0.00	0.00	0.01
Pesaran (2007)						
CIPS	0.01	0.01	0.01	0.02	0.01	0.02
CIPS*	0.01	0.01	0.01	0.02	0.01	0.02
Choi (2006)						
Pm	0.00	0.00	0.00	0.00	0.00	0.00
Inv. Normal(Z)	0.00	0.00	0.00	0.00	0.00	0.00
Logit (L*)	0.00	0.00	0.00	0.00	0.00	0.00

Note: (1) Energy variables and PC-GDP are per capita.
(2) A maximum of two lags were included.

Fourth, we consider not only total energy consumption, but also electricity, coke, coal and crude oil, which may provide new insights on the nature of the relationship between different types of energy and economic development. Besides, given the aforementioned trends between the 1990s and 2000s, we examine both the full sample and a recent subsample (1995–2009 and 1999–2009) to test long-and short-run causality across the regions. We use data sourced from the National Bureau of Statistics of China (NBS), therefore our sample starts in 1995 and not in 1986 as some other studies do ([12,10]).

Our results are mixed from 1995 to 2009 due the break around 1999. However, unlike [11], in all cases our estimations provide empirical evidence that from 1999 to 2009 there is unidirectional causation from economic growth to energy consumption in the long-run. Therefore, energy-saving policies can be adopted without interrupting the path of growth. In addition, our findings also suggest that, in the short-run, there is bidirectional causality between total energy, electricity and coal to per capita GDP (PC-GDP), and unidirectional causality from PC-GDP to oil and coke for the full sample period, and that there is Granger causality from PC-GDP to energy, electricity, coal, oil and coke in the short-run in the later sub-period. There is also some evidence of feedback between electricity and PC-GDP.

The paper is organized as follows. In Section 2, we present a review of the literature. Section 3 covers data and methodological issues. In Section 4, we report the empirical results. We discuss our conclusions in Section 5.

2. Survey of the literature

The role of energy in economic growth has long been a controversial topic in the economics literature. On the one hand, economic theory provides few arguments on the mechanisms that determine the nature of the relationship between energy consumption and growth, [20]. On the other hand, although [21] finds a strong correlation between electricity usage and the level of economic development and growth, such correlation does not necessarily imply a causal relationship. Thus, to assess the effect of energy conservation policies on economic growth, the direction of the causality between these two variables is usually tested empirically.[3] This topic is the core of the ongoing debate due to its significant policy implications for governments in the design of energy and environmental policies and its linkage with economic development [23].

Kraft and Kraft in 1978, in their pioneering work [24], investigate the relationship between energy consumption and growth in the United States over the period 1947–1974. Their findings suggest a unidirectional long-run relationship running from growth to energy consumption. Following this initial framework, researchers have extended the analysis to other developed and developing countries using different methodological approaches, creating a significant amount of empirical evidence, yet with conflicting results on the role of energy in economic development.[4] Thus, since the direction of the causality between these two variables is undetermined a priori, a better understanding of whether energy consumption causes growth or vice versa, there is a feedback relationship or the absence of causality, represents an interesting and open question to be investigated.

Previous empirical evidence in the literature[5] relies on one of the following four different scenarios: (a) economic growth Granger-causes energy consumption, (b) energy consumption Granger-causes economic growth, (c) bi-directional causality between energy consumption and growth and (d) absence of causality; in turn each scenario provides insights helping to choose among different energy policies.

The first view – unidirectional Granger causality running from GDP to energy consumption – implies that energy conservation policies designed to cut energy consumption, and in turn to protect the

[3] See a recent survey on this issue in [8,22].
[4] These conflicting results may arise due to the different data sets, different countries' characteristics and different econometric methodologies used. See [25].
[5] See [26–30].

Table 2
Panel cointegration tests: PC-GDP independent variable.[d]

	Total energy	Electricity	Coal	Oil[c]	Coke
1995–2009					
Pedroni[a]					
Panel v-stat	−0.69	0.47	−1.21	−0.74	−0.53
Panel rho-stat	0.27	0.40	0.55	−1.32	0.63
Panel pp-stat	−3.46*	−3.50*	−3.00*	−6.53*	−3.10*
Panel adf-stat	−4.20*	−2.97*	−4.74*	−6.19*	−3.86*
Group rho-stat	2.16	2.46	2.61	1.36	2.62
Group pp-stat	−2.96*	−3.00*	−1.98*	−4.64*	−2.42*
Group adf-stat	−4.13*	−2.99*	−4.73*	−4.18*	−3.60*
Westerlund[b]					
Bootstrap p-value	0.89	0.92	0.98	0.08	0.96
1999–2009					
Pedroni[a]					
Panel v-stat	0.91	1.48	−0.89	−0.29	−0.45
Panel rho-stat	−0.58	−0.03	0.35	−1.13	0.74
Panel pp-stat	−8.14*	−6.41*	−6.55*	−10.88*	−5.13*
Panel adf-stat	−7.75*	−6.62*	−8.31*	−8.64*	−4.97*
Group rho-stat	1.88	2.13	2.44	1.18	2.68
Group pp-stat	−7.44*	−5.97*	−6.67*	−12.09*	−5.02*
Group adf-stat	−7.22*	−6.25*	−7.73*	−9.18*	−6.10*
Westerlund[b]					
Bootstrap *p*-value	0.92	0.98	0.79	0.45	0.93

[a] 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. Common time dummies and a trend were included in the cointegrating regression.
[b] For the Westerlund and Edgerton (2007) test the null is cointegration. A constant was included in the cointegrating regression, except for oil where a constant and a trend were included.
[c] Only 24 provinces were included for the cointegration tests with oil due to missing observations for three provinces.
[d] Energy variables and PC-GDP are per capita.

environment, will have little or no effect on economic growth. Studies falling into this subset of evidence include works like [31–37] which use time-series analysis, while panel cointegration techniques are used by [14,38,39]. In the case of China, researchers have mainly addressed this question at the national level. Ref. [40] find that economic growth causes energy consumption from 1960 to 2007 by using cointegration techniques in time series analysis.

By contrast, if the causality runs from energy to economic growth it can be indicative that energy conservation policies may have a detrimental effect on economic development. Besides, such causality implies that the economy is energy-dependent, and in consequence any adverse shock can alter the path of economic growth and can constrain any effort to reduce greenhouse gas emissions. Among the empirical evidence within the time series analysis that find this relationship, it is worth mentioning works like [41–47]. Works using panel cointegration include [26,28,29,48–52]. In the case of China, [11,53,54] find that the direction of causality runs from total energy consumption to economic growth. Similar findings are observed in [55] for oil consumption, [56] for electricity consumption and [57] for coal consumption.

The feedback hypothesis corresponds to bi-directional causality between energy consumption and economic growth. Such a feedback can imply that energy-saving policies may not have adverse effects on economic growth. Works that conduct the research under a time series framework are: [23,35,44,58–66]. Research using panel cointegration techniques includes [27,28,39,67]. In the case of China, [68,69] find bi-directional causality between energy consumption and growth for the economy as a whole and [70] across the Chinese regions from 1995 to 2007. [12,70] find bi-directional causality between the same variables for some provinces and not others.

Finally, the neutrality hypothesis indicates that energy conservation programs do not have any effect on economic growth. General evidence supporting this last view is provided with time-series analysis by [31,38,71–77], and with panel cointegration techniques only by [25]. In the Chinese case, Ref. [56] find that total energy consumption and coal consumption do not have any effect on economic development in China.

The variety of the results on the causal relationship between energy consumption and economic growth often depends on the variables included, the statistical methods applied, the sample of countries or regions and the period considered. Thus, in this paper we attempt to provide fresh empirical evidence on this relationship by using recent econometric methods such as panel cointegration, allowing for cross-sectional dependence and, most importantly, heterogeneity in the case of Chinese regions from 1995 to 2009 and from 1999 to 2009, due the aforementioned break.

3. Methodology

We analyze the causal relationship between energy consumption and economic development across 27 Chinese regions from 1995 to 2009.[6] In doing this, we disaggregate total per capita energy consumption into coal, coke, electricity, and crude oil, and then investigate the causal relations between these different sources of energy and real per capita provincial GDP in the long- and short-run by pooling cross-section and time series data.[7] In light of the existence of a break around 1999, we also examine the sub-period

[6] The 27 regions include three municipalities, Beijing, Shanghai, Tianjin, and 24 provinces, Anhui, Fujian, Gansu, Guangdong, Guangxi, Guizhou, Hebei, Heilongjiang, Henan, Hubei, Hunan, Inner Mongolia, Jiangsu, Jiangxi, Jilin, Liaoning, Qinghai, Shaanxi, Shandong, Shanxi, Sichuan, Xinjiang, Yunnan and Zhejiang.

[7] We use regional deflators and the base year is 2000. Energy consumption is measured in SCE millions of tons, coal and crude oil in millions of tons, and electricity in billions KWH. We took the original data published in the National Bureau of statistics of China.

Table 3
Causality tests: Summary (Y indicates rejection of non-causality at 5% level or less).

Variable causality (From → To)	Short-run causality 1st diff	Short-run causality levels	Long-run causality group mean t test	Long-run causality Lambda–Pearson test
1995–2009				
Total energy → PC-GDP	Y	Y	N	N
Electricity → PC-GDP	Y	Y	N	Y
Coal → PC-GDP	Y	Y	N	N
Oil → PC-GDP	N	N	N	N
Coke → PC-GDP	N	N	N	Y
PC-GDP → total energy	N	Y	Y	Y
PC-GDP → electricity	Y	Y	Y	Y
PC-GDP → coal	N	Y	Y	Y
PC-GDP → oil	N	Y	Y	Y
PC-GDP → coke	N	Y	Y	Y
1999–2009				
Total energy → PC-GDP	N	N	N	N
Electricity → PC-GDP	N	Y	N	N
Coal → PC-GDP	N	N	N	N
Oil → PC-GDP	N	N	N	N
Coke → PC-GDP	N	N	N	N
PC-GDP → total energy	N	Y	Y	Y
PC-GDP → electricity	N	Y	N	Y
PC-GDP → coal	N	Y	Y	Y
PC-GDP → oil	N	Y	Y	Y
PC-GDP → coke	N	Y	Y	Y

Note: Energy variables and PC-GDP are per capita.

1999–2009.[8] The annual data come from the National Bureau of Statistics of China.

Before we carry out causality and cointegration tests between the variables of interest, we perform unit root tests. We use panel techniques which allow for cross-section dependence among the regions. We also test for short-run and long-run bivariate causality between per capita GDP and the energy variables. We test the relationships between per capita GDP and the energy variables allowing for heterogeneity of the dynamic models for all the regions in the sample. Because the time series dimension of our panel is small (15 observations for the full sample and 11 for the sub-sample) we use only panel causality tests.

Refs. [19,78] introduce short-run causality tests within a stationary VAR framework with fixed coefficients. Ref. [19] proposes a simple test of the Homogeneous Non Causality (HNC) hypothesis against an alternative of Heterogeneous Non Causality (HENC). In this context the VAR models for the different regions are allowed to have a distinct lag structure as well as heterogeneous unconstrained coefficients under both the null and the alternative. The null is no causality in any region against the alternative of causality for some non-negligible fraction of the regions.

To study long-run causality allowing for panel heterogeneity, we use tests developed by [17]. Their test is a test of the null of no long-run causality in any region against the alternative of long-run causality for some non-negligible fraction of the regions instead of the usual alternative of long-run causality present in at least one of the regions.

Finally, we estimate the long-run elasticities using the group-mean Panel Dynamic Ordinary Least Squares (Panel DOLS) proposed by [18].

3.1. Panel unit root and cointegration tests

3.1.1. Panel unit root tests

We present four panel unit root tests: the Im, Pesaran and Shin (IPS), Maddala and Wu, Pesaran and Choi tests ([15,79–81]). In the presence of cross-section dependence panel unit root tests suffer from severe size distortion (see for example [82]). This is likely to be a problem for the GDP variable. Whereas the first two tests assume independence, the last two do not and should therefore be more reliable.

The IPS test used in this study is the adjusted average of the Augmented Dickey Fuller (ADF) individual unit root test statistics. The null is that each series in the panel has a unit root against the alternative that for a 'significant' fraction of the regions the series are stationary.

The test suggested in [80] combines the p-values from unit root tests for each region i:

$$P = -2\sum_{i=1}^{N} \ln p_i \tag{1}$$

P has a χ^2 distribution with $2N$ degrees of freedom as $T_i \to \infty$ for finite N, where N is the number of regions and T_i is the number of time series observations for each region.

The unit root tests in [81] can be applied to cross-sectionally correlated panels. They are derived by combining p-values from Dickey–Fuller-GLS tests computed for each region after removal of deterministic trends and cross-sectional correlations. They have a standard normal asymptotic distribution.

Ref. [15] assumes that the cross-section dependence is due to a common factor and shows that this factor can be proxied by lagged values of the cross-section mean of the series and its first difference. The first test, constructed from the averages of the individual IPS ADF statistics, is called a cross-sectionally augmented IPS test or CIPS test. The second test, a truncated version of the CIPS test, is recommended for small T (CIPS*).

3.1.2. Panel cointegration tests

The tests applied in this paper were developed by [16,83–85]. They are robust to bi-directional causality and allow for both heterogeneous cointegrating vectors and short-run dynamics.

First, we use Pedroni's tests [84] based on the following model:

$$y_{it} = \alpha_i + \delta_i t + \beta_{1i} x_{1it} + \ldots + \beta_{Ki} x_{Kit} + e_{it} \tag{2}$$

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

[8] Another reason is that there was a methodological change in the Census of Population in 2000.

If the error term in (2) is stationary then the dependent variable is cointegrated with the explanatory variables with a unit coefficient (assuming that they all have a unit root). To test the stationarity of the error term [84,85] propose seven tests using common time dummies to handle cross section dependence. The null hypothesis is of no cointegration for all regions. The pooled tests are specified against the homogeneous alternative that the first order autocorrelation coefficient of the residuals is the same for all the cross section units and less than one. The group-mean tests, based on cross-sectional averages of individual estimates of the first order autocorrelation coefficient of the residuals, are specified against the heterogeneous alternative.

We reject the null of no cointegration with the group-mean tests if we have cointegration for a significant fraction of the cross-section units. This is not the case for the pooled tests but those are restrictive since they assume homogeneity under the alternative (and the null of course).

Ref. [86] evaluate the performance of panel cointegration tests. They conclude that the two tests applying the ADF principle perform best, whereas all other tests are severely undersized and have low power when $T \leqslant 25$.

In addition to Pedroni's tests, we use Westerlund and Edgerton's tests [16]. These authors propose a bootstrap panel cointegration test of the null hypothesis of cointegration in panel data. Their test is based on the Lagrange multiplier test of [87], but allows dependence both within and between the individual cross-section units. They show through simulations that bootstrap techniques using the sieve approach improve the performance of the McCoskey and Kao test in small samples.

3.2. Short- and long-run causality

In what follows we assume that x and y are two covariance stationary processes generated by a VAR model:

$$y_{it} = \alpha_i + \sum_{k=1}^{p} \gamma_i^{(k)} y_{it-k} + \sum_{k=1}^{p} \beta_i^{(k)} x_{it-k} + \varepsilon_{it} \tag{3}$$

The individual effects α_i are fixed, and starting values for y_{it} and x_{it} are observed. $\gamma_i^{(k)}$ and $\beta_i^{(k)}$ may differ across regions. For each region the error terms ε_{it} are assumed to be $i.i.d.(0, \sigma_i^2)$ and independently distributed across regions.

Ref. [19] proposes a test for HNC between x and y:

$$H_0 : \beta_i = 0 \quad \forall\ i = 1, \ldots, N \tag{4}$$

where $\beta_i = (\beta_i^{(1)}, \ldots, \beta_i^{(p)})'$. Under the alternative hypothesis, there is causality from x to y for at least one region:

$$H_1 : \beta_i = 0 \quad \forall i = 1, \ldots, N_1 \quad \beta_i \neq 0 \quad \forall i = N_1 + 1, N_1 + 2, \ldots, N \tag{5}$$

where N_1 is unknown and $N_1 < N$.

Their test for Granger non causality is similar to the IPS unit root test. The Wald statistics to test for Granger non causality are calculated for each region. The panel statistic is then derived as the cross-sectional average of the individual Wald statistics. Ref. [19] shows that this statistic converges to a normal distribution under the HNC hypothesis, when T tends to infinity first and then N tends to infinity. A standardized statistic, $Z_{N,T}^{HNC}$, can also be constructed.

The VAR model in (3) has heterogeneous unconstrained coefficients under both the null and the alternative. Therefore, if the null of HNC is rejected, the causal relationships are allowed to be heterogeneous across regions.[9] This is a very important feature of the test in our context since we can expect heterogeneity across regions. [19] examines the small sample properties of their test statistics and conclude that the power of their test substantially exceeds that of time series Granger causality tests for small values of T even in the presence of cross-section dependence (for example around 10).

Since the test in [19] requires stationarity of the x and y processes, for the variables found to have a unit root we apply the test after first differencing the series. For cointegrated $I(1)$ variables we use the approach proposed by [17] to test for long-run causality.[10]

If y and x are cointegrated, Ref. [90] shows that there exists an Error Correction Model (ECM) relating those two series. We estimate the error correction model for each region in two steps. We first estimate the long-run cointegrating relationship between y and x using Fully Modified Ordinary Least Squares (FMOLS) and obtain the error correction term, $\hat{e}_{it}$. Second, we estimate the ECM:

$$\begin{aligned} \Delta y_{it} &= c_{1i} + \lambda_{1i}\hat{e}_{it-1} + \sum_{j=1}^{p}\gamma_{11ij}\Delta(y_{it-j}) + \sum_{j=1}^{p}\gamma_{12ij}\Delta x_{it-j} + \varepsilon_{1it}\Delta x_{it} \\ &= c_{2i} + \lambda_{2i}\hat{e}_{it-1} + \sum_{j=1}^{p}\gamma_{21ij}\Delta(y_{it-j}) + \sum_{j=1}^{p}\gamma_{22ij}\Delta x_{it-j} + \varepsilon_{2it} \end{aligned} \tag{6}$$

for each region i, where ε_{1it} and ε_{2it} are the disturbance terms. Ref. [90] shows that if y and x are cointegrated at least one of the adjustment coefficients λ_{1i}, λ_{2i} must be significantly different from zero. Replacing the error correction term with its estimate does not affect the asymptotic properties of the estimators in (6) due to the super-consistency of the estimates for the cointegrating relationship. To test the null hypothesis that there is no long-run causation from x to y (or from y on x) we use a group mean test computed as: $\bar{t}_{\lambda_s} = \frac{\sum_{i=1}^{N} t_{\lambda_{si}}}{N}$ where $t_{\lambda_{si}}$ is the individual region t-test on λ_{si}, for $s = 1, 2$. This test statistic has an asymptotic normal distribution under the null of no long-run causal effect. We also compute the accumulated marginal significance associated with the t-tests. This lambda–Pearson statistic is equal to $P_{\lambda_s} = -2\sum_{i=1}^{N} \ln p_{\lambda_{si}}$ where $\ln p_{\lambda_{si}}$ is the log of the p-value of the ith province t-test. The P_{λ_s} statistic is distributed as a χ^2 with $2N$ degrees of freedom under the null of no long-run causation for the panel. The null and alternative hypotheses for the two tests are the same under the assumption that the λ_{si} coefficients are homogenous across regions, explicitly that $\lambda_{si} = 0$ for all regions under the null, and that $\lambda_{si} \neq 0$, for some non-negligible portion of the regions under the alternative.[11] The lambda–Pearson test is a useful complement to the group mean t-test particularly when the λ_{si} parameters are heterogenous. For example, if the t-ratios are negative and significant for some of the regions and positive and significant for some others, it is possible that the average t is insignificant. The lambda–Pearson test would turn out to reject the null in that case.

Finally, given the small time series dimension of our panel we complement these tests with the between-dimension, group-mean Panel DOLS estimates proposed by [18]. Ref. [86] compares the performance of a number of panel cointegration estimators. They find that in the case of a single cointegrating relationship the DOLS estimator outperforms all other estimators. The DOLS estimator is also found to be the least sensitive to cross-section dependence and cross-unit cointegration.

[9] In contrast, [88] test the same null hypothesis but set their alternative as homogeneous causality.

[10] In the case of cointegrated $I(1)$ time series processes, tests for Granger causality can be applied by estimating an augmented VAR for the variables in level ([89]). There does not exist, at this point in time, a generalization of this result for a panel VAR model.

[11] Many studies test a null of no causality for all regions against an alternative of long-run causality present in at least one of the regions using a likelihood ratio test or a Wald test. Such tests are much stricter than the group mean t-test and therefore would reject the null more often.

Table 4
Causality tests[a,c] (*p*-values in brackets).

Variable causality (From → To)	Short-run causality 1st diff[b]	Short-run causality levels[b]	Long-run causality group mean *t* test	Long-run causality Lambda–Pearson test
1995–2009				
Total energy → PC-GDP	2.29**	3.30**	−0.07	56.84
	(0.02)	(0.01)	(0.95)	(0.37)
Electricity → PC-GDP	2.08**	5.01**	0.02	77.58**
	(0.03)	(0.00)	(0.98)	(0.02)
Coal → PC-GDP	2.48**	3.77**	−0.45	61.86
	(0.01)	(0.00)	(0.65)	(0.22)
Oil → PC-GDP	−0.65	0.3	−0.13	54.02
	(0.51)	(0.76)	(0.9)	(0.26)
Coke → PC-GDP	1.64*	0.7	−0.73	81.40**
	(0.1)	(0.49)	(0.46)	(0.00)
PC-GDP → total energy	−0.72	11.22**	−2.20**	171.58**
	(0.47)	(0.00)	(0.03)	(0.00)
PC-GDP → electricity	2.42**	7.90**	−1.94**	150.36**
	(0.01)	(0.00)	(0.05)	(0.00)
PC-GDP → Coal	−1	7.76**	−2.55**	196.14**
	(0.32)	(0.00)	(0.01)	(0.00)
PC-GDP → Oil	−1.07	7.85**	−2.34**	157.31**
	(0.29)	(0.00)	(0.02)	(0.00)
PC-GDP → Coke	1.85**	12.26**	−2.14**	158.31**
	(0.06)	(0.00)	(0.03)	(0.00)
1999–2009				
Total energy → PC-GDP	0.01	1.74*	−0.1	52.35
	(0.99)	(0.08)	(0.92)	(0.54)
Electricity → PC-GDP	0.05	2.27**	−0.06	70.65*
	(0.96)	(0.02)	(0.95)	(0.06)
Coal → PC-GDP	0.57	0.8	−0.52	47.43
	(0.57)	(0.42)	(0.61)	(0.72)
Oil → PC-GDP	−0.48	0.4	−0.23	51.1
	(0.63)	(0.69)	(0.82)	(0.35)
Coke → PC-GDP	−0.01	0.22	−0.8	67.54
	(0.99)	(0.83)	(0.42)	(0.1)
PC-GDP → total energy	1.38	2.15**	−2.03**	147.67**
PC-GDP → electricity	(0.16)	(0.03)	(0.04)	(0.00)
	0.87	6.09**	−1.4	102.75**
	(0.38)	(0.00)	(0.16)	(0.00)
PC-GDP → coal	−1.03	3.34**	−2.44**	166.56**
	(0.3)	(0.00)	(0.01)	(0.00)
PC-GDP → oil	−0.67	4.57**	−2.25**	135.90**
	(0.5)	(0.00)	(0.02)	(0.00)
PC-GDP → coke	0.08	9.45**	−2.25**	152.47**
	(0.93)	(0.00)	(0.02)	(0.00)

[a] *Rejects the null of homogeneous non causality at 10% level. **Rejects the null of homogeneous non causality at 5% level.
[b] For all tests one lag was used. All tests statistics are asymptotically distributed as $N(0,1)$. The Z test is a two-sided test.
[c] Energy variables and PC-GDP are per capita.

4. Results

4.1. Unit root tests and cointegration

The panel unit root tests are displayed in Table 1. The panel unit root test results provide strong evidence that the energy series and GDP per capita series have a unit root. The only exceptions are the Maddala–Wu tests which reject the null of a unit root for total energy and electricity. When we perform the tests in first differences, our results indicate that the hypothesis of unit root is rejected. We can therefore conclude that the variables are $I(1)$.

The [16,84,85] panel cointegration test statistics are displayed in Table 2. The tests are performed with the dependent variable chosen to be one of the energy-related consumption variables. When evaluating the results it will be useful to recall that for small 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. For the full and sub sample periods and all energy variables we reject the null of no cointegration at the 5% level with the group and panel-ADF tests and the group and panel Phillips and Perron tests. With the LM test we do reject cointegration for oil for the full sample period at the 10% level but not at 5%, for the sub-period we do not reject cointegration with the LM test for all pairs.

4.2. Short- and long-run causality

We report in Tables 3 and 4 Dumitrescu and Hurlin's short-run causality tests applied to the first differences and the levels of our variables. We should be aware, however, that for $I(1)$ variables those tests are only valid when applied to the first differences. For the full sample of regions, we reject the null of HNC from PC-GDP to the five energy variables if we use the data in level. We find feedback from total energy, electricity and coal for the full sample, but only from electricity for the 1999–2009 period. The electricity–growth feedback over 1999–2009 can be explained by power shortages in China over that period. Shortages were due to insufficient physical capacity in the first half of the 2000s, fully made good by subsequent large-scale investment in new power plants. However since then, and especially in 2008, renewed power

Table 5
Comparison of causality tests results with other relevant studies for China.

Authors	Period	Method	Geographical coverage	Conclusion
Our study	1995–2009	Panel cointegration, VAR	Regional	GDP → E, coal, oil; long-run GDP ↔ electricity, coke; long-run GDP → oil, coke; short-run GDP ↔ E, electricity, coal; short-run
	1999–2009	Panel cointegration, VAR	Regional	GDP → E, electricity, coal, oil, coke; long-run GDP → E, coal, oil, coke; short-run GDP ↔ electricity; short-run
[11]	1972–2006	ARDL method	National	E → GDP; short and long-run
[10]	1985–2008	Panel cointegration without break	Regional	Coa l ↔ GDP; long-run, for Coastal and Central regions GDP → Coal; long-run, for Western regions Coal ↔ GDP; short-run, full panel
[12]	1986–2008	Panel cointegration without break	Regional	E ↔ GDP; short-run, only for some provinces
[40]	1960–2007	Cointegration time series	National	GDP → E; long-run
[53]	1971–2000	Cointegration time series	National	Electricity → GDP; short and long-run
[54]	1985–2007	Panel cointegration without break	Regional	E → GDP; long-run (DOLS estimates)
[55]	1953–2002	Cointegration time series	National	Oil → GDP; short and long-run
[56]	1963–2005	Cointegration time series	National	Electricity, Oil → GDP; short-run GDP → E, coal, oil; short-run
[57]	1977–2008	Cointegration time series	National	Coal → GDP, short- and long-run
[68]	1978–2000	Cointegration time series	National	E ↔ GDP; short-run
[69]	1995–2008	Panel cointegration without break	Regional	E ↔ GDP; short- and long-run
[70]	1995–2007	Panel cointegration without break	Regional	E ↔ GDP; short- and long-run

E → GDP denotes causality running from energy consumption to GDP. GDP → E denotes causality running from GDP to energy consumption. E ↔ GDP denotes bi-directional causality between GDP and energy consumption. The notation is identical for electricity, coal, oil, and coke.

Table 6
Panel DOLS estimates (*t*-statistics are in brackets).

	Explanatory variable: PC-GDP	
	1995–2009	1999–2009
Dependent variable	Long-run elasticity	Long-run elasticity
Total energy	0.64	0.65
	[111.09]	[234.39]
Electricity	0.9	0.87
	[196.48]	[438.24]
Coal	0.55	0.68
	[81.59]	[150.98]
Oil	0.59	0.51
	[51.85]	[75.06]
Coke	0.88	1.06
	[41.29]	[114.02]

Notes: For the 1999–2009 one lag was used in the Panel DOLS estimation due to the small sample size. In the full sample period using one or two lags made no difference. Energy variables and PC-GDP are per capita.

shortage has been due to a highly regulated energy pricing system. Price-caps for coal used by the power sector have negatively affected coal supply to that sector [91], and price-ceilings for electricity supply have often led to the suspension of power plant operation (see [2] for an overview). Power-grid insufficient interconnectivity may be yet another factor behind power shortages.

Applying the causality tests to the first differences we find no causality in either direction on the sub-period. For the full sample period, we find causality going from total energy, electricity and coal to PC-GDP, and from PC-GDP to electricity and coke.

The results for the long-run causality tests are presented in Tables 3 and 4. Using the group mean *t*-test we find that for both sample periods long-run causality runs from per capita GDP to the energy variables for total energy, coal, oil and coke. For electricity this test does not reject no causality from GDP to electricity in the sub-period.

We find causality running from GDP to all five energy variables with the Lambda–Pearson test for both the full sample and the sub-period. There is, however, also feedback from coke and electricity to GDP in the full sample period but not in the sub-period (if a 10% significance level is considered there is also feedback in the sub-period).

Table 5 summarizes the results of panel short-run and long-run causality tests in our study and compares them with other studies using Chinese data. In the short-run and using the full sample, we find bidirectional causality between GDP per capita and energy, electricity and coal. This result is in accordance with [10,12,68–70]. Except for [68] these studies are all panel cointegration studies, although using different sample periods to ours. In the long-run over the same period we observe unidirectional causality from GDP to the energy variables and feedback from electricity and coal to GDP. This is consistent with [10] for Western regions and [40].

For the 1999–2009 period in the short- and long-run we find unidirectional causality from GDP to the energy variables except for electricity for which we have evidence of feedback in the short-run. This result differs from previous studies.

There are some important conclusions which can be drawn from those results. First, in the long-run, causality flows from income to the energy consumption variables for the post 1999 sub-period. The same holds in the short-run except for electricity. This indicates that the measures launched in the mid-nineties to cut energy consumption have been to some extent successful (see also [92]). Second, the presence of bidirectional causality between GDP and electricity implies that electricity consumption and economic growth are interdependent. The interdependence between electricity consumption and economic growth indicates that energy policies designed to decrease electricity intensity are particularly pertinent. It also highlights that electricity supply shocks can be expected to have a large impact on GDP growth. It is therefore important that electricity generation capacity be expanded and price policies be reviewed to avoid electricity shortages. Third, these results suggest that the long-run relationship between GDP and energy variables can best be specified as a consumption/demand model. Therefore, the long-run coefficients may be interpreted as long-run elasticities of the energy variables with respect to income. The long-run coefficient estimates, presented in Table 6, using the panel DOLS estimates are of similar magnitude for both sample periods. For total energy, coal and oil long-run elasticities are between 0.51 and 0.68, for electricity and coke long-run elasticities are between 0.87 and 1.06.[12] This indicates that in the long-run energy intensity is lower for coal

[12] Comparing our elasticities with [10] in the case of coal, we find similar magnitudes, although our elasticities are slightly higher.

and oil than it is for electricity and coke. Although new plants and equipment might have improved efficiency in industries using coal as a source of energy, it is noteworthy that there has been some deterioration in the later part of the sample (elasticity for coal increased from 0.55 to 0.68). It also increased for coke over that period (from 0.87 to 1.06), but decreased for both oil and electricity. The better performance of coal can be explained by the fact that in this sector state-owned firms play a lower role than in electricity, allowing incoming foreign direct investment and liberalization of coal prices, which in turn stimulates advances in the use of new technology to lower energy intensity [93]. The oil industry has started a similar process than coal, yet is at an earlier stage of development.

These results can help to clarify the dilemma of Chinese regulators of promoting energy policies at the expense of economic growth, since they imply that energy-saving measures such as the promotion of technological progress can be adopted, without interrupting the path of economic development, to mitigate climate change. In addition, given that coal is the most important source of energy in China, but at the same time the most polluting, policies that aim to promote clean energies may reduce such dependence and make the environment cleaner. Recently, the Chinese government completed some infrastructure projects to transport gas from the West to the East of China that may improve the use of energy resources in this economy ([94,95]). In addition, it has started to exploit new oil reserves in the West of China to reduce the increasing trend in oil imports to satisfy the demand. Now China faces a new scenario where energy and environmental policies will determine the future sustainability of economic growth and welfare of the whole population.

5. Conclusions

Analyzing the direction of causality between energy consumption and economic growth has created a large body of empirical research, yet with conflicting results. Different countries, time periods, variables included in the model and econometric methods can account for those mixed results. In this paper, we apply recent panel cointegration techniques, allowing for cross-sectional dependence and heterogeneity between regions whenever possible, to investigate the direction of the causality between energy and economic growth in China over the period 1995–2009. We also examine the sub-period 1999–2009 to consider the effect of policy changes around 1999–2000. Conclusions from this analysis are useful to clarify whether the implementation of energy-saving measures in China can smooth the path of economic growth, or by contrast whether suitable policies can be adopted to mitigate climate change, and moderate pollution.

A novel aspect of our work is that we consider not only total energy consumption, but also coal, coke, oil and electricity to provide a more detailed analysis of such relationships. We also test the direction of causality both in the long and short-run.

Our results indicate that causality runs from economic growth to energy variables in the long-run. These results suggest that, when modeling relationships between energy consumption and economic growth, they will best be specified and interpreted as a consumption/demand model. However, empirical evidence in the short-run is mixed.

According to our findings, energy-saving measures such as the promotion of technological progress can be adopted to lessen global warming without interrupting the path of economic growth.

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References

[1] Pittel K, Rübbelke D. Climate policy and ancillary benefits: a survey and integration into the modelling of international negotiations on climate change. Ecol Econ 2008;68:210–20.
[2] Qiang W, Qi H-N, Yaoqiu K. Market-driven energy pricing necessary to ensure China's power supply. Energy Policy 2009;37:2498–504.
[3] Zhang Z. Why did the energy intensity fall in China's industrial sector in the 1990s? The relative importance of structural change and intensity change. Energy Econ 2003;25:625–38.
[4] Zhao X, Ma C, Hong D. Why did China's energy intensity increase during 1998–2006: Decomposition and policy analysis. Energy Policy 2010;38:1379–88.
[5] Herrerias MJ, Orts V, Tortosa E. Weighted convergence and regional clusters across China. Pap Reg Sci 2011;90:703–34.
[6] Herrerias MJ. Weighted convergence and regional growth in China: an alternative approach (1952–2008). Annal Reg Sci 2012;49:685–718.
[7] Karanfil F. How many times again will we examine the energy income nexus using a limited range of traditional econometric tools? Energy Policy 2009;37:1191–4.
[8] Ozturk I. A literature survey on energy-growth nexus. Appl Energy 2010;38:340–9.
[9] Yalta AT, Cakar H. Energy consumption and economic growth in China: a reconciliation. Energy Policy 2012;41:666–75.
[10] Li R, Leung GCK. Coal consumption and economic growth in China. Energy Policy 2012;40:438–43.
[11] Wang Y, Wang Y, Zhou J, Zhu X, Lu G. Energy consumption and economic growth in China: a multivariate causality test. Energy Policy 2011;39:4399–406.
[12] Akkemic KA, Göksal K, Li J. Energy consumption and income in Chinese provinces: heterogeneous panel causality analysis. Appl Energy 2012;99:445–54.
[13] Campbell JY, Perron P. Pitfalls and opportunities: what macroeconomists should know about unit roots. In: NBER macroeconomics annual, vol. 6, National Bureau of Economic Research; 1991. p. 141–220.
[14] Al-Iriani MA. Energy–GDP relationship revisited: an example from GCC countries using panel causality. Energy Policy 2006;34:3342–50.
[15] Pesaran H. A simple panel unit root test in the presence of cross-section dependence. J Appl Econ 2007;22:265–312.
[16] Westerlund J, Edgerton D. A panel bootstrap cointegration test. Econ Lett 2007;97:185–90.
[17] Canning D, Pedroni P. Infrastructure, long-run economic growth and causality tests for cointegrated panels. Manch Sch 2008;76:504–27.
[18] Pedroni P. Purchasing power parity tests in cointegrated panels. Rev Econ Stat 2001;83:727–31.
[19] Dumitrescu EI, Hurlin C. Testing for Granger non-causality in heterogeneous panels. Econ Model 2012;29:1450–60.
[20] Joyeux R, Ripple R. Energy consumption and real income: a panel cointegration multi-country study. Energy J 2011;32:107–42.
[21] Ferguson R, Wilkinson W, Hill R. Electricity use and economic development. Energy Policy 2000;28:923–34.
[22] Payne J. A survey of the electricity consumption-growth literature. Appl Energy 2010;87:723–31.
[23] Jumbe CBL. Cointegration and causality between electricity consumption and GDP: empirical evidence from Malawi. Energy Econ 2004;26:61–8.
[24] Kraft J, Kraft A. On the relationship between energy and GNP. J Energ Dev 1978:401–3.
[25] Acaravci A, Ozturk I. Electricity consumption-growth nexus: evidence from panel data for transition countries. Energy Econ 2010;32:604–8.
[26] Apergis N, Payne J. Energy consumption and economic growth in Central America: evidence from a panel cointegration and error correction model. Energy Econ 2009;31:211–6.
[27] Apergis N, Payne J. Energy consumption and economic growth: evidence from the Commonwealth of Independent States. Energy Econ 2009;31:641–7.
[28] Apergis N, Payne J. Coal consumption and economic growth: evidence from a panel of OECD countries. Energy Policy 2010;38:1353–9.
[29] Apergis N, Payne J. Energy consumption and growth in South America: evidence from a panel error correction model. Energy Econ 2010;32:1421–6.
[30] Apergis N, Payne J. A panel study of nuclear energy consumption and economic growth. Energy Econ 2010;32:545–9.
[31] Yu ESH, Choi JY. The causal relationship between energy and GNP: an international comparison. J Energ Dev 1985;10:249–72.
[32] Abosedra S, Baghestani H. New evidence on the causal relationship between United States energy consumption and gross national product. J Energy Dev 1989;14:285–92.
[33] Ghosh S. Electricity consumption and economic growth in India. Energy Policy 2002;30:125–9.
[34] Fatai K, Oxley L, Scrimgeour FG. Modelling the causal relationship between energy consumption and GDP in New Zealand, Australia, India, Indonesia, the Philippines, and Thailand. Math Comput Sim 2004;64:431–45.

[35] Oh W, Lee K. Energy consumption and economic growth in Korea: testing the causality relation. J Policy Model 2004;26:73–81.
[36] Thoma M. Electricity energy usage over the business cycle. Energy Econ 2004;26:463–85.
[37] Yoo SH. Causal relationship between coal consumption and economic growth in Korea. Appl Energy 2006;83:1181–9.
[38] Huang BN, Hwang MJ, Yang CW. Causal relationship between energy consumption and GDP growth revisited: a dynamic panel data approach. Ecol Econ 2008;67:41–54.
[39] Ozturk I, Aslan A, Kalyoncu H. Energy consumption and economic growth relationship: evidence from panel data for low and middle income countries. Energy Policy 2010;38:4422–8.
[40] Zhang XP, Cheng XM. Energy consumption, carbon emissions, and economic growth in China. Ecol Econ 2009;68:2706–12.
[41] Masih AMM, Masih R. A multivariate cointegrated modeling approach in testing temporal causality between energy consumption, real income and prices with an application to two Asian LDCs. Appl Econ 1998; 30:1287–98.
[42] Chang T, Fang W, Wen L. Energy consumption, employment, output, and temporal causality: evidence from Taiwan based on cointegration and error correction modeling techniques. Appl Econ 2001;33:1045–56.
[43] Altinay G, Karagol E. Electricity consumption and economic growth: evidence from Turkey. Energy Econ 2005;27:849–56.
[44] Lee CC. The causality relationship between energy consumption and GDP in G-11 countries revisited. Energy Policy 2006;34:1086–93.
[45] Wolde-Rufael Y. Electricity consumption and economic growth: a time series experience for 17 African countries. Energy Policy 2006;34:1106–14.
[46] Francis BM, Moseley L, Iyare SO. Energy consumption and projected growth in selected Caribbean countries. Energy Econ 2007;29:1224–32.
[47] Akinlo AE. Electricity consumption and economic growth in Nigeria: evidence from cointegration and co-feature analysis. J Policy Model 2009;31:681–93.
[48] Lee CC. Energy consumption and GDP in developing countries: a cointegrated panel analysis. Energy Econ 2005;27:415–27.
[49] Chen ST, Kuo HI, Chen CC. The relationship between GDP and electricity consumption in 10 Asian Countries. Energy Policy 2007;35:2611–21.
[50] Narayan PK, Singh B. The electricity consumption and GDP nexus for the Fiji Islands. Energy Econ 2007;29:1141–50.
[51] Narayan PK, Smyth R. Energy consumption and real GDP in G7 countries: new evidence from panel cointegration with structural breaks. Energy Econ 2008;30:2331–41.
[52] Lee CC, Chang CP. Energy consumption and economic growth in Asian economies: a more comprehensive analysis using panel data. Resour Energy Econ 2008;30:50–65.
[53] Shiu A, Lam PL. Electricity consumption and economic growth in China. Energy Policy 2004;32:47–54.
[54] Li F, Dong S, Li X, Liang Q, Yang W. Energy consumption-economic growth relationship and carbon dioxide emissions in China. Energy Policy 2011;39:568–76.
[55] Zou G, Chau KW. Short- and long-run effects between oil consumption and economic growth in China. Energy Policy 2006;34:3644–55.
[56] Yuan JH, Kang JG, Zhao CH, Hu ZG. Energy consumption and economic growth: evidence from China at both aggregated and disaggregated levels. Energy Econ 2008;30:3077–94.
[57] Bloch H, Rafiq S, Salim R. Coal consumption, Co_2 emission and economic growth in China: empirical evidence and policy response. Energy Econ 2012;34:518–28.
[58] Stern DI. Energy and economic growth in the USA: a multivariate approach. Energy Econ 1993;15:137–50.
[59] Stern DI. A multivariate cointegration analysis of the role of energy in the U.S. macroeconomy.. Energy Econ 2000;22:267–83.
[60] Yang HY. Coal consumption and economic growth in Taiwan. Energy Sources 2000;22:109–15.
[61] Soytas U, Sari R. Energy consumption and GDP: causality relationship in G-7 and emerging markets. Energy Econ 2003;25:33–7.
[62] Ghali KH, El-Sakka MI. Energy use and output growth in Canada: a multivariate cointegration analysis. Energy Econ 2004;26:225–38.
[63] Paul S, Bhattachachrya RB. Causality between energy consumption and economic growth in India: a note on conflicting results. Energy Econ 2004;26:977–83.
[64] Soytas U, Sari R. Energy consumption and income in G-7 countries. J Policy Model 2006;28:739–50.
[65] Lise W, Monfort KV. Energy consumption and GDP in Turkey: Is there a co-integration relationship? Energy Econ 2007;29. 1166–78.
[66] Chontanawat J, Hunt LC, Pierse R. Does energy consumption cause economic growth? Evidence from a systematic study of over 100 countries. J Policy Model 2008;30:209–20.
[67] Mishra V, Smyth R, harma S. The energy-GDP nexus: evidence from a panel of Pacific Island countries. Resour Energy Econ 2009:31 210–20.
[68] Han ZY, Wei YM, Jiao JL, Fan Y, Zhang JT. On the cointegration and causality between Chinese GDP and energy consumption. J Sys Eng 2004;12:17–21.
[69] Zhang C, Xu J. Retesting the causality between energy consumption and GDP in China: evidence from sectoral and regional analyses using dynamic panel data. Energy Econ 2012;34:1782–9.
[70] Wang SS, Zhou DQ, Zhou P, Wang QW. CO_2 emissions, energy consumption and economic growth in China: a panel data analysis. Energy Policy 2011;39:4870–5.
[71] Akarca A, Long TV. On the relationship between energy and GNP: a reexamination. J Energy Dev 1980;5:326–31.
[72] Yu ESH, Hwang BK. The relationship between energy and GNP: further results. Energy Econ 1984;6:186–99.
[73] Erol U, Yu, ESH. On the causal relationship between energy and income for industrialized countries. J Energy Dev 1987;13:113–22.
[74] Yu SH, Jin JC. Cointegration test of energy consumption, income and employment. Resour Energy 1992;14:259–66.
[75] Cheng BS. An investigation of cointegration and causality between energy consumption and economic growth. J. Energy Dev 1995;21:73–84.
[76] Asafu-Adjaye J. The relationship between energy consumption, energy prices and economic growth: time series evidence from Asian developing countries. Energy Econ 2000;22:615–25.
[77] Altinay G, Karagol E. Structural break, unit root, and causality between energy consumption and GDP in Turkey. Energy Econ 2004;26:985–94.
[78] Hurlin C, Venet B. Financial development and growth: a re-examination using a panel Granger causality test. Working Papers halshs-00319995_v1, HAL; 2008.
[79] Im KS, Pesaran MH, Shin Y. Testing for unit roots in heterogeneous panels. J Econom 2003;115:53–74.
[80] Maddala GS, Wu S. A comparative study of unit root tests with panel data and a new simple test. Oxford B Econ Stat 1999;61:631–52.
[81] Choi I. Combination unit root tests for cross-sectionally correlated panels. In: Corbae D, Durlauf SN, Hansen B, editors. Econometric Theory and Practice: Frontiers of Analysis and Applied Research: Essays in Honour of Peter C.B. Phillips. Cambridge University Press; 2006. p. 311–33.
[82] Baltagi BH, Bresson G, Pirotte A. Panel unit roots and spatial dependence. J Appl Econom 2007;22:339–60.
[83] Pedroni P. Cross sectional dependence in cointegration tests of purchasing power parity in panels. Working Paper in Economics. Indiana University; 1997.
[84] Pedroni P. Critical values for cointegration tests in heterogeneous panels with multiple regressors. Oxford B Econ Stat 1999;61:727–31.
[85] Pedroni P. Panel cointegration, asymptotic and finite sample properties of pooled time series tests with an application to the PPP hypothesis. Econom Theory 2004;20:597–625.
[86] Wagner M, Hlouskova J. The performance of panel cointegration methods: results from a large scale simulation study. Econom Rev 2010;29:182–223.
[87] McCoskey S, Kao C. A residual-based tests of the null of cointegration in panel data. Econom Rev 1998;17:57–84.
[88] Holtz-Eakin D, Newey W, Rosen HS. Estimating vector autoregressions with panel data. Econometrica 1988;56:1371–95.
[89] Toda HY, Phillips PCB. Vector autoregressions and causality. Econometrica 1993;61:1367–93.
[90] Engle RF, Granger CWJ. Co-integration and error correction: representation, estimation, and testing. Econometrica 1987;55:251–76.
[91] Peng W. Coal sector reform and its implications for the power sector in China. Resour Policy 2011;36:60–71.
[92] Sharma SS. The relationship between energy and economic growth: empirical evidence from 66 countries. Appl Energy 2010;87:3565–74.
[93] Herrerias MJ, Cuadros A, Orts V. Energy intensity and investment ownership across Chinese provinces. Energy Econ 2013;36:286–98.
[94] Wang ZH, Zeng HL, Wei YM, Zhang YX. Regional total factor energy efficiency: an empirical analysis of industrial sector in China. Appl Energy 2012;97:115–23.
[95] Liao H, Du J, Wei YM. Energy conservation in China: key provincial sectors at two-digit level. Appl Energy 2013;104:457–65.