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Energy consumption and income in Chinese provinces: Heterogeneous panel causality analysis

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HIGHLIGHTS

- ▶ We examine the Granger causality between GDP and energy use for Chinese provinces.
- ▶ We use panel causality techniques and take into consideration panel heterogeneity.
- ▶ Homogeneous causality tests fail and we test for panel heterogeneous causality.
- ▶ Causality holds for 19 provinces from GDP to energy and in the opposite direction for 14 provinces.
- ▶ The results point to the importance of the government's recent energy-saving policies.

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ABSTRACT

Recently, energy production in China fell behind energy consumption. This poses important challenges for the rapidly growing Chinese economy. As a consequence, the causal relationship between energy consumption and GDP is an important empirical issue. This paper examines Granger causality between energy consumption and GDP in China using province-level data. The current paper extends the Granger causality analysis employed in previous studies by taking into account panel heterogeneity. Specifically, four different causal relationships are examined: homogeneous non-causality (HNC), homogeneous causality (HC), heterogeneous non-causality (HENC), and heterogeneous causality (HEC). HC and HNC hypotheses are rejected for causality in either direction, from GDP to energy or from energy to GDP, which implies that the panel made up of Chinese provinces is not homogeneous. Then, heterogeneous causality tests (HEC ad HENC) are conducted for each province. For the causality running from GDP to energy, 19 provinces exhibit HEC and 11 provinces exhibit HENC. For the causality running from energy to GDP, 14 provinces exhibit HEC and 16 provinces exhibit HENC. The results suggest that the Chinese government should incorporate a regional perspective while formulating and implementing energy policies.

1. Introduction

China's total energy consumption surpassed total energy production in the late 1990s and this situation persisted since then (see Fig. 1). Extensive energy shortage, particularly, electricity shortage, has been witnessed repeatedly in the last decade. Due to energy shortages, energy imports increased after 1998 and averaged 3.1% of total energy consumption during 1998–2007. China has been a net importer of oil since 1993. China has suffered from frequent and extensive electricity, coal, and oil shortages since 2003. In 2004, 24 provinces experienced power brownouts, the power deficit amounting to 10% of the installed capacity. In 2008, 19 provinces experienced power brownouts [1]. In addition, the dependence on coal contributes to low efficiency of energy sector and worsening environmental problems.[3]

As a result of energy shortages, the focus of recent energy policies has gradually shifted from enhancing supply to efficiency improvement and energy conservation. Compared to advanced economies, China's performance in energy efficiency and energy intensity is inferior [3]. According to Price et al. [4], China

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[3] 85% of the sulfur dioxide, 70% of the smoke and 60% of the nitrogen oxides emitted into the atmosphere in China come from the burning of coal [2].

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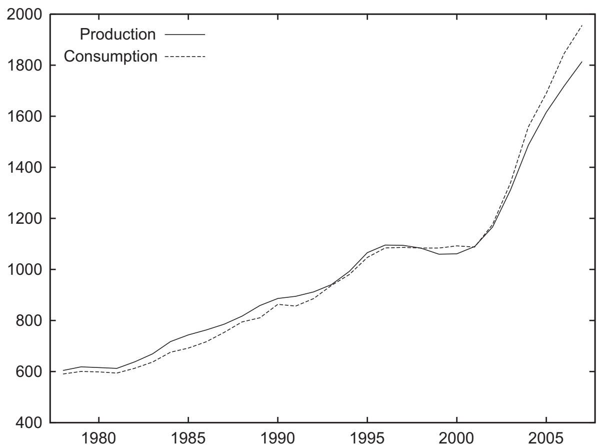

Fig. 1. Energy production and consumption, 1978–2008 (unit: million tons of oil equivalent).

experienced a 5% average annual reduction in energy intensity of GDP (i.e., energy use per unit of GDP) from 1980 to 2002, but this trend reversed to a 5% increase per year during 2002–2005. The recent efficiency deterioration is largely related to the shift of industrialization strategy from light and less energy-intensive one, which helped improve energy efficiency, towards one emphasizing heavy and energy-intensive industries since the late 1990s [5]. To address this issue, the Chinese government implemented a series of energy efficiency policies and programs in the last decade such as the Energy Conservation Law (2007), Medium and Long-term Energy Saving Plan (2004), 10 Key Energy-saving Program, and Top-1000 Energy-consuming Enterprises Program [4,6–11]. The government announced its aim to reduce energy intensity of GDP by way of energy conservation investments and agreements with large energy-consuming enterprises. National Development and Reform Commission (NDRC) reported that the Top-1000 Energy-consuming Enterprises Program saved 150 million tons sce during 2006–2010, 50 million tons sce more than original target [6]. 12th Five-Year Plan, launched in March 2011, introduced additional targets to reduce GDP energy intensity and carbon intensity.

The energy shortage problems and the recent emphasis of the central government led researchers to investigate the causal relationship between energy consumption and income in China. Examination of the causal relationship between energy consumption and GDP may have important policy implications. From the long-term policy perspective, if there exists causality running from energy to income, reducing energy consumption may lead to lower economic growth. Given the sustaining pressure on employment, industrial upgrading, and the growing pace of urbanization, it would be difficult for the central government in China to shift to a policy regime which places the priority on energy conservation. In addition, the current high dependence of Chinese energy-consumption structure on coal poses challenges to environment. On the other hand, if there is a causal relationship from income to energy, it may be implied that energy conservation policies can be implemented without or with limited adverse impacts on economic growth.

There are a large number of empirical studies in the literature examining the causal relationship between energy consumption and GDP. However, it is observed that they did not reach a general conclusion. A review of these studies is available in Ma et al. [12] and a review of more recent studies is presented in Table 1. The studies listed in the table yielded conflicting results due to different analytical methods, different study periods, and different indicators of energy consumption (total energy consumption, electricity, coal, oil, natural gas). These are listed in Table 1. While some studies [13–20] found that energy consumption causes GDP growth, some others [21–32] found the opposite, that GDP Granger causes energy consumption. On the other hand, some other studies [33–39] found bidirectional causality relationship or no causality relationship at all [40,41]. Yuan et al. [42] found a more complex picture for different energy consumption indicators. They found that Granger causal relationship from energy consumption to GDP in the case of electricity and oil but not for coal and total energy. Most recently, three studies shed light on the regional difference of energy-income relationship in China [3,43,44]. They used provincial panel dataset to investigate the causal relationship between energy consumption and economic growth respectively for east region and west region. All three studies found a bidirectional causal relationship for the east region of China. However, with regard to the west region, Xu et al. [43] and Yu and Meng [44] found a unidirectional causal relationship from energy to income, while Yang and Yang [3] found the opposite. These studies suggest the existence of heterogeneity at the sub-national level.

In this paper, we take a look at the causality relationship between energy consumption and GDP in China from a disaggregated perspective at the provincial level. For this purpose, we construct a panel made up province-level data. Granger causality between energy consumption and GDP for panel data is generally examined by dynamic panel Granger causality techniques. In the literature about energy-income nexus in China, most studies used aggregate time series techniques to examine causality (see Table 1). Recently, there is a surge on the studies using panel data in which province-level data are collected over limited time periods. An important shortcoming of these panel data studies is the implicit assumption of panel homogeneity. If the panel is heterogeneous when Granger causality assumes a homogeneous panel, then there is a heterogeneity bias. [46] Hurlin and Venet [47] offers a new approach to test homogeneous causality against heterogeneous causality. This method was used by He and Zhang [48] to examine the causal relationships between exports and economic growth in China.

The purpose of this paper is to examine Granger causality between energy consumption and GDP for 30 provinces in China for the period 1986–2008. Due to the recent policy shift from one emphasizing energy supply to one encouraging improvements energy efficiency and energy saving, which is discussed in Section 2 in detail, the findings of this paper has important policy implications. In technical terms, the novelty of this paper is the extension of panel Granger causality techniques beyond those currently available. We take into account panel heterogeneity and, to this end, we use the method for panel data Granger causality with fixed coefficients proposed by Hurlin and Venet [47].

The rest of the paper is organized as follows. Data and method of analysis are explained in the nest section. The results are presented in Section 3. Finally, the fourth section concludes with a summary of the results and policy implications.

2. Methodology and data

The standard Granger causality that is used to examine the existence of causality between two time series is not appropriate for panel data. Different approaches developed for dynamic panel Granger causality were reviewed and categorized into two main approaches by Erdil and Yetkiner [49]. The first method, represented by Holtz-Eakin et al. [50] takes the autoregressive coefficients and slope coefficients in panel VAR model as variable. The second method, represented by Hurlin and Venet [47] takes autoregressive and slope coefficients as constant. The length of the time period determines the appropriateness of either of the methods.

Table 1
Select list of studies examining causality between energy and GDP in China.

Authors	Dataset	Period	Causal relationship (method used)	Energy variable(s)	Data source
Those which found E → Y					
Chan and Lee (1996) [13]	Time series	1953–1993	E → Y (cointegration and error correction)	Total energy consumption	Official (NBS)
Shiu and Lam (2004) [14]	Time series	1971–2000	E → Y (error-correction)	Electricity consumption	Official (NBS), China State Electricity Power Information Center
Wang and Liu (2007) [15]	Time series	1978–2005	E → Y (error-correction)	Total energy consumption	Official (NBS)
Yuan et al. (2007) [16]	Time series	1978–2004	E → Y (error-correction)	Electricity consumption	Official (NBS), China State Electricity Power Information Center
Lee and Chang (2008). [17]	Time series	1971–2002	E → Y (error-correction)	Total energy consumption	World Development Indicators
Wang and Shen (2008) [18]	30-province panel	1999–2005	E → Y (Cobb-Douglas production function, Granger)	Electricity consumption	Official (NBS)
Zhang et al. (2009) [19]	Time series	1953–2007	E → Y (error-correction)	Coal, oil, gas	Official (NBS)
Ding and Zhou (2010) [20]	Time series	1953–2007	E → Y (error-correction)	Total energy consumption	Official (NBS)
Those which found Y → E					
Zhang and Li (2004) [21]	Time series	1961–2001	Y → E (Granger)	Total energy consumption	Official (NBS)
Fan and Zhang (2005) [22]	Time series	1978–2002	Y → E (Granger)	Total energy consumption	Official (NBS)
Wu et al. (2005) [23]	Time series	1979–2002	Y → E (cointegration)	Total energy consumption	Official (NBS)
Liu (2006) [24]	Time series	1985–2003	Y → E (Granger)	Total energy consumption	Official (NBS)
Liu et al. (2007) [25]	Time series	1988–2005	Y → E (variance decomposition)	Total energy consumption	Official (NBS)
Wang and Yang (2007) [26]	Time series	1978–2005	Y → E (error-correction)	Total energy consumption	Official (NBS)
Wang and Yao (2007) [27]	Time series	1978–2003	Y → E (Granger)	Total energy consumption	Official (NBS)
Zhao and Fan (2007) [28]	Time series	1977–2005	Y → E (smooth transfer regression)	Total energy consumption	Official (NBS)
Chen et al. (2007) [29]	Time series	1971–2001	Y → E (error-correction)	Electricity consumption	World Bank
Wang and Zhao (2008) [30]	Time series	1980–2005	Y → E (Autoregressive distributed lag, Toda-Yamamoto)	Total energy consumption	Official (NBS)
Zhang and Cheng (2009) [31]	Time series	1960–2007	Y → E (Toda-Yamamoto)	Total energy consumption	Official (NBS)
Ning (2010) [32]	Time series	1965–2006	Y → E (error correction)	Total energy consumption	International Energy Agency, Maddison (2007) [45]
Those which found E ↔ Y					
Han et al. (2004)	Time series	1978–2000	E ↔ Y (Granger)	Total energy consumption	Official (NBS)

(*continued on next page*)

Table 1 (*continued*)

Authors	Dataset	Period	Causal relationship (method used)	Energy variable(s)	Data source
[33]					
Ma et al. (2004) [34]	Time series	1954–2002	E ↔ Y (Granger)	Total energy consumption	Official (NBS)
Huang and He (2006) [35]	Time series	1985–2003	E ↔ Y (Cobb-Douglas production function)	Total energy consumption	Official (NBS)
Qian and Yang (2009) [36]	Time series	1953–2006	E ↔ Y (Granger)	Total energy consumption	Official (NBS)
Yang and Chi (2009) [37]	Time series	1952–2008	E ↔ Y (error-correction)	Total energy consumption	Official, China Economic Information Network
Zhou and He (2009) [38]	Time series	1953–2007	E ↔ Y in the long run (demand function, Cobb-Douglas production function, error correction)	Total energy consumption	Official (NBS)
Li et al. (2010) [39]	Time series	1953–2008	E ↔ Y (Granger)	Total energy consumption	Official (NBS)
Those which found mixed results					
Yuan et al. (2008) [42]	Panel	1963–2005	Electricity, oil → Y in the short run; Y → total energy, coal and oil consumption in the short run (neoclassical production model, error-correction)	Total energy consumption, coal, oil, electricity	Official (local statistical yearbooks)
Xu et al. (2008) [43]	West (12 provinces), east (10 provinces)	1986–2005	East: E ↔ Y in both the short and long run; West: Y → E in both the short and long run (error-correction)	Total energy consumption	Official (local statistical yearbooks)
Yu and Meng (2008) [44]	West (10 provinces), east (10 provinces)	1986–2006	East: E ↔ Y in both the short and long run; West: Y → E in both the short and long run (error-correction)	Total energy consumption	Official (local statistical yearbooks)
Yang and Yang (2010) [3]	West (9 provinces), east (7 provinces)	1999–2007	East: E ↔ Y in both the short and long run; West: E → Y in the long run (error correction)	Total energy consumption	Official (NBS, local statistical yearbook), Shanghai Gildata Inc.

Note: Some of these references are obtained from Ma et al. [12].

For short periods, the second method is advised. In this study, the time period (1986–2008) is long enough to use the method proposed by Hurlin and Venet [47].

To investigate the causality relationship between energy consumption and GDP, we employ dynamic panel Granger causality method with fixed coefficients as in Hurlin and Venet [47]. Hurlin and Venet propose four types of dynamic panel Granger causality with fixed coefficients: (i) homogeneous causality (HC), (ii) homogeneous non-causality (HNC), (iii) heterogeneous causality (HEC), and (iv) heterogeneous non-causality (HENC). The procedure for testing causality is as follows. First, we test for HNC and if it is rejected, we test for HC. If HC is also rejected, then HENC is tested. If HENC is not rejected, then we conclude that some cross-sections do not yield any causal relationship. If HENC is rejected, HEC applies, i.e., there is Granger causality for all cross-sections despite heterogeneity across cross sections.

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

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

Here i refers to individual provinces, t denotes time, and j is the number of lags. α, β, and γ are parameters to be estimated. In this equation, E and Y are stationary variables and the autoregressive coefficients γ^j and the slope coefficients β_i^j are assumed to be constant over the period of analysis. In addition, γ^j are identical across cross-sections and β_i^j are allowed to vary across cross-sections.

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

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

Hurlin and Venet make the following assumptions about the error term $\epsilon_{i,t}$:

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

Next, we define the best linear predictor of $E_{i,t}$, i.e., $E(E_{i,t}|\widetilde{E}_{i,t}, \widetilde{Y}_{i,t})$, given the past values of $E_{i,t}$, i.e., $\widetilde{E}_{i,t} = (E_{i,-p}, \ldots, E_{i,0}, \ldots, E_{i,t-1})$, and the past values of $Y_{i,t}$, i.e., $\widetilde{Y}_{i,t} = (Y_{i,-p}, \ldots, Y_{i,0}, \ldots, Y_{i,t-1})$.

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

$$\text{For all } i, E(E_{i,t}|\widetilde{E}_{i,t}, \alpha_i) = E(E_{i,t}|\widetilde{E}_{i,t}, \widetilde{Y}_{i,t}, \alpha_i) \tag{3}$$

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

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

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

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

where RSS_2 is the sum of squared residuals obtained under H_0 and RSS_1 is that obtained under the unrestricted model shown by Eq. (1). T is the number of periods, N is the number of cross-sections (provinces), and n is the number of lags. If we fail to reject the HNC hypothesis, we conclude that there is no Granger causality from Y to

E (or the other way around if we consider Eq. (2)). Then, the causality examination procedure stops at this point. If we reject the HNC hypothesis, we then proceed to test the homogeneous causality hypothesis.

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

$$\text{For all } i, E(E_{i,t}|\widetilde{E}_{i,t}, \alpha_i) \neq E(E_{i,t}|\widetilde{E}_{i,t}, \widetilde{Y}_{i,t}, \alpha_i) \quad (6)$$

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

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

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

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

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

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

$$\text{For all } i, \exists i \in [1, N], E(E_{i,t}|\widetilde{E}_{i,t}, \alpha_i) \neq E(E_{i,t}|\widetilde{E}_{i,t}, \widetilde{Y}_{i,t}, \alpha_i) \quad (9)$$

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

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

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

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

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

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

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

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

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

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

$$\begin{aligned} &\exists i \in [1, N], E(E_{i,t}|\widetilde{E}_{i,t}, \alpha_i) \neq E(E_{i,t}|\widetilde{E}_{i,t}, \widetilde{Y}_{i,t}, \alpha_i) \\ &\exists (i, k) \in [1, N], E(E_{i,t}|\widetilde{E}_{i,t}, \widetilde{Y}_{i,t}, \alpha_i) \neq E(E_{k,t}|\widetilde{E}_{k,t}, \widetilde{Y}_{k,t}, \alpha_k) \end{aligned} \quad (14)$$

Hurlin and Venet [47] also extend these tests to instantaneous homogeneous/heterogeneous causality/non-causality tests as well. Since we are interested in a long-run relationship based on the past values of the variables at hand, we do not run such tests. The test statistics for all these null hypotheses are available in [47].

We gathered data on real GDP and energy consumption for 30 provinces in China. Real GDP data in renminbi are measured in constant 1986 prices. Final energy use is measured in tons of oil equivalent. Provincial GDP data are obtained from *China Compendium of Statistics 1949–2008* published by the National Bureau of Statistics [51]. Energy consumption data are obtained from various issues of *Chinese Energy Statistical Yearbook* which is also published by the National Bureau of Statistics [52]. The data are available for all provinces from 1978 to 2008. Among 31 provinces, province-level autonomous regions, and municipalities, Tibet's data on energy consumption are not available. Among 30 provinces for which energy consumption data are available, 26 provinces have full set of data from 1986 to 2008. 1992–1994 data are missing for Shandong, Hunan and Sichuan, and 1986–1989 data are missing for Hainan. We estimated these missing data by assuming exponential growth of adjacent years. Accordingly, our dataset covers 30 provinces and the period 1986–2008.

An important problem in empirical studies regarding the energy issues in China is the reliability and accuracy of the official data. We employ officially published provincial GDP and energy consumption data in this paper as they are the most consistent available longitudinal database. However, we explain the relevant issues circumventing the reliability of official statistics in appendix at the end of this paper.

3. Empirical results

3.1. Panel unit root tests

Prior to the Granger causality tests, we search for the existence of unit roots for two series, energy consumption, E, and real GDP, Y. The conventional augmented Dickey-Fuller (ADF) tests for detecting unit root are known to be weak hypothesis testing of stationarity for panel data. Therefore, we use two other more powerful unit root tests that are used widely for panel data, based on Levin et al. [53] and Im et al. [54]. We abbreviate the former as LLC and the latter as IPS. While the LLC test assumes common unit root for all panel members, the IPS test allows for individual unit roots for panel members. Panel unit root test results are shown in Table 2. The results of both IPS and LLC tests lead us to accept the existence of unit root at levels. For the first differences, both series are stationary. Therefore, we conclude that both series are integrated of degree one, I (1).

3.2. Granger causality

We found that both E and Y series are stationary only in first differences and there is a cointegration relationship between the two. We then examine the Granger causality relationships between

Table 2
Unit root tests.

		Level		First difference	
		Individual Intercept	Individual Intercept + trend	Individual Intercept	Individual Intercept + trend
Y	LLC test	6.305	3.016	−5.744***	−4.283***
	IPS test	13.179	3.769	−7.587***	−4.484***
E	LLC test	4.011	0.281	−6.579***	−7.497***
	IPS test	11.368	1.453	−6.399***	−7.886***

* Significant at 10% level.
** Significant at 5% level.
*** Significant at 1% level.

Table 3
Tests of homogeneous non-causality (HNC) and homogeneous causality (HC) (causality running from GDP to energy consumption).

Lag	HNC		HC	
	$Y \to E$	$E \to Y$	$Y \to E$	$E \to Y$
1	6.007***	6.043***	4.387***	4.388***
2	2.955***	3.781***	2.480***	2.427***
3	2.441***	3.438***	2.038***	2.141***

* Significant at 10% level.
** Significant at 5% level.
*** Significant at 1% level.

these two variables in this subsection. We use the first difference of both series in causality tests. We do not choose lags according to lag selection criteria such as Akaike or Schwarz but rather present the results for up to three lags. By doing so, we can also test the sensitivity and robustness of the test results. All causality equations are estimated as fixed effects equations. Critical values for F tests are based on F distribution with $(Nn,\ NT - N(1+n) - n)$ degrees of freedom [47].

Table 5
Tests of heterogeneous non-causality (HENC).

Lag	$Y \to E$	$E \to Y$
1	20.324***	18.946***
2	2.173***	4.170***
3	5.111***	6.788***

* Significant at 10% level.
** Significant at 5% level.
*** Significant at 1% level.

3.2.1. Results for causality running from GDP to energy consumption

The results for homogeneous non-causality (HNC) and homogeneous causality (HC) for the causal relationship running from GDP to energy consumption ($Y \to E$) are presented in the second and fourth columns of Table 3. If we fail to reject the HNC hypothesis (F_{HNC} statistic smaller than the critical F value), we conclude that

Table 4
Results of heterogeneous non-causality tests (causality running from GDP to energy consumption).

	$Y \to E$			$E \to Y$		
Province	1 Lag	2 Lags	3 Lags	1 Lag	2 Lags	3 Lags
Beijing	1.368*	0.207	0.306	0.011	0.055	0.038
Tianjin	12.365***	6.779***	1.744***	0.773	0.017	0.301
Hebei	0.099	0.750	0.130	4.374***	4.792***	5.216***
Shanxi	0.984	0.764	0.629	1.215	1.224	0.338
Inner Mongolia	9.966***	4.865***	2.233***	11.230***	7.419***	2.782***
Liaoning	7.752***	5.471***	1.593***	0.789	0.758	0.076
Jilin	6.860***	2.168***	0.887	1.615**	0.555	1.603***
Heilongjiang	0.905	1.328*	0.330	1.395	0.151	0.138
Shanghai	3.363***	0.669	0.828	2.650***	3.904***	1.124
Jiangsu	0.312	1.831***	0.232	1.424*	1.163	0.227
Zhejiang	4.434***	2.070***	1.096	5.530***	4.097***	3.280***
Anhui	8.242***	3.551***	1.669***	0.153	0.436	0.003
Fujian	1.679**	1.351**	0.398	22.832***	17.350***	5.863***
Jiangxi	4.655***	1.316*	0.486	2.009***	2.449***	1.897***
Shandong	2.800***	0.900	0.004	3.033***	3.302***	3.858***
Henan	0.007	0.035	0.207	9.567***	9.980***	9.700***
Hubei	1.300	0.690	0.235	1.685**	2.205***	2.984***
Hunan	0.604	0.418	0.014	1.321	1.952***	2.245***
Guangdong	0.911	0.417	0.141	2.018***	1.898***	0.222
Guangxi	1.696**	1.098	0.192	2.771***	1.968***	1.684***
Hainan	0.173	0.481	0.196	2.795***	1.839***	1.084
Chongqing	4.321***	2.667***	2.561***	0.030	0.458	0.400
Sichuan	1.312	1.038	0.371	0.563	0.549	0.983
Guizhou	5.624***	2.939***	0.560	0.825	0.401	0.212
Yunnan	2.877***	0.972	0.710	0.535	1.056	0.135
Shaanxi	1.821***	1.512***	0.932	1.087	0.477	0.911
Gansu	2.839***	1.426**	1.180	0.485	0.717	0.192
Qinghai	9.307***	4.789***	4.034***	0.736	0.153	0.099
Ningxia	2.773***	3.417***	0.718	0.895	0.490	0.191
Xinjiang	2.862***	2.490***	1.318**	0.061	0.045	0.013

* Significant at 10% level.
** Significant at 5% level.
*** Significant at 1% level.

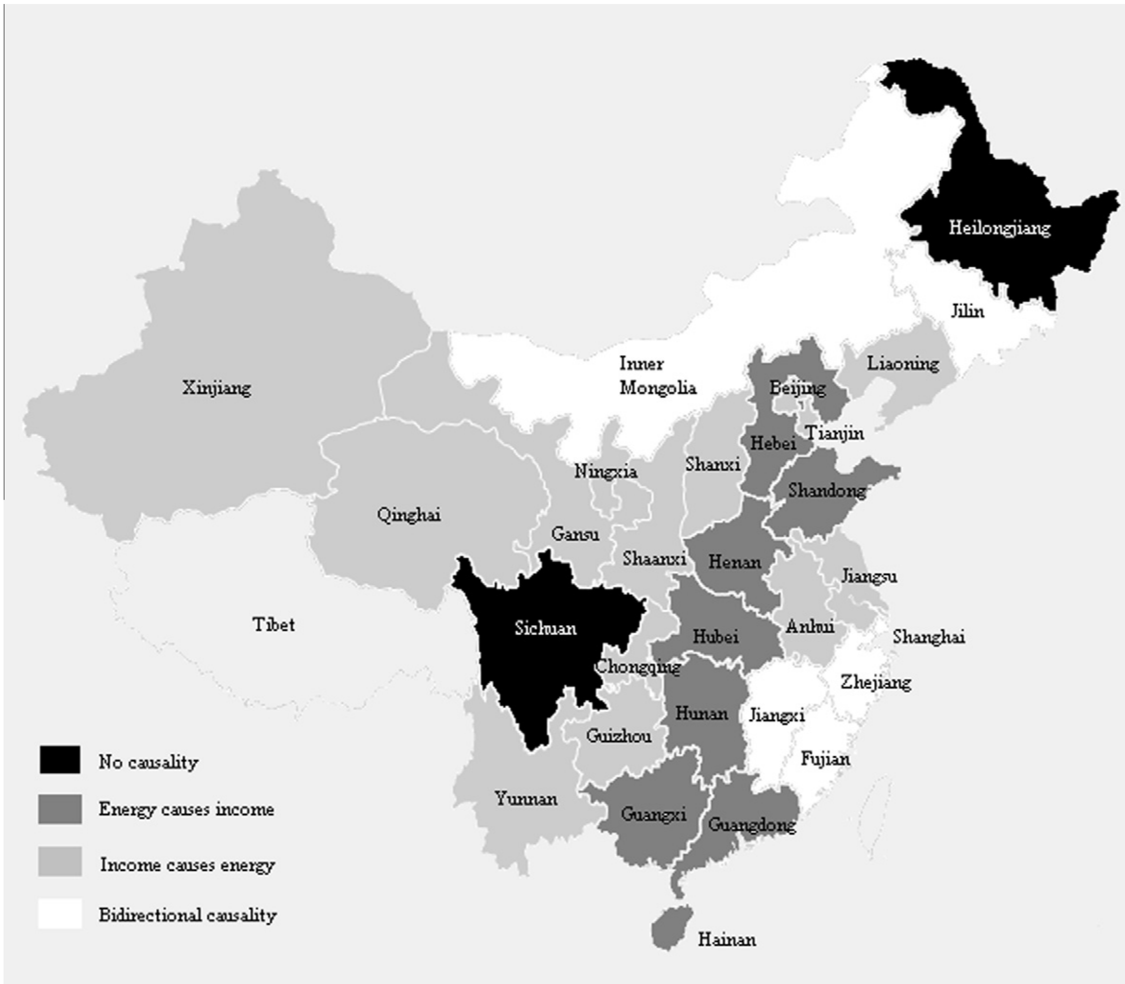

Fig. 2. The results of causality analysis.

there is no causal relationship from GDP to energy consumption. Table 3 demonstrates that in HNC hypothesis is rejected for all lags. In other words, for at least one province in the panel GDP Granger causes energy consumption. Then, we proceed with the HC test. The resulting F_{HC} statistics are greater than the critical F values, and therefore we reject the null hypothesis of homogeneous causality relationship running from GDP to energy for all lags. Accordingly, we conclude that panel heterogeneity is observed.

Next, we run HENC hypothesis tests. The results for each province are presented in the second, third, and fourth columns of Table 4. We base our conclusions for a significance level of at least 5%. Nineteen out of 30 provinces exhibit heterogeneous causality as the F^{i}_{HENC} statistics are greater than critical F values. Fig. 2 displays these provinces on the map. It is recognized that these provinces are scattered across the country but do not include central-eastern provinces. In the second step of the HENC hypothesis test, we test the joint hypothesis of no causality for these 19 provinces. The results of this test is presented in the second column of Table 5. The results indicate that HENC hypothesis is rejected when these 14 provinces are grouped. For the remaining 11 provinces HENC hypothesis is not rejected, i.e., there is no Granger causality running from GDP to energy consumption.

3.2.2. Results for causality running from energy consumption to GDP

The results for homogeneous non-causality and homogeneous causality for the causal relationship running from energy consumption to GDP ($E \rightarrow Y$) are presented in the third and fifth columns of Table 3. HNC hypothesis is rejected since F_{HNC} statistics are greater than the critical F statistics for all lags. HC hypothesis is also rejected since F_{HC} statistics are larger than critical F values. These results indicate panel heterogeneity. As a consequence, we examine causality relationships at the individual province level and proceed to heterogeneous non-causality (HENC) tests.

We present the results for the HENC hypothesis by provinces in the fifth, sixth, and seventh columns of Table 4. Based on individual HENC tests, we conclude that 14 provinces exhibit heterogeneous causality since the null hypothesis of HENC is rejected. Grouping these provinces we also tested the joint hypothesis that there is no causality for these 14 provinces. The results presented in the third column of Table 5 reveal that HENC hypothesis is rejected for these provinces as a group. Fig. 2 displays the 14 provinces that exhibit HEC on the map. It can be easily recognized that these provinces are located in the coastal eastern part of the country where industrial activities are more developed than the rest. Therefore, the availability of energy ensures higher GDP in these provinces. For the remaining 16 provinces, HENC hypothesis is not rejected, i.e., there is no Granger causality running from energy consumption to GDP.

3.2.3. Categorization of provinces

Based on the results from the causality tests, the provinces of China can be categorized into the following four groups.

(i) *Uni-directional causality from energy consumption to GDP*: Guangdong, Guangxi, Hainan, Hebei, Henan, Hubei, Hunan, Shandong. In these eight provinces, economic activities are dependent on the availability of energy. Other than Guandong, Shandong and Hebei, these provinces are located in the central-eastern region and their economic development level is in between the developed eastern coast and relatively poor western and central provinces.
(ii) *Uni-directional causality from GDP to energy consumption*: Anhui, Beijing, Chongqing, Gansu, Guizhou, Jiangsu, Liaoning, Ningxia, Qinghai, Shaanxi, Tianjin, Xinjiang, Yunnan. For these 13 provinces, the availability of energy does not cause GDP but rather higher GDP requires higher energy use. In these provinces, energy conservation should cause no harm to the provincial GDP. It is noticeable that apart from Anhui, Beijing, Jiangsu, Liaoning, Tianjin, these remaining eight provinces are located in the relatively poor western and central parts of the country.
(iii) *Bi-directional causality between GDP and energy consumption*: Fujian, Inner Mongolia, Jiangxi, Jilin, Shanghai, Zhejiang. Energy consumption and GDP are interrelated and cause each other in these six provinces. Higher GDP requires more energy and the availability of energy ensures higher GDP. These six provinces are located in the eastern coastal region and in the north and a common characteristic of these provinces, except for Inner Mongolia, is their relatively advanced industrial sectors.
(iv) *No causality between GDP and energy consumption*: Shanxi, Heilongjiang, Sichuan. For these three provinces, there is not causality relationship in either direction.

The policy implications of the findings are discussed in the concluding section.

4. Conclusion and policy discussion

In this paper, we examine the causality relationship between energy consumption and GDP in China using panel data covering 30 provinces for the period 1986–2008 and extend the conventional Granger causality analysis by taking into account panel heterogeneity using a technique developed for panels with fixed coefficients. Previous studies focused on cointegration and the conventional Granger causality tests where implicit assumption is made for homogeneity of the panel members.

The results can be summarized as follows. Our panel that consists of 30 Chinese provinces is characterized by panel heterogeneity and homogeneous causality tests fail. Heterogeneous causality and non-causality tests for the causality running from GDP to energy show that 19 provinces exhibit heterogeneous causality and 11 provinces exhibit heterogeneous non-causality. For the causality running from energy to GDP, 14 provinces exhibit heterogeneous causality and 16 provinces exhibit heterogeneous non-causality.

Although it is difficult to devise policy recommendations from a causality analysis, the results suggest that the Chinese government should incorporate a regional perspective while formulating and implementing energy policies. In general, though with exceptions, we find relatively advanced provinces appear to fall into the groups of unidirectional causality relationship running from energy to GDP or bi-directional causality. The relatively poor provinces located in north-west and south-west appear to fall into the group of uni-directional causality relationship running from GDP to energy. Therefore, the recent energy shortages and conservation policies more likely exert impacts on relatively advanced provinces in China. Given the fact that the relatively advanced provinces located in the southeast coastal line are the center of China's economic growth to date, prolonged energy shortages may dampen country's economic growth as a whole.[4] On the other hand, if, accompanied by the rapid economic growth led by industrialization, the relatively poor provinces also move to the causality pattern running from energy to GDP, the Chinese government may face a further difficult policy choice between growth and environment.

For eight provinces where there is a uni-directional causality relationship running from energy to GDP (Guangdong, Guangxi, Hainan, Hebei, Henan, Hubei, Hunan, and Shandong), we conclude that the development of these industries depends on continuous supply of energy since most of the energy demand originates from industrial activities. Therefore, efficient regulation of the energy sectors and the availability of imported energy to ensure the continuity of industrial production are vitally important. Energy shortages, that have persistently continued since the late 1990s would affect these provinces more. On the demand side, economic development and improvements in the living standards will increase the demand for energy further. For both demand-side and supply-side reasons, it seems necessary to increase the energy production capacity in these provinces.

Alternatively, for those provinces where there is a uni-directional causality relationship running from GDP to energy (Anhui, Beijing, Chongqing, Gansu, Guizhou, Jiangsu, Liaoning, Ningxia, Qinghai, Shaanxi, Tianjin, Xinjiang, and Yunnan), which number 13 in total, energy-saving policies can be implemented more easily with presumably little or no adverse effect on provincial GDP. On the other hand, rapid economic growth in these provinces is likely to increase energy consumption likewise.

Finally, for six provinces that exhibit bi-directional causality (Fujian, Inner Mongolia, Jiangxi, Jilin, Shanghai, and Zhejiang), economic growth and energy consumption are interrelated. Economic growth depends on energy use and the availability of energy ensures larger provincial GDP and economic growth. The recent energy-saving plans of the central government are likely to affect economic growth in these provinces. Therefore, it is necessary to increase energy efficiency on both the consumers' side and the side of industries while ensuring the continuous supply of the demanded energy via capacity expansion.[5] In the case of electricity, this requires the removal of the differences between rural and urban tariffs. It is also imperative for the government to promote energy-saving technologies as well as improving the energy supply infrastructure nation-wide.

At level of the aggregate economy, energy efficiency problem in China, which became serious after 2002, is worth mentioning. Inefficiency in energy use in China is a well-established fact by now [55,56]. Energy efficiency, which improved substantially after the reform, started to get worse after 2002. An important reason for the worsening energy efficiency is the changing industrial structure. After the reform, the Chinese industrialization strategy shifted from heavy industry-concentrated one to a lighter one which is more fit to its resources endowment. A more labor-intensive strategy consequently led to a less energy-intensive industrial structure. However, the industrial structure in China changed back

[4] In this regard, four provincial-level municipalities (Beijing, Chongqing, Tianjin, and Shanghai) appear to be exceptions.

[5] Energy shortages, although persistent since the 1980s, became serious after 2003. Efficiency improvement soon after the reform helped ameliorate the shortages in 1980s and 1990s to a certain extent. However, due to shifting of the industrial structure back to a heavy industry-oriented one and improving living standards, energy demand became larger. In addition, it was reported that the Chinese government made wrong judgments on energy consumption, it did not give permission to build any new power plants in the late 1990s. As a result of these developments, energy shortage problems broke out after 2003. Shiu and Lam [14] argued that adverse shocks to electricity supply will have a large impact on GDP growth and they pointed to the importance of expanding the electricity generation capacity to overcome future electricity shortages. They also stated that electricity demand in China has shifted from 'quantitative' to 'qualitative' growth.

Table A.1
Correlation coefficient between total energy consumption and industry value-added across provinces (1986–2008).

Beijing	0.992	Zhejiang	0.989	Hainan	0.975
Tianjin	0.991	Anhui	0.965	Chongqing	0.984
Hebei	0.984	Fujian	0.991	Sichuan	0.969
Shanxi	0.964	Jiangxi	0.977	Guizhou	0.969
In. Mongolia	0.974	Shandong	0.986	Yunnan	0.985
Liaoning	0.981	Henan	0.981	Shaanxi	0.987
Jilin	0.975	Hubei	0.987	Gansu	0.986
Heilongjiang	0.931	Hunan	0.955	Qinghai	0.975
Shanghai	0.997	Guangdong	0.993	Ningxia	0.936
Jiangsu	0.994	Guangxi	0.980	Xinjiang	0.977

to a heavier one in the mid 1990s, which is likely to have caused worsening energy efficiency. Another important reason is the process of market transition itself. In a planned economy, low energy efficiency can arise from the lack of incentives, inappropriate quotas, and distribution problems. Market reforms after 1978 were successful in fixing these problems to some extent, and subsequently, efficiency improved at the very beginning. To tackle the energy shortage problem, enhance energy efficiency, and ensure secure energy supply, Chinese government has been exercising regulation on energy sectors.

The findings of the paper can be enriched in the future by focusing on the different sources of energy. A more disaggregated sectoral analysis may also have important policy implications as well. We believe that future line of research should emphasize these two points.

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Appendix A. Issues related to energy consumption and GDP data in China

This paper used the energy statistics published by the National Bureau of Statistics of China (NBS hereafter). At the provincial level, energy statistics provided by NBS (*Chinese Energy Statistical Yearbook*) are the most comprehensive and consistent dataset.

Over recent years, there has been considerable discussion on the reliability of Chinese energy statistics [57–59]. The previous literature suggests that the official energy statistics can be used for meaningful analysis with careful consideration of the degree of accuracy [57–59]. Following this line of literature, we checked the consistency of energy consumption data and industry value-added data to increase the persuasive power of our dataset. In addition, the quality of energy statistics in recent years has improved. Therefore, it is appropriate to use official energy statistics for the econometric estimations conducted in this study. The detailed discussion about the Chinese energy statistics are as follows.

1. Data availability at the provincial level.
   The reason why we use official energy consumption data is that, NBS is the primary and only authoritative source for complete coverage of all supply and demand statistics of China's energy statistics [57–59]. The balance tables and other series published by NBS are the sources on which most other published materials are based [57–59].
   Regarding the energy statistics at the provincial level, the data mostly appear in *Chinese Energy Statistical Yearbook*, which is published by NBS on an annual base. Although statistical yearbooks of various provinces often include a section about energy production and consumption, the information is included occasionally and the situation varies among provinces. For example, *Shanghai Statistical Yearbook* used to include the energy statistics until 2006; however, during the period 2007–2010, energy statistics are missing in the yearbooks. The latest version of Shanghai Statistical Yearbook 2011 reported the energy statistics again.
2. Statistical collection and reporting system. There are statistical bureaus at different administrative levels. The lower levels of bureaus are responsible for collecting and reporting the statistics to the higher levels. Therefore, the materials published by NBS are based on the primary statistics collected by the local statistical bureaus. In addition, there is very low possibility that the statistical data provided by lower administrative levels of statistical bureaus are more accurate and reliable than NBS data. Instead, local officials sometimes misreport data to please higher-ups or look good for job evaluations.
   Recently, the central government in China has been addressing the data quality problems through the following three initiatives. The quality of statistics has improved accompanied by the implementation of these initiatives.
   - Since the 1990s, NBS has supplemented the information reported by local statistical bureaus with the information gathered through NBS' sample survey, and the reports from larger energy consumers.
   - The amended Energy Conservation Law (amended in 2007 with an effective date of April 1, 2008) clearly states that local governments (county-level and above) are responsible for the improvement of collection and reporting system of energy statistics, and ensure reliability of energy statistics (Article 21).
   - The Chinese government has established an online energy data collection system nationwide. In addition, the Energy Conservation Law (Article 53) states that large energy consumers should report the information of energy consumption and energy conservation to related government agencies annually.
3. Comparability of the various datasets at the national level from previous literature
   Numerous scholars have used energy data published by NBS to perform econometric analyses that are published in professional journals and subject to the review of referees (see Table 1 above). This indicates that most researchers believe that the official data are reliable.
   The conclusions drawn from different datasets are presumably similar because NBS is the only primary source of energy statistics. The original source of other influential datasets such as *China Energy Databook* published by Lawrence Berkeley National Laboratory, which is supported by the U.S. Department of Energy, refers to official publications as well. For example, Sinton and Levine used three different datasets of energy consumption and output value to examine the energy intensity changes [60]. Over different datasets, they reached the similar conclusion.
4. Consistency with other statistical indicators
   Energy consumption in China is dominated by industry use, which accounts for 70% of the final energy demand. Therefore, it is possible to check the reliability of the energy statistics by examining the consistency of energy consumption with industry value-added. In the case of our dataset, the correlation of energy consumption and industry value-added are high for all provinces (see Table A.1).[6]

[6] Garbaccio et al. [61] provide a method to refine the industry output data at the disaggregated industry-level for 29 industries using input–output analysis techniques. Since we are not conducting an analysis at the individual industry level, this issue is out of the scope of this paper.

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