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Article

The Relationship between Energy Consumption and Economic Growth: Evidence from China's Industrial Sectors

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Abstract: In this article, the relationship between energy consumption and economic growth is examined from the viewpoint of China's industrial sectors. Panel data from 37 industrial sectors in China covering the period from 1998 to 2010 was used in this study. Not only first generation panel unit root tests and panel cointegration tests, but also second generation tests that account for dependence between cross-sectional units were employed. The empirical results reveal that both energy consumption and economic growth are integrated as order one, and they are cointegrated. Panel fully modified ordinary least squares estimators show that a 1% increase in energy consumption increases the real value added of industrial sectors by 0.871%, and a 1% increase in real value added of industrial sectors increases energy consumption by 1.103%. The panel vector error correction models for causality tests are estimated by a system generalized moment method. We find a unidirectional causal relation running from economic growth to energy consumption in the shortrun. In the long run, however, there is evidence of a unidirectional causality running from energy consumption to economic growth.

Keywords: energy consumption; economic growth; industrial sectors; panel causality; cross-sectional dependence

1. Introduction

Energy is an indispensable input in the economic activity process. Since the reform and openness in 1978, China has become one of the fastest growing countries in the world, accompanied by rapidly increasing energy consumption. According to U.S. Energy Information Administration (EIA), China has become the largest global energy consumer and world's second largest oil consumer in 2010, just behind the U.S.

Coal accounted for the largest share (about 69%) in Chinese energy consumption in 2011. As a result, the country released 8.7 billion metric tons of carbon dioxide, and was the leading energy related carbon dioxide emitter in the world. Meanwhile, Chinese industrial sectors accounted for more than 60% of final energy consumption from 1980 to 2005, but they accounted for only 36%–53% of gross domestic product [1]. As the global environmental problem has become increasingly serious, in order to reduce heavy air pollution, the Chinese government planned to reduce energy intensity and carbon intensity by 16% and 17%, respectively, during the twelfth five-year plan period.

Against the background of energy conservation and emissions reduction, considering that Chinese industrial sectors account for the main carbon dioxide emissions, it is necessary to study the relationship of energy consumption and economic growth and offer policy suggestions on energy saving and emission reduction from the Chinese industrial sector perspective.

In this article, we use a data panel of 37 industrial sectors in China from 1998 to 2010 to examine the long-run equilibrium relationship and the causal relationship between energy consumption and economic growth. First, we examine these variables using panel unit root tests and panel cointegration tests. We use not only the first generation but also the second generation tests since the latter take dependence between cross-sectional units into consideration. We find that the two variables are both integrated of order one and cointegrated. Second, a panel fully modified ordinary least squares method is used to estimate the long run equilibrium equations. Third, sources of causality are examined through significance tests of coefficients in panel error correction models, which are estimated by system generalized moment method. We find that in the short run a unidirectional causal relation is running from economic growth to energy consumption while the direction is reversed in the long run.

The rest of the paper is organized as follows: Section 2 provides a brief literature review of energy consumption and economic growth from the viewpoint of data structure. Section 3 describes the industrial data that is used in the empirical research. Section 4 is the introduction of econometric methodologies. Section 5 presents empirical results and the interpretations. Section 6 concludes the paper with some policy implications.

2. Literature Review

Since the initial work of Kraft and Kraft [2], studying the relationship between energy consumption and economic growth has gradually aroused people's attention due to the growing concerns about global warming and climate change. There have been a large number of researches on this topic, see Ozturk [3], Payne [4] and Omri [5] for comprehensive surveys. Related studies focus on different countries, different variables and rely on various identification strategies, and not surprisingly, reach different results. In particular, Ozturk [3] synthesized the causal interaction between energy consumption and economic growth into four testable hypothesizes: neutrality, conservation (growth), and feedback hypothesis, which correspond to no causality, unidirectional causality running from economic growth (energy consumption) to energy consumption (economic growth), and bidirectional causality between them, respectively. In Omri [5], 48 country-specific studies about the causal relationship between energy consumption and economic growth over 1978–2012 were summarized, and the results revealed that 21%, 23%, 29%, and 27% supported the above four types of hypothesis, respectively,which means that empirical research about this field has not come to a consensus conclusion.

From the perspective of data structure, previous research mainly used time series data. Asafu-Adjave [6] examined the energy-income relationship for four Asian developing countries using nonstationary time series, and they considered a trivariate model rather than the usual bivariate model. In Shiu and Lam [7], and error correction model (ECM) with the annual data over the period 1971 to 2000 for China was used to identify the link between real gross domestic product (GDP) and electricity consumption, a long run equilibrium relationship and a growth hypothesis were found between the two series. Yuan *et al.* [8] tested the relationship between energy consumption and economic growth in China under the framework of the neo-classical one-sector aggregate production function where energy was treated as the third input besides capital and labor. They estimated the causality from a vector error correction (VEC) model using an annual data from 1963 to 2005, and supported growth hypothesis for electricity and GDP, while conservation hypothesis for total energy and GDP, and so on [9–13]. Most of these researches employed nonstationary time series methods, the main drawback for these methods is lack of power in small samples, which may result in wrong conclusions.

Compared with time series, panel data can provide much more information, so it has several advantages. Especially in nonstationary cases, panel unit root tests and cointegration tests have more power than those of time series data [14]. In recent years, with the improvement of data availability and the development of panel data methodologies, more and more researches about energy and economy have gradually switched to panel data. Lee and Chang [15] utilized panel data of 16 Asian economies from 1971 to 2002 to examine the causal interactions between energy consumption and real GDP, they found that in the long-run conservation hypothesis existed between energy consumption and GDP, but not *vice versa*. Taking into consideration panel heterogeneity, Akkemik and Goksal [16] examined the causality between energy consumption and GDP using panel Granger causality methodology developed by Hurlin and Venet [17], in which four different causal relationships, homogeneous (non-) causality, heterogeneous (non-) causality were presented, and so on [18–20].

Although more and more studies about the relationship between energy consumption and economic growth have started to use panel data, most of them were at a national or regional level [21–26]. There is little empirical research from the viewpoint of industrial sectors. Compared with regional level data, industrial level data has several advantages. First, Chinese industrial sectors account for more than a half of final energy consumption and main carbon dioxide emissions. Second, great differences in energy consumption can be observed across different industries, so researching on energy consumption and economic growth at an industry level is helpful for developing a more effective energy saving and emission reduction policy, as well as for adjusting industrial structure. As far as we know, the first one who studied energy consumption and economic growth from the perspective of industrial sectors was Hamit-Haggar [27]. The annual data for the period from 1990 to 2007 in 21 Canadian industrial sectors were collected, the long-run equilibrium and causal relationship among greenhouse gas emissions, energy consumption and economic growth were studied. Zhang and Xu [28] examined the relationship between energy consumption and economic growth from the view of sectors and regions using provincial level panel data from 1995–2008 in China, in which industrial, service, transport and residential sectors were examined, respectively. Meanwhile, this research also considered the regional level since the individual unit for the sector was still the province.

To the best of our knowledge, the causal relationship between energy consumption and economic growth for Chinese industrial sectors has not yet been studied. We will make up the gap with this article. Another advantage of using panel data is that we are able to allow for cross-sectional dependence. Most of existing studies in this area assumed that all the cross-sections were independent, this could be too restrictive for many cases [29]. In this paper, we will relax the assumption.

3. Data Description

This study makes use of panel data for 37 industrial sectors of China, covering the period from 1998 to 2010, detailed industries are reported in Table 1. A new identification (ID) for industrial sectoris defined in Table 1 for convenience. According to the national economy industry classification standard of China (GB/T 4754-2002) [30], there are 39 middle-categories industrial sectors. Due to data limitations, three industrial sectors are merged into other industrial sectors (ID: 37), they aremining of other ores (sector code: 11), manufacture of artwork and other manufacturing (sector code: 42) and recycling and disposal of waste (sector code: 43). Due to the adjustment of statistical caliber for industrial sectors of the National Bureau of Statistics of China, we limit the period from 1998 to 2010 to ensure the data consistency.

Due to data availability, only two variables are considered in this article. The first one is energy consumption (denoted by EC), and measured as total energy consumption in units of 10,000 tons of standard coal equivalent (tce). The EC data is obtained from the China Energy Statistical Yearbook. The second one is economic growth. We use the value added of industrial sectors as its proxy variable, and denote it as GDP. The statistical range for the value added of industrial sectors includes all state-owned industrial enterprises and the non-state-owned industrial enterprises with annual sales revenues over five million Yuan. The value added of industrial sectors is calculated based on the China Energy Statistical Yearbook. Then we transform the nominal value added of industrial sectors to the real valueusing the producer price indices for manufactured goods by sectors and 1990 is used as the base year. Both variables are converted into natural logarithms, and denoted as LEC (natural logarithms of EC) and LGDP (natural logarithms of GDP), respectively.

4. Methodology

We apply the panel Granger causality test to examine the relationship between energy and economic growth for Chinese industrial sectors in this article. It is well known that the data must be stationary when we use a Granger causality test [31]. Otherwise the regression may be spurious and will result in misleading conclusions, so stationarity tests for series should be conducted before performing the Granger test. Many researches in this field rely on the first generation unit root tests, such as Levin *et al.* (hereafter, LLC) [32] and Im *et al.* (hereafter, IPS) [33], to check the stationarity of series. An important assumption underlying the so-called first generation tests for unit roots is that units of the panel data are cross-sectional independent. However, this assumption is too restrictive in many empirical applications. For example, in this study, it is very likely that different industrial sectors are correlated, so the first generation tests may lead to unreliable results.

Table 1. Industrial sectors of China.

ID	Sector (Sector Code)
1	Mining and Washing of Coal (6)
2	Extraction of Petroleum and Natural Gas (7)
3	Mining and Processing of Ferrous Metal Ores (8)
4	Mining and Processing of Non-Ferrous Metal Ores (9)
5	Mining and Processing of Nonmetal Ores (10)
6	Processing of Food from Agricultural Products (13)
7	Manufacture of Foods (14)
8	Manufacture of Beverages (15)
9	Manufacture of Tobacco (16)
10	Manufacture of Textile (17)
11	Manufacture of Textile Wearing Apparel, Footware and Caps (18)
12	Manufacture of Leather, Fur, Feather and Related Products (19)
13	Processing of Timber, Manufacture of Wood, Bamboo, Rattan, Palm and Straw Products (20)
14	Manufacture of Furniture (21)
15	Manufacture of Paper and Paper Products (22)
16	Printing, Reproduction of Recording Media (23)
17	Manufacture of Articles For Culture, Education and Sport Activities (24)
18	Processing of Petroleum, Coking, Processing of Nuclear Fuel (25)
19	Manufacture of Raw Chemical Materials and Chemical Products (26)
20	Manufacture of Medicines (27)
21	Manufacture of Chemical Fibers (28)
22	Manufacture of Rubber (29)
23	Manufacture of Plastics (30)
24	Manufacture of Non-metallic Mineral Products (31)
25	Smelting and Pressing of Ferrous Metals (32)
26	Smelting and Pressing of Non-ferrous Metals (33)
27	Manufacture of Metal Products (34)
28	Manufacture of General Purpose Machinery (35)
29	Manufacture of Special Purpose Machinery (36)
30	Manufacture of Transport Equipment (37)
31	Manufacture of Electrical Machinery and Equipment (39)
32	Manufacture of Communication Equipment, Computers and Other Electronic Equipment (40)
33	Manufacture of Measuring Instruments and Machinery for Cultural Activity and Office Work (41)
34	Production and Supply of Electric Power and Heat Power (44)
35	Production and Supply of Gas (45)
36	Production and Supply of Water (46)
37	Other Industrial Sectors (11, 42, 43)

4.1. A Cross-Sectional Dependence Test

In this article, a simple cross-sectional dependence (CD) test suggested by Pesaran [34] is used. The proposed test is based on an average of pair wise correlation coefficients of the ordinary least squares residuals from individual regressions in the panel. The CD test is defined as:

$$CD = \sqrt{\frac{2T}{n(n-1)}}\left(\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\hat{\rho}_{ij}\right) \tag{1}$$

where $\hat{\rho}_{ij}$ is the sample estimate of the pair wise correlation between residual series i and j. Pesaran [34] showed that under the null hypothesis of no cross-sectional dependence, CD converges to a standard normal distribution as n tends to infinite and T is sufficient large.

4.2. Panel Unit Root Tests

Due to the lack of power of conventional unit root tests, panel unit root tests have been developed very quickly in recent twenty years. Panel unit root tests can be divided into two generations. The so called first generation tests include LLC test [32], IPS test [33], Breitung's test [35], Maddla and Wu [36] and Choi's Fisher-type tests using augmented Dickey-Fuller (ADF) and Phillips-Perron(PP) tests (hereafter Fisher-ADF and Fisher-PP tests) [37], and so on. Among these tests, LLC and Breitung's tests are homogeneous, *i.e.*, there is a common autoregression (AR) structure for all cross sections under the null hypothesis, which is too restrictive in reality. In this article, the other three heterogeneous panel unit root tests are chosen. In addition, compared with the first generation tests, the second generation tests that assume contemporaneous correlation are more and more popular in recent macroeconomic applications. Three main second generation panel unit root tests are proposed by Moon and Perron [38], Bai and Ng (hereafter, BN) [39] and Pesaran [40], respectively. According to the Monte Carlo comparisons by Lin *et al.* [41], the tests proposed by Pesaran are relatively robust, so we choose them in our empirical study.

4.3. Panel Cointegration Tests

If economic growth and energy consumption are non-stationary and integrated in the same order, then we should use the cointegration test to check the long-run equilibrium relationship between them. Panel cointegration tests can also be divided into two generations. The tests proposed by Kao [42] and Pedroni [43] are two famous representatives of the first generation [44]. Both tests are based on residuals of regression, which can be regarded as an extension of the traditional Engle-Granger two steps cointegration method [45]. In particular, Pedroni's tests allow for more heterogeneity [43]. However, both Kao [42] and Pedroni [43] assume cross-sectional independent, which is too strict in empirical studies. In order to avoid this shortcoming, the so called second generation panel cointegration tests that allow for cross-sectional dependence have been developed in recent years. One simple way to deal with the cross-sectional correlation is demeaning the data with respect to common time effects [46]. In our study, both the first and the second generation panel cointegration tests are used to explore the long-run equilibrium relationship between energy consumption and economic growth for the sake of robustness.

4.4. Panel Cointegration Tests

If the two variables in this article are cointegrated, then we could construct panel vector error correction model (PVECM) according to the Granger representation theorem as follows:

$$\Delta \mathrm{LGDP}_{it} = \alpha_{1i} + \gamma_1 \mathrm{ECT}_{1i,t-1} + \sum_{j=1}^{m} \Delta \mathrm{LGDP}_{it-j}\beta_{1j} + \sum_{j=1}^{n} \Delta \mathrm{LEC}_{it-j}\delta_{1j} + u_{1,it} \quad (2)$$

$$\Delta \mathrm{LEC}_{it} = \alpha_{2i} + \gamma_2 \mathrm{ECT}_{2i,t-1} + \sum_{j=0}^{p} \Delta \mathrm{LGDP}_{it-j}\beta_{2j} + \sum_{j=1}^{q} \Delta \mathrm{LEC}_{it-j}\delta_{2j} + u_{2,it} \quad (3)$$

in which, Δ is the difference operator, $\mathrm{ECT}_{1,it}$ and $\mathrm{ECT}_{2,it}$ are the error correction terms obtained from the residuals of the following cointegration equations, respectively:

$$\mathrm{LGDP}_{it} = \alpha_{1i} + \mathrm{LEC}_{it}\beta_1 + u_{1,it} \quad (4)$$

$$\mathrm{LEC}_{it} = \alpha_{2i} + \mathrm{LGDP}_{it}\beta_2 + u_{2,it} \quad (5)$$

in which, α_{1i} and α_{2i} are used to describe individual heterogeneity, and β_1 and β_2 denote the long-run equilibrium relationship. If LGDP and LEC are cointegrated, we could not use ordinary least squares (OLS) method or fixed effect method to estimate Equations (4) and (5). Since the *t*-statistic diverges. Kao and Chiang [47] suggested using fully modified ordinary least squares estimator (FMOLS) to estimate Equations (4) and (5).

Since lagged dependent variables are included in Equations (2) and (3), they are typical dynamic panel data models. In this case, both fixed and random effects estimator in static model are biased and inconsistent. In order to get consistent estimator, Arellano and Bond [48] developed generalized method of moments (GMM) estimator for dynamic panel data model, which was known as difference GMM (hereafter, DIF-GMM). Nevertheless, DIF-GMM often suffers from finite sample bias because of the weak instruments problem. Blundell and Bond [49] proposed so called system GMM (hereafter, SYS-GMM) to improve the property of DIF-GMM. Monte Carlo simulation results showed that SYS-GMM is more efficient and robust than DIF-GMM in finite sample. So, we choose SYS-GMM to estimate Equations (2) and (3) in this article.

After estimating the panel vector error correction models by SYS-GMM, three different sources of causality could be examined through the significance tests of coefficients forthe null hypotheses as follows:

(i) Short-run Granger causality
$H_0: \delta_{1j} = 0, \forall j = 1, \cdots, n$ in Equation (2)
$H_0: \beta_{2j} = 0, \forall j = 1, \cdots, p$ in Equation (3)

(ii) Long-run Granger causality
$H_0: \gamma_1 = 0$ in Equation (2)
$H_0: \gamma_2 = 0$ in Equation (3)

(iii) Strong Granger causality
$H_0: \delta_{1j} = 0, \forall j = 1, \cdots, n$ and $\gamma_1 = 0$ in Equation (2)
$H_0: \beta_{2j} = 0, \forall j = 1, \cdots, p$ and $\gamma_2 = 0$ in Equation (3)

5. Empirical Results

Table 2 presents the descriptive statistics and CD tests about natural logarithms of energy consumption (LEC) and natural logarithms of GDP (LGDP). The CD statistics show that the cross-correlations are statistically significant at 1% significance level for the raw data, so cross sectional dependence should be considered in the following steps.

Table 2. Descriptive statistics and cross-sectional dependence (CD) tests.

Variable	Obs	Mean	Std. Dev.	Min	Max	CD statistics
LGDP	481	6.404	1.216	1.792	9.843	89.05 *** (0.00)
LEC	481	7.235	1.397	4.383	10.960	66.82 *** (0.00)

*** indicates statistical significance at the 1% significance level. The *p*-values are given in parenthesis. Std. Dev, Min and Max are abbreviation for standard deviation, minimum and maximum, respectively.

Figure 1 provides an overview of the average energy consumption (measured in 10,000 tons of coal equivalent), average economic growth (the value added of industrial sectors, denoted by GDP) for the 37 industrial sectors in China over 1998 to 2010. In addition, we add the average energy intensity (calculated as units of total energy consumed per unit of GDP).The energy consumption of different industries is very different, so is the energy intensity. In particular, for the sector of Processing of Petroleum, Coking, Processing of Nuclear Fuel (ID = 18), Manufacture of Raw Chemical Materials and Chemical Products (ID = 19), Manufacture of Non-metallic Mineral Products (ID = 24), Smelting and Pressing of Ferrous Metals (ID = 25), Smelting and Pressing of Non-ferrous Metals (ID = 26), and Production and Supply of Electric Power and Heat Power (ID = 34), both the energy consumption and energy intensity are large.

Panel unit root tests are tabulated in Table 3. Columns 2–4 present the first generation tests, all of them do not reject the null hypothesis of unit root for the level data, and reject the null hypothesis of unit root for differential datasets, which mean that the series LGDP and LEC are integrated of order one. Column 5 presents the Pesaran's cross-sectionally augmented IPS (hereafter, CIPS) tests for the sake of cross sectional dependence. The limit distribution of CIPS are non-standard, for the case $(N, T) = (37, 13)$ with intercept and trend, the critical values of CIPS for 1%, 5% and 10% significance level are −2.8, −2.64, −2.55, respectively, and for $(N, T) = (37, 12)$ with intercept, the critical values of CIPS for 1%, 5% and 10% significance level are −2.26, −2.11, −2.03, respectively. Compared the CIPS statistics with the above critical values, the results show that for LGDP and LEC the unit root hypothesis is convincingly rejected. So we proceed as taking LGDP and LEC as $I(1)$ variables.

Then, panel cointegration tests are used to examine the long-run relationship between economic growth and energy consumption, which are reported in Table 4. From the first generation cointegration tests, all statistics consistently reject the null of no cointegration at 1% significance level except Pedroni's Group-rho statistic. In addition, the so called second generation tests that account for dependence between the cross-sectional units are also used. Westerlund [46] employed the bootstrap approach to deal with the cross sectional dependence. In this article, the number of replications for bootstrap is set to 50. And in most cases, the statistics reject the null of no cointegration. The results confirm the existence of co-movement between the two series. Then, we proceed as exploring the long run equilibrium relationship between the series by FMOLS.

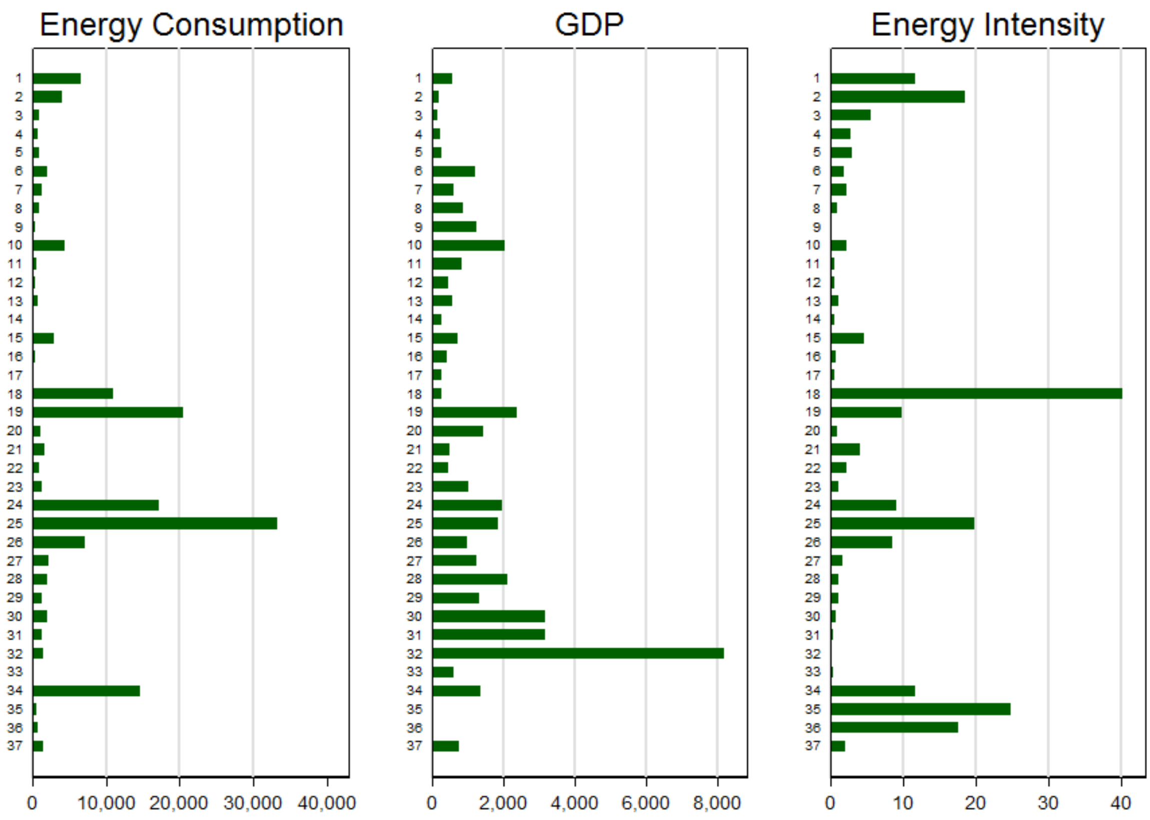

Figure 1. Energy consumption, GDP and energy intensity for 37 industrial sectors in China.

Table 3. Panel unit root tests.

Variable	IPS	Fisher-ADF	Fisher-PP	CIPS
LGDP	5.41 (1.00)	19.04 (1.00)	21.62 (1.00)	−2.22
LEC	5.00 (1.00)	30.99 (1.00)	25.15 (1.00)	−2.03
ΔLGDP	−4.29 *** (0.00)	124.94 *** (0.00)	149.99 *** (0.00)	−2.492 ***
ΔLEC	−8.23 *** (0.00)	200.55 *** (0.00)	320.63 *** (0.00)	−2.665 ***

*** indicates statistical significance at the 1% significance level. The *p*-values are given in parenthesis. Δ is the difference operator.

Using the panel FMOLS technique for cointegrated panels developed by Kao and Chiang [45], we estimate the long-run equilibrium relationship between economic growth and energy consumption. The advantage of using the FMOLS approach is that it corrects for both the endogeneity bias and serial correlation of the OLS estimators in presence of cointegrated panels, and allows for consistent and efficient estimators. Table 5 presents the results of the panel FMOLS. The slope coefficients of Equations (4) and (5) are positive and statistically significant at 1% significance level. The results indicate that 1% increase in energy consumption increases real value added of industrial sectors by 0.871%. In turn, 1% increase in real value added of industrial sectors increases energy consumption by 1.103%. The residuals of Equations (4) and (5) are saved as $ECT_{1,it}$ and $ECT_{2,it}$, respectively.

Then, panel error correction models (Equations (2) and (3) are estimated to determine the direction of the causal relationship between the real value added of industrial sectors and energy consumption. The Hansen's J test and testing for the absence of serial correlation in error term are used to determine the lags of Equations (2) and (3). The system GMM estimate results are presented in Table 6.

By testing the significance of the coefficient of the independent variables in Equations (2) and (3), the source of causation can be identified, and the results are reported in Table 7.

Table 4. Panel cointegration tests.

Methods	Statistics	Equation (4)	Equation (5)
Pedroni	Panel-variance	3.488 *** (0.000)	2.314 ** (0.011)
	Panel-rho	−2.142 ** (0.016)	−2.892 *** (0.002)
	Panel-PP	−6.156 *** (0.000)	−7.133 *** (0.000)
	Panel-ADF	−3.222 *** (0.001)	−7.243 *** (0.000)
	Group-rho	0.495 (0.689)	−0.046 (0.482)
	Group-PP	−6.757 *** (0.000)	−6.502 *** (0.000)
	Group-ADF	−5.619 *** (0.000)	−6.923 *** (0.000)
Kao	ADF	−3.237 *** (0.001)	−2.601 *** (0.005)
Westerlund	G_τ	−1.435 *** (0.000)	−2.686 *** (0.000)
	G_α	−2.612 (0.120)	−6.863 *** (0.000)
	P_τ	−5.539 * (0.080)	−10.384 (0.140)
	P_α	−1.523 * (0.080)	−5.596 ** (0.020)

***, **, * indicate statistical significance at the 1%, 5% and 10% significance level, respectively. The *p*-values are given in parenthesis. For Pedroni's panel variance ratio statistic, the right tail of the normal distribution is used to reject the null hypothesis of no cointegration, while for the remaining six statistics; the left tail of the normal distribution is used to reject the null hypothesis.

Table 5. Fully modified OLS estimates.

Coefficient	Equation (4)	Equation (5)
β	0.871 *** (11.875)	1.103 *** (42.054)

*** indicates statistical significance at the 1% significance level. The *t*-statistics are given inparenthesis.

Table 6. System generalized method of moments (SYS-GMM) estimates.

Variables	$\Delta LGDP_{it}$	ΔLEC_{it}
$ECT_{1i,t-1}$	−0.187 ** [−4.30]	-
$ECT_{2i,t-1}$	-	−0.0355 [−1.32]
$\Delta LGDP_{it-1}$	0.299 ** [2.25]	0.392 *** [3.96]
$\Delta LGDP_{it-2}$	0.048 [0.22]	−0.265 ** [−2.23]
$\Delta LGDP_{it-3}$	0.049 [0.48]	−0.028 [−0.24]
ΔLEC_{it-1}	0.041 [0.86]	0.038 * [0.54]
Constant	0.098 *** [6.68]	0.066 ** [2.52]
AR(1)	−4.28 *** (0.00)	−4.37 *** (0.00)
AR(2)	−0.76 (0.45)	−0.96 (0.34)
Hansen-J	36.14 (0.69)	35.66 (0.99)

***, **, * indicate statistical significance at the 1%, 5% and 10% significance level, respectively. The *p*-values are given in parenthesis, and the *t*-statistics are given in square brackets.

Table 7. Panel causality tests.

Dependent	Source of Causation				
	Short-Run		Long-Run	Strong (Joint)	
	ΔLGDP	ΔLEC	ECT	ΔLGDP & ECT	ΔLEC & ECT
ΔLGDP	-	0.74 (0.40)	18.50 *** (0.00)	-	9.37 *** (0.00)
ΔLEC	5.27 *** (0.00)	-	1.75 (0.19)	4.25 *** (0.01)	-

*** indicates statistical significance at the 1% significance level. The *p*-values are given in parenthesis.

From Table 7, a unidirectional causal relation running from LGDP to LEC is found in the shortrun. The coefficient of ECT is significant in Equation (2), but not significant in Equation (3), which means that there is evidence of unidirectional causality running from LEC to LGDP in the long-run. This result can be interpreted in the following aspects. From the perspective of industrial data, the heterogeneity of industrial energy consumption and energy intensity are significantas shown in Figure 1. In the short run, the government could eliminate some high-energy consumption and high-energy intensity enterprises (such as Processing of Petroleum, Coking, Processing of Nuclear Fuel (ID = 18), Smelting and Pressing of Ferrous Metals (ID = 25), Manufacture of Metal Products (ID = 34)) to control for the energy consumption without decreasing the economic growth. But in the long run, energy as a crucial factor of production, reducing energy consumption will reduce economic growth if we do not change the current production technology. Finally, strong bidirectional causality is found between LGDP and LEC.

6. Conclusions and Policy Implications

In this article, we use panel error correction models to study the panel causality between energy consumption and economic growth. Panel data of 37 industrial sectors in China from the period 1998 to 2010 are used. We check the series using cross-sectional dependence test, and find that the cross-correlations are statistically significant at 1% significance level for the raw data. Then the second generation panel unit root tests and panel cointegration tests that account for cross-sectional dependence are used to examine the data, we find that both series are integrated of order one. And long-run equilibrium relationship between energy consumption and economic growth are also found at industrial levels, in particular, a 1% increase in energy consumption increases the real value added of industrial sectors by 0.871%. Panel Granger causality tests show that there is a strong bidirectional causal relationship between energy consumption and economic growth. In the short run, unidirectional causal relation is running from economic growth to energy consumption, *i.e.*, conservation hypothesis is found. However, the causal relationship is reversed in the long run, *i.e.*, growth hypothesis is found.

Policy implications of the empirical results are presented as follows. In the short run, the industrial policies of conserving energy consumption may be implemented with little adverse effect on economic growth for several reasons. First, the government may control energy use for industries whose energy consumption and energy intensity are high in the short period. For example, the municipal government of Beijing released a Five-Year Clean Air Action Plan (2013–2017) to limit industrial and traffic pollution by a set of new measures in 2013, according to this plan, the government shut down a lot of heavy factories temporarily during the Asia-Pacific Economic Cooperation meetings in 2014 and so on. Second, the government could control the energy intensity of the enterprises in short term.

For example, the so called Top 10,000 Energy-Consuming Enterprises Program implemented by the Chinese government in the framework of the 12th Five-Year Plan. The designated enterprises are required to achieve the 16% energy intensity reduction relative to 2010. These measures could also reduce energy consumption without affect economic growth. From another perspective, Chinese economy is entering a new normal stage of structural adjustment, the slower pace of economic growth could reduce the energy consumption in short term. However, In the long run, energy is one of the indispensable factors for economic growth, policies of blindly restricting the use of energy in industrial sectors to achieve the purpose of energy saving and emission reduction may adversely affect economic growth. In order to maintain sustained economic growth while saving energy and reducing emission, the government could start from the following aspects. First, adjust the industrial structure and gradually switching from high energy-consuming and high energy-intensity to low energy-consuming and low energy-intensity industries. Second, adjust the energy consumption structure and gradually switching from high emission energy, such as coal, oil and other fossil energy to renewable energy, such as hydropower, solar energy, wind power and biofuels. Third, the government needs to promote enterprises to carry out technological innovation and improve the production process to reduce their energy intensity therefore achieve energy saving and emission reduction.

The main contribution of the paper is to investigate the relationship between energy consumption and economic growth in China at industrial level with bivariate panel econometric model. However, we only consider two variables in the model because of the limitations of available industrial data in China. Hopefully, we would be able to include more related variables, such as labor, capital and energy price, to conduct more rigorous analysis in the future.

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Author Contributions

All authors contributed to this work. Yi Hu was responsible for the empirical analysis using econometrics techniques. Dongmei Guo and Mingxi Wang were responsible for data collection and data preprocessing. Xi Zhang proposed the original idea of this work and performed the original manuscript. The project was supervised by Professor Shouyang Wang, he commented on the results and conclusions and gave us a lot of key suggestions. All authors revised the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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