

Drivers of Declining Energy Intensity all over the World: Based on the Perspective of National Industrial Production

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Abstract

Improving the world's aggregate energy efficiency is consequential for global sustainable development. This paper evaluated the world's aggregate energy intensity reduction along with economic growth and industrial transformation using the panel data of all countries around the world from 1971 to 2016. The overall energy intensity of the world was decomposed into activity mix and national intensity based on LMDI approach, and we found that the latter was the main driving force for the reduction of the world's overall energy intensity. We further analyzed the relationship between energy prices, technological progress, and national intensity. The results showed that technological progress and energy prices significantly decreased national intensity, with significant regional differences, however, no significant impact appeared in a price-declining period. To reduce energy intensity, localized measures in different supra-national regions are needed.

Keywords: *Energy intensity, LMDI approach, Regression analysis, Industrial production*

I. Introduction

Energy intensity, which is defined as the total amount of energy consumed per unit of gross domestic product (GDP), is an essential index of energy efficiency, carbon emissions, and sustainable development[1]. From the Kyoto Protocol passed in 1997 to the Paris Agreement signed in 2016, which would further promote the reshaping of the world's energy pattern, all countries were trying to reduce their energy intensity and have achieved remarkable results.

Along with economic growth and industrial transformation, global energy intensity has been significantly reduced. The focus of this research is the issue of declining energy intensity of all countries in the world, which combined Logarithmic Mean Divisia Index (LMDI) decomposition and regression analysis. The study explored the drivers of declining energy intensity all around the world from comprehensive perspectives of country-specific growth, energy prices, and technological progress. The research can be conducive to further tap the potential of energy intensity decline in the future by taking targeted measures, and it helps to construct an eco-friendly and low-carbon global energy governance pattern and to promote global sustainable development.

A brief overview of the article is as follows. In section 2, we review the research on the improvement of energy efficiency. Section 3 provides details of the methodology used. We measure the relative contributions of the activity mix and national intensity by employing the Logarithmic Mean Divisia Index (LMDI) approach to our sample in section 4. Section 5 employs regression analysis to investigate the association between energy prices, technological

progress and national intensity at the national level. Lastly, we present the discussions and conclusions in Section 6.

II. Literature Review

Due to the 1973 oil crisis, the importance of energy efficiency was realized by some major countries[2,3]. As a key indicator to measure energy efficiency, the magnitude of (and changing trends in) energy intensity is important for the overall energy consumption, the level of carbon emissions, and sustainable development capacity[1]. Relevant topics are widely concerned by scholars around the world. Theoretical and empirical studies regarding energy intensity are on the increase[2]. Previous studies in these fields were mostly based on decomposition methods[4,5], which could be divided into structural decomposition analysis (SDA) and index decomposition analysis (IDA)[6]. Based on the input-output table, SDA distinguishes the influencing factors of decomposed variables more meticulously, such as the Leontief effect[7] and the final demand structure effect[8]. Meanwhile, SDA also has a higher requirement for essential data. IDA, however, is more flexible and convenient in empirical studies, which can analyze the aggregated data to detect different influencing factors at an annual or even monthly level[9]. Under given conditions, SDA and IDA are consistent[9] and can be derived and transformed from each other[10]. The energy intensity changes in different countries from different years have been analyzed by related empirical studies, such as the United States in 1985–2010[11], Australia in 1978–2009[12], and Canada in 1990–2004[13]. Since the reform and opening up, a 70% reduction of China's energy intensity exceeded the global average level of 36%, which has drawn worldwide attention from the academic communities. Hence, more empirical analyses based on the decomposition method took China as the research sample[14,15].

Although the results of IDA and SDA are always robust in empirical analyses of the influencing factors on energy intensity[16]. However, according to Metcalf[17], significant deficiencies, such as missing core variables, undermine the theoretical basis of the decomposition method. Some scholars hold that energy prices were important factors affecting changes in energy intensity[18]. The rising energy prices would encourage new energy technology innovations, and thus reducing energy intensity by reducing energy demand[2]. Some studies based on econometrics have measured the influence of related factors (such as energy prices) on energy intensity or energy efficiency at the country (or limited national groups) level[19,20]. However, due to the limitation of lacking energy prices data, most empirical analysis was based on a single country. For example, some scholars have empirically assessed how price changes affected variations in energy intensity in a variety of industry sectors based on the output of Canadian industries and fuel price index data[20]. And others have demonstrated the negative impact of energy prices on energy intensity in the United States[17]. A few empirical studies have measured the differences in impact mechanism in the short- and long-term between different countries, using Brent crude oil prices to proxy for energy prices[21]. According to Jimenez and Mercado[22], the synthetic control method was applied to demonstrate that economic growth and energy prices were the determinants of energy intensity changes in Latin American countries by constructing counterfactual examples. Parker et al.[23] have illustrated that energy prices were instrumental in energy intensity and found different effects in different countries. Most of those studies confirmed that as energy prices increased, energy intensity would decrease sharply[2,18].

The literature review conducted for this paper identified several theoretical and practical gaps: (1) Existing research was short of a comprehensive theoretical analysis and empirical research framework, thus failed to give a full picture of changes in energy intensity. (2) Most empirical research using the decomposition method was conducted from the perspective of sub-industry sectors, while few studies focused on the country-specific. (3) The association between national intensity and energy prices across nations and time was difficult to be realized by relevant econometrics studies due to the lack of an accurate measure of the energy prices.

Compared with the predecessors, this paper focused on the issue of "drivers of declining energy intensity around the world" and proposed a conceptual framework for global energy intensity analysis. Firstly, using a country-specific LMDI method, the paper decomposed global energy intensity into country-specific activity mix and national intensity. Then, energy depletion or energy rent were used to estimate country-specific energy prices indicator, and

the mechanism that energy prices impacted national intensity was discussed based on the production cost function. Furthermore, we carried out empirical research and came to the conclusions and recommendations from panel data of countries.

III. Methodology and Data

3.1 LMDI approach

First, the energy intensity around the world was decomposed based on the IDA, where the results of LMDI was the most robust[24] and convergence, and it was an easy interpretation of the results. In traditional LMDI analyses, V is the variable to be decomposed, n factors are recorded as $x_1, x_2, x_3, \dots, x_n$, and the i subcategory is denoted as $V_1, V_2, V_3, \dots, V_i$ that represent the subclass of the decomposed variable.

$$V = \sum_i V_i = \sum_i x_{1,i} x_{2,i} \cdots x_{n,i} \quad (1)$$

The decomposed variables are denoted as V^{t_0} and V^{t_1} in time periods t_0 and t_1 . ΔV_{tot} is the difference between V^{t_1} and V^{t_0} :

$$\Delta V_{\text{tot}} = V^{t_1} - V^{t_0} = \Delta V_{x_1} + \Delta V_{x_2} + \cdots + \Delta V_{x_n} \quad (2)$$

In Eq. (2), the contribution of the k th factor can be calculated by the following formula:

$$L(V_i^{t_1}, V_i^{t_0}) = (V_i^{t_1} - V_i^{t_0}) / (\ln V_i^{t_1} - \ln V_i^{t_0}) \quad (3)$$

$$\Delta V_{x_k} = \sum_i L(V_i^{t_1}, V_i^{t_0}) \ln \left(\frac{x_{k,i}^{t_1}}{x_{k,i}^{t_0}} \right) = \sum_i \frac{V_i^{t_1} - V_i^{t_0}}{\ln V_i^{t_1} - \ln V_i^{t_0}} \ln \left(\frac{x_{k,i}^{t_1}}{x_{k,i}^{t_0}} \right) \quad (4)$$

Based on the traditional LMDI decomposition method, this paper further constructed a country-specific LMDI decomposition approach to study the changing of global energy intensity. The overall energy consumption of all countries in the world can be expressed as follows:

$$E = \sum_i E_i = \sum_i \frac{E_i}{Q_i} \frac{Q_i}{Q} = \sum_i I_i S_i Q \quad (5)$$

where E is the total energy consumption (TPES) of the countries around the world and Q represents the total output (GDP). E_i is the energy consumption (TPES) of country i , Q_i is the economic output (GDP) of country i , I_i represents the energy intensity of country i , and S_i is the proportion of economic output of country i in all countries. The energy intensity of all countries around the world can be further expressed as:

$$EI = \frac{E}{Q} = \frac{\sum_i E_i}{Q} = \sum_i \frac{E_i}{Q_i} \frac{Q_i}{Q} = \sum_i I_i S_i \quad (6)$$

The change of total energy intensity in all countries between period t_0 to t_1 is recorded as ΔEI . Equation (7) showed that ΔEI is affected by the factors of country-specific activity mix (ΔEI_s) and national intensity (ΔEI_i). Country-specific activity mix (ΔEI_s) measures the impact of different countries' growth on the overall energy intensity. National intensity (ΔEI_i) measures the impact of national intensity changes on the overall energy intensity.

$$\Delta EI = \frac{\sum_i E_i^{t_1}}{Q^{t_1}} - \frac{\sum_i E_i^{t_0}}{Q^{t_0}} = \Delta EI_s + \Delta EI_i \quad (7)$$

ΔEI_s , ΔEI_i can be calculated by equations (8) and (9) separately. r_{Q_i} and r_{E_i} represent the growth rate of economic output and the growth rate of the energy consumption of country i from period t_0 to t_1 .

$$\Delta EI_s = \sum_i \frac{\frac{E_i^{t1}}{Q_i^{t1}} - \frac{E_i^{t0}}{Q_i^{t0}}}{\ln(\frac{E_i^{t1}}{Q_i^{t1}}) - \ln(\frac{E_i^{t0}}{Q_i^{t0}})} \ln(\frac{S_i^{t1}}{S_i^{t0}}) = \sum_i \frac{\frac{E_i^{t1}}{Q_i^{t1}} - \frac{E_i^{t0}}{Q_i^{t0}}}{\ln(\frac{E_i^{t1}}{Q_i^{t1}}) - \ln(\frac{E_i^{t0}}{Q_i^{t0}})} \ln(\frac{1+r_{Q_i}}{1+r_{Q_i}}) \quad (8)$$

$$\Delta EI_i = \sum_i \frac{\frac{E_i^{t1}}{Q_i^{t1}} - \frac{E_i^{t0}}{Q_i^{t0}}}{\ln(\frac{E_i^{t1}}{Q_i^{t1}}) - \ln(\frac{E_i^{t0}}{Q_i^{t0}})} \ln(\frac{I_i^{t1}}{I_i^{t0}}) = \sum_i \frac{\frac{E_i^{t1}}{Q_i^{t1}} - \frac{E_i^{t0}}{Q_i^{t0}}}{\ln(\frac{E_i^{t1}}{Q_i^{t1}}) - \ln(\frac{E_i^{t0}}{Q_i^{t0}})} \ln(\frac{1+r_{E_i}}{1+r_{E_i}}) \quad (9)$$

3.2 How industrial production affected national intensity?

Formula (9) calculates the contribution of national intensity to overall changes in energy intensity all over the world. However, further theoretical analyses and empirical studies are needed because of a legion of influencing factors of energy intensity change in a country. Based on the Cobb-Douglas production function and previous studies, such as Fisher-vanden[19] and Samuel[20], we constructed a national intensity impact model through a typical industrial production costs under the assumption of constant returns to scale. The factors, capital (K), labor (L), energy (E), and raw materials (M), are mainly included in the production function. The production cost function of country i can be shown as:

$$C_i = C(P_{i,K}, P_{i,L}, P_{i,E}, P_{i,M}, Q_i; A_i^{-1}) = A_i^{-1} P_{i,K}^{\alpha_{i,K}} P_{i,L}^{\alpha_{i,L}} P_{i,E}^{\alpha_{i,E}} P_{i,M}^{\alpha_{i,M}} Q_i \quad (10)$$

where C_i is the production cost of country i ; Q_i represents the economic output. $P_{i,K}, P_{i,L}, P_{i,E}, P_{i,M}$ denotes the prices of capital, labor, energy, and raw materials, respectively; $\alpha_{i,K}, \alpha_{i,L}, \alpha_{i,E}, \alpha_{i,M}$ is the elasticity of each input element. A_i is used to measure technical progress. Based on Shephard's Lemma, we can obtain the energy demand (E_i) of each country:

$$E_i = \frac{\alpha_{i,E} A_i^{-1} P_{i,K}^{\alpha_{i,K}} P_{i,L}^{\alpha_{i,L}} P_{i,E}^{\alpha_{i,E}-1} P_{i,M}^{\alpha_{i,M}} Q_i}{P_{i,E}} \quad (11)$$

The average price of overall output, denoted as $P_{i,Y}$, can be expressed as $P_{i,K}^{\alpha_{i,K}} P_{i,L}^{\alpha_{i,L}} P_{i,E}^{\alpha_{i,E}} P_{i,M}^{\alpha_{i,M}}$ by reference to the studies of Samuel et al.[20], and shown in the following formula:

$$P_{i,Y} = P_{i,K}^{\alpha_{i,K}} P_{i,L}^{\alpha_{i,L}} P_{i,E}^{\alpha_{i,E}} P_{i,M}^{\alpha_{i,M}} \quad (12)$$

Then the energy intensity (I_i) of country i can be represented as:

$$I_i = \frac{E_i}{Q_i} = \frac{\alpha_{i,E} A_i^{-1} P_{i,Y}}{P_{i,E}} \quad (13)$$

We can obtain the model of influencing factors of national intensity by taking the logarithm of both sides of the above equation:

$$\ln(I_i) = \alpha + \beta \ln\left(\frac{P_{i,E}}{P_{i,Y}}\right) + \gamma \ln(A_i) + \varepsilon_i \quad (14)$$

The relative price of energy ($\frac{P_{i,E}}{P_{i,Y}}$) can be further measured as follows:

$$\frac{P_{i,E}}{P_{i,Y}} = \frac{P_{i,E} / P_{i,Y} * \text{Energy}_{i, \text{production}} / \text{Economy}_{i, \text{output}}}{\text{Energy}_{i, \text{production}} / \text{Economy}_{i, \text{output}}} = \frac{P_{i,E} * \text{Energy}_{i, \text{production}} / P_{i,Y} * \text{Economy}_{i, \text{output}}}{\text{Energy}_{i, \text{production}} / \text{Economy}_{i, \text{output}}} \quad (15)$$

$Energy_{i,production}$ and $Economy_{i,output}$ represent respectively the physical energy output and the economic output in country i . And $\frac{P_{i,E} * Energy_{i,production}}{P_{i,Y} * Economy_{i,output}}$ is the ratio of energy output to economic output by value.

The level of technological progress can be measured by the percentage of research and development in GDP or the number of technicians (per million). To address the lack of data in our long-time sequence, the paper uses the three-year average of GDP per capita growth to proxy for technological advance, as seen from Roberto et al.[21]. In addition, the regional dummy variable θ_i tracks regional fixed effects, and a year dummy variable θ_t controls for macroeconomic cyclical fluctuations. The model therefore becomes:

$$\ln(I) = \alpha + \beta \ln\left(\frac{P_{i,E}}{P_{i,Y}}\right) + \gamma \ln(\text{growth}) + \delta_1 \theta_i + \delta_2 \theta_t + \varepsilon_i \quad (16)$$

3.3 Data source

Our data on GDP_2010_PPP (billion 2010 US\$ using PPPs), Population (millions), Total primary energy supply (TPES, million tons of oil equivalent), and Energy production (EP, million tons of oil equivalent) of countries all around the world comes from the International Energy Agency (IEA). The data on GDP_Current (current US\$), energy depletion (current US\$), the share of natural rent (%), coal rent (%), oil rent (%), natural gas rent (%), and the data related to technological progress (R&D or TEC) are from the World Bank database. The summary statistics of the raw data used are shown in Table 1:

Table 1 Descriptive statistics of selected variables

| Variable | Obs | Mean | Std. Dev. | Min | Max |
|------------------|------|-----------|-----------|----------|----------|
| GDP_Current | 5407 | 2.63e+11 | 1.08e+12 | 1.27e+08 | 1.87e+13 |
| GDP_2010_PPP | 5690 | 432.9155 | 1322.068 | 0.37 | 19450.44 |
| POP | 5690 | 42.23676 | 138.1782 | 0.03 | 1378.67 |
| TPES | 5690 | 68.79776 | 236.7264 | 0.02 | 2991.43 |
| R&D | 1600 | 0.9679893 | 0.9370626 | 0.00544 | 4.42859 |
| TEC | 894 | 583.1745 | 636.5097 | 2.01666 | 3766.862 |
| Total rent | 5383 | 7.903636 | 12.23026 | 0 | 89.00431 |
| Coal rent | 5298 | 0.1584536 | 0.7295541 | 0 | 25.31577 |
| Oil rent | 5328 | 5.059299 | 11.27991 | 0 | 88.86557 |
| Gas rent | 5307 | 0.539352 | 2.668249 | 0 | 67.14671 |
| Energy depletion | 5986 | 2.96e+09 | 1.12e+10 | 0 | 2.29e+11 |

Note: Rent refers to the difference between the production value of resources calculated at international prices and the total cost of production. Natural resource rents mainly include oil rents, natural gas rents, coal (hard and soft coal) rents, mineral rents, etc. Energy depletion is equal to the ratio of the stock of energy resources to the remaining time of storage and development (25 years at most).

Sources: “changing the wealth of nations: a new millennium method for measuring sustainable development” (2011). Statistical calculations by the author.

IV. Empirical Results

First, our country-specific LMDI method was used to decompose and analyze the overall changes of energy intensity from 1971 to 2016, and then further examined the country differences affecting the aggregate energy intensity reduction of the world. Second, based on the regression analysis, we explored the drivers of the national intensity reduction, thus providing a scientific reference to improve energy efficiency all over the world.

4.1 Decomposition of the world's energy intensity

This paper decomposed the aggregate energy intensity of the world from 1971 to 2016. The results were detailed in Table 2.

**Table 2 Decomposition Results of Energy Intensity all over the world
(kilogram oil equivalent/ \$10,000, 2010 USD using PPPs)**

| | |
|---|-----------|
| | n= 108 |
| Time interval | 1971–2016 |
| Initial energy intensity | 2111.72 |
| Terminal energy intensity | 1181.21 |
| Energy intensity variation | -930.51 |
| Contribution of country-specific activity mix (ΔEI_s) | 267.00 |
| Contribution of national intensity (ΔEI_i) | -1197.51 |

Source: statistical calculations by the author.

Table 2 displayed that the energy intensity of the whole world showed a downward trend from 1971 to 2016. The aggregate energy intensity decreased from 2111.72 kgoe/\$10,000 to 1181.21 kgoe/\$10,000 in 46 years, which was a total decrease of about 930.51 kgoe/\$10,000. National intensity (ΔEI_i), with a contribution of more than 100%, became the main factor that promoted the overall energy intensity reduction all over the world.

The paper further examined the national differences affecting the overall reduction in energy intensity of the world. America, Germany, Japan, Britain, and France contributed the most to this reduction, with decreases of -535.213, -113.3091, -84.22095, -80.79302, and -50.70898 kgoe /\$10,000, respectively. When analyzed by the influencing factors, America, Germany, Japan, Britain, and France contributed the most to the activity mix, at -121.473, -47.89566, -30.71163, -27.65, and -26.81421 kgoe/\$10,000 respectively. Meanwhile, five countries (China, America, Germany, India, and Japan), contributed the most to the reduction in national intensity, at -419.1555, -413.7401, -65.41348, -58.68981, and -53.50932 kgoe/\$10,000, respectively.

4.2 The connection between energy prices, technological progress and national intensity

Based on the country-specific LMDI approach, the energy intensity of countries all around the world was analyzed in the previous section. However, there was no valid explanation of the sharp fall in national intensity. The following empirical analysis would further explore this issue. Based on formula (14) - (15) above, the quantitative relationship between energy prices, technological progress and national intensity was revealed.

First, according to Equation (15), the energy prices were estimated, where $Energy_{i,production}$ was the energy production of each country, and $Economy_{i,output}$ was the physical quantity of economic output measured by GDP_2010_PPP. $P_{i,Y} * Economy_{i,output}$ could be proxied by GDP_Current. Referring to the measurement of energy depletion provided by the World Bank, the proxy of $P_{i,E} * Energy_{i,production}$ could be measured using energy

depletion (current US\$). In general, the energy prices throughout the world grew 125% from 1971 to 2016.

In order to test the robustness of our results, another energy prices indicators ($\frac{P_{i,E}}{P_{i,Y_1}}$) were constructed. By applying the World Bank's method of measuring resource rents, the energy rent (calculated as the sum of coal rent, oil rent, and gas rent in each country) can also be used to proxy for $P_{i,E} * \text{Energy}_{i,\text{production}}$. Overall, the energy prices based on energy rent grew 227% during 1971–2016, the amplitude of growth was higher than that based on energy depletion. From a dynamic perspective, the trend of $\frac{P_{i,E}}{P_{i,Y}}$ and $\frac{P_{i,E}}{P_{i,Y_1}}$ were consistent (see Fig. 1). Overall, the energy prices in countries all around the world increased rapidly from 1971 to 1980, fell swiftly and then slowly bottomed out from 1980 to 1998, and increased with oscillation from 1998 to 2016.

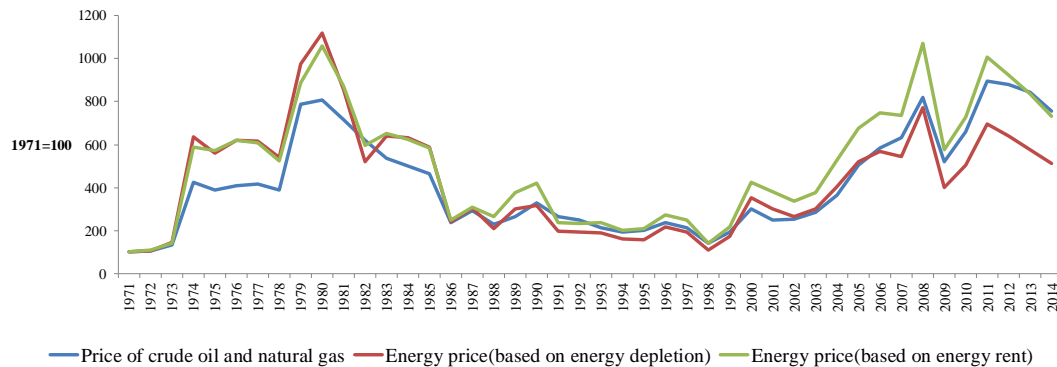


Fig 1:energy prices calculated by Energy Depletion and Energy Rent (1971=100)

At the same time, we used the crude oil and natural gas prices as the proxy for energy prices in the existing studies to verify the accuracy of this paper's measurement of energy prices. Fig. 1 showed that despite of the differences between the crude oil and natural gas prices, energy prices based on energy depletion, and energy prices based on energy rent, the trends were consistent.

Based on panel data from countries all around the world from 1971 to 2016, our empirical analysis was conducted using pooled OLS first. However, the heterogeneity, due to the existence of a series of unobserved features, may not have been noticed. Fixed-effects regressions and random-effects regressions were used to explain this possibility. The empirical findings in detail were shown in Table 4. Columns (1), (3), and (5) showed the association between energy depletion based energy prices and national intensity, while columns (2), (4), and (6) presented the relationship between energy rent based energy prices and national intensity. The results showed that an increase in energy prices always reduced national intensity significantly, whether the calculation of energy prices was based on energy depletion or energy rent. Meanwhile, there was a strong negative impact on the national intensity from technological progress.

Table 3 Basic Results

| | (1) | (2) | (3) | (4) | (5) | (6) |
|-----------|------------|------------|---------------|---------------|----------------|----------------|
| | Pooled OLS | Pooled OLS | Fixed effects | Fixed effects | Random effects | Random effects |
| VARIABLES | ln(I) | ln(I) | ln(I) | ln(I) | ln(I) | ln(I) |
| | | | | | | |

| | | | | | | |
|---|-------------|-------------|------------|------------|------------|------------|
| $\ln\left(\frac{P_{i,E}}{P_{i,Y}}\right)$ | -0.0410*** | | -0.0287*** | | -0.0291*** | |
| | (0.00394) | | (0.00407) | | (0.00399) | |
| $\ln\left(\frac{P_{i,E}}{P_{i,Y_1}}\right)$ | | -0.0413*** | | -0.0250*** | | -0.0256*** |
| | | (0.00473) | | (0.00496) | | (0.00485) |
| growth | -0.00735*** | -0.00717*** | -0.0144*** | -0.0144*** | -0.0143*** | -0.0143*** |
| | (0.00202) | (0.00204) | (0.00112) | (0.00112) | (0.00112) | (0.00113) |
| Constant | -2.636*** | -2.416*** | -2.595*** | -2.447*** | -2.620*** | -2.475*** |
| | (0.0748) | (0.0738) | (0.0311) | (0.0282) | (0.123) | (0.119) |
| year | yes | yes | yes | yes | yes | Yes |
| region | yes | yes | yes | yes | yes | Yes |
| Observations | 3,751 | 3,747 | 3,751 | 3,747 | 3,751 | 3,747 |
| R-squared | 0.229 | 0.222 | 0.164 | 0.157 | | |
| Number of code | | | 110 | 110 | 110 | 110 |

Notes: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

The fixed-effects regressions and the random-effects regressions may be biased due to cross-sectional correlation, so Driscoll and Kraay's approach was used to estimate equation (16). The regression results were detailed in columns (7) and (8) of Table 5. The influences of both energy prices and technological advances on national intensity were still significant. Considering the energy prices declined in 1980–1998, the relationship between which and national intensity was further inspected in that period. The results were shown in columns (9) and (10) in Table 5. Technological advances were the main factor contributing to national intensity reduction, but the energy prices could not reject the null hypothesis at the 10% level, which indicated that no significant impact appeared during the price-declining period.

Table 4 Results of Driscoll-Kraay Estimates

| | (7) | (8) | (9) | (10) |
|---|------------------------------|------------------------------|------------------------------|------------------------------|
| | Driscoll-Kraay regression | Driscoll-Kraay regression | Driscoll-Kraay regression | Driscoll-Kraay regression |
| VARIABLES | ln(I) | ln(I) | ln(I) | ln(I) |
| $\ln\left(\frac{P_{i,E}}{P_{i,Y}}\right)$ | -0.0287*** | | 0.00162 | |

| | | | | |
|---|------------|------------|-------------|-------------|
| | (0.00579) | | (0.00367) | |
| $\ln\left(\frac{P_{i,E}}{P_{i,Y_1}}\right)$ | | -0.0250*** | | 0.00511 |
| | | (0.00687) | | (0.00514) |
| growth | -0.0144*** | -0.0144*** | -0.00917*** | -0.00918*** |
| | (0.00240) | (0.00238) | (0.00126) | (0.00128) |
| Constant | -2.418*** | -2.151*** | -2.252*** | -2.271*** |
| | (0.0310) | (0.0164) | (0.00820) | (0.0153) |
| year | yes | yes | yes | Yes |
| region | yes | yes | yes | Yes |
| Observations | 3,751 | 3,747 | 1,559 | 1,555 |
| Number of groups | 110 | 110 | 102 | 102 |

Notes: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Consider that different countries were at different stages of development, the panel random coefficient regression[25] was also conducted in this paper. Columns (11) and (12) of Table 5 reported the empirical results from 1971 to 2016, while columns (13) and (14) displayed the results from 1980 to 1998. Consistent with the results above, the pulling effect of technological progress on the reduction in energy intensity remained significant, but the energy prices had no significant effect on the national intensity from 1980 to 1998.

Table 5 Results of Random Coefficient Regression Model

| | (11) | (12) | (13) | (14) |
|---|---|---|---|---|
| | Panel Random Coefficient Regression | Panel Random Coefficient Regression | Panel Random Coefficient Regression | Panel Random Coefficient Regression |
| VARIABLES | ln(I) | ln(I) | ln(I) | ln(I) |
| $\ln\left(\frac{P_{i,E}}{P_{i,Y}}\right)$ | -0.0704*** | | -0.0161 | |
| | (0.0201) | | (0.0203) | |
| $\ln\left(\frac{P_{i,E}}{P_{i,Y_1}}\right)$ | | -0.0676*** | | -0.0267 |
| | | (0.0208) | | (0.0227) |
| growth | -0.00684** | -0.00688** | -0.00895*** | -0.00849 |

| | | | | |
|----------------|-----------|-----------|-----------|-----------|
| | (0.00344) | (0.00350) | (0.00188) | (0.00592) |
| Constant | -2.429*** | -2.084*** | -2.127*** | -2.012*** |
| | (0.0726) | (0.0833) | (0.0886) | (0.0821) |
| year | no | no | no | no |
| region | no | no | no | no |
| Observations | 3,746 | 3,742 | 1,559 | 1,555 |
| Number of code | 108 | 108 | 102 | 102 |

Notes: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

We further examined factors influencing energy intensity within supra-national regions (due to the small number of samples in North America and South Asia, we combined North America and Latin America and Caribbean into America and Caribbean, combined South Asia and East Asia and Pacific into South and East Asia and the Pacific), results were shown in Table 6. The elasticity of energy prices in each supra-national region was also quite different. The elasticity of energy prices in America and Caribbean and Sub-Saharan Africa could not reject the null hypothesis at the 10% level, and the elasticity of energy prices in the Middle East and North Africa (based on energy rent) and South and East Asia and Pacific (based on energy depletion), also could not reject the null hypothesis at the 10% level, which indicated that the increase of energy prices did not significantly reduce the national intensity. The elasticity of energy prices in Europe and Central Asia exceeded -0.05, while the elasticity of energy prices in the Middle East and North Africa (based on energy depletion) is relatively high, reaching about -0.16, which showed that the effect of rising energy prices on the reduction of national intensity was relatively obvious.

Table 6 Results of Random Coefficient Regression Model across different supra-national regions

| | (15) | (16) | (17) | (18) | (19) | (20) | (21) | (22) | (25) | (26) |
|---|-------------------------------------|-------------------------------------|-------------------------|-------------------------|-----------------------|-----------------------|------------------------------|------------------------------|--------------------|--------------------|
| VARIABLE S | South and East Asia and the Pacific | South and East Asia and the Pacific | Europe and Central Asia | Europe and Central Asia | America and Caribbean | America and Caribbean | Middle East and North Africa | Middle East and North Africa | Sub-Saharan Africa | Sub-Saharan Africa |
| $\ln\left(\frac{P_{i,E}}{P_{i,Y}}\right)$ | -0.0710 | | -0.0581* | | -0.0727 | | -0.157** | | -0.0126 | |
| | (0.0551) | | (0.0253) | | (0.0693) | | (0.0720) | | (0.0182) | |
| $\ln\left(\frac{P_{i,E}}{P_{i,Y_1}}\right)$ | | -0.0947* | | -0.0725** | | -0.0592 | | -0.107 | | -0.00437 |
| | | (0.0559) | | (0.0248) | | (0.0754) | | (0.0748) | | (0.0289) |
| growth | -0.0126 | -0.0135 | -0.00421 | -0.00310 | -0.000540 | 0.00150 | -0.00991 | -0.0139* | -0.0107** | -0.0104** |
| | (0.0141) | (0.0138) | (0.00556) | (0.00573) | (0.00548) | (0.00683) | (0.00692) | (0.00668) | (0.00539) | (0.00501) |

| | | | | | | | | | | |
|----------------|---------------|---------------|---------------|-----------|---------------|---------------|---------------|---------------|-----------|-----------|
| Constant | -2.453** * | -2.033** * | -2.350** * | -2.017*** | -2.528** * | -2.227** * | -2.957** * | -2.261** * | -1.979*** | -1.954*** |
| | (0.251) | (0.175) | (0.0968) | (0.117) | (0.165) | (0.258) | (0.129) | (0.302) | (0.166) | (0.185) |
| Year | yes | yes | yes | yes | yes | yes | yes | yes | yes | yes |
| Region | yes | yes | yes | yes | yes | yes | yes | yes | yes | yes |
| Observations | 653 | 653 | 1,181 | 1,177 | 612 | 612 | 653 | 653 | 647 | 647 |
| Number of code | 17 | 17 | 41 | 41 | 15 | 15 | 17 | 17 | 18 | 18 |

Notes: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

V. Conclusion

In this paper, we aimed to figure out drivers of declining energy intensity around the world. A country-specific LMDI approach was introduced, which broke down the world's aggregate energy intensity into two factors: country-specific activity mix and national intensity. Our empirical results indicated that it was the national intensity that mainly caused the global energy intensity to decrease from 1971 to 2016.

In view of this, this paper concentrated on the determinants of national intensity, especially the relationship between energy prices, technological progress and national intensity. On basis of measuring the energy price of each country accurately, panel data of all countries since 1971 was used for empirical analysis. As a robustness check, we considered different regression methods of estimation, different temporal sample selections, and different proxy variable selections. The results showed that technological progress and rise in energy prices significantly decreased national intensity, but there existed huge regional differences, also no significant impact appeared in price-declining period.

Energy intensity is an indispensable variable for green development and sustainable development of the world economy and society. Through theoretical analysis and empirical tests, two policy implications were drawn:

First, with respect to the reduction in energy intensity and the promotion of energy efficiency, the rapid economic growth of a country often improves the country's energy consumption and has a positive impact on the overall energy intensity of the world. However, a country could bring down the overall energy intensity of the world by decreasing its national intensity.

Second, the national intensity is the critical factor to reduce the global energy intensity, but measures to reduce energy intensity need to be localized: 1) In the countries belonging to Europe and Central Asia, energy efficiency can be improved by increasing energy prices. 2) The policy effect of reducing energy intensity by increasing energy prices is not significant in the countries belonging to other supra-national regions. The focus of policy should be on the application of more stringent energy consumption standards and other more targeted measures.

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