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Environment, Energy, and Environmental Productivity of Energy: A Decomposition Analysis in China and the US

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Abstract

The global warming, if not global burning, is a dire warning about environmental pollution dangers to everyone, living on the only one Earth. This study aims to measure relative contributors to the environmental quality changes during 2002-2011 using Logarithmic Mean Divisia Index in China and the US. Since these countries are the biggest polluters in the world, the decomposition technique is used to cut their wide environmental issues into the tiny bits of problems, being easy to cope with. Moreover, we employed Environmental Performance Index (EPI) to evolve the concept of Environmental Productivity of Energy (EPE). The results suggest that economic growth and income equality are environmentally-friendly while energy consumption is environmentally-unfriendly; and the Environmental Productivity of Energy (EPE) and technology progress are environmentally-moody (with various effects on environment). Consequently, the policy makers are advised to develop those economic sectors which are independent of pollutant energies; to replace the black energies by the green ones; and to invest on the research about the products whose demand is price inelastic.

Key words: *Environment, Energy, Productivity, Decomposition*
JEL Classification: *F 64, Q 43, Q 44, Q 57*

1. Introduction

The global warming, if not global burning, is a dire warning about environmental pollution dangers to everyone, living on the only one Earth, albeit until now (Taghvaee and Parsa, 2015). “Nobody on the planet is going to be untouched by the impacts of climate change” said the chairman of the Intergovernmental Panel on Climate Change (IPCC) in Yokohama, Japan, in 2014 where and when a meeting was held on IPCC report of that year. According to the report, the scientific proofs’ level of the warming effects has roughly doubled in value since 2007. This report provides a detailed explanation for the main concerns, for example water and food insecurities due to more intensive drought, floods, and heat waves; sea level rise; ocean acidification which is highly dangerous for marine ecosystems; species extinctions; and 2-degree increment in temperature which in turn leading to 0.2-2.0 percent global income losses. Consequently, the most pollutant and infected economies should be found and then brought to the emergency room for performing an operation and starting an effective therapy.

China and the US are the biggest polluters in the world due to their extremely fuel-burning economies. In 2012, not only were they the largest energy importers in the world but also they were the biggest oil consumers. In 2012, the US and China consumed 18490 and 9980 thousand barrels of oil per day (a pollutant fossil fuel); 7372 and 5608 of which were provided by import respectively.[1] Furthermore, they hold the most substantial share of fossil fuel –as a pollutant fuel- in electricity production (China with 3785 million tons in the first place followed by US with 1643).[2] It has made the countries the largest CO2 emitters, China with 8547746 and US with 5270422 million metric tons.[3] Therefore, these eastern and western smoky countries with their overheated economies play an important role in global warming which should stop back soon.

These economies are likely to require an emergency surgery to diagnose the most significant contributory economic sectors to the changes in environmental quality. Since these advanced economies are extremely complicated to study as a whole, they should be broken down into the smaller parts. Then, there are smaller economic sectors on the desk, rather than an entire economy, leading to a relatively simple, detailed, and careful analysis. Many researchers, in this field, employed decomposition models, such as Freitas and Kaneko (2011), Ren et al. (2014), Vaninsky (2014). There is no doubt that many researchers have employed other approaches, frameworks, and methodologies dealing with the nexus between the global warming and the socioeconomic factors. Take Environmental Kuznets Hypothesis (EKH) for example, many studies, based on the EKH, have formulated conscious, effective,

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[1] US Energy Information Administration, available at: www.eia.gov
[2] US Energy Information Administration, Key World Energy Statistics, 2014
[3] US Energy Information Administration, available at: www.eia.gov

and controversial policies on economic, energetic, social, and environmental affairs for the key decision makers (Ajmi et al., 2015; Atici, 2012; Grossman an Kruger, 1990; Hettige et al., 2000; Kasman and Duman, 2015; Taghvaee and Shirazi, 2014; Taghvaee and Parsa, 2015; Tsurumi and Managi, 2010). However, it is by no means the only one (Ma and Stern, 2008); and another thing! It is overly simplistic and generally inadequate and alternative approaches should be employed (Stern, 2004). Subsequently, decomposition technique, as a credible alternative, might be used to cut the wide environmental issue, made by the major economies, into the tiny bits of problems, being easy to cope with.

2. Literature Review

There are a large number of factorial decomposition methodologies with various characteristics and wide-ranging uses. Laspeyres (1871) and Paasche (1874) might be the very early studies, developing decomposition methodologies with discrete time setting whereas, in contrast, Divisia (1925) considered continuous time span. Kaya (1990) mixed the previous methods to produce a single model for both the discrete and continuous time settings. Besides, decomposition techniques can be split in two broad categories: input-output techniques - structural decomposition analysis (SDA) (Okushima and Tamura, 2011) and disaggregation techniques - index decomposition analysis (IDA) (Leontief et al., 1936, 1941, 1970, 1972; Li et al., 2014; Ma and Stern, 2008). So, factorial decomposition analysis has expanded rapidly over time although they are integrated in some studies (Ang, 2004; Bhattacharyya, 2011).

Ang in 2004 reviewed an assortment of the decomposition analysis methodologies. He divided the "index decomposition analysis" into two general categories: methods linked to Divisia index (DI) and methods linked to Laspeyres index (LI). Laspeyres index (LI) is easy to understand but Divisia index (DI) is more scientific. Each category, in turn, can be split in half: multiplicative and additive decomposition. Both multiplicative and additive decomposition of Divisia index are of two distinct kinds: Logarithmic Mean Divisia Index (LMDI) and Arithmatic Mean Divisia Index (AMDI). Many researchers compared, ranked, and evaluated the above-mentioned index decomposition methods based on four criteria: 1) theoretical foundation, 2) adaptability, 3) ease of use, and 4) ease of understanding and result presentation. Each criterion is evaluated by some specific tests. Take theoretical foundation for example, it might include four distinctive tests: 1) factor-reversal, 2) time-reversal 3) proportionality and 4) aggregation tests. Consequently, Ang reviewed, categorized, and compared various decomposition models and considered the LMDI as the most preferable one among the others (Ang, 2004).

3. Methodology

3.1 Research Questions

The main objective of this study is to measure the relative contributors to the environmental quality changes in China and the US during 2002-2011 using Logarithmic Mean Divisia Index (LMDI). By this measurement, the driving factors are compared with each other to determine the strongest ones underlying the changes in environmental quality in China and the US. It paves the way to concentrate on the most fundamental causes where the problem is most deeply-rooted. To achieve these objectives, the following questions should be answered. Which driving factors do change the environmental quality in China and the US? How much is the share of each contributor to the environmental quality changes in China and the US? The above-mentioned questions can be analyzed from two different viewpoints (1- technological and structural changes; and 2- productive and energetic effects).

From the former perspective, the contributors are classified into two different types: technological changes and structural changes. How can the technological progress affect environmental quality whether positively or negatively? The positive effect, on the one hand, can be due to the fact that the more efficiency increases, the less energy is required to produce a given amount of goods. This leads to the more desired outputs (final and intermediate goods), less needed-inputs (energy, material, labor, etc), and less waste (environmental pollutants such as CO_x, NO_x, and so forth), see figure 1. We call this positive impact as "saving-effect" of the technology progress on energy consumption. The negative effect, on the other hand, can be rooted in consumerism. The increment in productivity, efficiency, and technology progress lowers the production cost and the selling price of goods including: energy-intensive products (such as cement, glass, steel etc), energy (gasoline, diesel, gas etc), and energy-saving products (such as cars, planes, electricity generators etc). It heightens the consumption level of these products, especially those with high price and income elasticity of demand (Baranzini and Weber, 2013; Dahl, 2012; Taghvaee and Hajiani, 2014). The more the technology advances, the more the price reduces, the more the demand increases, the more the energy is burned up. We name this negative effect as "price-effect" of technology progress on energy consumption which effects environment negatively through three ways: 1) increase in purchasing energy-intensive products with polluting productive-process, 2) increase in burning energy which is a major source of pollution, and 3) increase in utilizing energy–using products; despite the fact that using the energy-saving products relatively less energy, they are energy-using products which pollute the environment. Notwithstanding seemingly-underestimation of the negative effect, the price-effect probably, exceeds the saving-effect, albeit rarely, leading to a negative total-effect. In this case, presumably, the policy makers increase the research and development expenditures to advance technology, raise efficiency, and decrease energy consumption; but, unexpectedly, the resulted technology progress not only does not decrease the energy consumption and environmental pollution but also raises them. Bhattacharyya (2011) refers to it as "rebound effect" or "take-back effect". Structural changes have different effects on the environmental quality, depending on the tendency towards the economic sectors which are more effective against the environment. Thus, technological and structural changes might have various effects on the environmental quality.

Figure1: Schema of a process

Inputs → Process → Desired Output
↓
Waste

From the latter perspective, the contributors are categorized into two different types: productive and energetic effects. Whether does the productive-activity pollute the environment as a whole? Or it is the energetic productive-activities which increase the pollution. To many researchers, economic growth is consistent with efficiency, energy-saving, and environmental cleaning (Grossman and Kruger, 1990; Kasman and Duman, 2015; Taghvaee and Shirazi, 2014); but many studies argue that economic activities play a leading part in the environmental pollution by creating the serious disturbances to eco-systems (Ajmi et al., 2015; Hettige et al., 2000; Taghvaee and Parsa, 2015). If the latest theory is true, the question is whether all the economic activities are the culprit; or it is only related to those economic activities which consume energy. In order to answer these questions, we employed LMDI methodology and Environmental Performance Index (EPI), developed by the Yale University, to evolve the concept of Environmental Productivity of Energy (EPE) which is one of the distinctions of the study.

3.2 Modeling Volatility

Among the dozens of decomposition methods, researchers and decision makers believe that LMDI is the most appropriate decomposition method for the analysis of economic, energy, and environmental changes (Ang, 2004; Freitas and Kaneko, 2011; Xu et al., 2012). Ang claims that LMDI is the simplest and most flexible model, and, from the theoretical foundation viewpoint, the most elegant one which is recommended for general use. In addition, many argue that it gives only a very small residual term (Ang, 2004). Therefore, we employed LMDI with rolling base year to decompose the economic, energetic, and environmental changes in China and US as follows:

$$Energy\ Intensity = \frac{E}{Y} = \sum_{i=1}^{m}\left(\frac{E_i}{Y_i}.\frac{Y_i}{Y}\right) \tag{1}$$

where E stands for energy demand, Y for production, and i for country. Then we have:

$$E = Y.\sum_{i=1}^{m}\left(\frac{E_i}{Y_i}.\frac{Y_i}{Y}\right) \tag{2}$$

which, according to the multiplicative LMDI, is as follows:

$$\frac{E_t}{E_{t-1}} = exp\left[\sum_{i=1}^{m} L(W_{1i(t)}, W_{1i(t-1)})\ Ln\frac{Y_{(t)}}{Y_{(t-1)}}\right] \times exp\left[\sum_{i=1}^{m} L(W_{1i(t)}, W_{1i(t-1)})\ Ln\frac{(E/Y_i)_{(t)}}{(E/Y_i)_{(t-1)}}\right] \times exp\left[\sum_{i=1}^{m} L(W_{1i(t)}, W_{1i(t-1)})\ Ln\frac{(Y_i/Y)_{(t)}}{(Y_i/Y)_{(t-1)}}\right] \quad 3$$

Now for the first time, environmental productivity of energy (EPE) is defined as the environmental quality divided by the energy consumption which is formulated as below:

$$Environmental\ Productivity\ of\ Energy\ (EPE) = \frac{Env}{E} = \sum_{i=1}^{m}\left(\frac{Env_i}{E_i}.\frac{E_i}{E}\right) \quad 4$$

Where Env is the environmental quality and the remaining indices are as mentioned before. It is worth mentioning that environmental productivity of energy (EPE) might act as a proxy to measure the level of environmental quality for each unit of energy consumption. A high EPE can have two distinctive implications: 1- A high environmental quality (assuming a constant level of energy consumption). It implies a reduction in environmental pollution, representing a bigger share of green energies and smaller share of black energies; or a high productivity for pollutant-emitting processes in the environmental quality view point. A process with high productivity has low inputs, low wastes, high outputs, two mentioned factors, or all the three factors simultaneously. So productivity can be assessed by some criteria such as the amount of wastes which mainly includes the environmental pollutants. It is why we call it “environmental productivity”. 2- A low energy consumption (assuming a constant environmental quality). It represents a cut in the amount of energy as an input of a process, representing a high productivity for energy-using processes. Due to this relationship between productivity and energy consumption, the above-mentioned fraction is called environmental productivity of energy.

By multiplying both sides of the equation 4 by E, we have:

$$Env = E.\sum_{i=1}^{m}\left(\frac{Env_i}{E_i}.\frac{E_i}{E}\right) \quad 5$$

which, according to the multiplicative LMDI, is as follows:

$$\frac{Env_t}{Env_{t-1}} = exp\left[\sum_{i=1}^{m} L(W_{2i(t)}, W_{2i(t-1)})\ Ln\frac{E_{(t)}}{E_{(t-1)}}\right] \times exp\left[\sum_{i=1}^{m} L(W_{2i(t)}, W_{2i(t-1)})\ Ln\frac{(Env_i/E_i)_{(t)}}{(Env_i/E_i)_{(t-1)}}\right] \times exp\left[\sum_{i=1}^{m} L(W_{2i(t)}, W_{2i(t-1)})\ Ln\frac{(E_i/E)_{(t)}}{(E_i/E)_{(t-1)}}\right] \quad 6$$

Now, by merging the equations 2 and 5:

$$Env = \sum_{i=1}^{m} Y_i \,.\, \sum_{i=1}^{m} \left(\frac{E_i}{Y_i} \cdot \frac{Y_i}{Y}\right) . \sum_{i=1}^{m} \left(\frac{ENV_i}{E_i} \cdot \frac{E_i}{E}\right) \qquad 7$$

Equation 7 can be rewritten as

$$Env = \sum_{i=1}^{m} PP_i \,.\, \sum_{i=1}^{m} EI_i \,.\, PS_i \sum_{i=1}^{m} EP_i \,.\, ES_i \qquad 8$$

Where PP=Y is pure productive effect, EI=E/Y is energy intensity effect, PS=Yi/Y is productive-structural effect, EP=Env/E is environmental productivity of energy (EPE) effect, and ES=Ei/E is energetic-structural effect. The final decomposition equation is derived from the equation 6 following (Ang and Liu, 2001; Ang, 2005; Freitas and Kaneko, 2011). According to the multiplicative LMDI, the aggregated function for the environmental quality decomposition with rolling base year (changes between two years: t and t-1) is as follows:

$$\begin{aligned} \frac{Env_t}{Env_{t-1}} = exp &\left[\sum_{i=1}^{m} L(W_{3i(t)}, W_{3i(t-1)})\; Ln \frac{PP_{i(t)}}{PP_{i(t-1)}}\right] \qquad 9 \\ &\times exp \left[\sum_{i=1}^{m} L(W_{1i(t)}, W_{1i(t-1)})\; Ln \frac{EI_{i(t)}}{EI_{i(t-1)}}\right] \\ &\times exp \left[\sum_{i=1}^{m} L(W_{1i(t)}, W_{1i(t-1)})\; Ln \frac{PS_{i(t)}}{PS_{i(t-1)}}\right] \\ &\times exp \left[\sum_{i=1}^{m} L(W_{2i(t)}, W_{2i(t-1)})\; Ln \frac{EP_{i(t)}}{EP_{i(t-1)}}\right] \\ &\times exp \left[\sum_{i=1}^{m} L(W_{2i(t)}, W_{2i(t-1)})\; Ln \frac{ES_{i(t)}}{ES_{i(t-1)}}\right] \end{aligned}$$

The logarithmic weighting function is given by:

$$L(W_{i(t)}, W_{i(t-1)}) = \frac{W_{i(t)} - W_{i(t-1)}}{LnW_{i(t)} - LnW_{i(t-1)}} \qquad 10$$

3.3 Data

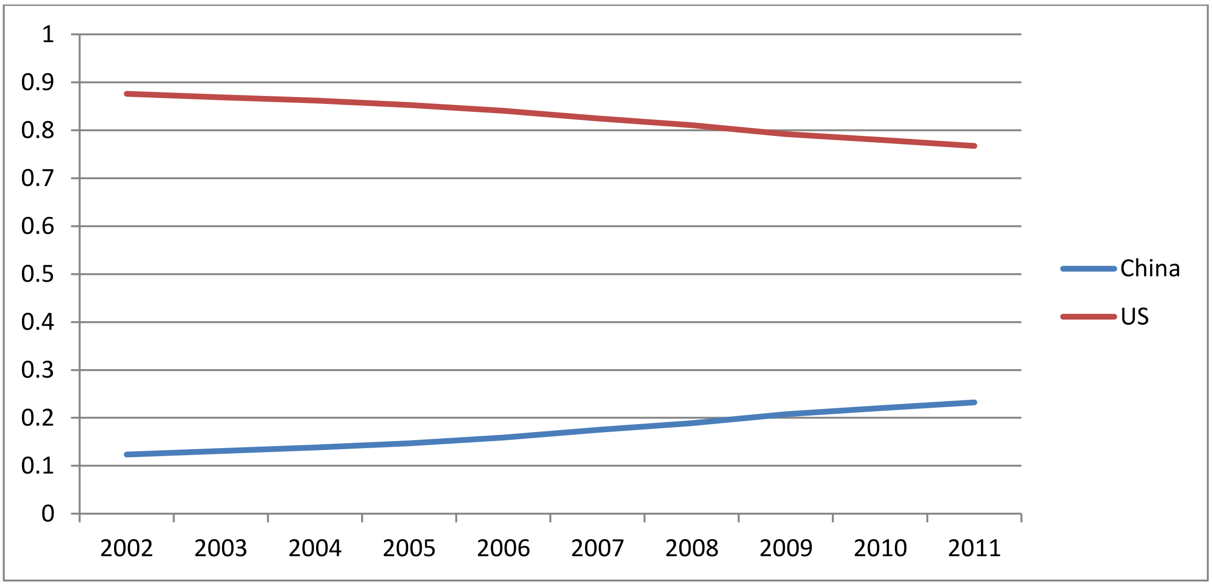
In this study the preliminary data has been derived from the World Bank database and the Yale University database within 2002-2012. Then they are employed to calculate the four fractions (as the secondary data) in the model: 1) energy intensity, 2) GDP share, 3) environmental productivity of energy (EPE), and 4) energy share. The time series of the fractions, finally, are analyzed with line graphs.

The preliminary data includes GDP, energy use, and EPI. Gross Domestic Production (GDP) is the proxy of production which is measured in constant 2005 US dollar. Energy use is the proxy of energy demand which is measured in kilo ton of oil equivalent. Both the GDP and energy use time series are derived from the World Bank database, World Development

Indicator (WDI)[4] for the period. The period of study is restricted by the availability of data for the Environmental Performance Index (EPI). EPI is the proxy of environmental quality, ranging from 0 to 100, which has been derived from the Yale University database[5]. "The Environmental Performance Index ranks how well countries perform on high-priority environmental issues in two broad policy areas: protection of human health from environmental harm and protection of ecosystems"[6]. The former policy area, in turn, is divided into three issue categories including: health impacts, air quality, and water and sanitation. The latter one is divided into six issue categories including: water resources, agriculture, forests, fisheries, biodiversity and habitat, and climate and energy.

The secondary data (the fractions which are mentioned in the model) are calculated by employing the above-mentioned preliminary data. These are graphed in the below-drawn figures during 2002-2011 for China and the US which are explained and interpreted in the following paragraphs.

Figure 2: GDP share of each country (China and the US) to the total GDP of both countries during 2002-2011



Source: World Development Indicator (WDI)[7]

Figure 2 depicts the GDP ratio of China and the US, separately, to the paired GDP altogether. US economic ratio, with extremely larger magnitude, is decreasing while that of China is increasing. The GDP share of the US is just under 90 percent in the first year and it is dropping continually, reaching just under 80 percent in the last year. In sharp contrast with the US, the GDP share of China is just over 10 percent in the first year and it is stepping up permanently, reaching just over 20 percent in the last year. Therefore, in spite of the much

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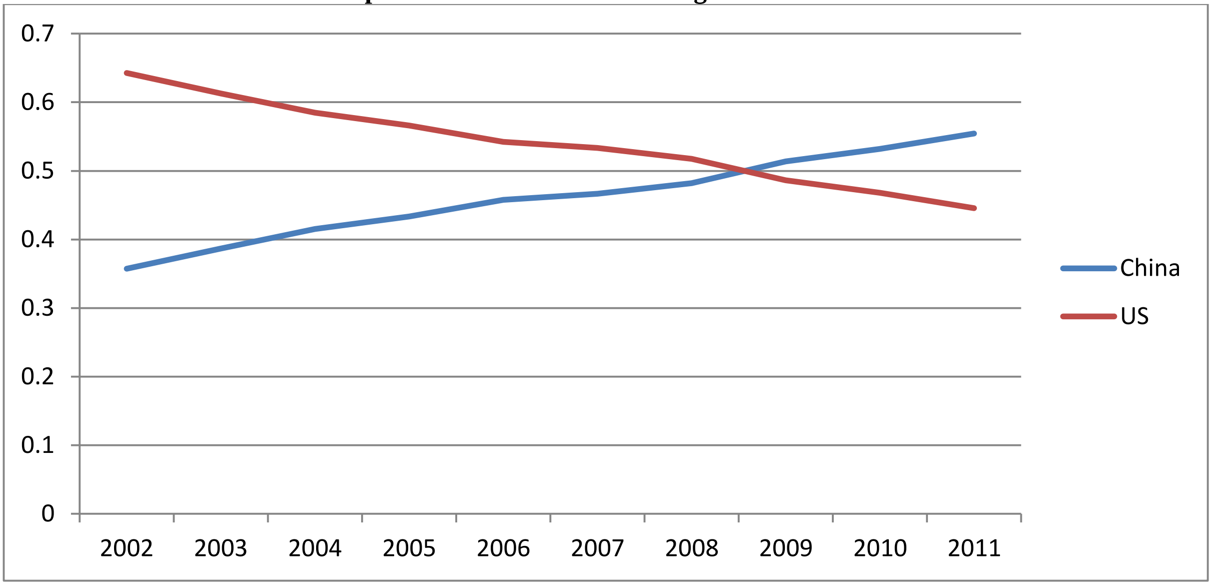
[4] Available at: http://www.worldbank.org
[5] Available at: http://epi.yale.edu/
[6] Environmental Performance Index 2014, available at: http://epi.yale.edu/
[7] Available at: http://www.worldbank.org

greater share of the US economy to the aggregated GDP, compared with China, all over the period, the former one is reducing while the latter one is heightening.

Figure 3: Energy consumption share of each country (China and the US) to the total energy consumption of both countries during 2002-2011



Source: World Development Indicator (WDI)[8]

Figure 3 indicates the energy share of China and the US, separately, to the paired energy consumption altogether. At the first year, the larger share of energy goes towards the US, approximately 65 percent (and about 35 percent to China). However, the US share is raising and the China share is falling all the time. In 2008, the share of each country in energy consumption is halved (50%:50%). The China share heavily, even, outnumbers the US one in the following years as, in 2011, the China and US shares are about 55% and 45%, respectively. Consequently, the US energy consumption makes up the bigger segment in both the countries but time put the allocation order in reverse.

These two figures imply that China economy is more energy-intensive than the US one. On the one hand, with regard to the figure 2, US economy comprises a bigger segment of production, all the time, ranging from three to more than seven times larger than the China. On the other hand, based on the figure 3, not only the difference of energy consumption share, in comparison with the GDP share, between the two economies is very little but also, in the three last years, the energy consumption share of China exceeds the US one. It implies that, regarding the wide gap between the two economic growth shares, China requires higher energy to offer a certain amount of products, compared with the US. As a result, US economy is more energy-efficient than China which is approved by the energy intensity time series graphed below.

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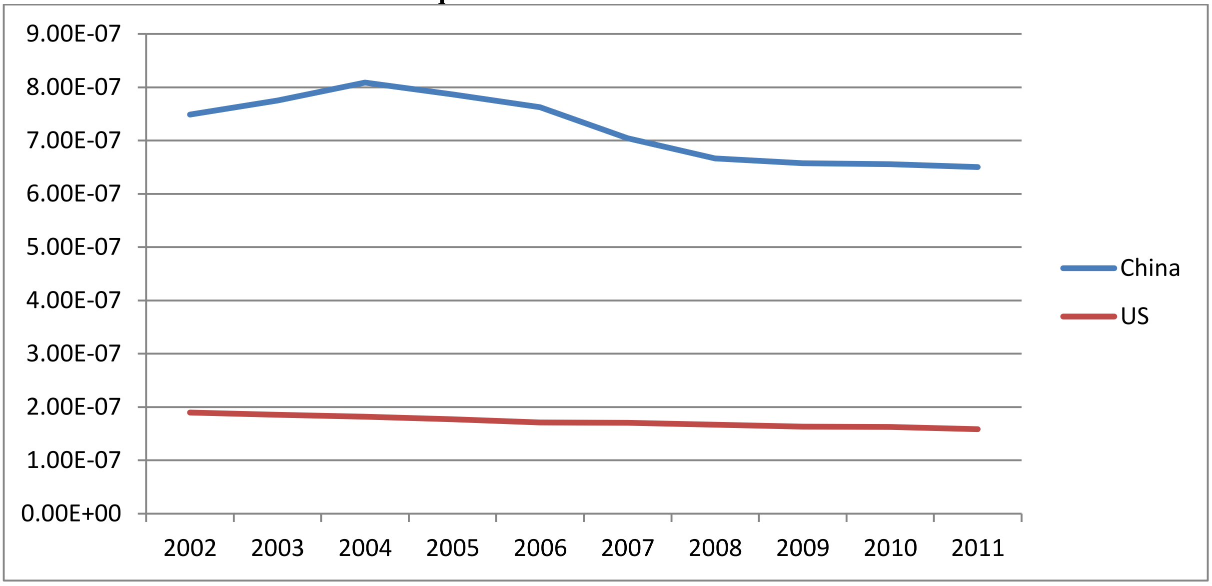
[8] Available at: http://www.worldbank.org

Figure 4: Energy intensity of each country (China and the US) during 2002-2011 measured in kilo ton of oil equivalent to constant 2005 US dollar



Source: World Development Indicator (WDI)[9]

Figure 4 reveals some information about energy intensity, considered as the inverse of technological efficiency (Bhattacharyya, 2011), in China and the US within 2002-2011. Despite the huge difference in the energy intensity volumes of the two countries, they show almost the same trends.

In China, it is three times larger than that of the US, which displays extremely low productivity, efficiency, and technology in China, compared with the US. Notwithstanding this fundamental distinction, both countries reflect approximately the identical trends (downward), except for the first years in China. These trends are downward due to the considerable increase in productivity, efficiency, and technology progress. The more efficiency increases, the less energy is required to produce a given amount of goods (saving-effect). It is why, in the US, energy intensity falls all over the period, albeit gradually, from 2.00E-07 to just above 1.50E-07. Similarly, in China, it indicates the same pattern during 2004-2011, supporting the negative saving-effect of technology progress on energy consumption. However, the trend is upward at the first two years in China owing to, again, the considerable increase in productivity, efficiency, and technology progress (rebound effect). So the US is employing more energy-conserving technologies in productive processes than China.

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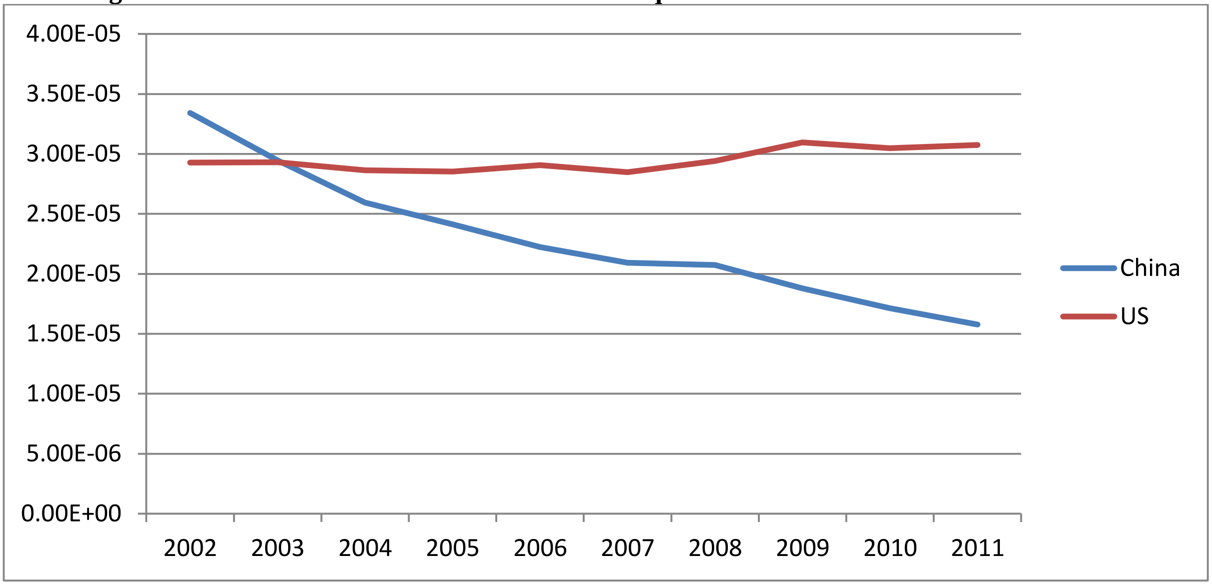
[9] Available at: http://www.worldbank.org

Figure 5: Environmental productivity of energy (EPE) of each country (China and the US) during 2002-2011 measured in EPI to kilo ton of oil equivalent to constant 2005 US dollar



Sources: World Development Indicator (WDI)[10] and Yale University database[11].

Figure 5 displays the environmental productivity of energy (EPE) in China and the US within 2002-2011. In the US, it is just below and above 3.00E-05 in the first and last year, respectively, with fairly small fluctuations within the span. In China, it falls moderately from 3.50E-05 to about 1.50E-05. This productivity in China is smaller than the US all over the course except the first two years. It is worth mentioning that the gap between the EPE in the two countries is becoming larger and larger with elapse of time. It shows that China is increasing not only the share of energy (as input) in productive processes but also the share of black energy in the consumptive energy portfolio. Consequently, the US economy has a more environmental productivity than China from energy view point.

4. Results and Discussion

Figures 6 and 7 represent the trends of driving factors for the environmental quality in China and the US during 2002-2011. Three driving factors show the identical behaviors in both countries (pure productive, energy intensity, and EPE effects) but the productive-structural effect and energetic-structural effect display the opposite effects. They have positive effect in China and negative effect in the US. In the following paragraphs, all the trends are analyzed in more details.

With regard to the figures 6 and 7, pure productive effect is positive in both countries (inconsistent with Ren et al. (2014) and Vaninsky (2014) and consistent with Grossman and Kruger (1990); Kasman and Duman (2015); Taghvaee and Shirazi (2014) while merely, in China, productive-structural effect is positive (supporting Freitas and Kaneko (2011)) and energetic-structural effects is positive too, merely during 2002-2011. In the US, pure

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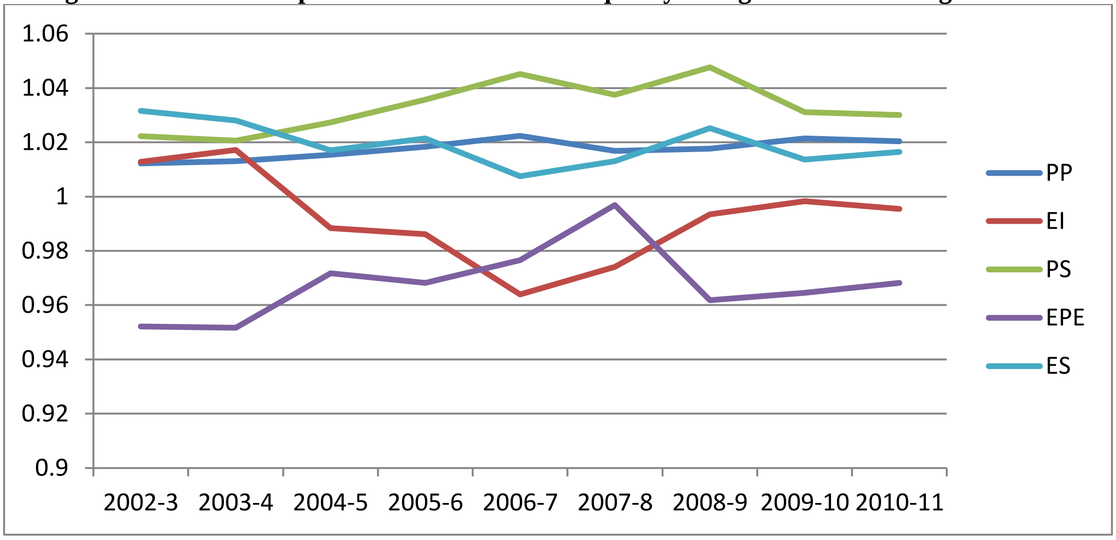
[10] Available at: http://www.worldbank.org
[11] Available at: http://epi.yale.edu/

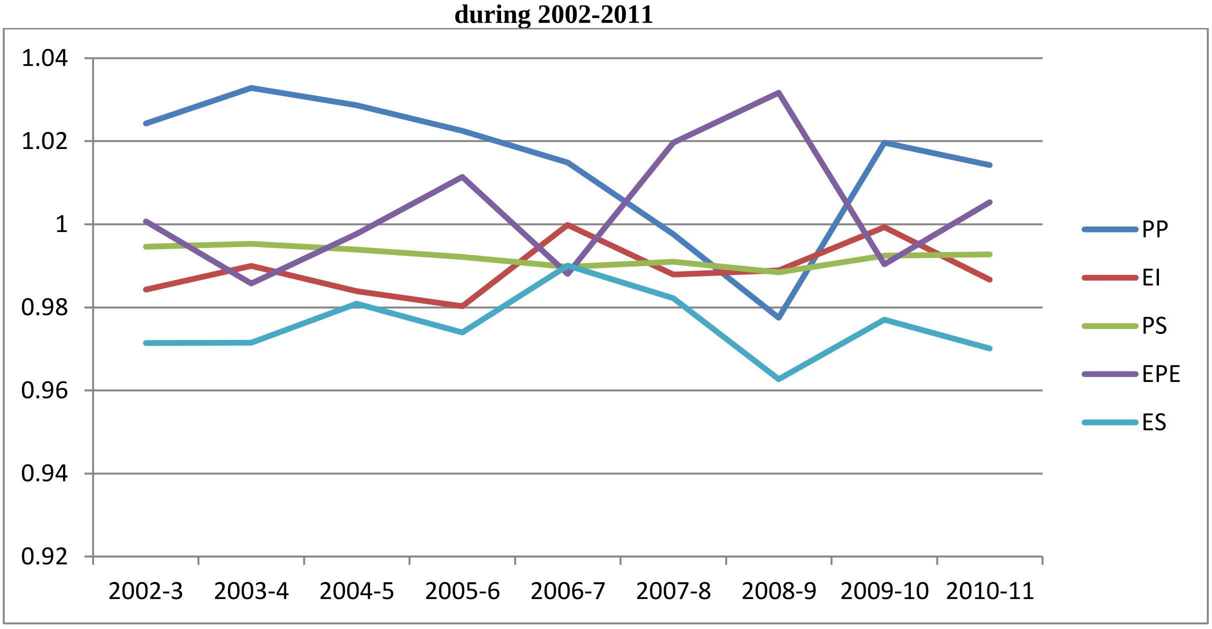
productive effect is the only and the strongest driving factor within the span (inconsistent with Ren et al. (2014)), except 2006-7 until 2008-9 in which it displays a negative effect. It waxes and vanes between 1.02 and 1.04 in the first years, then takes a nose dive to 0.98 in 2007, and finally recovered to about 1.02. In China, the pure productive effect is positive too but neither the only nor the strongest one. It is around 1.02 throughout the course just like the energetic-structural effect. The most dominant and positive effect, in China, is productive-structural effect (consistent with Ren et al. (2014) and inconsistent with Tsurumi and Managi (2010)). At the first years, it is just above 1.02 while it raises around 1.04 in 2005-6 and declines to 1.03 at the end of the span.

Figure 6: Index decomposition of environmental quality change in China during 2002-2011



In a multiplicative decomposition, the figures which are greater or less than one represent the positive or negative effects (Ma and Stern, 2008).

Figure 7: Index decomposition of environmental quality change in the United States of America during 2002-2011



In a multiplicative decomposition, the figures which are greater or less than one represent the positive or negative effects (Ma and Stern, 2008).

Environmental quality is influenced negatively by energy intensity effect in both countries (inconsistent with Freitas and Kaneko (2011) and Vaninsky (2014) and inconsistent with Ren et al. (2014)), and productive- and energetic-structural effects only in the US. In China, EPE effect is the weakest contributor through the span, except in the middle years during which it reaches close to one. On the one hand, it has a decreasingly negative effect until 2006-7 and increasingly negative effect until the final years, reaching just below one. On the other hand, energy intensity effect, other than the early years, has an increasingly negative effect until 2005-6, estimated just above 0.96 (which is consistent with Ma and Stern (2008); Zhang and Lahr (2014). Then it has a decreasingly negative effect until the final years, reaching just below one. Energy intensity effect, in the US, has a negative effect too, fluctuating between 0.98 and one, like productive-structural effect. Notwithstanding the negative effect of the mentioned driving factors, it is the energetic-structural effect which is the most significant contributor. In spite of some fluctuations between 0.96 and 0.99, it is 0.97 both in the first and the last years.

EPE effect, in the US, shows various effects over the term. Firstly, it is around one, and then it deteriorates into 0.98 approximately. After an upward trend towards just above one, it shows the secondary decline in 2006-7. The second raise starts in 2007-8, hitting a peak of more than 1.03 in 2008-9. The tertiary fall leads to the third negative effect, accounted for 0.97 which is followed by the latest rise, leading to the final positive effect, estimated to just above one.

All in all, pure productive effect and energy intensity effect are the same in the two countries, positive and negative effects, respectively. However, productive- and energetic-structural effects show the reverse situations, positive in China and negative in the US. Moreover, EPE effect has a negative contribution in China and variant contribution in the US to the environmental quality. It is worth mentioning that the major positive driving factors are as follows respectively: productive-structural effect and EPE effect in China; and pure productive effect and energetic-structural effect in the US.

Figure 8: Actual values versus estimated values

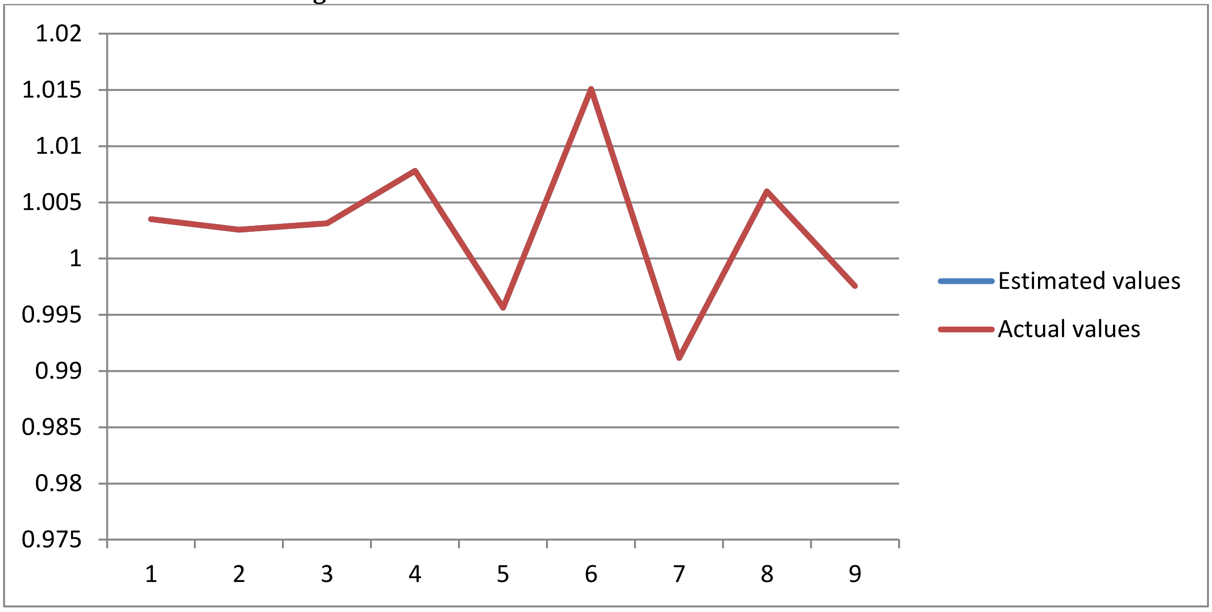


Figure 8 represents the actual and estimated values of the dependent variable in equation 9. The estimated values are so close to the actual ones as if they cover each other completely, proofing the accuracy of the model and its results. It is consistent with the results of Lermit and Jollands (2001), the US Department of Energy (Wade, 2002), the European SAVE project, and Ang (2004). Table 1 shows the exact numbers of these values and their differences. So it is an evidence to confirm the results.

5. Conclusions and Recommendations

The methodology of multiplicative LMDI is employed to decompose the driving forces of environmental quality changes in China and the US during 2002-2011. The results show that there are some similarities and differences between these countries about the trends of the driving forces. In order to interpret the results in more details, the driving forces are analyzed in five distinct frameworks which are as follows:

5.1 Productive effects

In this study, there are two driving factors, relating to production amount, for environmental quality including pure productive effect and productive-structural effect. The positive effect of pure productive effect implies that economic growth can be considered as an environmentally-friendly factor in these two countries because economic growth is deeply involved with improving efficiency, productivity, and technology. It is supporting the increasing phase of Environmental Kuznets Curve (EKC). So, the more economy grows, the more environment improves. The other productive driving force is the productive-structural effect. It is positive in China and negative in the US which implicitly approves of the above-mentioned interpretation upon pure productive effect. Owing to the increasing trend in GDP share of China, productive-structural effect is positive. In contrast, this effect is negative in the US since its GDP share is decreasing. Thus, productive-related factors (pure productive and productive-structural effects) are environmentally-friendly, due to the contribution of economic growth towards more efficiency, productivity, and technology, leading to a less energy consumption.

5.2 Energetic effects

There are two driving factors for environmental quality which are connected to energy consumption: energy intensity effect and energetic-structural effect. In both countries, both the contributors show negative effect on the environmental quality, except for the energetic-structural effect in China. In other words, energy-related driving factors degrade the environmental quality which implies that, mostly, energy can be deemed as environmentally-unfriendly element. As a result, notwithstanding some exceptional cases, energetic effects are negative.

5.3 EPE effect

The effect of environmental productivity of energy (EPE) is negative in both countries, although it is positive during many years in the US. In China, it goes up moderately from 0.95 to a peak of 1 in 2007-8 but it takes a nosedive to 0.96 in the next year, and then rises gradually to about 0.97. In the US, the EPE fluctuates between 0.99 and 1.03 throughout the period. Therefore, in the US, consumptive energy share, as an input, is decreasing in productive processes whilst green energy share is increasing in the consumptive energy portfolio, and vice versa in China.

5.4 Technological changes

Energy intensity effect plays a negative role in the environmental quality of both countries, other than the early years of the period in China which is positive. It shows that energy intensity (or technological efficiency) effect itself has two opposite effects which we name them as follows: 1) saving-effect and 2) price-effect of technology progress on the environmental quality. From the view point of saving-effect, technology progress declines the level of needed-inputs (for example energy) to produce a given amount of goods which, in turn, improves the environmental quality. Since the decrease in the use of energy (as an input) improves the environmental quality, the more energy intensity falls, the more environmental quality rises. Due to the considerable reduction of energy intensity during the overwhelming majority of the years in both countries (see figure 4), environmental quality level has risen which implicates the positive effect of technology, productivity, and efficiency on the environmental quality. However, energy intensity effect is positive in the early years of the period in China because energy intensity trend, unexpectedly, is upward in these years. It might be rooted in the price-effect of technology progress; the higher energy consumption which is originated from technology progress, lower production costs, and decrease in the price of energy-intensive goods. So, only within a few years and only in one country, the environmental degradation, resulted from increase in consumption of energy-intensive goods, outpaces the environmental improvement, resulted from development of energy-saving ones (the environmental rebound effect of technology progress on environmental quality).

5.5 Structural changes

Productive- and energetic-structural effects are two driving forces which reveal the relationship between the geographically distributive patterns of production and energy consumption, on the one hand, and environmental quality, on the other hand. As represented in the figure 6 and 7, the more the China's shares in production and energy go up, the more the environmental quality raises while it is the reverse in the US. It suggests that the equality of economic growth shares among countries raises the total environmental quality since the economic growth gap between China and the US narrows if the China's share increases. So income equality supports environment. Furthermore, by comparing the productive-structural effect with the energetic one, the former suggests a bigger environmental impact. As a result, assimilating the structures, especially the economic one, might support total environmental quality.

All in all, this study suggests that economic growth and income equality are environmentally-friendly while energy consumption is environmentally-unfriendly; and EPE and technology progress are environmentally-moody (with various effects on environment). So policy makers should give economy the green light to grow while showing energy the yellow card, if not the red one. Those economic sectors should be developed which are independent of energy for example financial development; otherwise, the black energy (such as fossil fuels) should be replaced by the green energies (solar, wind, hydro-power etc) to increase the EPE. Moreover, the governors are advised to adopt some strategies to reduce the income inequality (such as income tax and subsidy) due to the fact that income equality improves environmental quality which can be studied in a separate research work as a future research. Finally, the governors should invest on the research about the products whose demand is price inelastic to prevent the possible increase in demand resulted from decrease in price.

References

Ajmi, A. N., Hammoudeh, S., Nguyen, D. K., Sato, J. R., 2015, On the relationships between CO2 emissions, energy consumption and income: the importance of time variation, *Energy Economics*, DIO: 10.1016/j.eneco.2015.02.007

Ang, B.W., Liu, F.L., 2001. A new energy decomposition method: perfect in decomposition and consistent in aggregation, *Energy*, 26 (6), 537–548.

Ang, B.W., 2004, Decomposition analysis for policy making in energy: which is the preferred method, *Energy Policy*, 32 (9), 1131–1139.

Ang, B.W., 2005, The LMDI approach to decomposition analysis: a practical guide, *Energy Policy*, 33, 867–871.

Atici, C., 2012, Carbon emissions, trade liberalization, and the Japan-ASEAN interaction: A group-wise examination, *Journal of The Japanese and International Economies*, 26, 167-178.

Baranzini, A., Weber, S., 2013, Elasticities of Gasoline Demand in Switzerland, *Energy Policy*, 63, 674-680. DIO: http://dx.doi.org/10.1016/j.enpol.2013.08.084

Bhattacharyya, S.C., 2011, Energy Economics: concepts, issues, markets and governance, Springer, chapter 3, ISBN: 978-0-85729-267-4.

Dahl, C.A., 2012, measuring global gasoline and diesel price and income elasticities, *Energy Policy*, 41, 2-13. DIO: http://dx.doi.org/10.1016/j.enpol.2010.11.055

Divisia, F., 1925, L'indice Monetaire et la Theorie de la Monnaie. Rev, *Econ. Polit*, 39 (5), 980–1020.

Freitas, L.C. de., Kaneko, S., 2011, Decomposing the decoupling of CO2 emissions and economic growth in Brazil, *Ecological Economics*, 70, 1459–1469.

Grossman, G. M., Krueger, A. B., 1991, Environmental impact of a North American Free Trade Agreement, Working Paper 3914, National Bureau of Economic Research, Cambridge, MA.

Hettige, H., Muthukumara, M., Wheeler, D., 2000, “Industrial Pollution in Economic Development: the Environmental Kuznets Curve Revisited”, *Journal of development economics*, 62, 445-467.

Kasman, A., Duman Y. S., 2015, CO2 emissions, economic growth, energy consumption, trade, and urbanization in new EU member and candidate countries: A panel data analysis, *Economic Modelling*, 44, 97-103.

Kaya, Y., 1990. Impact of carbon dioxide emission control on GNP growth: interpretation of proposed scenarios. Paper presented to the IPCC Energy and Industry Subgroup, Response Strategies Working Group, Paris. (Mimeo)

Laspeyers, E., 1871, Die Berechnung einer mittleren Waarenpreissteigerung. Jahrb, National, Stat, 16, 296-315.

Leontief, W., 1941, The Structure of American Economy, 1919–1929:An Empirical Application of Equilibrium Analysis. Harvard University Press, Cambridge.

Leontief, W., 1970, Environmental repercussions and the economic structure: an input-output approach, *The Review of Economics and Statistics*, 52 (3), 262–271.

Leontief, W., Ford, D., 1972, Air pollution and the economic structure empirical results of input-output computations in: Brody, A., Carter, AP (Eds.), Input– Output Techniques, North-Holland, Amsterdam.

Leontief, W., Quantitative, 1936, Input and output relations in the economic system of the United States, *Review of Economic Statistics*, 18 (3), 105–125.

Lermit, J., Jollands, N., 2001, Monitoring energy efficiency performance in New Zealand: a conceptual and methodological framework, National Energy Efficiency and Conservation Authority Wellington.

Available at: http://www.energywise.co.nz/Strategy/Documents/Monitoring%201.pdf.

Li, F., Song Z., Liu, W., 2014, China's energy consumption under the global economic crisis: Decomposition and sectoral analysis, *Energy Policy*, 64, 193-202.

Ma, C., Stern, D.I., 2008, Biomass and China's carbon emissions: A missing piece of carbon decomposition, *Energy Policy*, 36, 2517– 2526.

ODYSSEE, 1999, Aggregate energy efficiency indicators in ODYSSEE for industry.

Available at: http://www.odyssee-indicators.org/Publication/PDF/indic-ind.pdf.

Okushimia, S., Tamura, M., 2011, identifying the sources of energy use change: Multiple calibration decomposition analysis and structural decomposition analysis, *Structural Change and Economic Dynamics*, 22(4), 313-326.

Paasche, H., 1874, Über Die Preisentwicklung der letzten Jahre nach den Hamburger Börsennotirungen, Jahrb National. Stat. 23, 168-178.

Ren, S., Yin, H., Chen, X.H., 2014, Using LMDI to analyze the decoupling of carbon dioxide emissions by China's manufacturing industry, *Environmental Development*, 9, 61-75.

Report of the Intergovernmental Panel on Climate Change (IPCC) Yokohama, Japan,(2014)

Stern, D.I., 2004, the rise and fall of the environmental Kuznets curve, *World Development*, 2(8), 1419-1439.

Taghvaee, V.M., Hajiani P., 2014, Price and Income Elasticities of Gasoline Demand in Iran: Using Static, ECM, and Dynamic Models in Short, Intermediate, and Long Run, *Modern Economy*, 5, 939-950.

Taghvaee, V.M., Parsa H., 2015, Accepted manuscript titled: Economic growth and environmental pollution in Iran: Evidence from manufacturing and services sectors, journal: *Custos E Agronecio Online*.

Taghvaee, V.M., Shirazi, J.K., 2014, Analysis of the relationship between economic growth and environmental pollution in Iran (evidence from three sections of land, water and atmosphere). *Indian Journal of Scientific Research*, 7(1), 31-42.

Tsurumi, T., Managi, S., 2010, Does energy substitution affect carbon dioxide emissions – Income relationship? *Journal of the Japanese and International Economies*, 24, 540-551.

US Energy Information Administration, Statistics, 2015.

Available at: www.eia.gov

US Energy Information Administration, Key World Energy Statistics, 2014

Vaninsky, A., 2014, Factorial decomposition of CO2 emissions: a generalized Divisia index approach, *Energy Economics*, 45, 389-400.

Wade, S.H., 2002, measuring change in energy efficiency for the annual energy outlook 2002, Energy Information Administration, Department of Energy, United States, Washington, DC. Available at: http://www.eia.doe.gov/oiaf/analysispaper/efficiency/pdf/efficiency.pdf.

World Bank, (2014), World Development Indicator.
Available at: http://databank.worldbank.org/data/views/variableselection/selectvariables.aspx?source=world-development-indicators.

Xu, J.H., Fleiter, T., Eichhammer, W., Fan, Y., 2012, Energy consumption a CO2 emissions in China's cement industry: a perspective from LMDI decomposition analysis, *Energy Policy*, 50, 821-832.

Yale University Database, Environmental Performance Index.
Available at: http://epi.yale.edu/

Zhang, H., Lahr, M.L., 2014, China's energy consumption change from 1987 to 2007: a multi-regional structural decomposition analysis, *Energy Policy*, 67, 682-693.

Appendix

Table 1: Actual values, estimated values, the differences and the percent of the differences in proportion to the actual values

Year	Actual values	Estimated values	Difference between estimated and actual values	Difference between estimated and actual values to the actual values in percentage term
2003	1.003520	1.003514	0.000006	0.000598
2004	1.002584	1.002577	0.000007	0.000698
2005	1.003130	1.003129	0.000001	0.000099
2006	1.007801	1.007799	0.000002	0.000198
2007	0.995629	0.995623	0.000006	0.000603
2008	1.015092	1.015091	0.000001	0.000098
2009	0.991170	0.991165	0.000005	0.000504
2010	1.006000	1.005995	0.000005	0.000497
2011	0.997560	0.997557	0.000003	0.000301

Table 2: Time series of the decomposition of China's environmental quality 2002-2011

	PP	EI	PS	EPE	ES
2002-3	1.012234860	1.012809066	1.022321632	0.952193624	1.031559825
2003-4	1.013006529	1.017214935	1.020619269	0.951656778	1.027992373
2004-5	1.015378150	0.988363791	1.027373118	0.971754690	1.017035434
2005-6	1.018423167	0.986109233	1.035739868	0.968258059	1.021465494
2006-7	1.022353598	0.963972032	1.045158698	0.976573294	1.007539523
2007-8	1.016880349	0.974066026	1.037508178	0.996851484	1.013038865
2008-9	1.017627732	0.993512030	1.047617308	0.961882584	1.025160125
2009-10	1.021479063	0.998293464	1.031129514	0.964595420	1.013646733
2010-11	1.020330701	0.995438860	1.030116102	0.968146664	1.016430682

Table 3: Time series of the decomposition of United States of America's environmental quality 2002-2011

	PP	EI	PS	EPE	ES
2002-3	1.024309701	0.984290249	0.994579826	1.000720004	0.971405635
2003-4	1.032793081	0.989960794	0.995276389	0.985705255	0.971486160
2004-5	1.028667703	0.983911101	0.993937934	0.997654140	0.980891078
2005-6	1.022539068	0.980287298	0.992143966	1.011385049	0.973935962
2006-7	1.014883856	0.999822123	0.989754340	0.988023789	0.990025582
2007-8	0.997626674	0.987936412	0.990965193	1.019674588	0.982158580
2008-9	0.977473886	0.988880524	0.988466754	1.031693340	0.962732970
2009-10	1.019653555	0.999307987	0.992414210	0.990364153	0.977063979
2010-11	1.014263688	0.986688400	0.992726198	1.005299852	0.970110065