Nonrenewable, renewable energy consumption and economic performance in OECD countries: A stochastic distance function approach

Nguyen Thi Ngan Thao
Vietnam-Netherlands Program
University of Economics HCMC
1A Hoang Dieu, Phu Nhuan Dist.
Ho Chi Minh City, Vietnam
Email: thao.ntn@vnp.edu.vn

Le Van Chon
School of Business
International University - VNU HCMC
Quarter 6, Linh Trung, Thu Duc Dist.
Ho Chi Minh City, Vietnam
Email: lvchon@hcmiu.edu.vn

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ABSTRACT

Kyoto Protocol with the target of lowering greenhouse gas emission levels to mitigate the harsh aftermaths of global warming and climate change, primarily caused by fossil fuel using, has put a great pressure on developed countries, including OECD countries, which accounts for a large share of the world's total energy consumption. This leads to the trend of shifting from nonrenewable energy to renewable energy recently, and also attracts the studies in this area. Utilizing the panel data of 34 OECD countries from 1990 to 2012, this paper estimates the stochastic distance function with four inputs (capital, labor, nonrenewable and renewable energy consumption) and one output (GDP) to analyze the effects of nonrenewable and renewable energy consumption on GDP, the relationship between two sources of energy, and the productivity change of OECD countries over the period. Nonrenewable and renewable energy are proved to be substitutes of each other and positively contribute to economic growth. On the other hand, the high values of technical efficiency suggest that average OECD country operates almost as effectively as the best performer in the whole group whereas the measurement of productivity change shows that all productivity gain is attributed to the outward shift of the production frontier.

Key words: nonrenewable energy, renewable energy, productivity change, distance function

JEL classification: C67, Q43.

1. Introduction

Energy is a vital resource for economic activities. Thus, the nexus between energy consumption and economic growth has attracted the attention of economic researchers, especially in recent years when industrial activity has proven its increasingly important role in growth (Lee and Chang, 2007; Narayan and Smyth 2008; Apergis and Payne, 2009). Not only economists but also climate activists take attentive look at energy consumption but due to a different reason: the use of energy, primarily nonrenewable energy, creates negative effects on the environment through greenhouse gas (GHG) emission, directly causing global warming and climate change (Intergovernmental Panel on Climate Change, 2007).

Since 2005 when Kyoto Protocol took into effect, the pressure is greatly added to developed economies which take principle responsibility for exceedingly high levels of six main GHGs in the atmosphere. According to United Nations Framework Convention on Climate Change (UNFCCC), countries are legally bound to cut down their joint GHG emission levels by 5.2% compared to that in 1990. The protocol targeted a 29% collective reduction by 2010 and that would tremendously ease the harsh impacts of economic activities on environment (UNFCCC, 2015). However, this protocol's influence on global warming and climate change does not meet the expectation due to conflicts among major economies since energy conservation policies are predicted to have a huge impact on their economic performances. Some of biggest emitters like United States, China, India refused to sign on Kyoto Protocol because of the fear of losing competitive advantages against those who do not ratify the agreement. Besides, the immediate outcomes of reducing GHG emissions on economic growth are what make governments reluctant to be aware of climate change's aftermaths. US leaders argued against scientists and climate activists that in compliance with the Protocol, about five million jobs would be potentially lost and the gross domestic product (GDP) would seriously suffer (Broehl, 2005). Nevertheless, under the increasing pressures from critics and countries which are following the Protocol and witnessing devastating consequences of natural calamity every year, those large countries will be no longer able to ignore the Protocol.

Besides some industrialized nations opposing Kyoto Protocol, more than 140 other countries, including the European Union, ratified this treaty and adopted new energy policies to reach their assigned emission levels (Broehl, 2005). In the process of compliance with the Protocol, renewable energy technologies have been accommodating countries with the most effective tool to fulfill their growing energy demands and attain global GHG reduction goals at the same time. The substitution between renewable energy for nonrenewable energy no longer serves the purpose of meeting emission levels but gradually becomes the new engine for countries to improve their technology and energy efficiency. International Renewable Energy Agency stated that the ramped up renewable energy policies from countries could double the share of renewable energy in global energy consumption by 2030 without any additional cost, while according to Intergovernmental Panel on Climate Change, 80% of global energy supply can be renewable energy by 2050 (UNFCCC, 2014). Being friendlier with the environment and potentially cost benefitted, renewable energy promoting policy is developing very fast globally. According to the Renewable Energy Policy Network for the 21st Century (REN21), more than 100 nations, including leading economies, set up their national renewable energy generation and consumption goals (Broehl, 2005). The trend of shifting from nonrenewable energy to renewable energy in countries, especially developed countries, has been stirring up studies in energy economics area.

Although there exist many researches digging the relationship between energy consumption and economic growth, most of them concentrates on energy consumption in general. With the use of time series data, significantly positive relationship between energy consumption and GDP is found in many empirical researches such as Stern (2000), Stresing, Lindenberger, and Kummel (2008), Yuan et al. (2008). Applying panel date, the same result is also proven in the studies of Lee and Chang (2007), Narayan and Smyth (2008), Apergis and Payne (2009).

Alper et al. (2013) utilized micro data of 47 US states and confirmed both short-run and long-run positive associations between energy and growth. Recently, researchers started to put renewable energy under investigation. Considering only renewable energy in a paper in 2010, Apergis and Payne demonstrated similar outcomes as above studies. Unlike previous empirical researches, Apergis and Payne (2012), Tugcu, Ozturk, and Aslan (2012) put both renewable and nonrenewable energy into the models to analyze the impact of each type on economic growth. Different results were drawn out from these studies: while both types of energy significantly positively correlated with GDP in the research of Apergis and Payne, Tugcu and his colleagues found out mixed outcomes when applying classic and developed production model.

Although there are differences in the samples, data and models used in above empirical papers, the main researching methods are similar, which are cointegration analysis and Granger causality test running based on the Cobb – Douglas production functions, either classic or developed or both. Besides, the authors did not investigate the relationship between renewable or nonrenewable energy consumption, whether they are substitutes or complements. Moreover, as the approaches are almost the same, except production functions adopted, the analytical results tend to be similar. Lastly, the number of studies about renewable energy is still small and commensurate with its growing important role in economic activities and environment protection.

In an effort to contribute to energy economics, this research will examine the impacts of both nonrenewable and renewable energy consumption on GDP of 34 countries in The Organization for Economic Cooperation and Development (OECD) in a different approach with previous studies. Following Atkinson, Cornwell, and Honerkamp (2003), Atkinson and Dorfman (2005), Fu (2009), Le and Atkinson (2010), multiple – input, one – output stochastic distance function will be employed in this paper. Unlike these researches taking into account multiple outputs (including bad and good outputs), only one good output (GDP) is put into the model. Besides, foresaid studies utilized the micro data of electric companies in the US whereas this study will use the macro data of OECD countries. With the adoption of stochastic distance function, this research will not only estimate the influences of two types of energy on GDP but also calculate the partial effects between any pair of inputs, on which the partial effect between nonrenewable and renewable energy consumption will be concentrated. Furthermore, average technical efficiency, efficiency change, technical change and productivity change of OECD countries will be computed.

2. Literature review

2.1 Definition and classification of energy

2.1.1 Energy definition

There are many forms of energy, thus many definitions of energy which people choose to explain it in the most comprehensive way, depending on the researching circumstances, for example thermal energy, nuclear energy, etc., (Nigg, MacIntosh, and Mester, 2000). The most common definition of energy is “the ability to do work” (US EIA, 2015). Another clearer interpretation which is broadly used in physics is that energy is an object’s property which is transferable to other objects or convertible into many different forms, however it is not able to be created nor sabotaged by itself (Kittel and Kroemer, 1980). This definition is similar with the description from The Laws of Thermodynamics. The first law of Thermodynamics declares that energy of a system is constant, except the case it is transferred in or out under the impacts of mechanical work or heat, however energy remains unchanged during the transfer (Denker, 2013). It means that energy itself is impossible to be created or destroyed.

2.1.2 Energy classification

Similar to the definition, there are various ways to classify energy, basing on the context where energy is studied. For instance, basing on its status, classical mechanics divides energy into two types: kinetic (working) energy, which is ascertained by the motion of an object through space; and potential (stored) energy, which is the energy that an object possesses thanks to its position in a force field or that a system possesses thanks to the configuration of its components (McCall, 2010). Or basing on its sources, energy can be categorized into: heat (thermal), light (radiant), motion (kinetic), electrical, chemical, nuclear energy, gravitational (US EIA, 2015). However, there is no clear border among classifications and many classifications overlap each other. For example, part of thermal energy is kinetic energy, and another part of it is potential energy.

In this study, basing on its renewable ability, energy is classified as nonrenewable and renewable energy. The descriptions of the two sources will be delivered in two following sections.

2.1.2.1 Nonrenewable energy

According to US EIA (2015), nonrenewable energy is an energy source which cannot be easily refilled up. In other words, it does not renew itself in a short period of time. Therefore, it is also called as a finite energy resource.

Nonrenewable energy comes from four main sources: crude oil, natural gas, coal, uranium (nuclear energy). The first three sources are regarded as fossil fuels as they were created millions of year ago from the fossils of dead plants and animals under the heat radiated from earth's core and the pressure of rock and soil. These sources cannot be replenished as quickly as the rate they are harvested and consumed. As a result, it does not cost humanity to create fossil fuels but it is gradually very costly to exploit them. The last nonrenewable energy source _ uranium, whose atoms are divided at nuclear power plants, is used to generate heat and eventually electricity.

Most of energy used in daily living or production activities is acquired from nonrenewable sources, for example, 90% of total energy consumed in the US in 2014 is nonrenewable energy (US EIA, 2015). The huge and continual demand for nonrenewable energy, especially petroleum, is originated from the invention of internal combustion engines in the 17th century. Nowadays, in spite of the creation of new green technologies, infrastructure and transportation systems which use combustion engines are still globally prominent. The ceaseless consumption of nonrenewable energy at the current rate is recognized as the primary cause for global warming and climate change (National Research Council, 2010).

2.1.2.2 Renewable energy

Renewable energy is an energy source which can be easily and naturally recreated over a short time scale. Different from limited energy sources like fossil fuels, humanity can replenish renewable energy from biological regeneration or other natural recurring mechanisms (US EIA, 2015).

Renewable energy is generated from five major sources below:

- Solar energy, transformed to electricity and heat
- Wind power
- Geothermal energy, radiated from heat from the earth's core
- Biomass from plants, including trees' firewood, corn's ethanol, vegetable oil's biodiesel
- Hydropower as known as water power, generated from falling water or fast running water through hydroelectric turbines

Unlike other energy sources which exist only in some countries such as petroleum in the Middle East, renewable energy sources spread widely over geographical areas. Most of renewable energy projects are implemented in large – scales, so they are very suitable with the rural and remote areas and can stimulate economic growth in these areas (Leone, 2001).

From 2004, global renewable energy production grew by 10 – 60% annually for many technologies, especially for wind power technology, and increasingly contributed to the world's energy consumption. According to the report of REN21, in 2014, renewable energy accounted for 19% of total global energy consumption, in which traditional biomass contributed 9%, heat energy 4.2%, hydro electricity 3.8%, and the rest 2% came from wind power, solar energy, geothermal energy and biomass (Sawin et al., 2014).

2.2. Energy consumption and growth

2.2.1 Economic effects of energy consumption

2.2.1.1 Theoretical arguments

Classical production models did not mention energy as one of the vital factors contributed to economic growth. Capital and labor are considered as basic factors of production function while energy is treated it as an intermediate factor.

With the recently rapid development of energy – consumed equipments used in production, energy claims itself as one of the crucial factors for economic growth nowadays and has been attracting the attention of many energy economists. The role of energy in production has been proved through different perspectives. Studying from biophysical point of view, Cleveland, Costanza, and Kaufmann (1997) expressed that future economic performance would rely greatly on the net energy production from various types of fuel sources, and some classical economic models might need to be adjusted to explain the biophysical constraints on economic activities. Beaudreau (1995) censured classical growth model for considering energy as unimportant factor and stated that engineering production could not work without energy. Adding energy into the model, he demonstrated that the gap between output growth rates and aggregate input growth rate, as known as Solow residual, in many previous classical growth studies was nearly eliminated in his research. Moreover, the growth in combined input growth indexes could almost account for the growth in manufacturing in US, German and Japan. On the other hand, through engineering economics viewpoint, Pokrovski (2003) expressed that manual labor tended to be replaced by energy – driven machines in many fields of modern economies, causing inputs of production function to be determined by capital, labor and energy service. Advocating previous authors, Thompson (2006) argued that energy, as a production input, transforms or combines physical capital and labor into an aggregate output.

To be concluded, modern economic activities require energy as a compulsive input. Excluding energy consumption out of augmented production function would result in a lack of judgment (Lee and Chang, 2007).

2.2.1.2 Empirical researches

In the effort of demonstrating the role of energy use in economic growth, Apergis and Payne (2009, 2012); Arbex and Perobelli (2010); Lee and Chang (2007, 2008); Narayan and Smyth (2008); Stern (2000); Stresing, Lindenberger, and Kummel

(2008); Yuan et al. (2008) along with many other researchers have generalized the energy – growth nexus into four hypotheses:

i) *The growth hypothesis* is the circumstance in which energy consumption is proved to take a vital role in economic growth directly and / or complementarily to transform and / or combine capital and labor. This hypothesis is advocated by uni – directional causality going from energy use to growth, which implies that reducing energy consumption would create negative impacts on growth. Energy policy in this case aims to seek green energy which decreases pollution caused by energy usage.

ii) *The conservation hypothesis* refers to the circumstance in which economic growth leads to the increase in energy consumption. This hypothesis is determined by the uni – directional causality going from growth to total of energy use. Energy policy which reduces the use of energy may not result in the decline of the growth.

iii) *The feedback hypothesis* shows a mutual relationship between GDP growth and energy use. This hypothesis is proved by the existence of bi – directional nexus between the two said factors. Energy conservation policy in this case may cause the decrease in economic growth; and economic performance would reflect back to the total use of energy.

iv) *The neutrality hypothesis* states that energy consumption has no significant effect on growth. This hypothesis is argued by the lack of causality between these two said factors. In this situation, energy policy supporting the reduction in energy consumption would not have any impact on growth.

Most of empirical researches on energy consumption – growth link applied cointegration analysis and Granger causality test on expanded production model with two basic inputs (capital and labor), adding energy consumption and some other factors like Research and Development, Education as new inputs. The main objective is to check the long-run cointegrating relationship and the causal relationship between GDP and energy consumption.

Positive long-run conintegration is proved in almost all studies whereas the causality varies according to samples examined. Running the regression on US's time series data from 1948 to 1994, Stern (2000) proved bi – directional connection between GDP and energy in both short run and long run. The same result is shown in the research of Alper et al. (2013), analyzing the annual data for 47 US states from 1997 to 2009. Besides, the bi – directional relationship may happen in short-run but not in long-run and vice versa. More specifically, employing both aggregated energy consumption and disaggregated consumption of coal, oil, electricity, Yuan et al. (2008) found out that electricity and oil consumption positively affect total output in long-run. Furthermore, GDP on this paper also brings positive influence on the use of total energy, coal and oil but only in short – run.

On the other hand, one – way effect from the use of energy on economic performance is the most frequent result derived from studies such as Lee and Chang (2007), Narayan and Smyth (2008), Apergis and Payne (2009) which the authors utilized the panel data of 16 Asian countries, G7 countries and Central America, respectively. The effect of energy consumption on GDP is found to be significantly positive in these researches. For example, 1% rise in energy consumption boosts G7 countries' GDP by 0.12-0.39%.

In summary, most of researchers advocate growth hypothesis, some prove feedback hypothesis and only few support conservation and neutrality hypothesis. This indicates the crucial role of energy on economic growth.

2.2.2 Environmental effects of energy consumption

Unlike the positive effects on economic growth, energy consumption is widely acknowledged as the principle reason for global warming and climate change. It is also broadly recognized that global warming and climate change are caused by

GHG emissions which are majorly originated from the use of fossil fuels (United States Environmental Protection Energy, n.d.). In 2013, the burning of fossil fuels released approximate 32 billion tons of carbon dioxide (CO_2) into the atmosphere and extra air pollution. The negative externalities from its harm to global environment and human health cost the world 4.9 trillion of US dollars if one ton of CO_2 is assumed to be accounted for 150 of US dollar loss (Ottmar, 2015). CO_2 is one of six GHGs which increase radiative forcing and make substantial contribution to global warming. Global warming enhances the average surface temperature of the Earth in response, leading to climate change. In turn, climate change will cause food and water shortage, global sea – level rise, continual flooding, etc., which will put billions of lives, especially those in developing counties, in extreme danger (Intergovernmental Panel on Climate Change, 2007).

Besides the damages to the environment, energy consumption is also harmful to human health. The most risky health impact comes from surrounding air pollution induced by the exploiting and burning of solid fuels, coal and biomass. Limited access to green fuels and electricity in poor households put their lives at serious risk (Smith et al., 2013).

The adverse impacts on the environment of energy accrue not only from consumption but also from the process of exploitation. One of the most obvious evidences is the firewood harvesting to produce charcoal. The overharvest of forest leads to deforestation which destroys the most useful protection cover of the atmosphere, i.e., CO_2 absorbing cover. In addition, the uncontrolled harvest causes the damage to biodiversity and erosion system (Rowan, 2009).

If taking above externalities of nonrenewable energy consumption, of which fossil fuels are major parts, into account, the cost of generating electricity from coal or oil would be twice as its present value, and that from gas would climb up by 30% (Dones et al., 2005). On the other hand, with increasing demand of energy to satisfy economic as well as living activities, energy resources have been exhausted.

Consequently, nonrenewable energy is no longer free source but more and more expensive because the exploitation becomes costly eventually. It is a serious threat to energy security.

Therefore, the searching for new energy sources, which is not only easy to be refilled up but also friendly to the environment, is an urgent issue to all nations. Renewable energy has been widely considered as the sustainable source which can satisfy the production demand and environmental protection requirements. According to Dones et al. (2005), the production of energy from hydropower creates the lowest level of CO_2 emission, emission from wind power production comes at second – lowest and third – lowest level of CO_2 emission belongs to nuclear energy production. Despite acknowledgement of the benefits renewable energy bringing to the environment, the switch from nonrenewable energy to renewable energy cannot happen immediately and smoothly due to the high initial cost of investment on renewable energy generation technologies and the fear of governments that GDP would be sacrificed if renewable energy is replaced nonrenewable energy in economic activities. This dilemma has been stimulating the studies in the relationship between nonrenewable and renewable energy consumption and economic performance. Some of empirical papers about that topic will be reviewed in succeeding section.

2.3 Nonrenewable and renewable energy consumption and economic growth

The rapid increase in using renewable energy in economic activities around the world, especially developed countries, has drawn the attention of economists into the impact of renewable energy. Inherited the methodology from previous studies in energy economics, most of researchers adopted cointegration and Granger causality test to analyze the influence of renewable energy consumption on the economy.

Apergis and Payne (2010) put renewable energy consumption, represented by renewable electricity consumption, into the production side model of a panel data of

11 countries in Eurasian region and figured out that long-run equilibrium exists among variables, including GDP and renewable energy consumption. Furthermore, there is bi – directional causality between these two variables in both short-run and long-run. Authors applied fully modified ordinary least squares method for heterogeneous cointegrated panels and revealed that the use of renewable energy increasing by 1% would lead to 0.195% rise in real GDP.

Employing the same approach, in 2012, Apergis and Payne included both nonrenewable and renewable energy into their study of a sample of 80 countries around the world. The results are similar to their previous paper in 2010. Long-run cointegrating relationship between variables and short-run and long-run bidirectional causality between the consumption of renewable and nonrenewable energy and GDP growth were found from the panel data. Both types of energy statistically significantly and positively affect economic growth. More particularly, 1% expansion in the use of nonrenewable and renewable energy consumption leads real GDP to increase by 0.384% and 0.371%, respectively. These results indicate the importance of energy in the economy, and despite the growth of renewable energy, nonrenewable still have more significant effect on economic growth.

Digging deeper into this area, Tugcu, Ozturk, and Aslan (2012) adopted two different production models on the annual data of Group of Seven (G7) countries. One is the classic function with capital, labor, nonrenewable and renewable energy consumption as inputs, the other is the modified function which research & development and human capital were added besides four foresaid inputs. Autoregressive distributed lag approach to cointegration was utilized to check between nonrenewable and renewable energy, which one contributes more to G7 countries' economic performance from 1980 to 2009. Moreover, unlike antecedent studies using Granger causality test, the authors applied a causality test method recently developed by Hatemi to examine the causality between energy consumption and GDP growth. These approaches gave out different results with most of previous studies in this field. The long-run estimation displays that both nonrenewable and renewable consumption did not make significant contribution to economic growth in the tested period. The researchers not only analyzed the whole sample but also ran the regression on individual countries. Bi – directional causality happened for all seven countries in classical production model whereas mixed results were detected for each country once modified production was applied.

For OECD countries, a recent study was conducted by Shafiei, Salim, and Cabalu (2014) to check if economies significantly benefits from the use of nonrenewable and renewable energy and to compare the influence of each source on total output. Two types of outputs were investigated: GDP and industrial output of the industry sector which plays a crucial role in economic growth and also occupies the largest part of total energy consumption. Besides cointegration and Granger causality test, recently developed technique, dynamic ordinary least squares was exercised. Regression results point out that both energy sources significantly push GDP in OECD countries. However, taking their impacts into comparison affirms that nonrenewable source still dominates and has relatively larger influence on developed countries. More clearly, when renewable and nonrenewable energy consumption grows by 1%, real GDP will be enhanced by 0.024% and 0.245%, respectively. However, renewable energy use was found to insignificantly affect industrial output while 1% expansion in nonrenewable energy use pushed the output up by 0.171%. Finally, the Granger causality test demonstrates the mutual causality between both renewable and nonrenewable energy consumption and real GDP in the short and long run.

In conclusion, like researches on energy – growth nexus, studies on nonrenewable and renewable energy consumption and economic growth once again highlights the essential role of energy in general and two energy sources in particular in modern economic activities. In spite of the growing use and benefit of renewable energy, nonrenewable still cannot be totally replaced, and gives relatively greater contribution to nations than renewable energy does. On the other hand, the two basic inputs, i.e., capital and labor, are proved to significantly and positively affect GDP growth on all above studies.

The number of papers conducted in renewable energy consumption is still very small compared with its accelerating development recently. Moreover, the methodology is almost repeated in different samples, so the given results are similar and does not fully reflect the influence of renewable energy and its interaction with nonrenewable energy consumption. Therefore, more exertion should be invested to make differences in this studying field.

Moreover, while renewable energy has been proved to positively affect GDP growth by many scholars, its impact to technical efficiency and productivity change, which is one of the vital factors policy makers take into consideration before making decision for national energy structure, is still an unanswered question. Hence, studies should be carried out to solve this question and provide more evidences to Governments with the ultimate goal to bring out the best policy which that not only mitigates the aftermaths of energy consumptions on environment but also enhances economic growth.

2.4 Productivity change and the Stochastic distance function

2.4.1Definition of productivity change

The definitions and explanations in this section are taken from OECD Glossary of Statistical Terms (2015).

First of all, productivity is briefly defined as the ratio of a measured amount of output over a measured amount of input used to produce that output. Productivity change (PC) implies the change in this ratio. Conceptually, PC refers to the combined effects of changes in technical efficiency, allocative efficiency, disembodied technical change and economies of scale. Following empirical studies which employ the stochastic distance function, PC assessment process in this paper will go through the measurement of technical efficiency (TE), efficiency change

(EC) and technical change (TC). Thus, the explanation of TE, EC, TC will be given next to have a comprehensive understanding throughout this paper.

Efficiency implies to the level which a production process shows its best – practice, either in the engineering aspect, which is called TE, or in the economic aspect, which is called allocative efficiency. Full efficiency in an engineering sense, i.e., TE, implies that a production process has reached the highest obtainable level of output or the maximum amount of output that it can produce with the utilization of current technology and a given amount of inputs (Diewert and Lawrence, 1999). An economy or a firm reaching its TE means that it is performing on its production frontier. EC thus refers to the movement forwards to or backwards from the best – practice, i.e. the production frontier. In other words, it is the process of eliminating or adding technical inefficiencies into the production.

Finally, TC is described as the change in the volume of output which a production process can produce with the same volume of inputs given. So, TC refers to the shifts of the production frontier over time, either inward or outward shift. A TC happens due to various reasons, such as the change in technology, organization, regulation or the production constraint like input prices.

2.4.2 Productivity change measurement and stochastic distance function

PC assessment is commonly conducted by using Malmquist indices. However this method still has some limitations that will be discussed in details next. Stochastic distance function is proposed as a new method to measure PC, which can eliminate limitations from Malmquist index approach.

The Malmquist output and input PC indices for the production with multiple inputs and outputs were originally built up by Caves, Christensen, and Diewert (1982) and can be applied for any returns to scale. Giving inputs (outputs), the output – (input-) based index is created through an output (input) distance function and shows the changes in maximum level of output or minimum level of input required. These indices cannot be calculated if the production form is defined for a nonparametric production frontier. The authors stated that as an index number alternative, for the translog construct of production function, the Tornqvist output (input) index could be built as the geometric mean of two Malmquist output (input) indices with the use of price and quantity data, and no need for translog parameters which define the production frontier.

Foresaid paper was extended by Färe, Norris, and Zhang (1994), summarizing into two main points. The first point is that they explain how Malmquist indices are calculated in case of nonparametric specification of the production frontier. This can do by employing the nonparametric, linear programming techniques of data envelopment analysis to fit distance functions to data on input and output quantities. Not using either translog functional structure or data for price, PC is directly computed by taking the geometric mean of two Malmquist productivity indices. Second, derived from Caves, Christensen, and Diewert's study, PC index can be decomposed into TC and EC. However the nonparametric approach of this paper has the big limitation is that constant returns to scale is required on the frontier technology.

Caves, Christensen, and Swanson (1981) gave a stochastic alternative which can be applied in a flexible production function, using a translog cost function. The dual relationship between a transformation function and a cost function is utilized to prove that PC assessment based on input – oriented distance can be stated as the minus the time rate of change in the cost function. It is also TC. So, PC can be measured as the negative of the time derivative of analyzed translog cost function. Nevertheless, this method has a big assumption that all firms' technology must be at their efficient level for EC to be zero. In addition, the authors did not develop the approach to make a direct estimation of the input distance function.

Inherited the best elements from Fare, Norris, and Zhang (1994); Caves, Christensen, and Swanson (1981); Atkinson, Cornwell, and Honerkamp (2003) developed the PC computing method through a stochastic input distance frontier, which PC is computed as the sum of TC and EC. No requirement on returns to scale is one of the advantages of this approach. Furthermore, the methods provided by previous paper are nonstochastic. So, all deviations from the reference technology are ascribed to inefficiency, causing improbably wild volatilities in PC, EC and TC from time to time, hence the imprecise results. By employing a parametric model and taking the noise into account, the authors of this paper found less fluctuation in PC's temporal patterns and its elements.

To prove their arguments on the differences of measuring PC using these two methods, Atkinson, Cornwell, and Honerkamp (2003) utilized the panel dataset of 43 US electric utilities from 1961 to 1962. Three inputs (fuel, labor and capital) and two good outputs (residential and industrial – commercial electricity) were taken under investigation. The results yielding from two methods were put into comparison. In general, both gave positive and similarly yearly rates of PC. However, there are sharp differences in term of the relative significance of TC and EC in explanation of overall growth of PC. More specifically, PC's average annual rate given from Malmquist indices approach is 1.04% compared with 0.56% yielded from stochastic distance function approach. Nonetheless, while average productivity gain derived from Malmquist indices approach is approximately equally balanced between TC and EC, that generated from stochastic distance function approach is mainly attributed to TC. Besides, there is sharp conflict regarding the temporal patterns in PC, TC and EC produced from these two methods. Considerably greater volatility was found in Malmquist indices method. Failing to solve the noise in this method is most likely the reason explaining for above different results.

The advantages of using stochastic distance function to measure PC were recognized by many followers. This approach was adopted in Atkinson and Dorfman (2005) with one bad output, i.e., sulfur dioxide (SO_2) emission, comprised. The main outcome inferred from this research is the negative EC over the examined period which is greatly ascribed to the exertions of firms in cutting SO_2 emissions. With the same context, Fu (2009) did the estimation of a directional distance function on a panel data, containing 78 privately – owned electricity firms in the period 1988 – 2005. She took three bad outputs, i.e., emissions of SO_2, CO_2, nitrogen oxides (NO_x), into account and found out the decrease in efficiency and productivity over the period. Le and Atkinson (2010) added the annual costs spent on devices used to eliminate SO_2, NO_x and particulate into the dataset of Fu (2009). The multiple – input, multiple – output directional distance function was applied with six inputs (fuel, labor, capital for production and capital spent on SO_2, NO_x and particulate eliminating equipments), two good outputs (residential and industrial – commercial electricity) and three bad outputs (SO_2, CO_2, NO_x emissions). Similar to two former studies, the decline in efficiency and productivity was detected in this paper.

Also learning from Atkinson, Cornwell, and Honerkamp (2003), this thesis will adopt the stochastic distance function to reach the research goals set from the beginning.

3. Econometric model

3.1 Stochastic Distance Function Form

This section follows Atkison, Cornwell, and Honerkamp (2003). Considering a country's production technology where N nonnegative good inputs are combined, $x = (x_1, x_2, \dots, x_N) \epsilon R_+^N$ to create M nonnegative good outputs, $y = (y_1, y_2, \dots, y_M) \in R_+^M$

The country's production technology can be written in term of an input correspondence as following:

$$y^t \rightarrow L^t(y^t) = \{x^t \epsilon R_+^N : at\ least\ y^t\ is\ created\ in\ period\ t\}$$

in which $L^t(y^t)$ is the set of input requirement.

For a given country, the input distance function is translated as the maximum scale factor essential for x^t to be on the frontier of $L^t(y^t)$.

$$D_i^t(y^t, x^t) \equiv \max_{\lambda} \left[\lambda : \left(\frac{x^t}{\lambda}\right) \in L^t(y^t)\right] \quad (1)$$

$x^t \epsilon L^t(y^t)$ happens if and only if $D_i^t(y^t, x^t) \geq 1$. This is because of the assumption of inputs' free disposability. More clearly, it is $x^t \in x^t \epsilon L^t(y^t), x'^t \geq x^t \Rightarrow x'^t \epsilon L^t(y^t)$

Above function is served to compute the PC using Malmquist indices.

Atkison, Cornwell, and Honerkamp (2003) expressed (1) for country c over period t under a more typical of an econometric model:

$$D_i(y_{ct}, x_{ct}, t) \equiv D_i^t(y^{ct}, x^{ct})$$

According to Fare and Primont (1996), this model can be appealed to the duality between the input distance function and the cost function, $C(y_{ct}, p_{ct}, t)$ in which p_{ct} presents the vector of input prices. Authors assumed that the cost function $C(y_{ct}, p_{ct}, t, g(\varepsilon_{ct}))$ is a multiplicative function, thus it can be translated under the form of $C(y_{ct}, p_{ct}, t)g(\varepsilon_{ct})$, in which ε_{ct} and $g(\varepsilon_{ct})$ are given as a random variable and a function of ε_{ct} , respectively.

Similarly, the distance function $D_i(y_{ct}, x_{ct}, t, g(\varepsilon_{ct}))$ can be defined as the same context:

$$D_i\big(y_{ct}, x_{ct}, t, g(\varepsilon_{ct})\big) = \min_p \left\{\frac{p_{ct}x_{ct}}{C(y_{ct}, p_{ct}, t)g(\varepsilon_{ct})}\right\}$$
$$= \frac{D_i(y_{ct}, x_{ct}, t)}{g(\varepsilon_{ct})}$$
$$= D_i(y_{ct}, x_{ct}, t)h(\varepsilon_{ct})$$

In which $h(\varepsilon_{ct}) = \frac{1}{g(\varepsilon_{ct})}$ and $g(\varepsilon_{ct}) > 0$

Inferred from (1), $1 \leq D_i(y_{ct}, x_{ct}, t)$, and the equality happens only if x_{ct} belongs to the isoquant of input requirement set. Because of technical inefficiency, divergences from 1 are adjusted through the specification of $h(\varepsilon_{ct})$, the stochastic input distance function can be expressed as:

$$1 = D_i(y_{ct}, x_{ct}, t)h(\varepsilon_{ct}) \quad (2)$$

Therefore, if (2) is given as a functional form, it can be analyzed through econometrical methods after inputs are set under linear homogeneity.

3.2 Parametric specification

The translog functional form is employed to flexibly approximate the distance function in (2). Hence, the empirical model for country c over period t is written as following:

$$0 = \gamma_0 + \sum_m \gamma_m lny_{mct} + \sum_n \gamma_n lnx_{nct} + \gamma_t d_y$$
$$+ \frac{1}{2}\sum_m \sum_k \gamma_{mk} lny_{mct} lny_{kct} + \frac{1}{2}\sum_n \sum_l \gamma_{nl} lnx_{nct} lnx_{lct}$$
$$+ \sum_m \sum_n \gamma_{mn} lny_{mct} lnx_{nct} + \sum_m \gamma_{mt} d_t lny_{mct}$$
$$+ \sum_n \gamma_{nt} d_t lnx_{nct} + \ln h(\varepsilon_{ct}) \qquad (3)$$

$d_t(t = 1, 2, \dots, T)$ is the time dummy for specific year.

The composite error $\ln h(\varepsilon_{ct})$ is the additive error, combining two elements. One is $u_{ct} \geq 0$, called one – sided element, and the other is v_{ct}, called standard noise with zero mean.

Many parametric restrictions are imposed on (3). First of all, the symmetric requirements include following conditions:

$$\gamma_{mk} = \gamma_{km} \; ; \; \forall \, m, k \; ; \; m \neq k$$

$$\gamma_{nl} = \gamma_{ln} \; ; \; \forall \, n, l \; ; \; n \neq l$$

Besides, the linear homogeneity property of input quantities suggests that:

$$\sum_n \gamma_n = 1 \, , \sum_n \gamma_{nl} = \sum_l \gamma_{nl} = \sum_n \sum_l \gamma_{nl} = 0$$

$$\sum_n \gamma_{nt} = 0 \, , \; and \sum_n \gamma_{mn} = 0 \, , \; \forall m$$

Following Le and Atkinson (2010), country – specific dummy variables are added to (3). This addition can loosen the assumption of strong distribution on both u_{ct} and v_{ct}. On the other hand, there are 34 different countries in the sample of OECD countries. Each nation has specific characteristics of geography, population, regulation, etc., and is distinguished with other nations. The utilization of dummy variables for countries would take those differences into account.

3.3 Computing partial effects among variables

Following Le and Atkinson (2010), Agee, Atkinson, and Crocker (2012), the implicit function theorem allows us to analyze the partial impact of one variable on another variable.

Firstly, we take the partial derivative of function (3) with respect to each variable, including both output and input variables, i.e., $\overrightarrow{D_0}/\partial y_m$ and $\partial \overrightarrow{D_0}/\partial x_n$, respectively. Then, the impact of an input on an output is $-(\partial \overrightarrow{D_0}/\partial x_n)/(\partial \overrightarrow{D_0}/\partial y_m)$ with $\forall \, m, n$. The impact of an input on another input is $-(\partial \overrightarrow{D_0}/\partial x_n)/(\partial \overrightarrow{D_0}/\partial x_{n'})$ with $\forall \, n, n' and \; n \neq n'$

3.4 Computing technical efficiency, efficiency change, technical change and productivity change

This section follows Atkison, Cornwell, and Honerkamp (2003). EC, TC and PC are measured in terms of percentage changes.

The measurement of TE, EC, TC and PC is conducted based on the results from the estimation of (3). As the non-negativity is not imposed on one – sided element u_{ft} when estimating (3) earlier, it is conducted afterwards by doing the addition and subtraction from the fitted model $\hat{u}_t = min_c(\hat{u}_{ct})$ that determines the frontier intercept.

$\ln \widehat{D}_i(y,\ x, d_t)$ is given as the analyzed translog part of function (3), excluding $\ln h(\varepsilon_{ct})$. Adding and subtracting $\hat{u}_t$ from (3), it is re – written as following:

$$0 = \ln \widehat{D}_i(y,x,d_t) + \hat{v}_{ct} - \hat{u}_{ct} + \hat{u}_t - \hat{u}_t$$
$$= \ln \widehat{D}_i^*(y,x,d_t) + \hat{v}_{ct} - \hat{u}_{ct}^* \qquad (4)$$

in which $\ln \widehat{D}_i^*(y,x,d_t) = \ln \widehat{D}_i(y,x,d_t) - \hat{u}_t$ is the estimation of the frontier distance function at period t and $\hat{u}_{ct}^* = \hat{u}_{ct} - \hat{u}_t \geq 0$.

From equation (4), the level of technical efficiency of country c over period t, TE_{ct}, is estimated as:

$$TE_{ct} = \exp\left(-\hat{u}_{ct}^*\right) \quad (5)$$

With TE_{ct} from (5), the change in TE, EC_{ct}, is computed as following:

$$EC_{ct} = \Delta TE_{ct} = TE_{ct} - TE_{c,\ t-1} \quad (6)$$

This is the catching – up rate to the frontier from period t – 1 to period t.

Technical change, TC_{ct}, is the difference between the examined frontier distance function in two periods: t and t – 1, outputs and inputs holding constant. TC is measured through below function:

$$TC_{ct} = ln\widehat{D}_i^*(y,x,d_t) - \ln \widehat{D}_i^*(y,x,d_{t-1})$$
$$= \sum_m \hat{\gamma}_{mt} \ln y_{mct}(d_t - d_{t-1}) + \sum_n \hat{\gamma}_{nt} \ln x_{nct}\,(d_t - d_{t-1})$$

$$+ (\hat{y}_t - \hat{y}_{t-1}) + (\hat{u}_t - \hat{u}_{t-1}) \quad (7)$$

Therefore, if the frontier intercept, i.e., $\hat{u}_t$, changes, it will affects both TC and EC.

Finally, with given TC_{ct} and EC_{ct}; productivity change of country c at time t, PC_{ct}, is constructed as:

$$PC_{ct} = EC_{ct} + TC_{ct}$$

3.5 Model specification

Following empirical studies, beside two classic inputs, capital and labor, nonrenewable energy consumption and renewable energy consumption are included into the production function. Unlike previous researches applying distance function, there is only one output in this paper, i.e., GDP. Capital, labor, nonrenewable and renewable energy consumption are denoted as K, L, NE and RE, respectively.

The data set is obtained for 23 years (period 1990 – 2012). So, there are 23 time – specific dummy variables, denoted as year1, year2, year3, …, year23. To avoid the dummy variable trap, only 22 time – specific dummy variables are put into the model. From the calculation of TC in (7), year1 will be dropped so that we can measure average TC of countries from year2 (1991) to year23 (2012) afterwards.

As explained in Section 3.2, country – specific dummy variables are added to (3). The OECD samples consists of 34 countries, hence there are 34 dummy variables for countries, denoted as d1, d2, …, d34. Like the case of dummy variables for time, only 33 out of these 34 variables are included into the model.

The empirical model for country c over period t from (3) is specified as following:

$$0 = \alpha_0 + \alpha_y \ln GDP_{ct} + \alpha_k \ln K_{ct} + \alpha_l \ln L_{ct} + \alpha_{ne} \ln NE_{ct} + \alpha_{re} \ln RE_{ct}$$
$$+ \tfrac{1}{2} \alpha_{yy}(\ln GDP_{ct})^2 + \tfrac{1}{2} \alpha_{kk}(\ln K_{ct})^2 + \tfrac{1}{2} \alpha_{ll}(\ln L_{ct})^2 + \tfrac{1}{2} \alpha_{nene}(\ln NE_{ct})^2 + \tfrac{1}{2} \alpha_{rere}(\ln RE_{ct})^2$$
$$+ \alpha_{kl} \ln K_{ct} * \ln L_{ct} + \alpha_{kne} \ln K_{ct} * \ln NE_{ct} + \alpha_{kre} \ln K_{ct} * \ln RE_{ct} + \alpha_{lne} \ln L_{ct} * \ln NE_{ct}$$
$$+ \alpha_{lre} \ln L_{ct} * \ln RE_{ct} + \alpha_{nere} \ln NE_{ct} * \ln RE_{ct}$$
$$+ \alpha_{yk} \ln GDP_{ct} * \ln K_{ct} + \alpha_{yl} \ln GDP_{ct} * \ln L_{ct} + \alpha_{yne} \ln GDP_{ct} * \ln NE_{ct} + \alpha_{yre} \ln GDP_{ct} * \ln RE_{ct}$$

$+ \alpha_{yyear2}\ln GDP_{ct}*year2 + \alpha_{yyear3}\ln GDP_{ct}*year3 + \ldots + \alpha_{yyear23}\ln GDP_{ct}*year23$

$+ \alpha_{kyear2}\ln K_{ct}*year2 + \alpha_{kyear3}\ln K_{ct}*year3 + \ldots + \alpha_{kyear23}\ln K_{ct}*year23$

$+ \alpha_{kyear2}\ln L_{ct}*year2 + \alpha_{kyear3}\ln L_{ct}*year3 + \ldots + \alpha_{kyear23}\ln KL_{ct}*year23$

$+ \alpha_{kyear2}\ln NE_{ct}*year2 + \alpha_{kyear3}\ln NE_{ct}*year3 + \ldots + \alpha_{kyear23}\ln NE_{ct}*year23$

$+ \alpha_{kyear2}\ln RE_{ct}*year2 + \alpha_{kyear3}\ln RE_{ct}*year3 + \ldots + \alpha_{kyear23}\ln RE_{ct}*year23$

$+ \alpha_{year2}year2 + \alpha_{year3}year3 + \ldots + \alpha_{year23}year23 + \alpha_{d1}d1 + \alpha_{d2}d2 + \ldots + \alpha_{d33}d33$ (8)

The restrictions imposed on this model to meet linear homogeneity properties in section 3.2 are defined below:

1. $\alpha_{k} + \alpha_{l} + \alpha_{ne} + \alpha_{re} = 1$
2. $\alpha_{kl} + \alpha_{kne} + \alpha_{kre} = 0$
3. $\alpha_{lk} + \alpha_{lne} + \alpha_{lne} = 0$
4. $\alpha_{rek} + \alpha_{rel} + \alpha_{rene} = 0$
5. $\alpha_{nek} + \alpha_{nel} + \alpha_{nere} = 0$
6. $\alpha_{kyear2} + \alpha_{kyear3} + \ldots + \alpha_{kyear23} = 0$
7. $\alpha_{lyear2} + \alpha_{lyear3} + \ldots + \alpha_{lyear23} = 0$
8. $\alpha_{neyear2} + \alpha_{neyear3} + \ldots + \alpha_{neyear23} = 0$
9. $\alpha_{reyear2} + \alpha_{reyear3} + \ldots + \alpha_{reyear23} = 0$
10. $\alpha_{yk} + \alpha_{yl} + \alpha_{yne} + \alpha_{yre} = 0$

Furthermore, the symmetric restrictions are imposed on (8), so the following requirements must be satisfied:

$$\alpha_{kl} = \alpha_{lk}\ ;\ \alpha_{kne} = \alpha_{nek}\ ;\ \alpha_{kre} = \alpha_{rek}\ ;\ \alpha_{lne} = \alpha_{nel}\ ;\ \alpha_{lre} = \alpha_{rel}\ ;\ \alpha_{nere} = \alpha_{nere}$$

Following Le and Atkinson (2010) and Agee, Atkinson, and Crocker (2012), after conducting the estimation on the distance model (8), some tests are carried out. The null hypothesis that all of the squared terms of inputs as well as the interaction terms among inputs are collectively equal to zero is tested. Similarly, the null hypothesis that the interaction terms between an output and inputs are collectively equal to zero is also checked.

Before investigating partial impacts among K, L, NE, RE and GDP, the derivatives of the stochastic distance function with respect to the natural logarithm of each variable (i.e., $\partial\overrightarrow{D_0}/\partial lnx_n$; $\partial\overrightarrow{D_0}/\partial lny_m$) are computed for each country each year. Following Le and Atkinson (2010) and Agee, Atkinson, and Crocker (2012), these derivatives are averages weighted for the sum of good outputs. In this paper, there is only one output, i.e., GDP. Then, partial effect of inputs on the output is $-\,(\partial\overrightarrow{D_0}/\partial lnx_n)\,/\,(\partial\overrightarrow{D_0}/\partial lny_m)$. Partial effect of an input on another input is $-(\partial\overrightarrow{D_0}/\partial lnx_n)/(\partial\overrightarrow{D_0}/\partial lnx_{n'})$, with $n, n'\, and\, n\ \neq n'$. Because all variables are under natural logarithm form, the partial effects can be interpreted like the explanation of elasticity. Likewise, the average TE, EC, TC and PC of OECD countries each year are averages weighted for GDP.

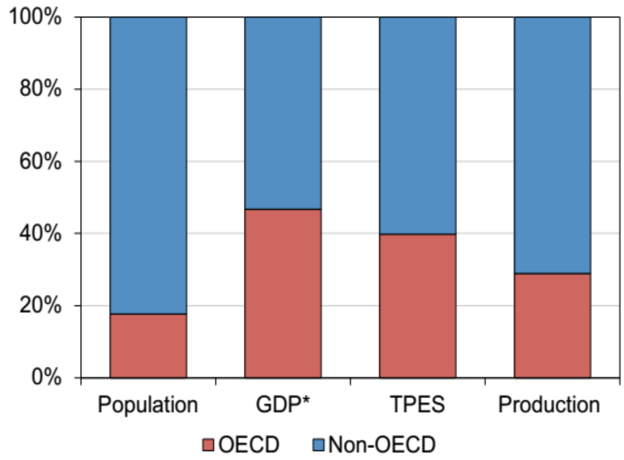
4. Energy consumption and supply in OECD countries

4.1 OECD versus Non – OECD

The Organization for Economic Cooperation and Development (OECD) was originated in 1960 when the US and Canada joined 18 European countries to create an international organization in dedication to economic development. It was officially established in 1961 when OECD Convention was taken into effect. Nowadays, OECD includes 34 countries, spreading all over the world from America to Europe and Asia – Pacific. Many members are the world's most developed countries, but there are also a few emerging economies like Chile, Mexico and Turkey. Therefore, OECD has a great influence on the world in term of both economics and politics, and also holds a remarkably large portion in the global supply and demand of energy.

In 2013, OECD countries captured 18%, 47% and 40% of the world's population, GDP and total primary energy supply (TPES), respectively, displaying in Figure 4.1 below. Outstandingly, accounting for only 1/5 of global population, OECD produces about half of the world's output.

Figure 4.1: OECD versus Non – OECD in terms of population, GDP, total primary energy supply and production



Source: International Energy Agency (IEA) (2015)

OECD also ranks number one in terms of energy – intensive region in the world. The ratio of TPES / population of OECD in 2013 was 4.2 TOE (tonne of oil equivalent) per capita whereas that of the world was 1.9. This can be explained by several factors. For instances, the OECD has the big industry and service sectors which consume a huge amount of energy; nearly 100% of the group is electrified; or the rate of vehicle per household is high (IEA, 2015).

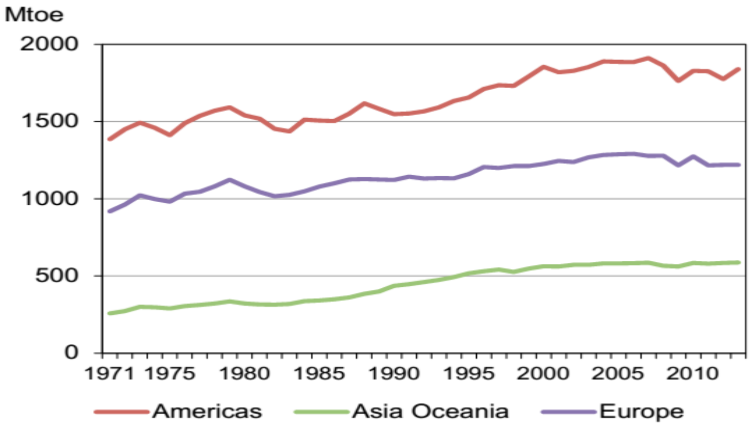
Unlike the high level of energy per capita, level of energy per GDP, i.e., energy intensity, of OECD is generally lower than that average level of the world. This reflects a more advanced development in technology, which allows less energy consumed in production to create one more unit of output (IEA, 2015).

4.2 Energy consumption in OECD countries

4.2.1 Overview of energy consumption in OCED countries

Generally, total final consumption of energy, which is the sum of all energy provided to final consumers in all sectors, in the OECD has increased by time. Countries from America accounts for the largest part of the energy consumption, next are those from Europe, and Asia Oceania took the last position. These trends are demonstrated in Figure 4.2. This difference in energy consumption reflects the general decoupling of economic performance by region from the observation of energy consumption over time.

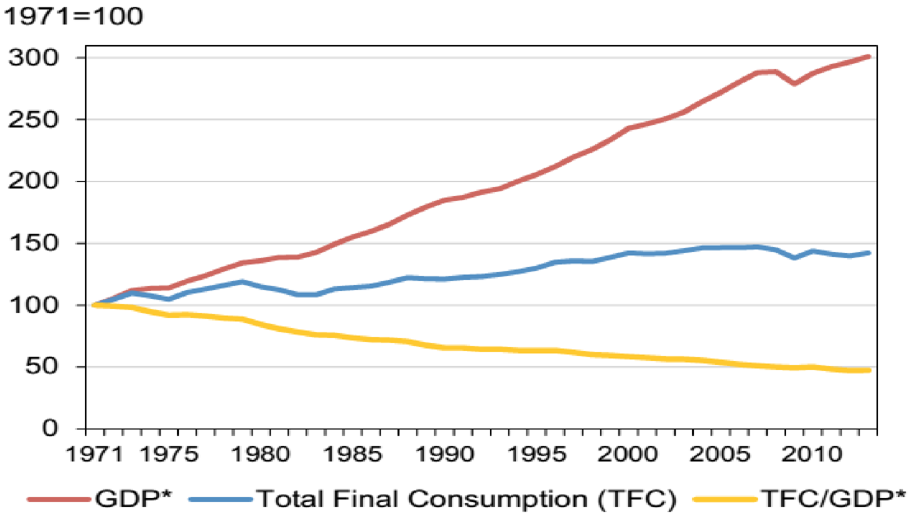
Figure 4.2: Total final energy consumption by region in OECD (1971 – 2013)



Source: IEA (2015)

Contrary to total final energy consumption, the final energy intensity, calculating by taking total final energy consumption over GDP, tends to decrease through time, showing in Figure 4.3. According to IEA (2015), this ratio in 2013 was less than half of it in 1997. It shows that the effectiveness in using energy in the OECD has quickly improved over years.

Figure 4.3: Final energy intensity in OECD (1971 – 2013)

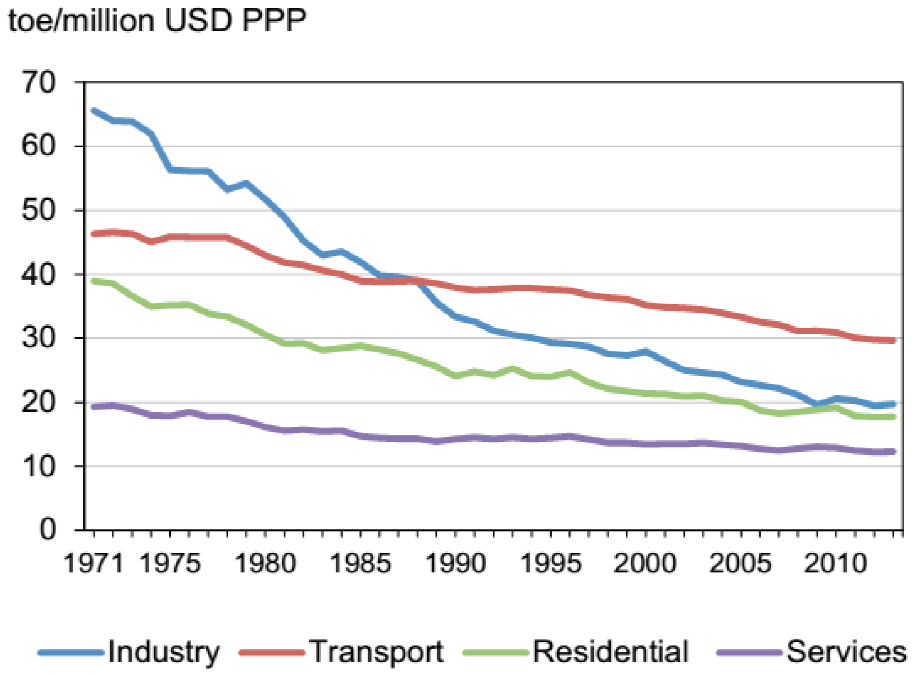


Source: IEA (2015)

On the other hand, the ratios of final energy intensity are very different among countries, based on their economic structures and the effectiveness of energy consumption in each country.

Regarding to final energy consumption by sectors, figure 4.4 below displays the energy intensities in economic sectors. Industry and transportation sectors generally account for the largest part of total energy consumption and their ranks change by year. For example, according to IEA (2015), in 2013, about a third of total final energy consumption was consumed by transport whereas in 1971, industrial activities took 41% of total final consumption and transport took only 24%. Residential sector ranks 3^{rd} position in term of energy consumption. Similar to final energy intensity, sectorial energy intensities (i.e., the ratios of sectorial final energy consumptions over GDP converted to US dollars using purchasing power parity rates (USD PPP)), also have tendencies to decrease over time. It once again reflects the improvement in effectiveness of energy consumption in each sector. Deeper studying in national level should be conducted to explain the reasons.

Figure 4.4: Sectorial energy intensities in OECD (1971 – 2013)

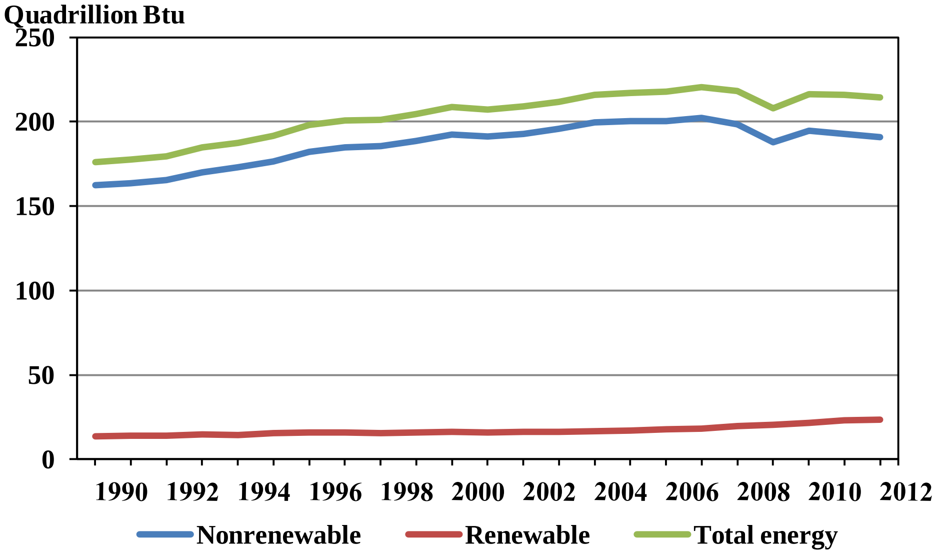


Source: IEA (2015)

4.2.2 Renewable energy consumption versus nonrenewable and total energy consumption

In overall, the consumption of total energy and each source of energy tended to increase during the investigated period in this paper (1990 – 2012). Figure 4.5 delivers a clear picture of this.

Figure 4.5: Energy consumption in OECD (1990 – 2012)

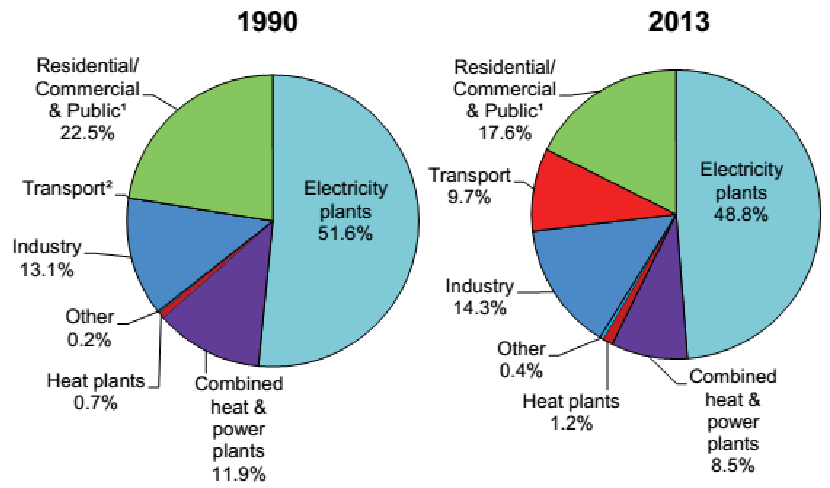


Sources: US EIA (2015)

Nonrenewable and total energy consumption went up relatively fast from 1990 to 2008, but they fell in period 2008 – 2010 due to global economics recession. After recovery, the increasing rate of using energy in general and nonrenewable in particular has slowed down. Meanwhile, although the portion of renewable energy in total renewable is small, it has steadily risen year by year, from about 7.82% in 1990 to 10.93% in 2012. Remarkably, during economic downfall period, while both the use of energy in general and nonrenewable energy dropped sharply, renewable energy consumption still stably climbed up. This is partly explained by the forces and pressure of Kyoto Protocol which started taking into effect from 2005.

In term of renewable energy consumption by sector, Figure 4.6 demonstrates the shares of renewable energy used in sectors of OECD countries in 1990 and in 2013 to show the changes in sectorial renewable energy consumption over time. Electricity plants accounts for the biggest part of total renewable energy consumption. However, this part has slightly become smaller by time, from 51.6% in 1990 narrowing to 48.8% in 2013. Getting along with this dropping in electricity plants is the falling in Residential / Commercial & Public sector and Combined heat & power plants.

Figure 4.6: Sectorial renewable energy consumption in OECD in 1990 and 2013



Source: IEA (2015)

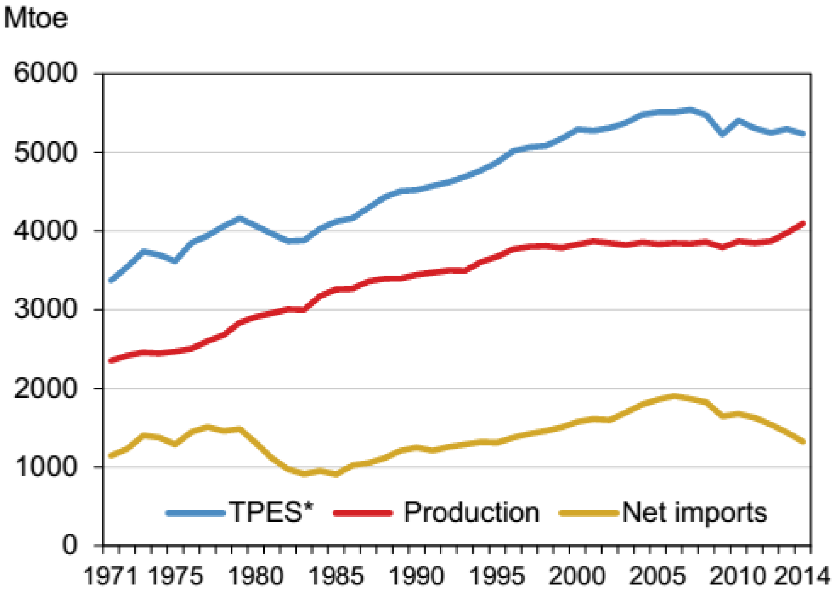
On the contrary, the use of renewable energy in final consumption sectors like residential, industry or most considerably, transportation sector has considerably grown. There is a remarkable rise in the use of renewable energy in Transportation sector, from 0.05% in 1990 to 9.7% in 2013. This growth is supported by the presence of bio-fuels which are utilized for heat generation and directly consumed on-site at foresaid sectors (IEA, 2015).

4.3 Energy supply in OECD countries

4.3.1 Overview of energy supply in OECD countries

Figure 4.7 displays the TPES, energy production and net imports of energy through the period 1971 – 2014. TPES of the OECD has unsteadily grown over time. From 1984 to 2007, it experienced a relatively stable annual growth with average growth rate of 1.4% per year. During the economic downfall in 2008 – 2009, TPES sharply dropped. After this period, TPES tended to go around the same levels of the years 2000. It reached the level of 5238 Mtoe in 2014, which is 4% lower compared to the level in 2004, but 16% and 55% higher compared to the level in 1990, 1971, respectively.

Figure 4.7: Total primary energy supply in OECD (1971 – 2014)



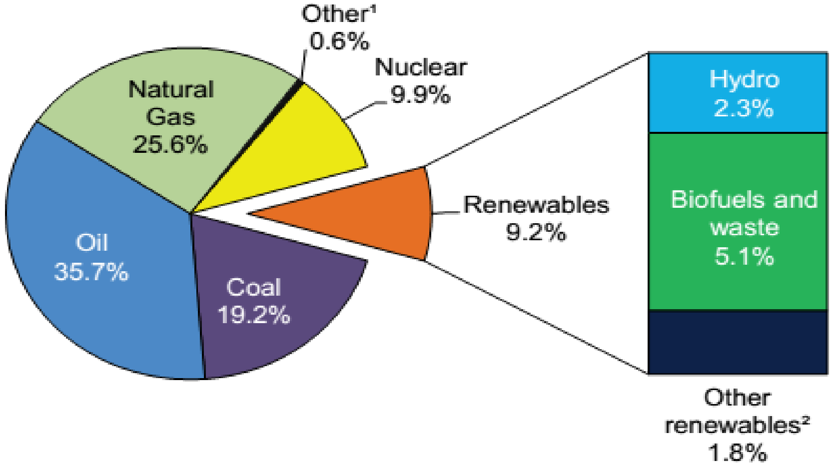
Source: IEA (2015)

Dissimilar to TPES, energy production in OECD steadily increased over the period whereas the net imports are relatively small compared to energy production and wildly fluctuated. Because the energy production rose with higher rate than energy use did, OECD's level of self – sufficiency, calculated by taking energy production over TPES, was really high and came close to the level of being self – sufficient in 2014 when this ratio is 99% (IEA, 2015).

4.3.2 Renewable energy supply in OECD countries

Figure 4.8 demonstrates the composition of TPES in OECD in 2014. The increasing rate of the portion of renewable energy supply in TPES of OECD countries is considerably higher than that of nonrenewable energy supply. In period 1990 – 2014, the former is 3.3% compared to 0.5% of the later (IEA, 2015). In 2014, renewable energy supply made a contribution of 9.2% in TPES. Nevertheless, nonrenewable energy sources are still dominant with the largest portion belonging to oil.

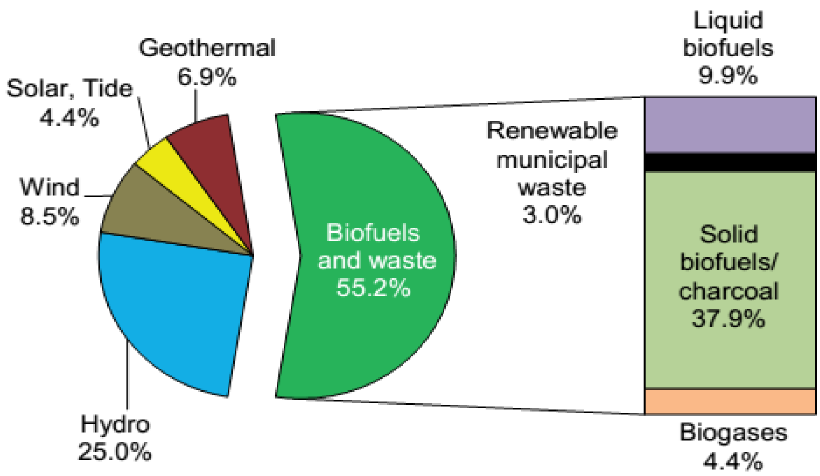
Figure 4.8: Composition of total primary energy supply in OECD (2014)



Source: IEA (2015)

Figure 4.9 displays the composition of renewable primary energy supply in OECD countries in 2014. Bio-fuels and waste shared the largest part with 55.2%. The second largest portion came from hydroelectric power source. Out of bio-fuels and waste, solid bio-fuels sources, such as wood, wood wastes, etc., and charcoal made the biggest share of 37.9%.

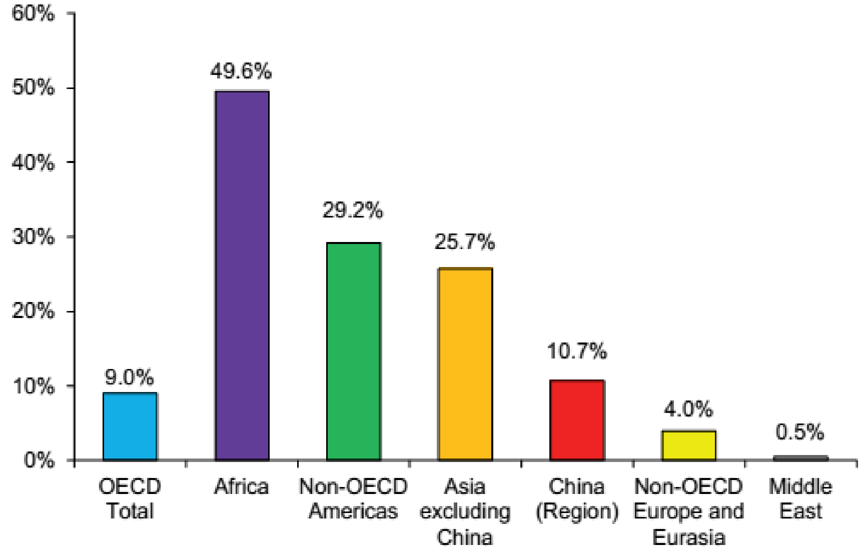
Figure 4.9: Composition of total renewable primary energy supply (2014)



Source: IEA (2015)

Compared with the world, while OECD countries made contribution of only 26.1% in global total renewable energy supply, they captured 39.1% of the global TPES in 2013. As a result, the share of renewable energy in total energy supply of OECD countries is only 9% in comparison with 49.6% of Africa, 29.2% of Non-OECD countries in America, 25.7% of Non-OECD in Asia and 10.7% of China. Figure 4.10 shows the portions of renewable energy in TPES of OECD countries and other regions.

Figure 4.10: Renewable energy shares in TPES of OECD versus other regions (2013)



Source: IEA (2015)

Nonetheless, OECD countries are the pioneers and also play significant roles when it comes to the generation of new types of renewable energy. They provided 66.1% of global renewable energy from solar, wind, tide, renewable municipal waste, biogases and liquid bio-fuels in 2013 (IEA, 2015).

5. Empirical results

5. 1 Data

Annual data of gross domestic product, capital, labor, nonrenewable energy consumption and renewable energy consumption are collected for the sample of 34 OECD countries in the period 1990 – 2012. The data set is an unbalanced panel with 760 observations.

The definitions and sources of variables investigated in this thesis are expressed in Table 5.1. The third column presents the expected signs of partial effects of capital, labor, nonrenewable energy and renewable energy consumption on GDP. They are derived from empirical studies which are discussed in Chapter 2.

Table 5.1: Variables definition

Variable name	Definition	Expected sign	Source
Gross domestic product (GDP)	Data of GDP in dollar (constant 2005 US$) are collected to present this variable. It is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. Dollar figures for GDP are converted from domestic currencies using 2005 official exchange rates.		World Bank's World Development Indicators (2015)
Variable name	**Definition**	**Expected sign**	**Source**
Capital (K)	Data for gross fixed capital formation in dollar (constant 2005 US$) are collected to represent this	+	World Bank's World Development

	variable. Gross fixed capital formation (formerly gross domestic fixed investment) includes land improvements; plant, machinery, and equipment purchases; and the construction of roads, railways, and the like, including schools, offices, hospitals, private residential dwellings, and commercial and industrial buildings.		Indicators (2015)
Labor (L)	Total labor force comprises people ages 15 and older who meet the International Labor Organization definition of the economically active population: all people who supply labor for the production of goods and services during a specified period. It includes both the employed and the unemployed.	+	World Bank's World Development Indicators (2015)
Nonrenewable Energy consumption (NE)	Nonrenewable energy consumption is measured as the aggregate of the consumption of coal and coal products, oil, and natural gas in quadrillion Btu units.	+	U.S. Energy Information Administration (2015)
Variable name	**Definition**	**Expected sign**	**Source**
Renewable Energy consumption	Renewable energy consumption is measured as the aggregate of the consumption of wood, waste,	+	U.S. Energy Information Administration

(RE)	geothermal, wind, photovoltaic, and solar thermal in quadrillion Btu units.		(2015)

Following the explanation in Chapter 3, all variables are converted to natural logarithm before conducting the econometrical estimation.

5.2 Descriptive analysis

The summary of descriptive statistics of all variables is reported in Table 5.2 below:

Table 5.2: Descriptive statistics of variables

Variable	Obs	Median	Mean	Std. Dev.	Min	Max
GDP	760	$2.99x10^{11}$	10^{12}	$2.09x10^{12}$	$7.18x10^{9}$	$1.41x10^{13}$
K	760	$6.44x10^{10}$	$2.16x10^{11}$	$4.41x10^{11}$	$1.32x10^{9}$	$3.05x10^{12}$
L	760	5101889	$1.67x10^{7}$	$2.73x10^{7}$	143061	$1.59x10^{8}$
NE	760	1.168	5.64	13.809	0.03	86.186
RE	760	0.190	0.515	0.996	.00007	7.174

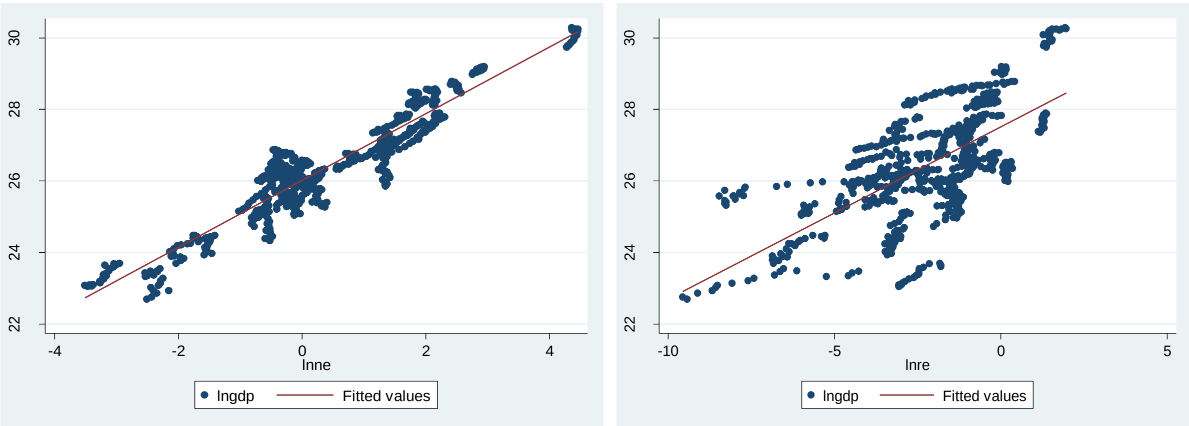
Source: US EIA (2015)

For GDP and Capital, the gaps between the median, mean, maximum and minimum values are not significant. It reflects a relative equality in growth and capital levels among OECD countries. Because some countries is small in terms of size and population compared with the rest, such as Iceland or Luxembourg, the gap between Labor’s maximum and minimum values is considerably large. However, there is not much difference between its mean and median values. This suggests that OECD countries’ labor forces are fairly even.

Contrary to above factors, the gaps in median, mean, maximum and minimum values of Nonrenewable energy and Renewable energy consumption are significantly large. This is due to the difference in countries’ sizes, population and economic structures. For examples, Iceland’s overall energy consumption is rather small in comparison with other countries because its population and size are mall and the most important industry contributed to its economic growth is fishery which does not consume much energy (Sigfusson and Gestsson, 2012). By contrast, nations like US, Japan or Germany are not only enormous in size and population but also have big energy – consumed industries, hence the massive demand for energy. On the other side, the considerable differences between statistic values of nonrenewable and renewable energy consumption once again prove the dominance of nonrenewable energy in energy use in OECD countries.

The correlations between nonrenewable and renewable energy consumption and GDP are displayed in graph in the left and the right of Figure 5.1, respectively. GDP appears to positively correlate with the consumption of two sources of energy.

Figure 5.1: Correlation between GDP and nonrenewable, renewable energy consumption



Source: Author's calculation

Also from Figure 5.1, while GDP seem to spread around fitted line of nonrenewable energy consumption, it scatters farther from the line of renewable energy consumptions. This suggests a relatively higher correlation of nonrenewable energy consumption than renewable energy consumption to GDP.

Finally, the correlation matrix among variables is reported in below table where Ln(GDP), Ln(K), Ln(L), Ln(NE), Ln(RE) are the denotations of the natural logarithm of GDP, capital, labor, nonrenewable and renewable energy consumption, respectively.

Table 5.3: Correlation matrix between variables

	Ln(GDP)	Ln(K)	Ln(L)	Ln(NE)	Ln(RE)
Ln(GDP)	1				
Ln(K)	0.993	1			
Ln(L)	0.914	0.911	1		
Ln(NE)	0.948	0.944	0.960	1	
Ln(RE)	0.663	0.65	0.582	0.549	1

Source: Author's calculation

The positive nexuses between GDP and both nonrenewable and renewable energy consumption are once again demonstrated. Capital and Labor are also shown to be highly correlated with GDP. Among all, capital has the strongest connection with GDP with the highest correlation value of 0.993. Not surprisingly, renewable energy consumption has weakest link with GDP with lowest correlation value of 0.663 due to the fact that it has recently developed, hence small contribution to economic growth.

To be concluded, the descriptive statistics displays that both nonrenewable and renewable energy consumption appear to be positively correlated with GDP. Besides, nonrenewable energy consumption seems to have relatively higher correlation with GDP than renewable energy consumption does. More precise estimation of these relationships is econometrically conducted and reported in next section.

5.3 Regression and calculation results

5.3.1 Partial effects among variables

After running the regression on the stochastic distance function (8), F-test is conducted to check whether the squared terms of inputs and interaction terms among inputs are jointly equal to zero. The interaction terms between inputs and output are also put under the test to check if they are jointly equal to zero. The p-values of F-test in both cases are lower than 0.01. Thus, the null hypotheses can be rejected at significance level of 1%. It means that at least one of squared terms of inputs and interaction terms among inputs is statistically significant; and at least one of interaction terms between inputs and output is statistically significant. The F-test results are reported in Appendix 3.

The estimations results of four inputs and one ouput are presented in following table:

Table 5.4: Regression results

Variable	**Coefficient**	**Standard error**
Output		
Ln(GDP)	-0.851	(0.022)***
$(Ln(GDP))^2$	0.0005	0.001
Input		
Ln(K)	-0.082	(0.011)***
Ln(L)	-0.03	0.021
Ln(NE)	0.970	(0.022)***
Ln(RE)	0.082	(0.009)***
$(Ln(K))^2$	-0.030	(0.001)***
$(Ln(L))^2$	-0.017	(0.002)***
$(Ln(NE))^2$	0.037	(0.001)***
$(Ln(RE))^2$	0.001	(0.000)***
Variable	**Coefficient**	**Standard error**
Interaction terms among output and inputs		
Ln(K) x Ln(GDP)	0.03	(0.001)***
Ln(L) x Ln(GDP)	0.007	(0.001)***
Ln(NE) x Ln(GDP)	-0.036	(0.001)***
Ln(RE) x Ln(GDP)	-0.001	(0.000)***
Ln(K) x Ln(L)	0.003	(0.0000)***
Ln(K) x Ln(NE)	0.0003	-0.0003

Ln(K) x Ln(RE)	-0.003	(0.0002)***
Ln(L) x Ln(NE)	-0.003	(0.002)***
Ln(L) x Ln(NE)	0.0003	0.0003
Ln(NE) x Ln(RE)	0.003	(0.000)***

Notes: *** denotes significance at the 1% level

Source: Author's calculation

The partial derivative of the stochastic distance function with respect to GDP can be computed from the estimation results in Table 5.4. It is average weighted for GDP and has the value of – 0.009, indicating that the distance function is decreasing in GDP. It is consistent with the condition of the distance function that when GDP increases, the country moves closer to its production frontier (the gap between country's production level and its production frontier decreases). Contrarily, the calculated partial derivatives of the distance function with respect to capital, labor, nonrenewable and renewable energy consumption are all positive, suggesting that the distance function is increasing in inputs. This also satisfies the conditions for input distance function (Atkinson, Cornwell, and Honerkamp, 2003).

The partial impacts among variables, which are averages weighted for GDP, are provided in Table 5.5. Because all variables are in natural logarithm form and the derivatives are taken with respect to natural logarithm of each variable, the relationship between variables can be explained as the elasticity. From the Table 5.5, other things being constant, increases in nonrenewable and renewable energy consumption would both raise GDP but with different magnitudes. More specifically, 1% increase in using nonrenewable energy would boost GDP by 0.51% whereas 1% addition into renewable energy consumption slightly raises GDP by 0.03%. These results are consistent with the outcomes from empirical studies discussed in Chapter 2, stating that despite the expansion in the use of renewable energy recently, nonrenewable energy is still the primary source fostering economic growth.

Table 5.5: Partial effects among variables

	Partial effects
Partial effects of inputs on output	
$\partial GDP / \partial K$	0.999
$\partial GDP / \partial L$	-0.093
$\partial GDP / \partial NE$	0.510
$\partial GDP / \partial RE$	0.034
Partial effects among inputs	
$\partial NE / \partial RE$	-0.098
$\partial NE / \partial K$	3.389
$\partial RE / \partial K$	0.202
$\partial NE / \partial L$	3.520
$\partial RE / \partial L$	0.152

Source: Author's calculation

On the other hand, out of all input factors, capital appears to have the strongest influence on GDP. As countries put 1% more capital into economies, their outputs rise by approximate 1% in average. This reflects the effectiveness in capital utilization in the OECD where most of countries are advanced economies. On the contrary, the partial effect of labor on GDP is negative with 1% increase in labor force causing GDP to slightly drop by 0.093%. This surprising result may be due to two following reasons. First, most of OECD countries are advanced countries where technology plays a significant role in production and the importance of labor has been lessened than before. Second, it is probably because of the development of labor unions. In developed countries like the OECD, along with the increase in labor force, labor unions have been rapidly and strongly grown to protect and claim the benefits of employees. This also partially leads to many labor strikes which not only cause the stagnancy in production but also affect social security. In OECD countries, the dispute rates in industry sector such as manufacturing, electricity, construction, etc., are usually twice as high as that in service sector, except transportation section (OECD, 2007). Although employment rate in service sector has been increased, industry sector still accounts for a large share of labor force. Moreover, recently, strike rate tends to rise in transportation section, especially airline and public transportation. Nevertheless, the negative impact of labor on GDP found in this thesis is insignificant with very small ratio of partial effect.

Regarding the partial effects among inputs, other things remaining unchanged, the negative sign of partial effect between renewable and nonrenewable energy consumption indicates that they are substitutes. More clearly, 1% rise in the use of renewable consumption will lead to 0.098% fall in the use of nonrenewable energy. Although the ratio of effect is small, the substitution between two energy sources contributes to ease the harsh impacts of nonrenewable energy consumption on the environment.

Other noticeable results are the impacts of capital and labor on the use of two energy sources. Capital appears to have relatively higher impact on nonrenewable energy consumption than on renewable energy consumption. As capital is expanded by 1%, renewable energy consumption increases only by 0.202% whereas nonrenewable energy use strikingly rises by 3.389%. Similar outcomes are proved for the relationship of each source of energy and labor. When labor force grows by 1%, the use of nonrenewable and renewable energy will go up by 3.52% and 0.152%, respectively. These results again stress the dominance of nonrenewable energy in the economies of OECD countries.

5.3.2 Technical efficiency, efficiency change, technical change and productivity change

Table 5.6 displays estimated technical efficiencies for OECD countries and their standard deviations. They are computed from equation (5) in Chapter 3 and averages weighted for GDP.

Table 5.6: Average technical efficiencies of OECD countries (1990 – 2012)

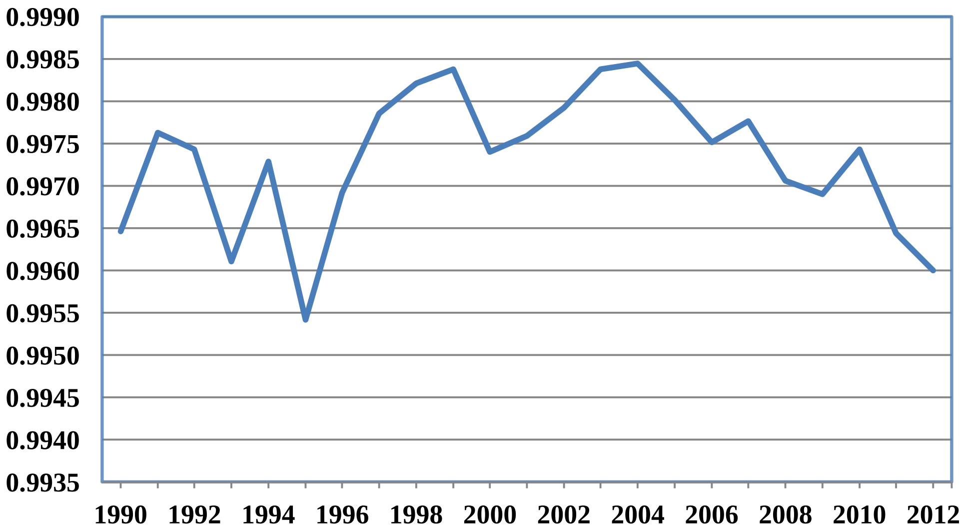
Year	Mean	Std. Dev.
1990	0.9965	0.0019
1991	0.9976	0.0013
1992	0.9974	0.0012
1993	0.9961	0.0015
1994	0.9973	0.0013
1995	0.9954	0.0016
1996	0.9969	0.0015
1997	0.9979	0.0010
1998	0.9982	0.0010
1999	0.9984	0.0008
2000	0.9974	0.0008
2001	0.9976	0.0010
2002	0.9979	0.0008
2003	0.9984	0.0010
2004	0.9984	0.0010
2005	0.9980	0.0010
2006	0.9975	0.0012
2007	0.9978	0.0011
2008	0.9971	0.0011
2009	0.9969	0.0015
2010	0.9974	0.0011
2011	0.9964	0.0014
2012	0.9960	0.0017
Weighted average	0.9973	

Source: Author's calculation

The weighted – average value of TE of 34 OECD countries in 1990 is 0.9965. This value implies that if the average country in 1990 combined the inputs (capital, labor, nonrenewable and renewable energy) as effectively as the best – practice country that year, then its output (GDP) would increase by about 0.355% (1 / 0.9965 = 1.00355). The number is quite small, indicating that the average OECD country performed closely with the efficiency level of the best performer in 1990.

Figure 5.2 below delivers a clearer picture of the change in TE over the examined period. From 1990 to 2004, average TE fluctuated and reached its peak in two last years, then tended to drop from 2005 afterwards. Global economic downturn in period 2008 – 2012 might be responsible for this fall with lesser capital investing into economies and higher unemployed rates than previous period.

Figure 5.2: Average technical efficiency of OECD countries (1990 – 2012)



Source: Author's calculation

Nonetheless, the weighted – average annual rate of EC for the whole period is very high, 0.9973, suggesting that if OECD's average country combined all examined inputs as effectively as the best – practice country in this organization, its annual GDP would increase by about 0.266% in period 1990 – 2012. On the other hand, the values of standard deviation of TE measurement are very small, suggesting that the dispersion of TE is insignificant over the period.

Average EC, TC and PC, which are computed through equation (6), (7) and (8) in Chapter 3 respectively, are reported in Table 5.7. EC, which is the difference between the TE of one year with its previous year, exhibits the movement of countries towards the production frontier. Average EC is interpreted in same pattern with average TE. As discussed above, average TE of OCED countries generally increased in period 1990 – 2004 but decreased after that, resulting in positive and negative values of EC in these two periods, respectively. The steady fall of EC in second period leads to the negative annual TC of – 0.0046% for the whole period.

Table 5.7: Average efficiency change, technical change, productivity change of OECD countries (1991 – 2012)

Year	EC	TC	PC
1991	0.0012	-0.1712	-0.1701
1992	-0.0002	-0.0014	-0.0016
1993	-0.0013	-0.0336	-0.0349
1994	0.0012	0.0327	0.0339
1995	-0.0019	-0.0015	-0.0033
1996	0.0015	0.0188	0.0203
1997	0.0009	0.0358	0.0368
1998	0.0004	0.0152	0.0156
1999	0.0002	0.0015	0.0017
2000	-0.0010	0.0473	0.0463
2001	0.0002	0.0041	0.0043
2002	0.0003	0.0289	0.0292
2003	0.0005	0.0196	0.0201
2004	0.0001	0.0189	0.0190
2005	-0.0004	0.0281	0.0277
2006	-0.0005	0.0356	0.0351
2007	0.0002	0.0373	0.0375
2008	-0.0007	0.0099	0.0092
2009	-0.0002	0.0060	0.0059
2010	0.0005	-0.0080	-0.0074
2011	-0.0010	0.0666	0.0656
2012	-0.0004	0.0097	0.0093
Weighted average	-0.000046	0.012107	0.012061

Source: Author's calculation

TC is the difference of the examined frontier distance functions between two continuous years: t+1 and t with output and inputs being constant. It exhibits the shift of the production frontier. Contrary to EC, TC rates are generally positive with the exception of 1991 – 1995 period, resulting in a positive average annual rate of 1.2107%. The results indicate that the average production frontier shifted outwardly over the period.

PC is the sum of EC and TC. From Table 5.7, except the period 1991 – 1995, the average country experienced positive productivity change over time. PC's weighted average rate of 1.2061% implies that all of productivity gain of OECD countries from 1990 to 2012 is contributed by TC. In other words, the improvement in productivity of OECD countries is completely thanks to the outward shift of the production frontier. This is mainly due to negative values of EC, suggesting that OECD countries operated very closely to their best – practice level, thus less incentive for them to invest in improving technical efficiency. The result that TC is the fundamental impulse behind PC is similar with the result derived from Atkinson, Cornwell, and Honerkamp (2003) although the context is different (as discussed in Chapter 2, this paper took investigation on the sample of US electricity firms).

In summary, there are three highlights derived from the estimated results. Firstly, both nonrenewable and renewable energy consumption positively contribute to OECD countries' GDP, and despite the growing role of renewable energy to economic activities, nonrenewable energy is still the primary force behind GDP growth. Secondly, two energy sources are substitutes, albeit with small ratio of substitution. Thirdly, average OECD country operated near its production frontier and all the productivity gain comes from outward shift of the production frontier.

6. Conclusion

This thesis conducts the estimation on a multiple – input, one – output stochastic distance function for 34 OECD countries, utilizing the panel data from 1990 to 2012. Besides two basic inputs, i.e., capital and labor, nonrenewable and renewable energy consumption are added into the classical production function to create one output, i.e., GDP. Following Atkison, Cornwell, and Honerkamp (2003), Le and Atkinson (2010), the research not only finds out the impacts of the use of nonrenewable and renewable energy on GDP and the relationship between the consumptions of these two sources, but also measures the productivity change of OECD countries through computing their technical efficiency, efficiency change and technical change.

Three main findings can be derived from the regression and calculation results. First of all, the increase in the use of nonrenewable and renewable energy would both boost OECD countries' GDP. Although renewable energy has been proving its increasing importance in the economy, nonrenewable energy is still a dominant and principle source fostering GDP growth, proved through the relatively higher partial impact on GDP of nonrenewable energy consumption than that of renewable energy consumption. The second point is that renewable energy is a substitute of nonrenewable energy. The ratio of substitution is small but it still indicates that renewable energy helps to mitigate the negative impacts of nonrenewable energy consumption on the environment. Lastly, the calculated technical efficiency results suggest that average OECD country performs closely to the level of the best – practice country in the whole OECD, hence less incentive in improving technical efficiency. Therefore, not efficiency change but technical change is the force taking full responsibility for the productivity gain in the examined period.

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APPENDICES

Appendix 1: List of 34 OECD countries

No.	Country
1	Australia
2	Austria
3	Belgium
4	Canada
5	Chile
6	Czech Republic
7	Denmark
8	Estonia
9	Finland
10	France
11	Germany
12	Greece
13	Hungary
14	Iceland
15	Ireland
16	Israel
17	Italy
18	Japan
19	Korea, Rep.
20	Luxembourg
21	Mexico
22	Netherlands
23	New Zealand
24	Norway
25	Poland
26	Portugal
27	Slovak Republic
28	Slovenia
29	Spain
30	Sweden
31	Switzerland
32	Turkey
33	United Kingdom
34	United States

Source: OECD, 2015

Appendix 2: Regression results

y	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lnk	-.0818739	.011816	-6.93	0.000	-.105081	-.0586668
lnl	.0297484	.0214207	1.39	0.165	-.0123225	.0718193
lnre	.0818311	.0091907	8.90	0.000	.0637804	.0998819
lnne	.9702943	.022367	43.38	0.000	.9263647	1.014224
lngdp	-.8505995	.0226893	-37.49	0.000	-.895162	-.806037
lnk2	-.0299642	.0012272	-24.42	0.000	-.0323744	-.027554
lnklnl	.002586	.0003621	7.14	0.000	.0018748	.0032972
lnklnre	-.0028503	.0001894	-15.05	0.000	-.0032224	-.0024782
lnklnne	.0002643	.000343	0.77	0.441	-.0004093	.0009379
lnl2	-.0168208	.0019323	-8.71	0.000	-.0206159	-.0130257
lnllnre	.0002643	.000343	0.77	0.441	-.0004093	.0009379
lnllnne	-.0028503	.0001894	-15.05	0.000	-.0032224	-.0024782
lnre2	.0005984	.0001264	4.73	0.000	.0003501	.0008467
lnrelnne	.002586	.0003621	7.14	0.000	.0018748	.0032972
lnne2	.036718	.0008255	44.48	0.000	.0350967	.0383393
lngdp2	.0005145	.0009818	0.52	0.600	-.0014139	.0024428
lnklngdp	.0295924	.0011995	24.67	0.000	.0272366	.0319481
lnllngdp	.006884	.0014766	4.66	0.000	.0039839	.0097841
lnrelngdp	-.0005657	.0001865	-3.03	0.003	-.000932	-.0001995
lnnelngdp	-.0359106	.0008372	-42.89	0.000	-.0375549	-.0342663
lngdpyear2	.0063481	.0019278	3.29	0.001	.0025619	.0101343
lngdpyear3	.0076757	.001958	3.92	0.000	.0038301	.0115212
lngdpyear4	.0110898	.0014956	7.42	0.000	.0081524	.0140271
lngdpyear5	.0097704	.0015142	6.45	0.000	.0067964	.0127445
lngdpyear6	.0089193	.0014489	6.16	0.000	.0060736	.011765
lngdpyear7	.0069031	.0014534	4.75	0.000	.0040486	.0097577
lngdpyear8	.0048721	.0015581	3.13	0.002	.001812	.0079322
lngdpyear9	.0044341	.0018079	2.45	0.014	.0008833	.0079849
lngdpyear10	.0039077	.0018378	2.13	0.034	.0002983	.0075171
lngdpyear11	.0012696	.0018617	0.68	0.496	-.0023869	.0049261
lngdpyear12	.0037909	.0016457	2.30	0.022	.0005588	.007023
lngdpyear13	.0027148	.0016389	1.66	0.098	-.000504	.0059337
lngdpyear14	.001738	.0016127	1.08	0.282	-.0014294	.0049053
lngdpyear15	.0008529	.0017147	0.50	0.619	-.0025148	.0042206
lngdpyear16	-.0026913	.0016751	-1.61	0.109	-.0059812	.0005986
lngdpyear17	-.007025	.0016327	-4.30	0.000	-.0102317	-.0038184
lngdpyear18	-.0073645	.001784	-4.13	0.000	-.0108684	-.0038607
lngdpyear19	-.0084088	.0018669	-4.50	0.000	-.0120756	-.0047421
lngdpyear20	-.0053585	.0016184	-3.31	0.001	-.008537	-.0021799
lngdpyear21	-.0057675	.001636	-3.53	0.000	-.0089807	-.0025543
lngdpyear22	-.0075495	.001614	-4.68	0.000	-.0107194	-.0043796
lngdpyear23	-.0091476	.001447	-6.32	0.000	-.0119897	-.0063056
lnkyear2	-.0003442	.0014324	-0.24	0.810	-.0031574	.0024691
lnkyear3	-.001619	.0015176	-1.07	0.286	-.0045995	.0013615
lnkyear4	-.0038876	.0013322	-2.92	0.004	-.0065041	-.0012712
lnkyear5	-.0035652	.0013475	-2.65	0.008	-.0062119	-.0009186
lnkyear6	-.0030456	.0012937	-2.35	0.019	-.0055865	-.0005046
lnkyear7	-.0010967	.0013486	-0.81	0.416	-.0037454	.0015521
lnkyear8	-.0002322	.0015267	-0.15	0.879	-.0032307	.0027662
lnkyear9	-.0003216	.0018065	-0.18	0.859	-.0038696	.0032265
lnkyear10	-.0002913	.0017557	-0.17	0.868	-.0037395	.0031569
lnkyear11	.0009817	.0017958	0.55	0.585	-.0025453	.0045087
lnkyear12	-.0020315	.0015742	-1.29	0.197	-.0051233	.0010603
lnkyear13	-.0018041	.0015541	-1.16	0.246	-.0048563	.0012481
lnkyear14	-.0012475	.0015268	-0.82	0.414	-.0042463	.0017512
lnkyear15	-.0007636	.0016536	-0.46	0.644	-.0040114	.0024842
lnkyear16	.001827	.0016648	1.10	0.273	-.0014427	.0050967
lnkyear17	.0052337	.0016048	3.26	0.001	.0020818	.0083857
lnkyear18	.004066	.0017839	2.28	0.023	.0005624	.0075696

lnkyear19	.0044947	.0019655	2.29	0.023	.0006344	.008355
lnkyear20	.0005645	.0016227	0.35	0.728	-.0026225	.0037516
lnkyear21	.0014351	.0016951	0.85	0.398	-.001894	.0047643
lnkyear22	.0005948	.0016452	0.36	0.718	-.0026363	.003826
lnkyear23	.0010525	.0013844	0.76	0.447	-.0016665	.0037715
lnlyear2	.0009273	.000656	1.41	0.158	-.0003611	.0022157
lnlyear3	.0008055	.0006531	1.23	0.218	-.0004772	.0020883
lnlyear4	.0006753	.0006431	1.05	0.294	-.0005877	.0019383
lnlyear5	.0003846	.0006271	0.61	0.540	-.0008471	.0016162
lnlyear6	.0009917	.000622	1.59	0.111	-.0002299	.0022133
lnlyear7	.0002673	.0006119	0.44	0.662	-.0009344	.0014691
lnlyear8	.0001072	.0006147	0.17	0.862	-.0011001	.0013145
lnlyear9	.0000757	.00064	0.12	0.906	-.0011812	.0013326
lnlyear10	.0008508	.0006311	1.35	0.178	-.0003886	.0020902
lnlyear11	.0001187	.0006171	0.19	0.848	-.0010933	.0013307
lnlyear12	.0004182	.0006168	0.68	0.498	-.0007931	.0016295
lnlyear13	-3.90e-06	.0006096	-0.01	0.995	-.0012011	.0011933
lnlyear14	-.0004547	.0006104	-0.74	0.457	-.0016536	.0007443
lnlyear15	-.000907	.0006043	-1.50	0.134	-.0020939	.0002799
lnlyear16	-.0008825	.0006206	-1.42	0.156	-.0021013	.0003364
lnlyear17	-.0013173	.0006388	-2.06	0.040	-.0025719	-.0000627
lnlyear18	-.0012704	.0006633	-1.92	0.056	-.0025731	.0000323
lnlyear19	-.0008879	.0006571	-1.35	0.177	-.0021784	.0004026
lnlyear20	-.0002081	.0006454	-0.32	0.747	-.0014757	.0010596
lnlyear21	-.0003445	.0006623	-0.52	0.603	-.0016453	.0009564
lnlyear22	-.0003413	.0006777	-0.50	0.615	-.0016723	.0009897
lnlyear23	.0009951	.0006965	1.43	0.154	-.0003729	.0023632
lnreyear2	-.000928	.000194	-4.78	0.000	-.001309	-.0005469
lnreyear3	-.0008254	.0001902	-4.34	0.000	-.0011989	-.0004519
lnreyear4	-.0010461	.0001882	-5.56	0.000	-.0014157	-.0006764
lnreyear5	-.0009199	.0001927	-4.77	0.000	-.0012984	-.0005414
lnreyear6	-.0007003	.0001531	-4.57	0.000	-.001001	-.0003996
lnreyear7	-.0003574	.0001534	-2.33	0.020	-.0006586	-.0000562
lnreyear8	-.0001059	.0001526	-0.69	0.488	-.0004057	.0001939
lnreyear9	.0001286	.0001582	0.81	0.417	-.0001821	.0004392
lnreyear10	.000044	.0001561	0.28	0.778	-.0002625	.0003505
lnreyear11	.0000247	.000155	0.16	0.873	-.0002798	.0003292
lnreyear12	.0000953	.0001561	0.61	0.542	-.0002113	.0004019
lnreyear13	7.24e-06	.0001612	0.04	0.964	-.0003094	.0003239
lnreyear14	.0000837	.0001657	0.51	0.614	-.0002417	.0004091
lnreyear15	.0002247	.0001681	1.34	0.182	-.0001055	.0005549
lnreyear16	.0002852	.0001745	1.63	0.103	-.0000575	.0006279
lnreyear17	.0003808	.0001772	2.15	0.032	.0000328	.0007287
lnreyear18	.0004861	.000185	2.63	0.009	.0001229	.0008494
lnreyear19	.0004981	.0001876	2.66	0.008	.0001297	.0008665
lnreyear20	.000527	.0002144	2.46	0.014	.0001058	.0009482
lnreyear21	.0004995	.000229	2.18	0.030	.0000497	.0009493
lnreyear22	.0007713	.0002521	3.06	0.002	.0002761	.0012664
lnreyear23	.0008267	.0002614	3.16	0.002	.0003133	.0013401
lnneyear2	-.0058287	.0008639	-6.75	0.000	-.0075254	-.004132
lnneyear3	-.0058303	.0008627	-6.76	0.000	-.0075247	-.004136
lnneyear4	-.0064655	.0007682	-8.42	0.000	-.0079742	-.0049568
lnneyear5	-.0053505	.0007794	-6.86	0.000	-.0068813	-.0038197
lnneyear6	-.0054806	.0007752	-7.07	0.000	-.007003	-.0039581
lnneyear7	-.0051448	.0007728	-6.66	0.000	-.0066625	-.003627
lnneyear8	-.004003	.0007899	-5.07	0.000	-.0055545	-.0024516
lnneyear9	-.0035739	.0008456	-4.23	0.000	-.0052348	-.0019131
lnneyear10	-.0036631	.0008439	-4.34	0.000	-.0053205	-.0020056
lnneyear11	-.0014624	.0008251	-1.77	0.077	-.0030829	.000158
lnneyear12	-.0011564	.0008377	-1.38	0.168	-.0028017	.000489
lnneyear13	.0001378	.0008264	0.17	0.868	-.0014853	.001761
lnneyear14	.0008869	.0008261	1.07	0.283	-.0007356	.0025094
lnneyear15	.0015438	.0008094	1.91	0.057	-.0000458	.0031335
lnneyear16	.0025231	.0007877	3.20	0.001	.0009759	.0040702

lnneyear17	.0038554	.0007908	4.88	0.000	.0023023	.0054085
lnneyear18	.0052576	.0007925	6.63	0.000	.0037012	.0068141
lnneyear19	.0057097	.0007948	7.18	0.000	.0041488	.0072707
lnneyear20	.0060129	.0008089	7.43	0.000	.0044242	.0076015
lnneyear21	.0057601	.0008215	7.01	0.000	.0041467	.0073736
lnneyear22	.0080936	.0008025	10.09	0.000	.0065175	.0096697
lnneyear23	.0081782	.0008321	9.83	0.000	.006544	.0098124
year2	-.1727623	.0240596	-7.18	0.000	-.2200163	-.1255083
year3	-.1741315	.0239142	-7.28	0.000	-.2210998	-.1271632
year4	-.2063216	.0193308	-10.67	0.000	-.2442879	-.1683552
year5	-.1747763	.0198289	-8.81	0.000	-.2137208	-.1358317
year6	-.1741319	.019162	-9.09	0.000	-.2117668	-.136497
year7	-.1570297	.0190059	-8.26	0.000	-.1943579	-.1197015
year8	-.1222217	.0192797	-6.34	0.000	-.1600876	-.0843558
year9	-.1073525	.0203656	-5.27	0.000	-.1473512	-.0673539
year10	-.1063143	.0203584	-5.22	0.000	-.1462988	-.0663298
year11	-.0579722	.0204346	-2.84	0.005	-.0981065	-.0178378
year12	-.0538434	.0205211	-2.62	0.009	-.0941475	-.0135393
year13	-.0252505	.0206927	-1.22	0.223	-.0658916	.0153907
year14	-.0060487	.0211326	-0.29	0.775	-.0475539	.0354565
year15	.0126438	.020986	0.60	0.547	-.0285733	.053861
year16	.0409305	.0208216	1.97	0.050	.0000362	.0818249
year17	.0769392	.0210585	3.65	0.000	.0355796	.1182987
year18	.1140414	.0214234	5.32	0.000	.0719651	.1561178
year19	.1247035	.0216123	5.77	0.000	.0822561	.1671509
year20	.1311235	.0218743	5.99	0.000	.0881617	.1740854
year21	.1226832	.0225328	5.44	0.000	.078428	.1669384
year22	.1901836	.0223036	8.53	0.000	.1463785	.2339888
year23	.2002902	.0231466	8.65	0.000	.1548295	.2457509
d1	-.0463089	.0073759	-6.28	0.000	-.0607954	-.0318225
d2	-.0467858	.008303	-5.63	0.000	-.0630932	-.0304785
d3	-.0429627	.0082241	-5.22	0.000	-.0591152	-.0268102
d4	-.0481497	.0061887	-7.78	0.000	-.0603046	-.0359949
d5	-.0601936	.0080983	-7.43	0.000	-.0760989	-.0442882
d6	-.0588927	.0084647	-6.96	0.000	-.0755177	-.0422677
d7	-.0461682	.0085025	-5.43	0.000	-.0628674	-.0294689
d8	-.0378555	.0090789	-4.17	0.000	-.0556867	-.0200244
d9	-.0430836	.0086215	-5.00	0.000	-.0600165	-.0261506
d10	-.0410888	.0055479	-7.41	0.000	-.0519849	-.0301926
d11	-.0306406	.0045665	-6.71	0.000	-.0396094	-.0216718
d12	-.0496759	.0082792	-6.00	0.000	-.0659365	-.0334153
d13	-.0556932	.0085835	-6.49	0.000	-.0725516	-.0388349
d14	.0093361	.0104077	0.90	0.370	-.011105	.0297771
d15	-.0421089	.0088457	-4.76	0.000	-.0594821	-.0247357
d16	-.0496859	.0088049	-5.64	0.000	-.0669791	-.0323928
d17	-.0387624	.0056749	-6.83	0.000	-.0499082	-.0276166
d18	-.0218496	.0036246	-6.03	0.000	-.0289684	-.0147307
d19	-.0453151	.0066852	-6.78	0.000	-.0584451	-.032185
d20	.0227387	.0111506	2.04	0.042	.0008385	.0446389
d21	-.0384185	.0058648	-6.55	0.000	-.0499372	-.0268999
d22	-.0436113	.0074847	-5.83	0.000	-.0583114	-.0289111
d23	-.0451892	.0087829	-5.15	0.000	-.0624391	-.0279394
d24	-.044707	.0086635	-5.16	0.000	-.0617224	-.0276917
d25	-.0575523	.0073679	-7.81	0.000	-.0720231	-.0430816
d26	-.0541633	.0081798	-6.62	0.000	-.0702287	-.038098
d27	-.0576923	.0087559	-6.59	0.000	-.0748892	-.0404953
d28	-.0394787	.009071	-4.35	0.000	-.0572945	-.0216628
d29	-.0436379	.0065397	-6.67	0.000	-.0564821	-.0307938
d30	-.0541513	.0081647	-6.63	0.000	-.0701869	-.0381156
d31	-.0631038	.0083054	-7.60	0.000	-.0794159	-.0467918
d32	-.0488694	.0067914	-7.20	0.000	-.062208	-.0355308
d33	-.0364362	.0052452	-6.95	0.000	-.0467379	-.0261344
_cons	11.94704	.4125103	28.96	0.000	11.13685	12.75722