ELECTRICITY SECTOR REFORM AND PROMOTING RENEWABLE ENERGY GENERATION

By

LEE, Yoonha

THESIS

Submitted to

KDI School of Public Policy and Management

In Partial Fulfillment of the Requirements

For the Degree of

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ABSTRACT

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Yoonha Lee

From 1980s, countries started to reform the structure of stated owned companies for more efficiency and productivity. Electricity market has been targeted the first privatised or liberalised industry among major utilities such as transportation or telecommunication in most countries. Many researches have conducted to analyse the phenomenon of this liberalisation and its impact on economy. Some say that in privatised energy sector, renewable energy is rarely promoted since it is considered as less cost effective than fossil fuel generation. However, under the present situation that sustainable energy use has been being important and renewable energy issue has been gradually progressed, it seems worthwhile that revealing the relationship between these two contradicting concepts. Based on panel regression analysis, this paper finds that electricity market liberalisation has significant impact on renewable electricity generation. This paper also suggests that most of energy related variables affect differently for different groups based on their income level.

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1. Introduction

Restructuring stated owned or government owned companies have undergone in many countries over last several decades. Under competition theory, competitive market is more efficient than monopolised market in general. However, there are few exceptions in real economy. Electricity market is one of the typical examples where natural monopoly exists. Electricity market requires massive initial investment to set up generation, transmission, and distribution facilities which are relatively costly than facilities in other industries. With this reason, in many countries, almost all utility infrastructure sand their management is owned by government or state-owned companies. From 1980s, countries started to reform the structure of stated owned companies for more efficiency and productivity. Electricity market has been targeted the first privatised or liberalised industry among major utilities such as transportation or telecommunication in most countries. Many researches have conducted to analyse the phenomenon of this liberalisation and its impact on economy.

Along with market structures, sustainability is another important issue in whole energy sector. With increasing importance of sustainable energy, renewable energy generation has been promoted by policies with various methods. Since renewable energy generation requires great amount of investment and initiative, it has been promoted at the state level. One possible reason is that privatised companies tend to build their revenue structures focusing more on immediate profit-making than government or stated-owned companies. That is, two competing needs, liberalisation of market structure and stated level of renewable energy promotion, exist in current energy sector. The purpose of this study is to figure out the relationship between those conflicting concepts and to compromise on desirable way of pursuing sustainable energy.

Using the panel data set for the period 1980 to 2012, this paper provides an econometric analysis of impact of effects of liberalisation on renewable generation promotion in the electricity sectors of 36 countries. The remainder of this study is structured as follows. The second section briefly introduces issues related to this study. It suggests the importance of energy sector for economic development and describes why the energy sector is chosen as an area of this study. Besides, this section explains how privatisation and liberalisation have been studied up to recently in academia, introducing studies of great scholars and currently prominent researchers. Also, it explains the characteristics of renewable energy and why renewable energy promotion conflicts to the objective of the privatised companies. Most of previous studies introduced in this section are based on empirical analysis. The third section reveals main objectives and aims of this paper for setting up hypothesis. Then, in the fourth section, econometric methodologies and data characteristics of this study are introduced. This section explains the process of selecting which model to use for this analysis and also exhibits several regression equations used in this study. Detailed data descriptions of variables are also showed in this section. The results are presented in the fifth section. Along with main regression results, results from different models are also provided for comparisons. The sixth section, last part of the paper, provides a summarized content of the entire study and conclusion along with some remarks, limitations, and recommendations for the future study.

2. Literature reviews

2.1 Importance of energy sector for development

There are mainly two reasons why this study focused on economic phenomenon in energy sector. First of all, one of the most important environmental issues related to economic growth is energy problem including energy consumption, energy security, or renewable energy. Consuming energy has significantly improved the quality of economic activities including both industrial and residential parts of world economy. Improved energy services result a various kinds of economic and social benefits including better education, improved access to information and digital system, greater productivity, improved health services, and improved indoor air quality (World Energy Assessment, 2000; Waddams Price, 2000). In the past several decades, numerous studies have been conducted to figure out the causal relationship between energy consumption and output using empirical analysis methods. A recently published study (Bruns, Gross, and Stern, 2014) carried out a meta-analysis of 574 pairs of causality test from 72 selected studies from vast literature. Although they cannot find a genuine causal effect in the whole literature and the direction of the causality is still unclear, this obviously shows that consuming energy is a critical factor in economic development. After industrialisation was completed, fuel prices, such as oil price, have directly influenced world economy. The energy sector has a profound effect on a country's economic condition because energy industry is one of the most capital-intensive industries requiring enormous amount of investment. Also, electricity is a number one essential intermediate good in every industry sector from agriculture to high technology industries. For these reasons, energy sector must be operated efficiently for better economic condition.

Second reason is that most countries started to privatise energy sector first among infrastructure industries. There are several types of market structure based on the degrees of competitiveness. Industries which require economies of scale tend to be monopolised by government, and energy sector is a classic example of natural monopoly in competition theory. In most countries, electricity market has vertically integrated and owned by government in early ages. However, this tendency of 'natural monopoly' in electricity sector has been changed over the last several decades, especially in generation and supply market of electricity. The movements to reform electricity sector have already started in many developing countries, and some countries have almost completed them. Chile first began the liberalisation and privatisation of the electricity sector in 1982. England and Norway also began to reform power sector during the 1980s and these movements have motivated many countries including Europe, the United States, Australia, and Latin developing to follow them during the 1990s (Bacon and Besant-Jones, 2001). Jamasb(2006) examined the sequence of electricity sector reform measures in 20 selected developing countries. Most of them started reformation activities in late 80s or early 90s. Although the restructuring models have varied among countries, the common objective of reform has been to improve the market efficiency of the energy sector by liberalizing markets and introducing private capital.

2.2 Privatisation and liberalisation

Neoclassical economic theory addresses that for a well-functioning market, there must be competition and private property. According to this economic doctrine, privatising tendency in many countries seems desirable phenomenon for improving market efficiency and productivity.

It is true that some countries have almost completed privatisation process without much difficulty but it is also true that structural reform is not always successful in many countries. The two largest countries, Russia and China, have experienced contrasting transition during recent decades. Stiglitz(1999) described China's success and Russia's failure of transition, and argued that rapid switch to the market economy not always derives development success. Russia has undertaken mass privatisation in 1990s after former Soviet Union dissolved, while China adopted market economy principles in the very recent years. Not only Russia, but also other countries like Mexico have suffered from difficulties of structural reform especially in energy sector. As mentioned above, Chile first started electric sector reform in early 80s but now has negative symptoms of a poorly managed energy system such as blackouts or high energy prices. Why some could not success this process and failed to achieve significant development?

For the success of growth, technological change is a major source of market efficiency but the development of institutional arrangement is also essential to improve the efficiency of product and factor market (North, 1971). Most of economic theories regard adopting competition and privatisation as the important aspects of market economy. However, the outcomes cannot be guaranteed to be efficient without proper institutional infrastructure (Rodrik et al., 2004). Hogan (2001) argues that the success of market-oriented electricity reforms must be based on market oriented institutional framework to support the reforms. The success of market oriented economy is not based on short-sighted economic incentives such as prices but trust, sound institutions, and social capital play important roles (Fukuyama, 1995; Stiglitz, 1999; Arrow, 1972). In this context, privatisation is not a simple economic operation because it requires broad institutional efforts which take enough time. In case of electricity sector, the energy industry is relatively complex, and the process of separating its components to operate in competitive market imposes a greater burden (Hogan, 2001). Academia, industry field, and many policy makers are studying the effectiveness and desirable method of electricity sector reform until now, but it is still controversial whether it should be owned by private or not. Hence, this is more important for developing countries because privatisation, competition and the reform of state regulation are key themes in donor aid programmes while most of studies have focused on developed countries (Zhang et al., 2002)

2.3 Privatisation versus Renewable energy Issue

While controversy surrounding market structure of electricity sector is going on worldwide, renewable energy issue has been gradually but significantly progressed. Rifkin(2011) convinces of the strong influence of energy sector over mankind as a whole and emphasizes that renewable energy is taking critical role. Fossil fuel exhaustion and Climate Change issue accelerate many countries to promote renewable energy generation. Recently decelerated Sustainable Development Goals(SDGs) includes “Ensure access to affordable, reliable, sustainable and modern energy for all” as seventh initiatives. Clean and sustainable energy was reemphasized during COP21 in Paris, the most recent Climate Change conference, and transition from fossil fuels to renewable energy is now inevitable phenomenon. Countries have made various efforts to promote renewable energy by developing renewable technologies and implementing appropriate policies.

Some takes optimistic perspective of balancing energy efficiency and sustainability in post-reform electricity market. Since post-reform sector requires more efficient fuel use, their exist incentives for economic efficiency that stimulate coal-burning plants to shift relatively cleaner natural gas plants (Dubash, 2003). However, there is no guarantee that the privatised energy sector, which is more liberalised than state owned, promotes renewable energy use. One reason is that renewable energy generation has been considered as less efficient and less productive than fossil fuel generation, because great amount of capital investment for implementation and maintenance is required. In the countries where succeed with introducing renewable energy generation, renewable energy performs an effective action to push generation price down. For the developing countries have not yet adopted renewable technologies, in contrast, utilising renewable energy is still an expensive progress, and this conflicts to the objective of electricity sector reform.

Ruiz-Mendoza and Sheinbaum-Pardo (2010) examined four selected Latin developing countries experienced radical electricity sector reform during 1990s, and found that renewable energy generation decreased in its participation in total installed capacity while natural gas generation increased during same period. This is because private electricity generators require the higher rate of return and only have short-term vision that renewable energy has little possibilities of development. In a reformed electricity market where private utilities operate the system and no regulation is enforced, the major operating principle is profitability, regardless of the environment, the social issue, and energy security (Ruiz-Mendoza and Sheinbaum-Pardo, 2010).

In this urgent need of transition to sustainable energy use for sustainable development, both sector reform and renewable energy issues should be dealt with simultaneously even they are in conflict each other to a certain extent. In contrast to studies scrutinizing the phenomenon of electric sector reform have done vigorously, not many studies regarding relationship between electricity sector reform and promoting renewable energy have done with empirical analysis.

Marques and Fuinhas (2011) examine drivers promoting renewable energy with dynamic panel estimators of 24 European countries. The model in the study contains energy consumption, fossil fuel generation, nuclear power, price, and income as variables but cannot control for variables of policies, such as incentive tariffs or R&D incentive programs (Marques and Fuinhas, 2011). Nagayama (2009) precisely categorises electric power liberalisation model to figure out empirical relationship between electricity sector liberalisation and various energy related factors, but does not use renewable energy related variables. There are studies about how electricity price changes after sector reform in developing countries (Nagayama, 2009; Nagayama and Kashiwagi, 2007), relationship between renewable energy and growth (Omri et al., 2015), or effectiveness of regulatory instruments to promote renewable energy generation (Finon and Perez, 2007), but few studies examine how electric sector reform affects to renewable energy generation.

3. Objectives and aims of the Study

The long term goal of the study is to examine how market structure of electricity sector affects to sustainable energy consumption and to anticipate a desirable way of improving both energy market efficiency and energy sustainability. The aim of the current research is to analyse how renewable energy generation and energy market privatisation related. The research pursues the following two objectives. One is to propose desirable ways of structure reform in energy industry, which contribute to energy efficiency and sustainable development in the same time. The other is to examine differences of impact of market reform on renewable energy among different country groups, such as high income and low income countries, for providing more effective adoption methods of market restructuring appropriate for each country.

Electricity market is the most actively liberalised market in energy industry. In addition, among utilities, electricity sector has been primarily privatised or liberalised in many countries. With this common aspect, limiting the scope of energy sector to electricity sector, the following research questions need to be addressed for potential hypothesis: (1) Does degree of liberalisation/privatisation of electricity market affects to the extent of renewable energy generation promotion? (2) The effects of liberalisation/privatisation have different magnitude of impact on renewable energy generation promotion in each country? From the above research questions the following hypothesis are derived. Based on panel data of 36 countries from 1980 to 2012, this study empirically examines the impact of electricity market liberalisation on renewable energy generation promotion.

4. Methodologies and Dataset

4.1 Data set overview

The above research questions are examined by using panel data for 36 countries which have data availability of sector liberalisation, and the time span is from the start of electricity sector reform to recent years. Since most of market privatisation or liberalisation started in mid 80s and to capture this transition of market liberalisation, the time span of the data is from the year 1980. As the last year for which data are available at the time the study was conducted is 2012, this study covers 33 years from 1980 to 2012.

The study used following variables; renewable energy generation proportion, the degree of electricity market liberalisation, electricity generation capacity, nuclear generation ratio, fossil fuel generation, log of population, CO_2 emissions, economic growth rate, electricity consumption, and energy intensity of industrial and residential sectors. Dependant variable of this regression analysis is the proportion of renewable energy generation. Data of renewable energy generation and total electricity generation are taken from U.S. Energy Information Administration (EIA), and the ratio is calculated by dividing renewable electricity generation into total electricity generation. The proportion of nuclear electricity generation, one control variable in this study, is calculated with same method above.

The data for policy variable, the degree of electricity market liberalisation, is acquired from OECD statistic database. Some institutions and economists have made effort to define degrees of liberalisation or privatisation based on various criteria. This has been considerably useful when investigating how sequential degrees of liberalisation/privatisation interact with other economic barometers. Steiner (2001) introduced empirical assessment of the effects of electric sector reform using panel data for 19 OECD countries. In this study, several regulation and structure related indicators used as dummy variables for random effect panel regressions analysis. Nagayama (2009) investigated electricity market structure of 78 countries in detail, and then define four stages of power sector liberalisation transition. The purpose of the study is to figure out how the effects of electric power sector reforms are different among countries. European Bank for Reconstruction and Development (EBRD) provides ‘Transition Indicators’ that describes what extent the transition countries have changed from a centrally planned economy to an industrialised market economy with the scale of 1 to 4+. EBRD provides separated indicators representing transition of regulated infrastructure sectors such as electricity, railways, telecommunications, and water sectors. Nepal and Jamasb(2012) used those transition indicators as well as bias corrected dynamic fixed effect analysis (LSDVD) to assess the impact of structure reforms on power sector and macroeconomic outcomes. In addition to EBRD, OECD also provides competition and regulation related indicators of OECD countries that measure regulatory management practices in six sectors including electricity, gas, telecom, railroad transports, airports and ports. The scale of indicators are from 0 to 6 and calculated by answer of questions over three main components, independence, scope of action, and accountability (Beiter et al., 2014). Although EBRD indicator and OECD indicator are differently scaled, they are still useful when analysing both developing and developed countries by converting one indicator’s scale to another indicator’s scale. Erodugo (2014) converted 1 to 4+ scale of EBRD indicators into 0 to 6 scale and reverse the 6 to 0 scale order of OECD indicators to examine the effect of liberalisation in both developing countries and developed countries. By this conversion, the study could cover 92 countries covering from many continents, which allowed considerable enough number of samples for meaningful analysis of examining the impact of power sector reform on investment and carbon emission. However, only 36 countries including OECD countries and few non-OECD countries are covered in this study because required data of several control variables are lacking. For this reason, OECD's 0 to 6 scaled indicator is used as it is, and the scale conversion is not needed in this study. Nonetheless, this is still important for later study because future researches covering many developed and developing countries simultaneously are still needed. Other control variables are taken from EIA, World Bank, and OECD. Most of energy related variables such as electricity capacity, nuclear generation, fossil fuel generation, and electricity consumption are collected from EIA. Rest of energy related variables, CO2 emissions per capita, industrial energy intensity, and residential energy intensity are obtained from World Bank data. Additional control variables, population and annual growth rate are also acquired from World Bank database. Further information of each variable is described in detail with following Table 4-1.

[Table 4-1. Descriptive statistics of data]

Variables (units)	Type of variable in the analysis	# of obs.	# of countries	# of years	Mean	Std. dev	Min.	Med.	Max.
Renewable generation ratio	Dependent	1135	36	1980-2012	0.29	0.31	0.00	0.16	1.00
Electricity market liberalisation degree	Independent	1190	36	1980-2012	4.48	1.68	0.87	5.00	6.00
Electricity generation capacity (Million Kwh)	Control	1140	36	1980-2012	39.55	47.79	0.7	19.50	293
Nuclear generation (Billion Kwh)	-	608	21	1980-2012	65.44	87.98	0.1	36.00	431
Nuclear generation ratio	Control	608	21	1980-2012	0.15	0.20	0.00	0.0.	0.80
Fossil fuel generation (Billion Kwh)	Control	1105	36	1980-2012	90.14	121.55	0.1	35.00	829
Log of popupation	Control	1188	36	1980-2012	16.45	1.55	12.34	16.21	19.55
CO_2 emissions (metric tons per capita)	Control	1093	36	1980-2012	8.88	4.55	1.26	8.11	30.28
Growth rate (%)	Control	1108	36	1980-2012	2.78	3.13	-14.72	2.85	21.83
Electricity consumption (Bilion Kwh)	Control	1138	36	1980-2012	232.94	543.22	2.9	78.50	3890
Energy intensity of industrial sector (MJ/2011$,PPP)	Control	813	36	1990-2012	5.95	3.31	1.72	4.84	26.88
Energy intensity of residential sector (GJ/household)	Control	828	36	1990-2012	69.39	35.55	16.52	65.38	270.86
GDP per capita, PPP (Constant 2011 international $)	-	1070	36	1980-2012	28716.0	12679.7	5088.5	27844.3	89911.1
GNI per capita (2011$, PPP)	-	1224	36	1980-2012	34383.5	12613.6	11976.6	34962.5	63404.0

4.2 Methodology

In this study, panel regression equations are formulated based on Steiner's model which analyses the impact of electricity sector reform on the renewable energy generation (Steiner, 2001). In panel regression, both cross-country and time-series features can be considered by using data from various countries for certain period of time. Following Steiner, many researchers developed and applied the model to examine impact of market restructuring on various energy or electricity indicators. Erdogdu (2011) used following regression equation to analyse the impact of electricity industry reform on power sector efficiency:

$$\boldsymbol{Y_{it} = \beta_1 + \sum_{j=2}^{k} \beta_j X_{jit} + \sum_{p=1}^{s} \gamma_p Z_{pi} + \delta t + \varepsilon_{it}} \quad (1)$$

In this equation, *i* represent country unit of observation and *t* represent time. *j* and *p* stand for observed and unobserved variables, respectively. That is, $\boldsymbol{X_{jit}}$ and $\boldsymbol{Z_{pi}}$ represent observed and unobserved variables, and $\boldsymbol{X_{ji}}$ includes both independent variable and control variable. $\boldsymbol{\varepsilon_{it}}$ is the disturbance term (Erdogdu, 2011). This model contains unobserved term $\boldsymbol{Z_{pi}}$ which does not necessarily have to represent some specific variables. For convenience, the model can be transformed into following equation, using a term $\boldsymbol{\alpha_i}$ as the unobserved effect rather than remaining $\boldsymbol{\sum_{p=1}^{s} \gamma_p Z_{pi}}$ (Erdogu, 2011). Then, the model can be rewritten as follows:

$$\boldsymbol{Y_{it} = \beta_1 + \sum_{j=2}^{k} \beta_j X_{jit} + \alpha_i + \delta t + \varepsilon_{it}} \qquad (2)$$

In Erdogdu's equation, various variables represent $\boldsymbol{Y_{it}}$ as dependent variables, but in this study only one dependent variable is used, the proportion of renewable electricity generation.

However, different from many models following Steiner's model, a set of regulatory structure indicators are replaced by one-year lagged liberalisation indicator in this study. This time lag is rational because it takes time for constructing renewable generation plant or implementing energy policies that reflect current energy issues. Since the liberalisation indictor is lagged for one year, endogeneity problem is not carefully considered in this study. Applying one year lag, the model can be transformed as follows:

$$\boldsymbol{Y_{it} = \beta_1 + \beta_2 X_{2it-1} + \sum_{j=3}^{k} \beta_j X_{jit} + \alpha_i + \delta t + \varepsilon_{it}} \qquad (3)$$

$\boldsymbol{X_{2it-1}}$ represents a regulatory structure indicator of the time one year before t, the independent variable in this study.

Using panel data across countries over several decades, country specific effect expected to occur in the constant term in this model. When control variables capture adequate characteristics of each individual, pooled OLS regression can be used for this model, regarding every observation for every period as a single sample. Practically, it cannot be guaranteed that control variables always capture enough characteristics of each country, so some other analytics models are required. A fixed effect model and a random effect model are both appropriate, while those selected countries assumed to be drawn from a large population, a random-effect model seems to be more appropriate. Breusch-Pagan test and Hausman test will determine which model is more suitable in this study.

The null hypothesis of Breusch-Pagan test is that the error variances are constant while the alternative is that the error variances are increasing function with one or more variables. Breusch-Pagan / Cook-Weisberg test for heteroskedasticity is first conducted, and it rejects the null. As expected above, pooled OLS model is not preferred in this study. Rather, either a fixed effects or random effects regressions may have greater explanatory power.

In fixed effects model, some country specific characteristics are estimated and represented by a fixed value parameter. In random effects model, country specific characteristics are treated as probabilistic values. The fixed effects model composed with consistent estimates, while the random effects model estimates more efficient values. Some countries have been under the influence of international or regional regulations upon CO_2 emissions, such as Kyoto Protocol, or some former Soviet Union countries may have undergone similar privatisation or liberalisation process in electricity industry. Therefore, it cannot be convinced that whether the observations are randomly selected from given population, and cannot be simply determined which regression model to use. Hausman test is followed after B-P test to examine whether the random effects model can be used or not, and it is rejected with panel data of this study. Further detail of the test is described in the following section.

5. Empirical analysis and results

Before running the regression, several variables have taken logarithms for more effective and precise interpreting of analysis result. As seen in data description table above, each variable has different units and ranges of data set. Logarithmic form reduces gap among units of variables and enables more efficient interpretation. In this study, electricity generation capacity, fossil fuel generation, population, and electricity consumption are transformed into natural logarithmic value. *ln* expresses the logarithm format of the variable. Then, the model can be rewritten as follow:

$$\boldsymbol{Y_{it} = \beta_1 + \beta_2(eleclib)_{it-1} + \beta_3 ln(eleccap)_{it} + \beta_4(ngratio)_{it} + \beta_5 ln(fossgen)_{it} + \beta_6 ln(pop)_{it} + \beta_7(co2)_{it} + \beta_8(growth)_{it} + \beta_9 ln(eleccon)_{it} + \beta_{10}(iinten)_{it} + \beta_{11} ln(rinten)_{it} + \alpha_i + \varepsilon_{it}} \tag{4}$$

First of all, the fixed effect model with all control variables and random effects model with all control variables are estimated and stored sequentially. With these stored result, the Hausman test is conducted. It rejects the null at a significance level of 5%, with p-value less than 0.05. Therefore, the fixed effects model is chosen, which is consistent.

The fixed effects model is adopted as a result of two tests, but results of Pooled OLS and the random effects model are also presented for comparison. Following table presents estimation results of given equation (4) for each model, but interpreting the other two models might be less worthy.

[Table 5-1. Estimation results of different models]

Dependent variable	Renewable electricity generation ratio		
Variables	Pooled OLS	Random Effects	Fixed Effects
eleclib/L.eleclib	-0.0191***	-0.0098***	-0.0106***
	(0.0035)	(0.0022)	(0.0023)
lneleccap	0.1134***	0.0855***	0.0901***
	(0.0154)	(0.0290)	(0.0322)
ngratio	-0.6283***	-0.5016***	-0.4892***
	(0.0265)	(0.0641)	(0.0768)
lnfossgen	-0.1760***	-0.1622***	-0.1539***
	(0.0054)	(0.0081)	(0.0092)
lnpop	-0.0130	0.0333	-0.0417
	(0.0151)	(0.0256)	(0.0665)
co2	-0.0158***	-0.0166***	-0.0177***
	(0.0021)	(0.0030)	(0.0031)
growth	0.0001	0.0008	0.0008
	(0.0016)	(0.0007)	(0.0007)
lneleccon	0.0719***	0.0282	0.0216
	(0.0192)	(0.0317)	(0.0351)
iinten	0.0243***	0.0036*	0.0028
	(0.0021)	(0.0019)	(0.0020)
lnrinten	-0.0473***	0.0902***	0.1058***
	(0.0180)	(0.0238)	(0.0247)
constant	0.8147***	-0.2220	0.9654
	(0.2243)	(0.3994)	(1.0596)
Obs.	708	708	708
Adj R^2	0.7902	-	-
R^2(Within)	-	0.4949	0.4970
R^2(Between)	-	0.7346	0.5716
R^2(Overall)	-	0.7217	0.5794

Standard errors in parentheses, *p<0.10, **p<0.05, ***p<0.01

Following table shows various estimation results based on fixed effects model. FE1 to FE6 are results of equations including each control variable sequentially, and FE7 is final result of the given estimation equation. As shown in various results from model FE1 to model FE7 in Table4-2, this model is relatively stable. As control variables being added or excluded, the result of each model is relatively consistent.

[Table5-2. Estimation results of the fixed effects model]

Variables	Renewable electricity generation ratio						
	FE1	FE2	FE3	FE4	FE5	FE6	FE7
L.eleclib	-0.0001 (0.0015)	-0.0095*** (0.0019)	-0.0106*** (0.0015)	-0.0097*** (0.0016)	-0.0074*** (0.0017)	-0.0059*** (0.0017)	-0.0106*** (0.0023)
lneleccap		-0.0743*** (0.0094)	0.1168*** (0.0111)	0.1070*** (0.0128)	0.1217*** (0.0141)	0.0580*** (0.0215)	0.0901*** (0.0322)
ngratio			-0.3780*** (0.0374)	-0.4243*** (0.0422)	-0.4524*** (0.0437)	-0.4943*** (0.0447)	-0.4892*** (0.0768)
lnfossgen			-0.1586*** (0.0065)	-0.1617*** (0.0070)	-0.1529*** (0.0080)	-0.1564*** (0.0080)	-0.1539*** (0.0092)
lnpop				0.0628* (0.0366)	0.0361 (0.0397)	-0.0196 (0.0419)	-0.0417 (0.0665)
growth				-0.0004 (0.0006)	-0.0000 (0.0006)	-0.0001 (0.0006)	0.0008 (0.0007)
co2					-0.0071*** (0.0023)	-0.0107*** (0.0025)	-0.0177*** (0.0031)
lneleccon						0.0855*** (0.0220)	0.0216 (0.0351)
iinten							0.0028 (0.0020)
lnrinten							0.1058*** (0.0247)
constant	0.3014*** (0.0072)	0.5668*** (0.0343)	0.5719*** (0.0289)	-0.4219 (0.5842)	0.0030 (0.6337)	0.7873 (0.6605)	0.9654 (1.0596)
Obs.	1071	1071	1039	1010	966	966	708

Standard errors in parentheses, *p<0.10, **p<0.05, ***p<0.01

Before looking into the regression results, the relationship between the dependant variable and the policy variable, electricity market liberalisation degree, should be established carefully. The degree 0 stands for a fully competitive market, and the degree 6 stands for a totally state-owned market. That is, the lower the degree of electricity market liberalisation is, the more the structure of electricity market is liberalised. Considering these degrees, negative coefficients of *L.eleclib* which are shown in entire seven results, mean that as an electricity market is more liberalised, the renewable electricity generation is more promoted.

The result of FE1 in Table4-2 shows that, electricity market liberalisation does not have any significant effect to renewable electricity generation under the circumstance of that none of the variables is controlled. However, the liberalisation variable is statistically significant from FE2 model, after various control variables are included. This shows the importance of control variables have in this empirical analysis.

The negative coefficients of *L.eleclib* are presented in six models with 1% of significance except FE1. This reveals that in most of countries in the model, the ratio of renewable electricity generation increases when the electricity market is more liberalised. Other energy related variables also show relatively significant results. Electricity capacity and electricity consumption shows positive relationship. Nuclear generation ratio reveals the greatest magnitude of all variables, with negative coefficient. This is rational because nuclear generation has been considered by far the most cost effective than any other generation sources. There are several countries where do not have any history of nuclear generation, but this accompanies a very important policy implication for the countries partly depend on nuclear power. Fossil fuel generation also shows negative coefficient, and the magnitude is relatively high following nuclear generation ratio, which is also appropriate. The negative coefficient of CO_2 emissions presents that countries emitting less carbon generates more with renewable energy. Different from energy related variables, both of general economic indicators, population and growth, are statistically not significant.

[Table 5-3. Results of FE models with different groups of countries]

Variables	Renewable electricity generation ratio							
	GNI		Electricity consumption		CO_2 emissions		1997 Kyoto protocol	
	←	→	←	→	←	→	←	→
Leleclib	-0.0108*** (0.0021)	-0.0096** (0.0043)	0.0005 (0.0035)	-0.0061*** (0.0014)	-0.0125*** (0.0021)	-0.0094** (0.0046)	-0.0144** (0.0061)	-0.0032 (0.0025)
lneleccap	0.1308*** (0.0282)	0.0470 (0.0560)	0.1625*** (0.0429)	0.0925*** (0.0216)	0.0835*** (0.0303)	0.0912 (0.0574)	0.0853 (0.0637)	0.1283*** (0.0257)
ngratio	-0.4566*** (0.0686)	-0.6944*** (0.1379)	-0.5852*** (0.1360)	-0.4797*** (0.0447)	-0.6583*** (0.0731)	-0.4501*** (0.1290)	-0.7369*** (0.1416)	-0.3504*** (0.0647)
lnfossgen	-0.2418*** (0.0133)	-0.1201*** (0.0123)	-0.3194*** (0.0134)	-0.0311*** (0.0059)	-0.1335*** (0.0119)	-0.1468*** (0.0140)	-0.1286*** (0.0191)	-0.0462*** (0.0087)
lnpop	0.0578 (0.0572)	0.0110 (0.1399)	-0.0681 (0.0848)	-0.0161 (0.0449)	-0.1403* (0.0757)	-0.3485*** (0.1166)	0.1872 (0.1834)	-0.2814*** (0.0738)
growth	0.0008 (0.0006)	0.0010 (0.0015)	0.0018** (0.0008)	-0.0000 (0.0005)	0.0024*** (0.0007)	0.0017 (0.0011)	0.0010 (0.0011)	0.0002 (0.0005)
co2	0.0001 (0.0046)	-0.0265*** (0.0041)	-0.0224*** (0.0038)	-0.0087*** (0.0026)	-0.0370*** (0.0064)	-0.0279*** (0.0043)	-0.0609*** (0.0043)	-0.0252*** (0.0033)
lneleccon	0.0397 (0.0341)	0.1253* (0.0690)	0.1751*** (0.0449)	-0.1190*** (0.0256)	-0.0035 (0.0366)	0.1860*** (0.0623)	0.1643** (0.0650)	-0.0134 (0.0326)
iinten	-0.0008 (0.0016)	0.0149*** (0.0041)	-0.0055* (0.0031)	-0.0040*** (0.0012)	0.0107*** (0.0027)	0.0064** (0.0031)	0.0003 (0.0034)	-0.0058** (0.0026)
lnrinten	0.0166 (0.0185)	0.2513*** (0.0548)	0.1146*** (0.0347)	0.0426*** (0.0165)	-0.0005 (0.0220)	0.1939*** (0.0507)	0.1072** (0.0442)	0.0412* (0.0218)
constant	-0.3248 (0.9073)	-0.9656 (2.1653)	1.0535 (1.2596)	1.0190 (0.7632)	3.2425*** (1.2383)	4.9066*** (1.7773)	-3.0810 (2.8853)	4.9195*** (1.1653)
Obs.	316	392	325	383	329	379	242	466
sum of obs.	708		708		708		708	

Standard errors in parentheses, *p<0.10, **p<0.05, ***p<0.01

Table 5-3 shows results of the same fixed effects model dividing countries into two groups. First rows are below median and second rows are over median, based on four selected criteria. Electricity consumption and CO_2 emissions are already included in the regression model as variables while GNI and the year 1997 is only used as criteria. The year 1997 is relevant as a criterion because the Kyoto protocol was adopted in the exact year. Kyoto protocol is a meaningful threshold that facilitates solving climate change issues, adopted by UNFCCC in 1997. The Kyoto Protocol legally binds emission reduction targets for countries, and most of the targeted countries are already developed countries. It also derives the Kyoto Mechanisms which practically work for easing the economic burden of carbon reductions (UNFCCC, 1997). This requires much greater energy efficiency in entire industry sectors, and may have significant influence toward industry structures including electricity industry. Since the agreement applied to targeted Annex I countries and has enough legal binding force, it seems like valid enough to use this factor as one of the control variables. With this reason, whether being classified as the Annex I countries or not, could be a dummy variable in the model. However, it turned out to be less meaningful since most of OECD countries are classified as Annex I, only few of our population belong to non-Annex I group. Instead, use the year 1997 as an inflection point, assuming that some changes may have caused after Kyoto Protocol was adopted in 1997.

Results of different GNI groups exhibit distinctive features in terms of statistical significance. Electricity capacity shows positive value and significant in 1% level in lower median GNI group while it does not have any significance in over median GNI group. On the contrary, CO_2 emissions, electricity consumption, industrial energy intensity, and residential energy intensity are significant in over median GNI group while none of them are significant in lower median GNI group. Groups based on electricity consumption draw different results, in terms of both significance and coefficient value. Electricity liberalisation effects significantly only in over median electricity consumption group. In case of fossil fuel generation, the difference of coefficient is extremely large that below median group has ten times great magnitude than over median countries group. Electricity consumption, as a coefficient, shows completely reversed signs. It effects positively in below median group and effects negatively in the other group. Dividing countries by the level of CO_2 emissions, electricity capacity is significant only in below median group while electricity consumption and residential energy intensity are significant only in over median group. Before 1997, electricity market liberalisation is significant while it is insignificant after Kyoto Protocol is adopted in 1997. Electricity generation capacity, population, CO2 emissions, and industrial energy intensity are insignificant before 1997 but they are all negative and significant after 1997. Except few variables including electricity market liberalisation degree, most of variables are significant after 1997.

On the whole, most of estimations reveal that the degree of electricity market liberalisation affects positively to renewable electricity generation ratio. Electricity generation capacity and CO_2 emissions also consistently and significantly have impact on renewable electricity generation. It shows that the greater electricity generation capacity results the more ratio of renewable electricity generation, and the greater amount of carbon emission results the lower ratio of renewable generation. In terms of energy intensity, both industrial and residential intensity show significance in over median groups of all four criteria. However, population and economic growth rate are not significant throughout entire analyses.

6. Conclusion

There have been number of papers studying the impact of privatisation or market liberalisation on various economic outputs since 1980s, but not many studies have conducted to find relationship between electricity market liberalisation and renewable energy generation promotion.

This paper analysed the impact of electricity market liberalisation on proportion of renewable energy generation with panel data analysis. Dataset from 36 countries, from the year 1980 to 2012 are used for the regression estimations. Most of energy related variables, such as electricity market liberalisation degree, electricity generation capacity, nuclear generation, fossil fuel generation, and electricity consumption are acquired from EIA. After conducting several tests, the fixed effects model is selected as the most suitable estimation model for this study, and run several fixed effects model regression to answer the main research questions.

The empirical results of this study suggest following conclusions. First of all, the degree of electricity market liberalisation has significant impact on renewable electricity generation ratio in whole countries group. The more the electricity market is liberalised, the greater portion of electricity is generated by renewable energy sources. Majority of the control variables related to energy also have significant impact at 1% level, while population and growth do not have significant effects in most cases.

Countries are divided into two groups, below median and over median, in each category based on the level of GNI, electricity consumption, and CO_2 emissions. GNI and CO_2 emissions could not make any differences in terms of the impact of electricity market liberalisation on renewable energy generation, while only over median group of electricity consumption level shows significance with the same independent variable. For other control variables, electricity consumption could not reveal much difference in terms of statistical significance between below median and over median group. However, over median group of GNI shows that majority of variables are significant, while there are not many significant variables in below median group of GNI. This implies that energy related variables may affects differently based on the income levels of countries, so their economic characteristics should be carefully considered before energy policies are adopted. Another criterion is the year 1997, the year Kyoto protocol is adopted. Unlike our expectations, electricity market liberalisation is not significant after the year 1997.

However, this study has several limitations. Dataset of the analysis is mainly based on OECD countries, so it cannot be treated as a common phenomenon among the whole countries in the world. Also, data from about three decades have used but there has been very important turning point in recent years. Fukushima accident was happened few years ago, and this totally changed the direction of energy policies in many countries including Germany, where has declared the nuclear power phase-out as a national goal. Considering current limitations, it will be meaningful to study the same subject with more data from countries both developed and developing countries and with much longer time period including after Fukushima accident to trace what happened after then.

Appendix A. List of countries in the analysis

No	Country code	Country name	No	Country code	Country name
1	AUS	Australia	24	LUX	Luxemburg
2	AUT	Austria	25	MEX	Mexico
3	BEL	Belgium	26	NLD	Netherlands
4	BRA	Brazil	27	NOR	Norway
5	CAN	Canada	28	NZL	New Zealand
6	CHE	Switzerland	29	POL	Poland
7	CHL	Chile	30	PRT	Portugal
8	CZE	Czech Republic	31	SVK	Slovakia
9	DEU	Germany	32	SVN	Slovenia
10	DNK	Denmark	33	SWE	Sweden
11	ESP	Spain	34	TUR	Turkey
12	EST	Estonia	35	USA	USA
13	FIN	Finland	36	ZAF	South Africa
14	FRA	France			
15	GBR	UK			
16	GRC	Greece			
17	HUN	Hungary			
18	IRL	Ireland			
19	ISL	Island			
20	ISR	Israel			
21	ITA	Italy			
22	JPN	Japan			
23	KOR	Korea			

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