Environmental and Energy Efficiencies using the Stochastic Frontier Cost Function

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<Abstract>

The purpose of the paper is to measure the simultaneous efficiencies of environmental and fossil fuel using the stochastic frontier cost function for 0ECD countries. As the stochastic frontier cost function tries to minimize the cost, we use it to minimize pollutant. The empirical test reports that the change of fossil fuel is more sensitive than that of income in terms of the effect of CO_2 emission. The annual average efficiency of fossil fuel in OECD for 1996-2009 is 0.825, while the annual average efficiency of CO_2 is 0.750, in which possibility reducing the emission of CO_2 is higher than that of fossil fuel. The result reports that improving the efficiency of fossil fuel makes environmental efficiencies higher. To improve these efficiencies, we should make the effort transforming fossil fuel into renewable energies, regardless of the recent low prices of fossil fuels.

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I. Introduction

Recently it is recognized that the increase of CO_2 emission as a main factor of greenhouse gas emission is a phenomenon raised from fossil fuel use. Fossil fuel is a chief factor of CO_2 emission, and the use of fossil fuels arrives at the time to reduce it considering greenhouse gases. Thus, this paper presents a theoretic model to measure a simultaneous performance considering CO2 emission and fossil fuel use, and apply to empirical test . As the data of fossil fuels and CO2 emission is available for the OECD countries, the environment efficiencies for CO2 emission and the energy efficiency for fossil fuel are measured at the same time.

Reviewing the previous studies, the measure of environmental efficiencies has a certain limit to premise the assumption of weak disposability and strong disposability, or null-jointness between desirable outputs and undesirable outputs. Namely, the existing studies use the unrealistic assumptions that desirable outputs and undesirable outputs make a change given the constant state of input directly connected with pollutants, or use labor and capital stock with pollutants directly.

There are other types of existing studies which measure environmental efficiencies based of stochastic frontier analysis(SFA). These studies are Reinhard et al.(1999, 2000, 2002), Gang and Felmingham(2004), Herrala and Goel(2012), and Lansik and Wall(2014). Reinhard et al.(1999) measured environmental efficiency of dairy farms using SFA, and Reinhard et al.(2000) estimated environmental efficiency of the same dairy farms using SFA and DEA(data envelopment analysis), based on output and input approaches. Reinhard et al.(2002) tried to have two stage approaches, which firstly measured environmental efficiency and next regressed it with some impact factors. Gang and Felmingham(2004) confirmed environmental efficiency and its impacting factors in the Australian irrigation industry using input-oriented approach such as Reinhard et al.(2002).

By the way, Herrala and Goel(2012) measured the environmental efficiency for 170 countries making use of stochastic cost frontier analysis. They used CO2 emission as dependent variable, and GDP, population, and national land as independent variables. Lansik and Wall(2014) introduced several methods such as ecological efficiency and material flow balance approach as frontier approach explaining environmental efficiency.

However, these existing studies on stochastic frontier analysis excepting Herrala and Goel(2012) mostly put desirable output as a dependent variable, and pollutants as an input, when estimating environmental efficiency. Using stochastic cost frontier analysis, this article put pollutant as a dependent variable, and simultaneously measure environmental efficiency and energy efficiency for fossil fuel. This is distinguished from the existing studies in that this article use stochastic cost frontier analysis, and simultaneously estimate environmental efficiency and energy efficiency for fossil fuel in the one model, which influences pollutants.

The remainder of the paper is as follows. Section II introduces theoretic model on environmental efficiency and energy efficiency, SectionIII explains the data features in OECD countries, and empirical results. Section IV draws final conclusions.

Ⅱ. Theoretic Model

Environmental efficiency is measured as minimum pollution over actual pollution as it need to minimize harmful pollutant. There are two methods in getting it based on the definition of environmental efficiency. First, pollutants considers inputs, and minimize them in the production function. second, pollutants put outputs, and minimize them in the cost function. And then, most of the existing studies considered pollutants as inputs, especially in case of using desirable outputs and undesirable outputs at the same time. Here, the second approach that pollutants put outputs and minimize them in the cost function will be used to measure the environmental efficiency. The stochastic cost frontier in the theoretic model is introduced. This article particularly divide the types of efficiencies into environmental efficiency and energy efficiency for fossil fuels in the one model. Namely, the model for measuring two efficiencies together will be introduced.

First, Environmental efficiency is defined as follow;

$$\begin{aligned} \mathrm{EE}_{\mathrm{Z}} &= \min\{\theta : \theta \cdot \mathrm{Z} \in \mathrm{T}(\mathrm{y},\mathrm{Z})\} \\ &= \min\{\theta : \theta \cdot \mathrm{Z} \geq Z^{*}\} \\ &= \min\{\theta : \theta \geq Z^{*}/\mathrm{Z}\} \\ &= Z^{*}/\mathrm{Z} \end{aligned} \tag{1}$$

where, Z: actual pollutant, Z*: minimum pollutant, θ : environmental efficiency

Environmental efficiency has a value less than 1.   A pollutant is considered as a dependent variable, but also it is treated as byproduct to be minimized.

Meanwhile, as Herrala and Goel(2012) defined, y is desirable output, and Z is pollutants to be minimized in production possibility set(T). However, different from Herrala and Goel(2012), this article do not use environmental efficiency decided by regulation policy, but use environmental efficiency defined on the cost frontier, which is measured as minimum pollutants over actual pollutants. The basic model here premises the production technology such that pollutants are explained by desirable outputs and inputs. That is,

$$\mathrm{Z} \geq T(\mathrm{y}, \mathrm{x}) \tag{2}$$

where pollutant Z is the function of desirable outputs(y) and inputs (x). Namely, a production function uses x and produce y and Z simultaneously. Eq.(2) means that Z minimizes producing given y. Thus, Min(Z)= T(y, x).

Combining eq(1) with eq(2), environmental efficiency following stochastic cost frontier is defined as

$$\exp(\text{-u}_{\mathrm{it}}) = \min(Z_{it}) / Z_{it} \tag{3}$$

Now, stochastic frontier cost function including random error and environmental inefficiency error is expressed as

$$\mathrm{Z}_{\mathrm{it}} = T(y_{\mathrm{it}}, x_{\mathrm{it}} : \beta) \cdot \exp(v_{\mathrm{it}}) \cdot \exp(u_{\mathrm{it}}) \tag{4}$$

where, pollutants(Z) as dependant variable is the function of y, x, random error(v), and environmental inefficiency error(u). Eq(4) can be transformed into logarithm type of translog stochastic cost frontier function as

$$\begin{aligned} \ln(\mathrm{Z}_{it}) = {} & \beta_0 + \beta_1 \ln y_{it} + \beta_2 \ln K_{it} + \beta_3 \ln L_{it} + \beta_4 \ln ff_{it} + \beta_5 \ln nf_{it} \\ & + 1/2\beta_6 \ln^2 y_{it} + 1/2\beta_7 \ln^2 K_{it} + 1/2\beta_8 \ln^2 L_{it} + 1/2\beta_9 \ln^2 ff_{it} + 1/2\beta_{10} \ln^2 nf_{it} \\ & {}_{it} + \beta_{11} \ln y_{it} \cdot \ln K_{it} + \beta_{12} \ln y_{it} \cdot \ln L_{it} + \beta_{13} \ln y_{it} \cdot \ln ff_{it} + \beta_{14} \ln y_{it} \cdot \ln nf_{it} \\ & + \beta_{15} \ln K_{it} \cdot \ln L_{it} + \beta_{16} \ln K_{it} \cdot \ln ff_{it} + \beta_{17} \ln K_{it} \cdot \ln nf_{it} \\ & + \beta_{18} \ln L_{it} \cdot \ln ff_{it} + \beta_{19} \ln L_{it} \cdot \ln nf_{it} + \beta_{20} \ln ff_{it} \cdot \ln nf_{it} \\ & + v_{it} + u_{it} \end{aligned} \tag{5}$$

where, inputs are classified into capital stock, labor forces, fossil fuels, and non-fossil fuels. As already mentioned, stochastic cost frontier function is used because pollutants should be minimized. So, the environmental inefficiency error term shows plus(+) sign different from the case of production function. We can estimate environmental efficiency from eq.(5).

First of all, let's confirm energy efficiency of fossil fuel as one of factors affecting to environmental efficiency. We need to analyze the relation between energy efficiency of fossil fuel and environmental efficiency. The energy efficiency of fossil fuel is defined as

$$\mathrm{EE}_{\mathrm{ff}} = \min\{\delta : \delta \cdot \mathrm{ff} \in \mathrm{T}(\mathrm{y},\mathrm{Z})\} \tag{6}$$

following the definition of energy efficiency, the value of energy efficiency is also defined as follow;

$$\mathrm{EE}_{\mathrm{ff}} = \min(\mathrm{ff}_{\mathrm{it}})/\mathrm{ff}_{\mathrm{it}} \tag{7}$$

where, $\mathrm{EE}_{\mathrm{ff}}$: energy efficiency, min(ff) : minimum fossil fuel, ff : fossil fuel.

Energy efficiency is also defined as minimum fossil fuel over actual fossil fuel. If all including environmental efficiency and energy efficiency are efficient in the eq.(5), we need to substitute fossil fuel(ff) into δ·ff, and put environmental inefficiency error term (u_{it}) = 0. The stochastic frontier cost function satisfying these conditions is expressed as

$$\begin{aligned} \ln(\mathrm{Z}_{it}) = {} & \beta_0 + \beta_1 \ln y_{it} + \beta_2 \ln K_{it} + \beta_3 \ln L_{it} + \beta_4 \ln \delta \cdot ff_{it} + \beta_5 \ln nf_{it} \\ & + 1/2\beta_6 \ln^2 y_{it} + 1/2\beta_7 \ln^2 K_{it} + 1/2\beta_8 \ln^2 L_{it} + 1/2\beta_9 \ln^2 \delta \cdot ff_{it} + 1/2\beta_{10} \ln^2 nf_{it} \\ & {}_{it} + \beta_{11} \ln y_{it} \cdot \ln K_{it} + \beta_{12} \ln y_{it} \cdot \ln L_{it} + \beta_{13} \ln y_{it} \cdot \ln \delta \cdot ff_{it} + \beta_{14} \ln y_{it} \cdot \ln nf_{it} \\ & + \beta_{15} \ln K_{it} \cdot \ln L_{it} + \beta_{16} \ln K_{it} \cdot \ln \delta \cdot ff_{it} + \beta_{17} \ln K_{it} \cdot \ln nf_{it} \\ & + \beta_{18} \ln L_{it} \cdot \ln \delta \cdot ff_{it} + \beta_{19} \ln L_{it} \cdot \ln nf_{it} + \beta_{20} \ln \delta \cdot ff_{it} \cdot \ln nf_{it} \\ & + v_{it} \end{aligned} \tag{8}$$

Thus, eq.(5) should be equalized with eq.(8) in order to accomplish overall efficiency including two efficiencies. Namely, to accomplish two efficiencies, the next condition should be satisfied :

$$\frac{1}{2}\beta_9 \ln^2 \delta + (\beta_4 + \beta_{13}\ln y_{it} + \beta_{16}\ln K_{it} + \beta_{18}\ln L_{it} + \beta_{20}\ln nf_{it}) \cdot \ln \delta - u_{it} = 0 \tag{9}$$

This is quadratic formula expressed by lnδ, and δ can be solved. For simplification, Let's put the coefficient of second item as b. Namely,

$$\beta_4 + \beta_{13}\ln y_{it} + \beta_{16}\ln K_{it} + \beta_{18}\ln L_{it} + \beta_{20}\ln nf_{it} = b \tag{10}$$

in the Eq(9), lnδ can be solved as

$$\ln \delta = \frac{-b \pm \sqrt{b^2 + 2\beta_9(-u_{\mathrm{it}})}}{\beta_9} \tag{11}$$

thus, inserting the coefficients estimated by eq(5) into eq(11), the value of δ is derived. The value of δ is energy efficiency for fossil fuel, and exp(-u) is environmental efficiency for pollutants. As a result, we can get environmental efficiency(θ) in the eq(5) and energy efficiency in the eq(11), respectively.

III. Empirical Results

The proposed theory is applied to a sample of OECD countries for 1996-2009. The sample data include labor forces, capital stock, fossil fuel, non-fossil fuel, CO_2 emission, and GDP for 27 OECD countries. We use total labor forces by OECD statistics, and estimate capital stocks of OECD countries by perpetual inventory method, which is derived from new investment for OECD countries in the Penn World Table 8. Fossil fuel and non-fossil fuel data, which are marked by ton of oil equivalent, also come from OECD statistics. CO_2 emission comes from United Nations Framework Convention on Climate Change (UNFCCC).

The money value data such as capital stock and GDP is transformed into constant value based on 2005 year (2005=100). We use per capita variables, which are divided by population. We use the stochastic frontier cost function as an estimation method and estimate two efficiencies with 378 observations for 14 years. Of the 14 years, 4 years results (1996, 2000, 2005, 2009) representively are presented due to limited space. The summary of statistics for OECD countries is listed in <Table 1>.

<Table 1> Descriptive Statistics (1996-2009)

(Unit: ton, dollar, person, ton)

	CO2/P	GDP/p	K/p	L/p	FE/p	NFE/p
Australia	18.2	35,673	88,409	0.51	278.4	9.4
Austria	8.8	34,651	94,837	0.49	131.8	50.7
Belgium	11.8	32,045	88,635	0.43	224.1	17.3
Canada	17.7	34,489	73,376	0.53	294.7	123.5
Denmark	10.9	33,316	81,875	0.53	172.2	14.2
Finland	11.9	29,924	81,803	0.50	166.9	57.2
France	6.8	30,815	71,353	0.46	107.4	34.1
Germany	10.6	30,879	81,814	0.48	161.3	13.1
Greece	9.5	22,400	59,260	0.43	132.3	4.8
Hungary	5.8	14,568	33,572	0.41	97.4	5.4
Iceland	9.9	38,583	101,780	0.57	146.7	313.2
Ireland	11.0	35,702	81,829	0.47	165.8	4.3
Italy	8.0	28,958	82,407	0.41	132.7	9.0
Japan	9.8	30,607	107,586	0.53	159.7	16.2
Korea, South	10.5	20,573	66,589	0.48	166.2	9.0
Luxembourg	22.1	67,934	150,598	0.65	354.7	4.7
Mexico	3.7	10,774	24,817	0.38	60.8	3.8
Netherlands	10.8	35,580	79,434	0.52	252.8	4.7
New Zealand	8.3	24,910	50,035	0.52	146.8	70.1
Norway	9.4	46,492	118,271	0.52	144.2	268.2
Poland	8.5	12,517	23,081	0.45	110.6	1.0
Portugal	6.0	19,550	56,190	0.51	95.1	13.6
Spain	7.5	26,823	71,483	0.46	122.9	15.8
Sweden	6.1	31,421	62,619	0.51	100.0	107.3
Switzerland	6.1	36,648	115,660	0.60	92.4	62.0
United Kingdom	9.2	31,612	56,328	0.49	159.0	7.0

United States	19.1	39,610	86,385	0.50	317.6	22.8
Mean	10.3	31,002	77,408	0.49	166.5	46.8

The per capita mean of OECD for 1996-2009 is 10.3 ton (CO2 emission), 31,002 dollar(GDP), 77,408 dollar(capital stock), 0.49 person(labor forces), 166.5 ton (fossil fuel), and non-fossil fuel(46.8ton). We can classify Luxembourg, United States, Australia, Canada as high level countries in terms of per capita fossil fuel use

As we do not use production function, but use stochastic frontier cost function in the empirical test, this results may be different from those of the production function in the existing studies. The estimation equation of per capita CO2 emission by the stochastic frontier cost function is illustrated in <Table 2>. As is shown, per capita CO2 emission is mostly significant for per capital fossil fuel, but not significant for other explainable variables. However, variance(σ^2), ϒ, and environmental inefficiency error term(μ) are all significant at the 10 percent level , and over 60 per cents of composite-error terms results from environmental inefficiency error terms. The time-varying change of environmental inefficiency(eta) is not significant.

While log likehood value of maximum likelihood estimation(MLE) by stochastic frontier function is 277.9, the value of ordinary least square(OLS) is 212.7, and the LR test shows 130.5. Thus, the null hypothesis, which there are no environmental inefficiency and no change of environmental inefficiency, is rejected in one percent level (threshold value : 9.21) through $\chi 2$ distribution. So, we confirm environmental inefficiency exists. Using the estimated coefficients of the stochastic frontier cost function , we additionally estimate energy efficiency(δ) in eq.(11).

<Table 2 > The Estimation Results of Stochastic Frontier Cost Function

	Coefficient	Standard Deviation	t value
constant	-1.332	1.173	-1.135
ln(GDP/p)	-0.054	0.547	-0.099
ln(K/p)	0.015	0.504	0.030
ln(L/p)	0.110	0.280	0.391
ln(FE/p)	0.352***	0.225	1.562
ln(NFE/p)	0.146	0.498	0.292
1/2ln(GDP/p)^2	-0.098	0.176	-0.558
1/2ln(K/p)^2	-0.050	0.307	-0.164
1/2ln(L/p)^2	0.199	0.582	0.341
1/2Ln(FE/p)^2	0.478*	0.174	2.746
1/2Ln(NFE/p)^2	0.009	0.022	0.408
ln(GDP/p)*ln(K/p)	0.118	0.214	0.551
ln(GDP/p)*ln(L/p)	0.082	0.519	0.158
ln(GDP/p)*ln(FE/p)	0.056	0.292	0.192
ln(GDP/p)*ln(NFE/p)	-0.099	0.071	-1.384
ln(K/p)*ln(L/p)	-0.123	0.545	-0.227
ln(K/p)*ln(FE/p)	-0.229	0.240	-0.951
ln(K/p)*ln(NFE/p)	0.075	0.064	1.173
ln(L/p)*ln(FE/p)	-0.055	0.278	-0.198
ln(L/p)*ln(NFE/p)	0.313***	0.192	1.626
ln(FE/p)*ln(NFE/p)	0.048	0.044	1.100
sigma^2	0.027*	0.004	6.156
gamma	0.606 *	0.065	9.308
mu	0.256*	0.056	4.596
eta	0.009	0.009	1.005
log likelihood	277.911		
LR test	130.457		
number of sample	27		
observation	378		

note: LR of log likelihood test is estimated by -2(L(H0)-L(H1)).

Meanwhile, <Table 3> shows the elasticity of CO2 emission for GDP and fossil fuel, which is derived from the estimation equation of stochastic frontier cost function. The annual average elasticity of CO2 emission for GDP is 0.193, inelastistic for 1996-2009. Namely, one percent increase of GDP causes the 0.193 % increase of CO2 emission, implying that the increase of income do not much impact on the increase of CO2 emission. Whereas the annual average elasticity of CO2 emission for fossil fuel is 0.950, close to 1. Namely, the one percent increase of fossil fuel causes 0.95 percent increase of CO2 emission, showing that the use of fossil fuel is closely connected with CO2 emission. The countries that elasticity of CO2 emission for GDP is high fall on Poland, Luxembourg, Netherlands, and Ireland. On the other hand, of the countries that show very low elasticity of CO2 emission for GDP, Iceland, Ireland, and Greece specially display minus(-) sign of elasticity, implying that nonetheless of income increase, these countries reduced CO2 emission effectively.

<Table 3> Elasticity of CO2 Emission

	Elasticity for GDP					Elasticity for Fossil Fuel				
	1996	2000	2005	2009	평균	1996	2000	2005	2009	평균
Australia	0.279	0.289	0.300	0.329	0.296	1.158	1.182	1.180	1.119	1.170
Austria	0.099	0.083	0.104	0.095	0.096	0.883	0.865	0.894	0.845	0.876
Belgium	0.226	0.220	0.225	0.215	0.222	1.108	1.111	1.091	1.037	1.096
Canada	0.005	0.016	0.035	0.050	0.029	1.386	1.392	1.373	1.261	1.360
Denmark	0.338	0.240	0.195	0.208	0.238	1.086	0.972	0.909	0.845	0.964
Finland	0.117	0.083	0.089	0.110	0.096	1.037	0.997	0.982	0.940	1.019
France	0.089	0.090	0.102	0.110	0.096	0.842	0.847	0.823	0.755	0.823
Germany	0.257	0.243	0.229	0.212	0.235	0.949	0.933	0.933	0.895	0.935
Greece	0.301	0.320	0.291	0.281	0.309	0.811	0.866	0.873	0.837	0.854
Hungary	0.256	0.256	0.235	0.217	0.250	0.847	0.803	0.848	0.767	0.824
Iceland	-0.045	-0.063	-0.058	-0.096	-0.066	1.007	1.023	0.993	0.912	0.997
Ireland	0.373	0.351	0.331	0.278	0.338	0.860	0.938	0.903	0.834	0.902
Italy	0.248	0.248	0.267	0.239	0.255	0.822	0.842	0.840	0.767	0.828
Japan	0.246	0.251	0.254	0.260	0.253	0.876	0.880	0.877	0.830	0.873
Korea, South	0.301	0.284	0.279	0.293	0.288	0.926	0.947	0.970	0.990	0.957
Luxembourg	0.432	0.375	0.405	0.402	0.400	1.102	1.106	1.216	1.123	1.147
Mexico	0.219	0.226	0.250	0.272	0.246	0.629	0.656	0.637	0.612	0.637
Netherlands	0.393	0.371	0.326	0.307	0.355	1.115	1.097	1.127	1.111	1.110
New Zealand	0.005	0.020	0.042	0.043	0.031	1.070	1.097	1.063	0.987	1.070
Norway	-0.062	-0.085	-0.070	-0.038	-0.061	0.957	0.959	0.973	0.941	0.961
Poland	0.445	0.434	0.395	0.328	0.405	0.937	0.851	0.860	0.884	0.874
Portugal	0.152	0.204	0.272	0.201	0.208	0.704	0.781	0.735	0.698	0.741
Spain	0.166	0.195	0.220	0.195	0.194	0.752	0.850	0.881	0.790	0.839

Sweden	-0.002	-0.042	-0.043	-0.024	-0.030	0.950	0.878	0.846	0.746	0.867
Switzerland	0.104	0.084	0.103	0.090	0.091	0.679	0.678	0.655	0.618	0.663
United Kingdom	0.254	0.252	0.246	0.250	0.250	1.040	1.004	0.984	0.897	0.986
United States	0.176	0.197	0.213	0.213	0.201	1.350	1.320	1.271	1.197	1.287
Mean	0.199	0.190	0.194	0.187	0.193	0.959	0.958	0.953	0.898	0.950

In case of elasticity of CO2 emission for fossil fuel, Canada, United States, Luxembourg, Australia, and Netherlands show elasticity over one, while Mexico, Switzerland, Portugal, France relatively display lower elasticity of CO2 emission. In these countries , the impact of fossil fuel on CO2 emission is less sensitive. In conclusion, the impact of fossil fuel on CO2 emission is more sensitive than that of income.

<Table 4> shows the trend of fossil fuel efficiency for 1996-2009, which is derived by estimating eq.(11). Here, the efficiency of fossil fuel is driven in the stochastic frontier cost function. The energy efficiency is defined as minimum energy over actual energy. Annual average efficiency of fossil fuel in the OECD countries for 1996-2009 lied from 0.813 to 0.837 , and the level of efficiency had been improved. The improved energy efficiency represents that the gaps of fossil fuel among OECD countries had been reduced gradually. Netherlands, Mexico, Canada, United States, New Zealand, United Kingdom, and Switzerland show higher energy efficiencies. But, the reasons showing high efficiency are different from these countries. High efficiency reflects that actual fossil fuel use comes close to minimum fossil fuel use, whereas low efficiency implies actual use are far away from minimum use. So, even though Netherlands, Canada, and United States show high per capita fossil fuel, their fossil fuel uses come close to minimum use of frontier curve, and they show high fossil fuel efficiencies. While, Mexico and Switzerland relatively have low per

capita fossil fuels but, they also come close to minimum use of frontier curve , and also have high efficiencies.

However, Finland, Greece, Korea, Poland, Germany, and Japan display most low efficiencies of fossil fuels. Finland, Korea, and Greece show similar levels of per capital fossil fuel uses and per capita CO2 emission. Especially, Germany which shows higher proportion of manufacturing in the overall industry, reports that the average per capita fossil fuel use is 161 ton. Then that of France is 107.2 ton. So, the per capita fossil fuel and CO2 emission of Germany considerably show high levels. Poland's fossil fuel use is relatively large but, the sizes of per capital GDP and per capita capital stock are small. So, Poland show low efficiency of fossil fuel.

<Table 4> Energy Efficiency (1996-2009)

	1996	2000	2005	2009	Mean
Australia	0.766	0.776	0.789	0.800	0.783
Austria	0.756	0.765	0.777	0.785	0.771
Belgium	0.856	0.862	0.869	0.875	0.866
Canada	0.921	0.925	0.930	0.934	0.928
Denmark	0.782	0.787	0.796	0.806	0.793
Finland	0.722	0.730	0.743	0.755	0.737
France	0.788	0.796	0.807	0.815	0.802
Germany	0.751	0.759	0.768	0.776	0.764
Greece	0.725	0.736	0.748	0.758	0.742
Hungary	0.846	0.853	0.861	0.866	0.856
Iceland	0.836	0.843	0.852	0.858	0.847
Ireland	0.770	0.780	0.792	0.799	0.785
Italy	0.804	0.812	0.822	0.827	0.816
Japan	0.754	0.763	0.773	0.781	0.768
Korea, South	0.729	0.740	0.755	0.765	0.747
Luxembourg	0.770	0.778	0.791	0.800	0.785
Mexico	0.925	0.929	0.933	0.937	0.931

Netherlands	0.981	0.982	0.983	0.983	0.982
New Zealand	0.864	0.871	0.879	0.885	0.875
Norway	0.820	0.826	0.835	0.844	0.832
Poland	0.742	0.754	0.764	0.772	0.758
Portugal	0.784	0.797	0.812	0.816	0.802
Spain	0.792	0.802	0.814	0.821	0.808
Sweden	0.825	0.830	0.839	0.847	0.835
Switzerland	0.866	0.870	0.877	0.881	0.873
United Kingdom	0.865	0.871	0.878	0.884	0.875
United States	0.905	0.910	0.916	0.920	0.913
Mean	0.813	0.820	0.830	0.837	0.825

<Table 5> shows the results of environmental efficiency for CO2 emission, which is estimated by translog stochastic frontier cost function. The annual average environmental efficiency of OECD countries for 1996-2009 is 0.750, less than that of energy efficiency(0.850). The distribution of annual environmental efficiency in OECD countries for the same period lie from 0.737 to 0.762. This mean that in case of the CO2 emission, the CO2 emission of individual country is farther away from the performance of the best practice than that of fossil fuel use. Namely, it implies the CO2 emission has more possibility to reduce than fossil fuel use. As the energy efficiencies year by year have been improved, the environmental efficiencies show the same trend. It mean that the gaps of environmental efficiencies among OECD countries have also gradually reduced. Netherlands, Mexico, Canada, The United States, New Zealand, United Kingdom, and Switzerland show very high efficiencies as such like the energy efficiency. This is an anticipated result because CO2 emission generally has a significant connection with fossil fuel.

<Table 5> Environmental Efficiency (1996-2009)

	1996	2000	2005	2009	평균
Australia	0.663	0.673	0.685	0.695	0.679
Austria	0.657	0.668	0.680	0.690	0.674
Belgium	0.792	0.799	0.807	0.813	0.803
Canada	0.897	0.900	0.905	0.908	0.902
Denmark	0.682	0.692	0.703	0.713	0.698
Finland	0.615	0.626	0.640	0.650	0.633
France	0.709	0.718	0.729	0.737	0.723
Germany	0.640	0.650	0.663	0.673	0.657
Greece	0.612	0.623	0.637	0.647	0.630
Hungary	0.795	0.801	0.809	0.816	0.805
Iceland	0.778	0.785	0.794	0.801	0.789
Ireland	0.664	0.674	0.686	0.696	0.680
Italy	0.715	0.724	0.735	0.743	0.729
Japan	0.636	0.647	0.660	0.670	0.653
Korea, South	0.619	0.630	0.643	0.654	0.636
Luxembourg	0.643	0.654	0.667	0.676	0.660
Mexico	0.904	0.907	0.911	0.914	0.909
Netherlands	0.971	0.972	0.974	0.975	0.973
New Zealand	0.826	0.832	0.839	0.844	0.835
Norway	0.752	0.760	0.769	0.777	0.764
Poland	0.655	0.665	0.678	0.687	0.671
Portugal	0.707	0.716	0.727	0.735	0.721
Spain	0.710	0.719	0.730	0.738	0.724
Sweden	0.768	0.776	0.785	0.792	0.780
Switzerland	0.802	0.809	0.816	0.822	0.812
United Kingdom	0.812	0.818	0.825	0.831	0.822
United States	0.866	0.871	0.876	0.880	0.873
Mean	0.737	0.745	0.755	0.762	0.750

On the contrary to this, Greece, Finland, Korea, Japan, Germany, Luxembourg, and Poland show very low performance of environmental efficiency. Of these countries, the rank of environmental efficiency for Luxembourg somewhat remains behind more than the rank of energy efficiency, even though Luxembourg reports very high per capita fossil fuel and per capita CO_2 emission. Japan, Germany report similar levels of per capita fossil fuel use with

Korea, but a little higher level of per capita CO_2 emission than Korea. And then, Poland use more per capita fossil fuel than these countries, but emit less per capita CO_2 emission(8.5 ton) than Finland (11.9 ton), Korea(10.5 ton), and Greece (9.5 ton).

As a result, there are a bigger chance to reduce CO_2 emission because the environmental efficiency of OECD countries is lower than the energy efficiency of fossil fuel.

IV. Conclusions

This paper estimated energy efficiency and environmental efficiency together in the one model using stochastic frontier cost function. As Herrala and Goel(2012) tried, stochastic frontier cost function is available to measure environmental efficiency of pollutants in terms of minimization of pollutants. We estimated energy efficiency and environmental efficiency with the statistic data of OECD countries.

The empirical results showed the existence of environmental inefficiency, and over 60 per cents of composite-error terms results from environmental inefficiency error terms. The time-varying change of environmental inefficiency(eta) is not significant. The impact of fossil fuel change on CO_2 emission is more sensitive than that of income.

Annual energy efficiency of fossil fuel in the OECD countries for 1996-2009 lied from 0.813 to 0.837 , and the level of efficiency had been improved. The improved energy efficiency year by year represents that the gaps of fossil fuel among OECD countries had been reduced gradually. The annual average environmental efficiency of OECD countries for 1996-2009 is 0.750 , less than that of energy efficiency(0.850). This means that in case of the CO2 emission, the CO2 emission for individual country is farther away from the best practice than that of fossil fuel use. Eventually, the result means that there is a significant possibility to reduce not only fossil fuel but also CO2 emission.

As empirical results were shown, fossil fuel use is closely related with CO2 emission, and the increase of fossil fuel efficiency results in improvement of environmental efficiency. Hence, to get the high performance, the effort to reduce CO2 emission is needed itself, and more basically, the additional effort to transform fossil fuel use into renewable energy should be accompanied. It is anticipated that renewable energy will recover its competiveness in the long-run, even though in this point, the prices of renewable energy have relatively aggravated because of recent decrease of oil prices. So the investment for renewable energy should be achieved with long-run vision, regardless of the temporary decrease of oil price. With this, we should make efforts to introduce low-carbon energy system and go technological innovation side by side.

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