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Abstract:

Improving energy efficiency is the one of the best environmental/resource policy. Previous studies have measured energy efficiency in the industrial sector. We further contribute understanding what factors affect energy efficiency changes. This study measures energy efficiency based on plant level data in the Japan' paper/pulp industry and cement industry as energy intensive sectors. We then reveal the relationship between industry agglomeration effect and energy efficiency of each factory. Our results show several important findings. First, energy efficiency has improved in recent years in the paper and pulp industry as well as the cement industry. However, the factors for improvement of energy efficiency differ between each industry. Second, industry agglomeration affects energy efficiency. In the paper and pulp industry, the same industry agglomerations contribute to improvements in the energy efficiency. However the agglomeration effect is negative for energy efficiency in the cement industry.

Keywords: Energy efficiency, Productivity analysis, Industry agglomeration, Data envelopment analysis

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1. Introduction

To tackle worsening environmental and resource problems, increasing energy efficiency is the one of the most important policy issues in the world. Recently, some developing countries achieved high economic growth. Such countries need to use many energy resources. However, almost all countries cannot easily obtain these energy resources. In addition, increasing energy efficiency contributes to decreasing air pollution. Many developing countries suffered from air pollution in recent years. Thus increasing energy efficiency is an important policy in developing countries.

Of course, increasing energy efficiency is also important for developed countries. As a result of serious worsening climate change problems, developed countries need to decrease their CO_2 emissions. The post Kyoto protocol agreement has not been reached in every country yet. However, almost all developed countries have expressed their desire for greenhouse gas emission reduction. Therefore, increasing energy efficiency is an important issue not only for developing countries but also developed countries.

Many previous studies have tried to measure energy efficiency in the industrial sector. However, previous studies did not sufficiently analyze what factors affect energy efficiency changes. In particular, almost previous studies do not reveal the regional characteristic effect for energy productivity. In fact, some studies mention about the possibility of industrial agglomeration effect for energy efficiency. For example, Chertow et al.(2008) analyze the industrial agglomeration area in

Puerto Rico. They show the energy efficiency of plant level in such area is increased by the efficient cogeneration system between same industries and other industries. But such agglomeration effect for energy efficiency in each plant cannot well be revealed.

In this study, we try to measure energy efficiency based on plant level data in the Japanese industrial sector. In particular, we analyze the paper and pulp industry and cement industry. In addition, we focus on the industry agglomeration effect on energy efficiency. Recently, many researchers have mentioned the need to construct new energy systems based on regional characteristics. In fact, some previous studies show the compact city or smart city enjoys positive externalities from the high population density that increases the energy efficiency in such an area (Morikawa, 2012; Iwata and Managi, 2016). On the other hand, such regional situations could possibly affect the energy efficiency of production plants. In some industries, energy is an important input factor for production. If spillover effects that improve total production efficiency include energy use occur by industry agglomeration, changes in energy efficiency will be affected by such regional situations. Almost all previous studies related to the industrial sector only focus on the role of technological change. There is no previous study analyzing the industry agglomeration effect on the energy efficiency of the industrial sector and plants.

2. Previous studies

2.1 Energy productivity and energy efficiency

There are many previous studies that estimate energy efficiency and energy productivity[1]. In particular, some studies try to estimate energy productivity and energy efficiency by data envelopment analysis (DEA). For example, Chang and Hu (2010) measure the total factor energy productivity (Luenberger productivity index) in each province of china. Also, Vlontzos et al.(2014) estimate the energy efficiency and environmental efficiency in each EU countries. However, many studies use sectoral level or firm level data. To estimate the proper energy productivity and energy efficiency, we need to use more micro level data, such as plant or factory level data.

For example, Boyd and Pang (2000) try to measure energy productivity based on plant level data. Boyd and Pang (2000) measure energy efficiency and measures of production efficiency in the U.S. glass industry by an input-oriented model. They compare energy efficiency to production efficiency and find that productivity differences between plants are statistically significant in explaining differences in plant energy intensity. This result means energy is one of the important decision making factors for each plant.

Mukherjee (2008) measures the energy use efficiency in U.S. manufacturing by DEA. This study also measures the production efficiency including energy use by an input-oriented model. However, the model of Mukherjee (2008) hypothesizes each decision making unit (DMU) cannot adjust the

[1] In this study, we define the energy productivity as the index measures by the all over the input factors include energy use. On the other hand, we define the energy efficiency as the index only is considered the possibility of energy use saving.

inputs or exclude energy input. Then, he measures the potential for energy use reduction. His finding that the later years of his sample period (1970-2001) are more efficient probably implies that, in general, there has been technical progress. Blomberg et al. (2012) also measure the energy efficiency by the DEA. They focus on the electricity efficiency improvements in the Swedish paper and pulp industry.

As in the above, some research tries to measure energy efficiency and energy productivity based on plant level data. However, previous studies do not sufficiently reveal what factors influence changes in energy efficiency. Almost all previous studies focus on technological effects on energy efficiency. However, several factors affect energy efficiency changes. For example, Martin et al. (2012) show the correlation between management practices and energy intensity at the firm level.

2.2 Agglomeration effect for productivity

Firm and plant location are some of the most important research topics. In particular, many previous studies show that the agglomeration of firms and plants affects their productivity (Beaudry and Schuffauerova, 2009). For example, some previous studies find firms and plants located in high agglomeration area of labor show high labor productivity compared to firms and plants that locate in low labor agglomeration areas (Moretti, 2004; Anderson and Lööf, 2011). The labor pool is the one of the factors in location choices of plants, but other factors also affect the location choice of plants.

Energy could possibly be a factor as well.

Based on the traditional location choice theory of plants, plant location is decided by ease of access to raw materials (Weber, 1909). Energy is the one of the important intermediate goods in some industries. For example, the percentage of energy costs in the total production value is approximately 7 to 10 percent in Japanese paper and pulp companies (Japan paper association, 2013). Thus energy is the important input factor for such an industry. In fact, Core et al. (2013) find a correlation between firm location choice and CO_2 emission. CO_2 emissions have a strong relationship with energy use. Thus energy could possibly affect the location choice of plants.

3. Method

3.1 Measurement method of energy efficiency applied by Malmquist productivity index

We adopt the Malmquist index as a measurement of energy efficiency change. The Malmquist index is suitable for assessing the correspondence between inputs and outputs under multivariate input inefficiency. Using the distance function specification, our problem can be formulated as follows:

$$T(t) \equiv \left\{ \left(x_t, y_t \right) : x_t \text{ can produce } y_t \right\} \quad (1)$$

Let $x = (x^1, \ldots x^M) \in R_+^M$ and $y = (y^1, \ldots y^N) \in R_+^N$ be the vectors of inputs and outputs, respectively. The technology set, which is defined by (1), consists of all feasible input vectors, x_t and output vectors, y_t, at time t and satisfies certain axioms, which are sufficient to define meaningful distance functions. The distance function is defined as follows:

$$d_{T(t)}(x_t, y_t) = \min\{\delta; (\delta x_t, y_t) \in T(t)\} \quad (2)$$

where δ is the minimum proportional amount that x_t can decrease given the technology *T(t)*. This formulation produces an input-oriented distance function. DEA is used to estimate the distance function under constant returns to scale (CRS) by solving the following optimization problem:

$$\begin{aligned} & d_{T(t)}(x_t, y_t) = \min_{\delta,\lambda} \delta \\ & s.t. \quad Y_t\lambda \geq y_i^t \\ & \qquad X_t\lambda \leq \delta x_i^t \\ & \qquad \lambda \geq 0, \end{aligned} \quad (3)$$

where δ is the measure of efficiency for factory i in year t. λ is an N×1 vector of weights; Y_t and X_t are the vectors of outputs y_t and inputs x_t. To estimate productivity changes over time, several distance functions are used for the input-output vector for period $t+1$ and technology in period t. The Malmquist index (M_0) is defined as (10), with several distance functions:

$$TFPC = \left[\frac{d^t\left(y_{t+1}, x_{t+1}\right)}{d^t\left(y_t, x_t\ \right)} \times \frac{d^{t+1}\left(y_{t+1}, x_{t+1}\right)}{d^{t+1}\left(y_t, x_t\right)} \right]^{1/2} \qquad (4)$$

where d represents the geometric distance to the frontier, which is the best available technology in the map from the given inputs to outputs. Following Chambers et al. (1996), this indicator is decomposed into two components as follows:

$$TFPC = \frac{d_{T(t+1)}(x_{t+1}, y_{t+1})}{d_{T(t)}(x_t, y_t)} \times \left(\frac{d_{T(t)}(x_t, y_t)}{d_{T(t+1)}(x_t, y_t)} \right) \left(\frac{d_{T(t)}(x_{t+1}, y_{t+1})}{d_{T(t+1)}(x_{t+1}, y_{t+1})} \right)^{1/2} \qquad (5)$$

where the first difference represents efficiency change (*EFCH*) and the second arithmetic mean represents technological change (*TECH*):

$$EFCH = \frac{d_{T(t+1)}(x_{t+1}, y_{t+1})}{d_{T(t)}(x_t, y_t)} \qquad (6)$$

$$TECH = \left(\frac{d_{T(t)}(x_t, y_t)}{d_{T(t+1)}(x_t, y_t)} \right) \left(\frac{d_{T(t)}(x_{t+1}, y_{t+1})}{d_{T(t+1)}(x_{t+1}, y_{t+1})} \right)^{1/2} \qquad (7)$$

Therefore, positive change in the total factor productivity change (*TFPC*) is measured as a decrease in inefficiency and a shift of the frontier outward (*TECH*).

In short, decomposition of "*TFPC*" is defined as (8):

$$TFPC = EFCH \times TECH \qquad (8)$$

In addition, we can decompose "*EFCH*" to pure efficiency change (*PECH*) and scale efficiency change (*SECH*) following Färe (1994). Decomposition of "*TFPC*" is defined as (9):

$$TFPC = EFCH \times TECH = PECH \times SECH \times TECH \qquad (9)$$

The "*EFCH*" term refers to the efficiency change calculated relative to constant return to scale (CRS), and "*PECH*" is efficiency change calculated under variable return to scale (VRS). In this study, we measure the general productivity (*TFPC*) and productivity is considered in terms of energy use (*TFPC-EN*). The difference between "*TFPC*" and "*TFPC-EN*" is the input factor combination. When we measure the "*TFPC*", we only consider the labor and production capital as input factors. On the other hand, "*TFPC-EN*" includes energy input (GJ) as additional input. Thus "*TFPC-EN*" is also defined as (10):

$$TFPC\text{-}EN = EFCH\text{-}EN \times TECH\text{-}EN = PECH\text{-}EN \times SECH\text{-}EN \times TECH\text{-}EN \qquad (10)$$

3.2 Calculation of total energy efficiency indexes

Based on the result of the Malmquist productivity index, we calculate the total energy efficiency index (*TEEI*). *TEEI* is defined as (11) based on the Kaneko and Managi(2004):

$$\begin{aligned} TEEI &= \frac{TFPC\text{-}EN}{TFPC} = \frac{EFCH\text{-}EN}{EFCH} \times \frac{TECH\text{-}EN}{TECH} = EFCH\text{-}EEI \times TECH\text{-}EEI \\ &= \frac{PECH\text{-}EN}{PECH} \times \frac{SECH\text{-}EN}{SECH} \times \frac{TECH\text{-}EN}{TECH} = PECH\text{-}EEI \times SECH\text{-}EEI \times TECH\text{-}EEI \end{aligned}$$

(11)

"*TEEI*" divides "*TFPC-EN*" by "*TFPC*". When the Malmquist index is above 1, productivity makes an improvement. On the other hand, productivity goes down when the Malmquist index is below 1. If "*TFPC-EN*" becomes larger than "*TFPC*", "*TEEI*" is above 1. Thus "*TEEI*" represents how much energy use improves.

3.3 Factor analysis of energy efficiency

In the second stage, we analyze the determination of "*TEEI*" change. That is, productivity measures are estimated in the first stage. However, this type of two stage approach should be treated with caution. Following Simar and Wilson (2007), productivity measures estimated by DEA are serially correlated. They argue that a bootstrapping method should be used.

However, the use of panel data and dynamic specifications make this problem more complex. Alternatively, to eliminate the serial correlation problem, Zhengfei and Oude Lansink (2006) suggest the use of a dynamic panel analysis applying System GMM to analyze "*TFPC*" measures estimated by DEA. In fact, some studies employ this method to analyze the change in productivity indexes (for example, Nakano and Managi, 2008; Tanaka and Managi, 2013). Therefore, this article uses a System GMM model to analyze "*TEEI*" change. We estimate the following equation:

$$Index_{i,t} = Index_{i,t-1} + Index_{i,t-2} + AG_{i,t} + Oil_t + c + u_i + \varepsilon$$

where "*Index*" is the annual "*TEEI*" change, and the other energy efficiency indexes (such as

“*EFCH-EEI*” and “*TECH-EEI*”), are measured by the Malmquist productivity index, for factory *i* at time *t*. “*AG*” refers to the agglomeration index. In this study, we define the agglomeration index as share of labor force of same industry in each municipal that is located each factor (*i*). “*Oil*” is the oil price of each year. We use the average price of “*WTI*” in each *t*.

3.4 Data

In this first step, productivity indexes are computed using data from 2000 to 2010. A sample of 135 factories in the paper and pulp industry is used to measure the efficiency in each year. Therefore, the number of observations is 1350 in this study. To calculate productivity, three inputs and one output are used. The output is the shipment value for each factory (ten thousand Japanese Yen). The inputs include the number of employees working in each factory (head-count), physical fixed assets (ten thousand Japanese Yen), and input amount of energy (GJ).

Data on shipment values, the number of employees and physical fixed assets was obtained from the confidential micro database of the Kougyo Toukei Chousa (Census of Manufacturers), which is prepared annually by the Research and Statistics Department of the Ministry of the Economy, Trade, and Industry (METI). The energy input amounts were obtained from the confidential micro database of the Tokutei gyoushu Sekiyutou shouhi Doutai Toukei (Current Survey of Energy Consumption in the Selected Industries). Energy input data include several consumption of energy resources.

Therfore, we convert the each consumption amount of energy resources to GJ based on Total energy statistics published by METI. These microdata are also prepared annually by the Research and Statistics Department of the Ministry of the Economy, Trade, and Industry (METI). We match the data sets from 2000 to 2010.

In the econometric analysis, we use each energy efficiency index as the dependent variable. Independent variables include the oil price (WTI price). The oil price is obtained from open data of the IMF (IMF primary commodity price: IMF, 2015). "*AG*" is calculated based on the "Census of Manufactures". We aggregate employees in same region and same industry[2].

In this study, we focus on the paper and pulp industry and cement industry in Japan. The choice of a narrowly defined industry sector allows one to assume that the production processes and opportunities are comparable between plants in that sector. The paper and pulp industry is a major industry that has been analyzed by many previous studies. The cement industry has a simple energy use system compared to other energy-intensive industries. Therefore, we focus on the paper and pulp industry and the cement industry.

4. Results

4.1 Results of energy efficiency indexes

[2] In this study, we define the effect of agglomeration at the municipality level.

First, we explain the results from the paper and pulp industry. Figure 1 and table 1 show the average "*TEEI*" and other energy efficiency indexes of the paper and pulp industry in each year. Through almost all of our study period, the "*TEEI*" of the paper and pulp industry tends not to change much on average (see figure 1). However, other indexes show dynamic change between 2000 and 2003. These results are caused by a dynamic structural change of the paper and pulp industry in Japan. Each plant's dynamic productivity change occurs in association with restructuring. Through all of our study periods, average "*TEEI*" becomes 1.005 (see table 1). The "*TEEI*" of the paper and pulp industry tends to increase over the years. Between 2000 and 2005, average "*TEEI*" was 1.002. On the other hand, the average "*TEEI*" was 1.008 between 2006 and 2010. These results imply energy saving technologies and methods improved between 2000 and 2010 in the Japanese paper and pulp industry.

The greatest contributing factor to energy efficiency improvements is "*EFCH-EEI*". From table 1, we can understand that "*TEEI*" is increased by "*EFCH-EEI*" improvements. When we examine these results more closely, "*SECH-EEI*" contributes to increases of the "*EFCH-EEI*" between 2000 and 2005. However, "*SECH-EEI*" does not contribute to increases of "*EFCH-EEI*" between 2006 and 2010. These results imply scale efficiency contributes to improving energy efficiency between 2000 and 2005. However, the scale effect is not important in recent years in the Japanese paper and pulp industry.

Table 2 shows the average of each energy efficiency index in each prefecture. In this table, we do not show all prefecture results. We show only major prefectures that are located near pulp and paper plants. These results show that "*TEEI*" and other energy efficiency indexes are different in each prefecture. Therefore, regional characteristics could affect the energy efficiency in each plant.

Second, we show the results of the cement industry. Figure 2 and table 3 show the average "*TEEI*" of the cement industry in each year. In figure 1, we can see a slightly different trend in 2007-2008. This result is likely to be caused by a rapid change of demand. In 2008, a large scale economic recession occurred. In fact, total the demand for and supply of cement in Japan decreased from 2008 (Japan cement association, 2015). This economic situation affected the production in plants. Through all of our study periods, the average "*TEEI*" became 1.006 (see table 3). The "*TEEI*" of the cement industry also tended to increase across the years. However, the contributing factors in energy efficiency improvement were different in the paper and pulp industry. In the paper and pulp industry, the effect of the "*SECH-EEI*" became weak between 2005 and 2010. However, the effect of the "*SECH-EEI*" became strong between 2005 and 2010 in the cement industry. In addition, the "*SETC-EEI*" is the most effective factor for the "*TEEI*" growth in the cement industry. These results imply that the scale effects for energy efficiency have been important factors in recent years. Table 4 shows the average each energy efficiency indexes in major prefectures. Trends in "*TEEI*" and other energy efficiency indexes in each prefecture are also different in the cement industry.

4.2 Estimation results of System GMM

To confirm the effects of agglomeration on productivity, we conducted an econometric analysis. Table 5 shows the estimation results of econometric models in the pulp and paper industry. In most results (except for the "*TEEI*"), the lagged dependent variables are negative and significant, indicating that further improvement in productivity after higher prior growth seems to be more difficult.

"*AG*" shows the positive coefficient for the "*TEEI*". However, "*AG*" shows the negative coefficient for the "*TECH-EEI*". Although the agglomeration effect is negative for "*TECH-EEI*", the same industry agglomeration increases the total energy efficiency of the Japanese paper and pulp industry. These results imply industry agglomeration causes the diffusion of energy efficiency technology or methods to inefficient plants.

Additionally, "*Oil*" shows a positive coefficient for both the "*TEEI*" and "*EFCH-EEI*". However, the "*TECH-EEI*" has a negative coefficient for the "*TECH-EEI*". Generally, an upturn in oil prices increases energy efficiency. Thus, each plant tries to increase energy efficiency in the short run. However, drastic changes (for example, large investments in energy efficient equipment) in energy efficiency do not occur in the short term. Such drastic changes need more time. Therefore, oil prices decrease the "*TECH-EEI*".

On the other hand, the estimation results from the cement industry are different from the results of the paper and pulp industry. In particular, "*AG*" shows the negative coefficient for the "*TEEI*". In short, the same industry agglomeration effect is negative for energy efficiency in the Japanese cement industry. One of the main reasons for this result is due to the characteristics of location choices in the cement industry. Many cement plants locate near the mines of raw materials (caustic lime). Thus, cement plants are restrained in choosing a location suitable for energy efficient use. On the contrary, the paper and pulp industry can locate near bay areas where it is easy to use several energy types.

5 Discussion and conclusion

This study measures the energy efficiency by the DEA/Malmquist productivity indexes. We attempt to determine the industry agglomeration effect for energy efficiency. Our results show some important findings. First, energy efficiency has improved in recent years in the Japanese paper and pulp industry as well as the cement industry. However, contribution factors for the "*TEEI*" are different in each industry. In the paper and pulp industry, the "*PECH-EEI*" has contributed to improvements in the "*TEEI*" in recent years. However, the "*SECH-EEI*" is the most contributing factor in the cement industry.

Second, our results imply that regional characteristics affect energy efficiency. In the paper and pulp industry, the same industry agglomerations contribute to improvements in the energy efficiency. On the other hand, the agglomeration effect is negative for energy efficiency in the cement industry. These results imply regional situations affect energy efficiency. Of course, our estimation does not separate the several factors, including agglomeration effects. Generally, one of the typical agglomeration effects is the spillover effect. In short, a good way to produce product spillover is through labor. However, there are several reasons why increases in energy efficiency could be performed by industry agglomeration.

One reason is the condition of infrastructure related to energy use. Gas pipelines are insufficient in Japan. Generally, gas pipelines are created by private urban gas firms. Such firms can easily make new pipelines in industry agglomeration areas because there is a certain amount of demand in these areas. Therefore, agglomeration areas can provide easily access to the more suitable energy for production. However, our results also imply industry characteristics are important factors in whether industry agglomeration contributes to improvements in energy efficiency. Our results show the agglomeration index does not increase the "*TEEI*" in the cement industry.

Improving energy efficiency is important all over the world. Of course, diffusion and development of new technology is an important factor in energy saving. However, we need to also consider the regional situation more carefully when thinking of how to improve energy efficiency.

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Table 1 The average energy efficiency index in each year (paper and pulp industry)

Year	Index				
	EEI	EFCH-EEI	TECH-EEI	PECH-EEI	SECH-EEI
2000-2001	0.999	1.660	0.762	1.094	1.506
2001-2002	0.990	1.182	0.865	1.154	1.035
2002-2003	1.000	0.646	1.773	0.843	0.791
2003-2004	1.016	1.039	0.980	1.012	1.028
2004-2005	1.005	1.006	1.008	1.011	0.994
2005-2006	1.012	1.031	0.987	1.009	1.020
2006-2007	1.014	1.037	0.980	1.026	1.009
2007-2008	1.006	0.983	1.025	1.001	0.985
2008-2009	1.024	0.993	1.033	1.002	0.996
2009-2010	0.987	0.950	1.046	0.982	0.968
The first half of the 2000s	1.002	1.107	1.078	1.023	1.071
The second half of the 2000s	1.008	0.999	1.014	1.004	0.995
Average	1.005	1.053	1.046	1.013	1.033

Table 2 The average energy efficiency index of each prefecture

(Paper and pulp industry)

	EEI	EFCH-EEI	TECH-EEI	PECH-EEI	SECH-EEI
Hokkaido	1.0043	1.0117	1.0138	1.0083	0.9995
Gifu	1.0135	1.0516	1.0281	1.0106	1.0316
Shizuoka	1.0078	1.0306	1.0382	1.0127	1.0163
Osaka	1.0081	1.1667	1.1409	1.0270	1.0716
Aichi	1.0125	1.1019	1.0987	1.0138	1.0820

Table 3 The average energy efficiency index in each year (cement industry)

Year	Index				
	EEI	EFCH-EEI	TECH-EEI	PECH-EEI	SECH-EEI
2000-2001	1.001	0.982	1.021	0.994	0.990
2001-2002	1.004	0.945	1.065	0.965	0.982
2002-2003	0.998	0.990	1.010	1.003	0.989
2003-2004	1.006	0.999	1.010	1.009	0.990
2004-2005	0.995	1.007	0.991	1.026	0.983
2005-2006	1.001	0.995	1.011	0.977	1.019
2006-2007	1.011	0.999	1.014	0.991	1.010
2007-2008	1.004	1.177	0.878	1.063	1.111
2008-2009	1.031	0.960	1.087	0.987	0.975
2009-2010	1.005	0.986	1.038	1.034	0.959
The first half of the 2000s	1.001	0.985	1.020	0.999	0.987
The second half of the 2000s	1.011	1.023	1.006	1.010	1.015
Average	1.006	1.004	1.013	1.005	1.001

Table 4 The average energy efficiency index of each prefecture (cement industry)

	EEI	EFCH-EEI	TECH-EEI	PECH-EEI	SECH-EEI
Hokkaido	1.0000	0.9997	1.0118	1.0052	0.9942
Ibaraki	1.0031	1.0140	1.0126	1.0158	0.9984
Tochigi	1.0217	1.0335	1.0083	1.0287	1.0048
Saitama	1.0034	0.9924	1.0183	0.9948	1.0003
Yamaguchi	1.0060	1.0057	1.0114	1.0117	0.9957
Fukuoka	1.0027	0.9978	1.0064	1.0027	0.9955

Table 5 Factor analysis of each energy efficiency index in the paper and pulp industry

Dependent variables	Dependent variables (Energy Efficiency Index)		
	EEI	*EFCH-EEI*	*TECH-EEI*
$Index_{t-1}$	-0.2813***	-0.3789***	-0.1148***
	(-28.55)	(-33.28)	(-47.97)
$Index_{t-2}$	0.0847***	-0.1743***	-0.2416***
	(9.34)	(-26.95)	(-108.18)
AG	1.5116**	0.1156	-2.5218***
	(3.82)	(0.31)	(-6.15)
Oil	0.0001**	0.0018***	-0.0056***
	(2.21)	(18.75)	(-98.04)
c	1.1776***	1.4211***	1.8276***
	(63.18)	(71.52)	(185.17)
AR1	-4.00***	-4.16***	-3.95***
AR2	0.57	2.21**	2.55**
Sargan	287.50***	355.61***	1289.67***

Note) Values in parentheses are t-values. *Significant at the 10% level, **significant at the 5% level, ***significant at the 1% level.

Table 6 Factor analysis of each energy efficiency index in the cement industry

Dependent variables	Dependent variables (Energy Efficiency Index)		
	EEI	*EFCH-EEI*	*TECH-EEI*
$Index_{t-1}$	0.0192***	-0.1545***	-0.2130***
	(11.05)	(-66.67)	(-59.86)
$Index_{t-2}$	0.0325***	-0.1181***	-0.2557***
	(31.49)	(-79.53)	(-69.99)
AG	-11.2158**	19.2952***	-33.0314***
	(-26.75)	(15.86)	(-14.60)
Oil	0.0004***	0.0052***	-0.0002***
	(21.68)	(25.57)	(-98.04)
c	0.9523***	1.2227***	1.5280***
	(426.18)	(412.00)	(301.97)
AR1	-1.84*	-3.85***	-3.90***
AR2	1.06	0.68	1.80*
Sargan	122.35**	338.10***	346.16***

Note) Values in parentheses are t-values. *Significant at the 10% level, **significant at the 5% level,

***significant at the 1% level.

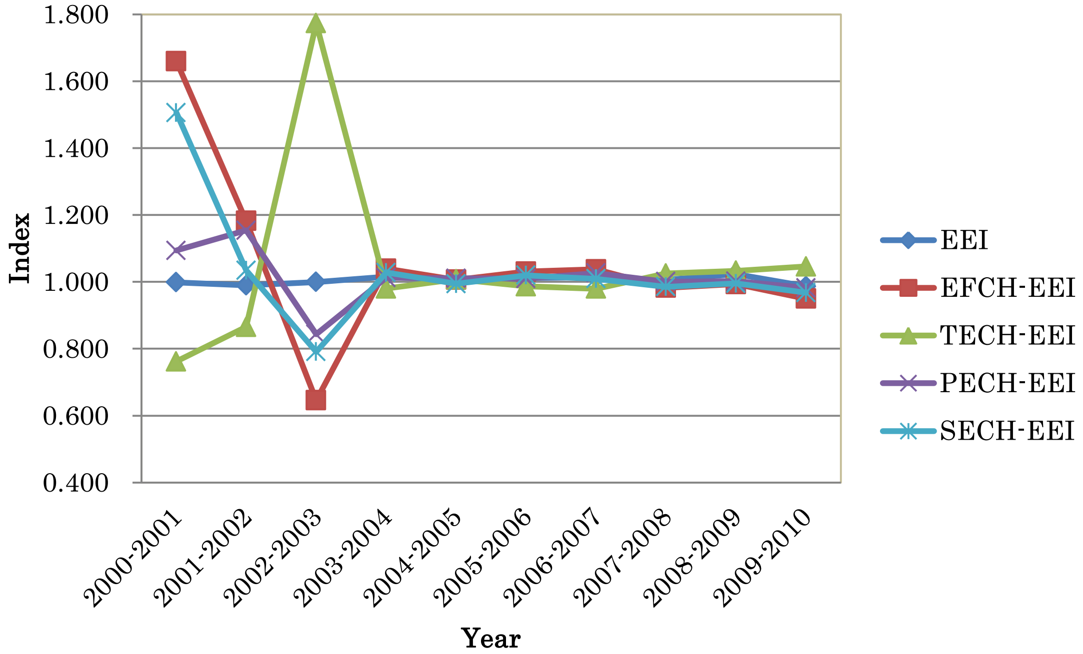

Figure 1 Trend of average energy efficiency index in each year

(pulp and paper industry)

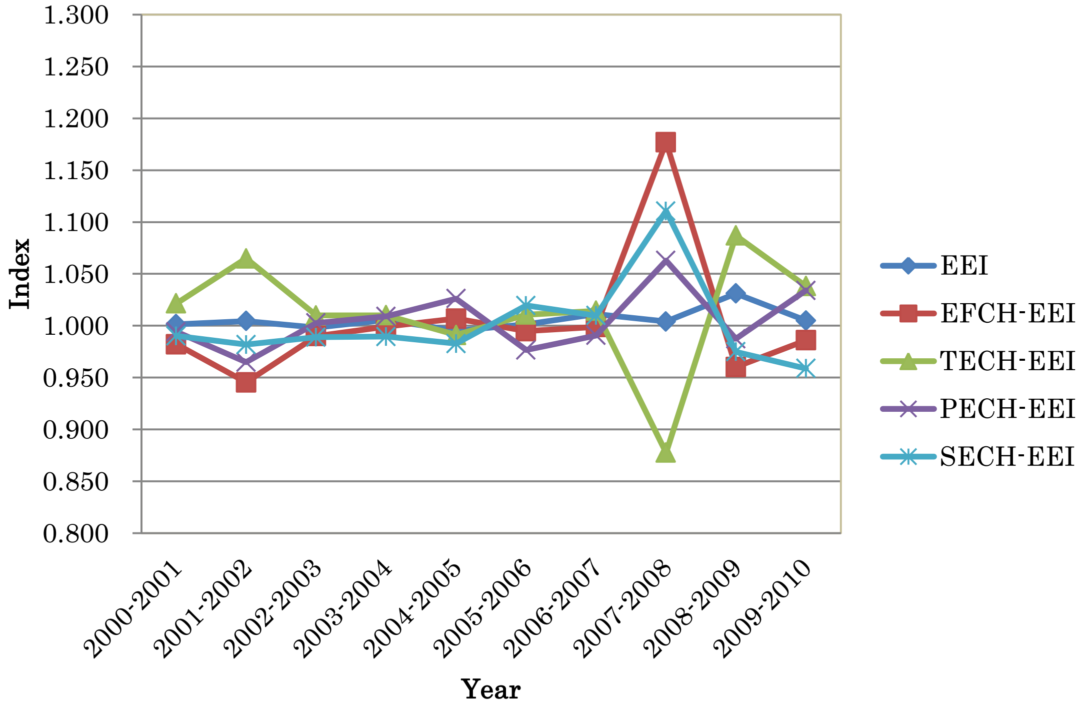

Figure 2 Trend of average energy efficiency index in each year

(cement industry)