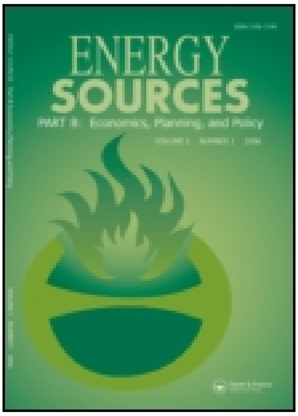

Energy Sources, Part B: Economics, Planning, and Policy
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/uesb20

Total-factor Energy Efficiency for Sectors in Japan

S. Honma [a] & J.-L. Hu [b]
[a] Faculty of Economics , Kyushu Sangyo University , Fukuoka , Japan
[b] Institute of Business and Management, National Chiao Tung University , Taipei , Taiwan
Published online: 10 Jan 2013.

Energy Sources, Part B, 8:130–136, 2013

ISSN: 1556-7249 print/1556-7257 online
DOI: 10.1080/15567240903289564

Total-factor Energy Efficiency for Sectors in Japan

S. Honma[1] and J.-L. Hu[2]
[1]*Faculty of Economics, Kyushu Sangyo University, Fukuoka, Japan*
[2]*Institute of Business and Management, National Chiao Tung University, Taipei, Taiwan*

In this article, we measure the energy efficiency of 17 sectors in the Japanese economy during 1998–2005 using data envelopment analysis (DEA), in which a total-factor framework is applied. We compute the total-factor energy efficiency, which is defined as the ratio of the target energy input suggested by the DEA to the actual energy inputs in a sector. Energy, labor, and capital are the three inputs, while the value added in each sector is the single output. Our major finding is that remarkably energy-inefficient sectors in the Japanese economy include energy-intensive industries (i.e., pulp and paper, chemical, cement and ceramics, and primary metal sectors) as well as agriculture, forestry and fishery, transportation and communication, and miscellaneous manufacturing. There is much room to improve energy efficiency in Japanese industrial sectors. Moreover, for 8 sectors, including energy-intensive industries, the inefficiency of energy use is much worse than that of other resource usage.

Keywords: data envelopment analysis (DEA), Japanese economy, total-factor energy efficiency

1. INTRODUCTION

The two oil crises in the 1970s significantly worsened the Japanese economy and forced the industry to implement energy conservation initiatives. Although energy-intensive industries in Japan consume a large amount of energy in the production process, their energy productivity is higher than in other advanced countries. For example, if the amount of energy consumption per unit of production in the iron and steel industry of Japan is taken as 100, the measure found in Germany is 117, and the measure found in the United States is 125 (Japan Business Federation, 2008). Moreover, if the amount of energy consumption per cement clinker in Japan is taken as 100, then the measure found in Western Europe is 130, and the measure found in the United States is 177. However, as our results will show, the energy efficiency of this sector is still inferior to that of other industries in Japan. Since the energy-intensive industry constitutes a large portion of the energy consumption in the Japanese manufacturing sector, energy savings remain a major issue. From the perspective of not only Japan's low self sufficiency of energy supply (4%) (Ministry of Economy, Trade, and Industry, 2008a) but also global warming, it is of particular importance to improve energy efficiency and to curb fossil fuel use. Japan must cut its greenhouse gas emissions by 6% from 1990 levels between 2008–2012, according to the Kyoto Protocol. However, Japan's carbon dioxide emission from energy use in 2007 had increased 15% against the 1990 baseline.

Data envelopment analysis (DEA) is a non-parametric linear programming method that can be applied to evaluate energy productivity. Hu and Wang (2006) advocated total-factor energy efficiency (TFEE), which is defined as the ratio of the target energy input suggested by the DEA

Address correspondence to Satoshi Honma, Faculty of Economics, Kyushu Sangyo University 2-3-1 Matsukadai, Higashi-ku Fukuoka 813-8503, Japan. E-mail: honma@ip.kyusan-u.ac.jp

to the actual energy inputs in a region in the multiple-input model, and computed the index of TFEE by regions in the Chinese economy. TFEE indices have been calculated for the economies in the Asia-Pacific Economic Coorperation (APEC), Japan, and Taiwan (Hu and Kao, 2007; Honma and Hu, 2008; Hu et al., 2012).

In this article, we measure energy efficiency in sectors of the Japanese economy using DEA, in which total-factor framework is applied as in previous studies (Hu and Wang, 2006; Hu and Kao, 2007; Honma and Hu, 2008; Hu et al., 2012). To the best of our knowledge, there has been no study applying the DEA method to measure sectoral energy efficiency in the Japanese economy. Sectoral productivity and economic growth in Japan have been investigated using growth accounting theory, since factors of economic stagnation in Japan after the collapse of the so-called bubble economy were controversial issues (Cabinet Office, Government of Japan, 2002, Fukao et al., 2004). For example, Fukao et al. (2004) observed the slowing of total factor productivity growth in the manufacturing sector in the 1990s. However, the only model inputs in the growth accounting studies were labor and capital stock; energy was not even taken as an input.

It is commonly known that DEA has been applied to comparison of regions rather than sectors in previous energy efficiency studies. Although production technologies obviously differ across sectors, our concern in this paper is the reduction of energy consumption without reducing the potential maximum economic value added. For this purpose, Japan should not only improve its specific inefficient sectors but also reshape its industrial structure, i.e., moving from inefficient industries to efficient ones such as the service industry.

2. METHODOLOGY AND DATA SOURCES

This article uses DEA to determine the input targets for each Japanese industry by comparing them with the annual efficiency frontier constituted by all the Japanese industries in each year. There is an efficiency frontier for each Japanese industry in each year that is constituted by data for all Japanese industries in that year. Since this follows an input-reducing focus, this article uses input-oriented measures following Farrell's (1957) original ideas. In order to control the effects of scale, our study adopts the variable-returns-to-scale (VRS) DEA model (Banker et al., 1984).

Our measure of relative efficiency is based on non-parametric techniques (Färe et al., 1994). Let us first define some mathematical notations. There are K inputs and M outputs for each of N objects. For the ith object, these are represented by the column vectors x_i and y_i, respectively. The $K \times N$ input matrix X and the $M \times N$ output matrix Y represent the data for all N objects. The input set $L(y_i)$ for the ith object is defined as $L(y_i) = \{x_i : y_i \geq f(x_i)\}$. The efficiency score θ equals the value of the distance function, $D(y_i, x_i) = \min\{\lambda : x_i\lambda \in L(y_i)\}$ (Shephard, 1970). The set $L(y_i)$ can be numerically computed by linear programming using observed data. The input-oriented VRS DEA model then solves the following linear programming problem for object i in each year:

$$\begin{aligned} & D(y_i, x_i) = \mathrm{Min}_{\theta,\lambda}\theta \\ \text{subject to } & -y_i + Y\lambda \geq 0, \\ & \theta x_i - X\lambda \geq 0, \\ & N1'\lambda = 1, \\ & \lambda \geq 0, \end{aligned} \tag{1}$$

where θ is a scalar; λ is an $N \times 1$ vector of constants; $N1$ is an $N \times 1$ vector of ones; and the constraint $N1'\lambda = 1$ is the convexity constraint.

The value of θ is the efficiency score for the ith object, with $0 \leq \theta \leq 1$. The value of unity indicates a point on the frontier and hence a technically efficient industry, according to Farrell's (1957) definition. The frontier is a piece-wise linear isoquant that is determined by the observed data points in the same year, i.e., all the industries in this study of the same year. The industry that constructs the frontier represents the "best practice" among the observed industries in that year. The weight vector λ serves to form a convex combination of observed inputs and outputs.

The $f(x_i)$ set in the frontier is the "best practice" production among the observed industries. An inefficient industry could reduce inputs by the amount indicated by the arrow and still remain in the input set $L(y_i)$ (Boyd and Pang, 2000). For the ith industry, the distance (amount) from the projected point on the frontier by radial reduction without reducing the output level, $(1-\theta)x_i$, is called the "radial adjustment."

The summation of slack and radial adjustment is the total reduction ("target") that can be reached without decreasing output levels. With respect to energy input, the above summation is called the "energy-saving target" (EST). The formula is as follows:

$$\text{EST}_{(i,t)} = \text{Slack Adjustment}_{(i,t)} + \text{Radial Adjustment}_{(i,t)}, \tag{2}$$

where the EST is in the ith industry and the tth year.

An inefficient industry can reduce or save EST in energy use without reducing real economic growth. The DEA model may suggest the slack and radial adjustments of any individual input for all objects to be efficient. Since the actual practice can be improved to the best practice, the actual energy consumption is always larger than or equal to the ideal energy input.

Efficiency is generally defined in terms of the ratio with which the best practice compares with actual operation. The indicator of energy efficiency therefore should be the ratio of the aggregate energy-saving target from Eq. (2) to the actual energy consumption. The amount of total adjustments in the energy input is regarded as the inefficient portion of actual energy consumption. Based on slack and radial adjustment of energy obtained from DEA, we can calculate the energy-saving target ratio (ESTR) while simultaneously considering other factors. The target inputs of an object in a year are found by comparing its actual inputs to the efficiency frontier in that year. The formula is as below:

$$\text{ESTR}_{(i,t)} = \frac{\text{Energy-Saving Target}_{(i,t)}}{\text{Actual Energy Input}_{(i,t)}}, \tag{3}$$

where the target inputs are in the ith industry and the tth year.

As Eq. (3) shows, the ESTR represents each industry's inefficiency level with respect to energy consumption. Since the minimum value of EST is 0, the value of ESTR is between 0 and unity. The total-factor energy efficiency (TFEE) index originally proposed by Hu and Wang (2006), Hu and Kao (2007), Honma and Hu (2008), and Hu et al. (2012) has the following relation with ESTR:

$$\text{TFEE}_{(i,t)} = 1 - \text{ESTR}_{(i,t)}, \tag{4}$$

where the index is in the ith industry and the tth year. A 0 ESTR value indicates an industry on the frontier with the best total-factor energy efficiency (up to 1) among the observed industries. A 0 ESTR means that no redundant or over-consumed energy use exists (target amount of 0) in this industry. For an inefficient industry with an ESTR value larger than o, energy should and could be saved at the same economic output level. A higher ESTR implies higher energy inefficiency and higher energy savings.

As mentioned previously, many studies criticize the commonly used indicator of energy inefficiency, energy intensity, as a direct ratio of the energy input to gross domestic product, for measuring energy efficiency (e.g., Patterson, 1996; Renshaw, 1981). This ratio is only a partial-

TABLE 1
Summary Statistics of Inputs and Output (1998–2005)

	Real Value Added (Million Yen)	*Labor Employment (10,000 Person)*	*Real Private Capital Stock (Million Yen)*	*Energy Usage (Tera Joule)*
Mean	27,672,124	348	55,293,926	534,456
Std. Dev.	29,454,796	493	44,726,193	621,375
Minimum	682,115	5	2,599,581	5,101
Maximum	121,491,395	2,176	195,491,885	2,165,839

Note: The base year for real value added and real private capital stock is 2000.

factor energy efficiency indicator, as energy input is the only input-considered factor. Another argument is that this partial-factor ratio is inappropriate for analyzing the impact of changing energy use over time (APERC, 2000). We then compute the energy efficiency by a total-factor framework including other inputs such as labor and capital. A total-factor efficiency indicator can provide more information and a more realistic comparative base to examine the de facto situation across industries.

We analyze the data by sectors in the Japanese economy from 1998–2005. In our model, there are three production factors: labor employment, real private capital stock, and energy. The real sectoral value added is the sole output. Data regarding labor (persons) were collected from *the Annual Report on Prefectural Accounts* published by the Cabinet Office (2008a). Data on real private capital stock were taken from *Gross Capital Stock of Private Enterprises* by the Cabinet Office (2008b). The real sectoral value added was collected from *the Annual Report on National Accounts* published by the Cabinet Office (2008c). The real value added and real capital stock are at the price level of the year 2000. Sectoral energy consumption levels were collected from the *Energy Balances in Japan* (Ministry of Economy, Trade and Industry, 2008b).

Table 1 presents the summary statistics of the inputs and output used in the DEA models. Table 2 provides a correlation matrix. As shown in Table 2, all inputs are positively correlated with the output, implying that all inputs satisfy the "isotonicity" property with the output of the DEA model.

3. EMPIRICAL FINDINGS

The empirical results are shown in Table 3. Mining, general machinery, real estate and housing service, and service sectors have TFEE scores of unity throughout the sample period. These sectors operate on Japan's efficient frontier in each year, so they cannot reduce their energy consumption without decreasing their own value added. The financial and insurance sector has a high average

TABLE 2
Correlation Matrix for Inputs and Output (1998–2005)

	Value Added	*Labor*	*Capital Stock*	*Energy*
Value added	1.000			
Labor	0.866	1.000		
Capital stock	0.727	0.824	1.000	
Energy	0.118	0.172	0.495	1.000

TABLE 3
Pure Technical Efficiency (PTE) and Total-Factor Energy Efficiency (TFEE) for Sectors in Japan

		1998		*1999*		*2000*		*2001*		*2002*		*2003*		*2004*		*2005*		*Average*	
ID	*Sector*	*PTE*	*TFEE*	*PTE*	*TFEE*	*PTE*	*TFEE*	*PTE*	*TFEE*	*PTE*	*TFEE*	*PTE*	*TFEE*	*PTE*	*TFEE*	*PTE*	*TFEE*	*PTE*	*TFEE*
1	Agriculture, Forestry and Fishery	0.082	0.082	0.082	0.082	0.091	0.091	0.094	0.094	0.095	0.095	0.092	0.092	0.094	0.094	0.102	0.102	0.092	0.091
2	Mining	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***
3	Construction	0.687	0.276	0.672	0.282	0.637	0.291	0.600	0.296	0.588	0.303	0.554	0.301	0.552	0.304	0.527	0.311	0.602	0.295
4	Food	0.415	0.136	0.394	0.133	0.380	0.139	0.376	0.146	0.371	0.150	0.374	0.159	0.356	0.166	0.329	0.179	0.374	0.151
5	Pulp and Paper	0.333	0.052	0.326	0.048	0.312	0.047	0.299	0.049	0.299	0.047	0.292	0.047	0.298	0.047	0.303	0.051	0.308	0.048
6	Chemical	0.461	0.032	0.483	0.031	0.456	0.030	0.456	0.032	0.473	0.032	0.466	0.034	0.458	0.033	0.447	0.034	0.463	0.032
7	Cement and Ceramics	0.257	0.052	0.252	0.050	0.242	0.050	0.244	0.051	0.251	0.050	0.243	0.049	0.254	0.052	0.246	0.055	0.249	0.051
8	Primary Metal	0.322	0.014	0.324	0.014	0.332	0.014	0.305	0.014	0.297	0.013	0.296	0.013	0.293	0.012	0.300	0.013	0.309	0.013
9	General Machinery	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***
10	Electric Machinery	0.538	0.538	0.585	0.585	0.664	0.664	0.649	0.649	0.735	0.735	0.894	0.894	0.997	0.997	***1.000***	***1.000***	0.758	0.758
11	Transportation Machinery and Parts	0.374	0.374	0.393	0.393	0.393	0.393	0.405	0.405	0.418	0.418	0.397	0.397	0.407	0.407	0.410	0.410	0.400	0.399
12	Other Industries	0.256	0.044	0.241	0.044	0.237	0.044	0.218	0.043	0.215	0.041	0.209	0.041	0.206	0.040	0.193	0.043	0.222	0.042
13	Wholesale and Retail Trade	***1.000***	***1.000***	0.940	0.940	0.779	0.779	0.750	0.750	0.744	0.744	0.635	0.635	0.572	0.572	0.536	0.536	0.745	0.745
14	Financial and Insurance	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	0.986	0.986	0.915	0.915	0.896	0.896	0.975	0.975
15	Real Estate and House Services	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***
16	Transportation and Communication	0.208	0.028	0.202	0.028	0.199	0.029	0.203	0.030	0.208	0.032	0.208	0.032	0.195	0.033	0.195	0.034	0.202	0.031
17	Service	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***	***1.000***
	Average	0.584	0.449	0.582	0.449	0.572	0.445	0.565	0.445	0.570	0.451	0.567	0.452	0.565	0.451	0.558	0.451	0.570	0.449

TFEE score (0.975). It is reasonable that the tertiary industries other than the transportation and communication sector, which has high fuel consumption, have TFEE scores that are at or near 1.

The TFEE of the electric machinery sector gradually improves from 0.538 in 1998 to 1.000 in 2005; however, this is mainly attributed to a more than twofold increase in the sector's value added during that period. The TFEE of the wholesale and retail trade sector gradually deteriorates from 1.000 in 1998 to 0.536 in 2005. Underlying this efficiency reduction is a decrease in the value added of the sector accompanied by an increase in energy demand and other input; the value added in 2005 decreases by 4.9% compared to 1998, private capital stock increases by 9.4% and energy increases by 7.3%, whereas labor decreases by 7.7%. TFEEs in the rest of the sectors are stable during the sample period.

Extremely energy-inefficient sectors include energy-intensive industries (i.e., pulp and paper, chemical, cement and ceramics, and primary metal sectors) as well as agriculture, forestry and fishery, transportation and communication, and other industrial sectors. Average TFEEs during the sample period are less than 0.1 for these sectors. Literally interpreted, these sectors can reduce their energy consumption by more than 90% without decreasing their own value added. The most energy-inefficient sector is primary metal, whose average score is only 0.013. If the primary metal sector could operate on the frontier of efficiency, its energy input could be cut by up to 98.7%.

Here we compare TFEE and pure technical efficiency (PTE). For eight sectors (construction, food, pulp and paper, chemical, cement and ceramics, primary metal, other industries, transportation and communication), the TFEE is less than the PTE in every year. This means that the inefficiency of energy use is much worse than that of the use of other resources. Thus, the energy inputs in particular leave much more to be improved. It should be noted that all energy-intensive industries have much lower TFEEs as compared to PTEs, and that the differences between the two scores in each sector are stable throughout the sample period. In particular, the difference between the TFEE and the PTE for the chemical sector in each year is always larger than 0.4. Our results show that energy-intensive industries are extremely energy-insufficient under the total-factor framework.

4. CONCLUDING REMARKS

This study employs the DEA method to measure the technical efficiency of sectors in the Japanese economy during 1998–2005. The index of TFEE can be obtained from the ratio of actual energy input to the ideal energy input as derived by the DEA. According to the empirical results, we can draw the following policy implications:

1. There is much room for improvement of efficiency in energy-intensive industries (i.e., pulp and paper, chemical, cement and ceramics, and primary metal sectors), agriculture, forestry and fishery, transportation and communication, and miscellaneous manufacturing. High initial cost and lack of information are both obstacles to energy conservation. Subsidies and tax exemption for energy-saving investment should be used instead of the current policy. Energy service companies should be further encouraged, as the market size of this sector was only 40.7 billion yen (approximately US $350 million) in 2007 in Japan.
2. For eight sectors including the energy-intensive industries, the inefficiency of energy use is much worse than that of the use of other resources. The current Japanese energy-saving activity based on energy use per output should take into account other inputs via the total-factor framework.
3. The Japanese economy as a whole can achieve more efficient energy use not only by improving the energy efficiency of inefficient industries but also by changing the industrial structure. This will rely on a shift away from inefficient sectors toward high-value-added service sectors. Of course, attention should also be paid to how carbon leakage (the shift of production to overseas locations) affects the sectoral energy efficiency of Japan.

ACKNOWLEDGMENTS

The authors thank seminar participants at the East Asian Symposium on Environmental and Natural Resource Economics. Partial financial support from Taiwan's National Science Council (98-2410-H-009-055) is gratefully acknowledged.

REFERENCES

Asia Pacific Energy Research Center (APERC). 2000. *APEC energy pricing practices.* Tokyo: APERC.

Banker, R. D., Charnes, A., and Cooper, W. W. 1984. Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Manage. Sci.* 30:1078–1092.

Boyd, G. A., and Pang, J. X. 2000. Estimating the linkage between energy efficiency and productivity. *Energ. Policy* 28:289–296.

Cabinet Office, Government of Japan. 2002. *Annual report on the Japanese economy and public finance 2001–2002: No gains without reforms II.* Tokyo: Cabinet Office, Government of Japan.

Cabinet Office, Government of Japan. 2008a. *Annual report on prefectural accounts.* Tokyo: Cabinet Office, Government of Japan.

Cabinet Office, Government of Japan. 2008b. *Gross capital stock of private enterprises.* Tokyo: Cabinet Office, Government of Japan.

Cabinet Office, Government of Japan. 2008c. *Annual report on national accounts.* Tokyo: Cabinet Office, Government of Japan.

Färe, R., Grosskopf, S., and Lovell, C. A. K. 1994. *Production Frontiers.* Cambridge, UK: Cambridge University Press.

Farrell, M. J. 1957. The measurement of productive efficiency. *J. R. Stat. Soc. Ser. A-G.* 120:253–290.

Fukao, K., Inui, T., Kawai, H., and Miyagawa, T. 2004. Sectoral productivity and economic growth in Japan, 1970–98: An empirical analysis based on the JIP database. In: *Growth and Productivity in East Asia*, Ito, T., and Rose, A. K. (Eds.). Chicago: University of Chicago Press/NBER.

Honma, S., and Hu, J. L. 2008. Total-factor energy efficiency of regions in Japan. *Energ. Policy* 36:821–833.

Hu, J. L., and Kao, C. H. 2007. Efficient energy-saving targets for APEC economies. *Energ. Policy* 35:373–382.

Hu, J. L., Lio, M. C., Kao, C. H., and Lin, Y. L. 2012. Total-factor energy efficiency for regions in Taiwan. *Energ. Source. Part B* 7:292–300.

Hu, J. L., and Wang, S. C. 2006. Total-factor energy efficiency of regions in China. *Energ. Policy* 34:3206–3217.

Japan Business Federation. 2008. *Results of the fiscal 2008 follow-up to the Keidanren voluntary action plan on the environment.* Tokyo: Japan Business Federation.

Ministry of Economy, Trade, and Industry Japan. 2008a. *White paper on energy.* Tokyo: Ministry of Economy, Trade and Industry Japan.

Ministry of Economy, Trade, and Industry Japan. 2008b. *Energy balances in Japan*. Tokyo: Ministry of Economy, Trade and Industry Japan.

Patterson, M. G. 1996. What is energy efficiency? Concepts, indicators and methodological issues. *Energ. Policy* 24:377–390.

Renshaw, E. F. 1981. Energy efficiency and the slump in labor productivity in the USA. *Energ. Econ.* 3:36–42.

Shephard, R. 1970. *Theory of Cost and Production Functions.* Princeton, NJ: Princeton University Press.