An Analysis of the Technical Efficiency of Industrial Water Input in Manufacturing[1)]

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공업용수의 기술적 효율성 분석

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국 문 요 약

90년대 이후 용수관리 정책이 공급중심에서 수요관리로 정책 전환이 되면서 공업용수 수요량이 급격히 감소하였다. 본 연구에서는 공업용수 사용의 기술적 효율성을 분석하여 이러한 공업용수 수요량 감소가 공업용수의 사용이 효율적으로 이루어진 결과인지 검토하고 향후 공업용수의 기술적 효율성 제고를 통하여 공업용수 사용량을 더 줄일 수 있는지 검토하였다. 본 연구결과에 의하면 공업용수의 기술적 효율성은 1998년도 0.5183에서 2003년도에는 0.4853으로 도리어 약간 감소한 것으로 나타났다. 이는 다른 투입요소의 기술적 효율성에 비하여 낮은 수치로 앞으로 기술적 효율성 제고를 통하여 공업용수 사용량을 더 절감할 수 있음을 보여준다.

주제어 기술적 효율성, 자료포락분석, 공업용수

Abstract

While water management policies in Korea have focused on industrial water demand during the last decade, the amount of industrial water usage has decreased significantly. This paper estimates the technical efficiency of industrial water in order to test whether the reduction of industrial water usage is a result of improving the level of technical efficiency of industrial water.

This paper shows that the technical efficiency of industrial water use slightly decreased from 0.5183 in 1998 to 0.4853 in 2003. In addition, these estimates are much less than those of other inputs and so, there is still much room for reducing the amount of industrial water use through improving technical efficiency even though the average productivity of industrial water has improved during this period.

Keywords Technical Efficiency, Data Envelop Analysis, Industrial Water

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Ⅰ. Introduction

Until the early 1990's, the water management policies of Korea focused on water supply. For example, the government had constructed several dams to meet the increasing demand for water. However, these supply-side policies encountered difficulties due to serious environmental damage during the 1990's. Therefore, the government shifted the focus of its water policies from supply to water demand management in order to resolve future water shortage problems.

However, until the 1990's the water demand management policy regarding industrial water was rarely applied due to a set of limiting factors. For example, it is difficult to estimate the exact amount of water used since industrial water is supplied from various sources, such as subterranean aquifers, sea water, and piped sources. Therefore, it is difficult to construct a reliable database for research and thus, there is little research that would support the designing of policies for industrial demand management. In addition, compared to the expense of other production inputs at most firms, the share held by industrial water is rather low. Thus, the expense of industrial water has rarely been a point of major concern by firm management.[2)] Even though there have been some difficulties in controlling the use of industrial water, industrial water usage has reduced since the 1990's thanks to water demand side management policies.

In this paper, the technical efficiency level of industrial water is estimated in order to check whether it would be possible to further reduce the use of industrial water through increased efficiency. Previous research on industrial water as an input has mostly focused on estimating the marginal value product and price elasticity of industrial water using the production function, cost function, or demand function.[3)] Most research in this area estimates a parametric function using econometric

2) Min, D.K., Kang, J.H. 2006. "Estimating the Contribution of Industrial Water on Output and Price Elasticities in Manufacture". *Environmental and Resource Economics Review*, 15(5): 961-974.

3) Renzetti, S. 1992. "Estimating the structure of industrial water demands: the case of Canadian manufacturing". *Land Economics*. 68: 396-404 Wang, Hua and Lall, S. 2002. "Valuing Water for Chinese Industries". Applied Economics 34(6) : 759-765. Young, R.A. 2005. *Determining the Economic Value of Water*. RFF Press.

methods which assume that every firm produces output efficiently. However, if the assumption is not acceptable, then the estimates may not give the proper implications for the water demand management policy. Thus, by relaxing this assumption, we may allow that some firms produce output inefficiently. By accepting the possibility of inefficient production, the technical efficiencies of firms based on the estimated frontiers can be measured. There are two principle methods to estimate frontiers: stochastic frontier analysis, which uses the econometric method, and data envelopment analysis, which uses linear programming.

Several papers have studied the technical efficiency of Korean Manufacturing.[4)]Han (2005)[5)] showed that the average technical efficiency of manufacturing in Korea is 0.587 using stochastic frontier analysis and 0.642 using data envelopment analysis. Using stochastic frontier analysis, Park and Ji (2004)[6)] showed that the average technical efficiency in 10 sub-sector industries is about 0.7~0.85.

Previous research on technical efficiency in Korea has focused on the firm's average technical efficiency assuming that all inputs are variable. However, some inputs are fixed in the short run. A recent paper by Min (2006)[7)], tested the technical efficiency of industrial water for each industry based on the industry-wide frontier. In this paper, the focus is on a single input, industrial water, not the firm with all its variable inputs. That is, the technical efficiency will be estimated by focusing on industrial water while all other inputs are fixed at the present level based on the 1998 and 2003 data set. Then, the estimated results will show the level of technical efficiency of industrial water use rather than the firm's technical efficiency. The results should provide some information for the efficient use of industrial water in manufacturing, as well as trends of efficient usage levels over time. For this

4) Han, G. 2001. "The Sources of Productivity Change in Korean Manufacturing: Non-parametric Malmquist Approach". *The Korean Economic Review* 49(4): 37-61. Hsiao, F.S.T and Changsuh Park. 2005. Korean and Taiwanese Productivity

5) Han, G., 2005, "Total Factor Productivity, Efficiency Change and Technical Progress in Korean Manufacturing Industry:Stochastic Frontier and Data Envelopment Analysis". *The Korean Economic Review* 53(4): 119-146.

6) Park, H., Ji, O., 2004. "Estimation of firm-level technical efficiencies with a stochastic frontier production function and panel data of high-technology industry in Korea" *Journal of KRSA*, 20(2): 1-20.

7) Min, D.K., Kang, J.H., 2006. "Estimating the Contribution of Industrial Water on Output and Price Elasticities in Manufacture", *Environmental and Resource Economics Review*, 15(5): 961-974.

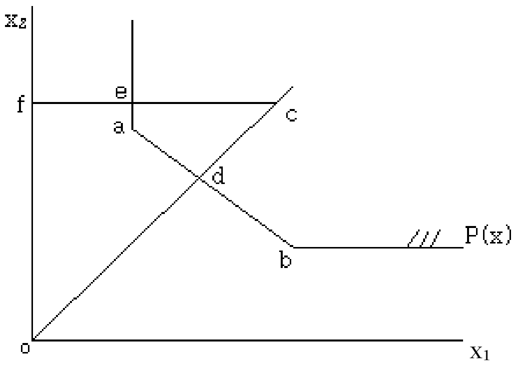
analysis, the data envelopment method is used.

In the next chapter, the model is described. In section 3, the data used is explained, and in section 4, the empirical work results are shown. Section 5 is the conclusion of the paper.

Ⅱ. Model

In this paper, the input-saving technical efficiency, i.e., the Farrell Input-Saving Measure of Technical Efficiency is used. By relaxing the assumption that all firms are producing efficiently, this study allows that there may be some firms which produce output inefficiently. Then, based on the actual observed input-output data, the best practice frontier will be constructed. The firm on the frontier produces the given amount of output with the fewest inputs.

Figure1 Technical Efficiency with Fixed Input



In the above figure, three firms which are producing the same amount of output y are labeled as a, b and c. Based on the observed data, the Input Requirement Set shows all the combinations of inputs that can be used to produce the given amount of output(Y), which can be constructed as P(x). All points above the line are the input requirement set and the lower boundary of the set is the best practice frontier.

In the figure, firms a and b are on the boundary of the input requirement set and thus, they are best practice firms while firm c, which is inside the boundary, is not. If all inputs are assumed as variable inputs, firm c can proportionally scale down its input use to point d while producing the same amount of output. Since the technical efficiency is measured by the ratio of the minimal feasible amount of input to actual amount of input with the same output, the technical efficiency of firm c is 0d/0c. Therefore, the technical efficiency of firms a and b is 1, while it is less than 1 for firm c. However, if some inputs are assumed as fixed inputs, it is not possible to reduce the amount of inputs proportionally. For example, in the figure, if x2 is assumed as a fixed input and x1 is assumed as a variable, then for firm c only the amount of input x1can be reduced in order to be on the best practice frontier. In this case, the technical efficiency of firm c is fe/fc instead of 0d/0c. In this paper, the focus is placed on the technical efficiency of industrial water input instead of the firm’s technical efficiency. Thus, the technical efficiency of industrial water input is estimated, while other inputs are fixed.

To estimate technical efficiency, the Farrell Input-Saving Measure of Technical Efficiency, as shown in the following equation, is used with the assumption of strong disposability and constant returns to scale.

$$
\begin{aligned}
& F^i(x^i, y^i) = \min \lambda^i \\
& s.t. \\
& \sum_{k=1}^{K} z_k y_k \geq y^i \\
& \sum_{k=1}^{K} z_k x_{k1} \leq \lambda^i x_1^i, \\
& \sum_{k=1}^{K} z_k x_{kn} = x_n^i, n = 2,3,\ldots, N \\
& z_k \geq 0, K = 1,2,\ldots\ldots\ldots, K
\end{aligned}
$$

Where $F^i(x,y)$ is the technical efficiency of firm i, x is the input vector and y is the output vector. Since all other inputs (x_n) are fixed at the present level while industrial water input (x_1) is variable, the constraint conditions for fixed and variable inputs are described as above. That is, to produce at the best practice frontier, the amount of industrial water use can be reduced while the amount of other inputs cannot be reduced. In order to estimate scale efficiency, three scale cases such as CRS(Constant Returns to Scale), NIRS(Non-Increasing Returns to Scale), and VRS(Variable Returns to Scale) were estimated by changing the z variable[8] constraint($z_k \geq 0$) to $0 \leq \sum_{k=1}^{K} z_k \leq 1$ for NIRS and $\sum_{k=1}^{K} z_k = 1$ for VRS. Scale efficiency is estimated by dividing the technical efficiency with the CRS constraint by the technical efficiency with VRS constraint as follows.

$$S_i = F_i(CRS)/F_i(VRS)$$

If the scale efficiency estimate is less than 1, then, the operation level of the firm can be either at decreasing or increasing returns to scale. If $F_i(NIRS) = F_i(CRS)$, then the firm operates at increasing returns to scale, and if $F_i(NIRS) \succ F_i(CRS)$, then the firm operates at decreasing returns to scale.

Ⅲ. Data

To estimate the technical efficiency of industrial water input in manufacturing, the data used comes from primary data for a comprehensive survey of Korean manufacturing enterprises conducted by the Korean Statistical Office in 1998 and

8) Fare, R. and Grosskopf. S. 2000. *Reference guide to OnFront*, Economic Measurement and Quality in Lund Co., Lund, Sweden

2003. The purpose of the survey was to enumerate the current amount of factor inputs used and the output level produced by manufacturing. The unit of monetary value in the survey is one million Korean won (approximately, in $1,000 units). Some firms which spent less than one million won for industrial water were excluded, and thus, report a value of zero for industrial water use. In addition, we also exclude those firms which use subterranean water or underground water. For these firms it is difficult to estimate the exact amount of water used since industrial water use was not measured, while the amount of industrial water used by the firms which used piped municipal and industrial water was measured. Thus, they have been excluded in order to escape a serious data bias problem. The data for 1998 and 2003 are 11,657 and 17,243 respectively. The summary statistics for the variables are found in <Table 1>. The average amount of water used by the surveyed firms was 109,779tons and the average output was 13,133million won, in 1998. In 2003, the average amount of industrial water used decreased to 60,424tons while the average output increased to 16,109 million won. That is, the average output per ton of water used increased significantly during that period.

Table1 Summary Statistics for the Variables

Year	Variable	Mean	SD	Min.	Max.
1998	Output	13,133.16	126,661.5	10	7,269,450
	Capital	8,863.32	117,776.6	1	5,516,448
	Labor	58.75	351.50	5	26,202
	Intermediate Inputs	6,762.48	70,307.23	1	4,298,102
	Water	109,779.2	1,787,956	1500	120,000,000
2003	Output	16,109.12	170,325.7	19	12,600,000
	Capital	7,535.12	105,396.6	1	9,681,999
	Labor	52.18	321.51	5	25,771
	Intermediate Inputs	8,543.58	87,175.75	1	6,184,174
	Water	60,424.46	668,294.8	1500	58,800,000

Unit: Million Won for Output, Capital and Intermediate Inputs, Ton for water, Number of workers for Labor

Table2 Technical Efficiency for sub-industry (1998)

ID(code)[9]	Fi(CRS)	Fi(NRS)	Fi(VRS)	Si	OBS	Fi ratio
Food and beverages (15)	0.0754	0.0876	0.3687	0.1588	949	0.9631
Textiles (17)	0.0395	0.0461	0.3099	0.2134	1,419	0.9774
Wearing apparel (18)	0.0777	0.0872	0.6206	0.1336	642	0.9782
Manuf. Of Luggage (19)	0.1999	0.2264	0.5726	0.3659	364	0.8817
Wood and Products (20)	0.2157	0.2496	0.5816	0.3169	162	0.9321
Pulp, Paper (21)	0.1704	0.1908	0.5041	0.2976	307	0.9315
Printing and Reproduction (22)	0.0641	0.0662	0.6270	0.1036	498	0.9960
Chemicals (24)	0.0902	0.1106	0.3540	0.2976	672	0.9033
Rubber (25)	0.1113	0.1209	0.4699	0.2432	774	0.9664
Other Non-Metallic Mineral (26)	0.1481	0.1811	0.4079	0.4130	343	0.8834
Basic Metal (27)	0.1631	0.2050	0.4248	0.3871	426	0.8685
Fabricated Metal (28)	0.0718	0.0793	0.4547	0.1526	1,285	0.9868
Other Machinery (29)	0.0530	0.0558	0.4834	0.1239	1,504	0.9934
Office Machinery (30)	0.2608	0.3211	0.6723	0.4142	65	0.8615
Other electrical machinery (31)	0.1467	0.1585	0.5385	0.2678	510	0.9529
Radio, television (32)	0.1014	0.1121	0.4706	0.2091	483	0.9669
Medical, Precision (33)	0.1888	0.2062	0.5609	0.3313	259	0.9459
Motor Vehicles (34)	0.1841	0.2046	0.4981	0.3690	410	0.9293
Other Transport (35)	0.1867	0.2377	0.6182	0.2901	79	0.9241
Furniture (36)	0.1037	0.1183	0.5068	0.2115	479	0.9562
Waste Collection (37)	0.5830	0.5830	0.8389	0.6849	27	1
Industry wide	0.1541	0.1737	0.5183	0.2850	11,657	0.9428

Table3 Technical Efficiency for sub-industry (2003)

ID(code)	Fi(CRS)	Fi(NRS)	Fi(VRS)	Si	OBS	Fi ratio
Food and beverages (15)	0.0469	0.0512	0.3603	0.1378	1,778	0.9753
Textiles (17)	0.0522	0.0599	0.3265	0.1277	1,729	0.9861
Wearing apparel (18)	0.1071	0.1131	0.7017	0.1543	918	0.9869
Manuf. Of Luggage (19)	0.1867	0.2078	0.5379	0.3767	256	0.9414
Wood and Products (20)	0.1819	0.2067	0.5765	0.2820	210	0.9524

9) 15. Manufacture of food and beverages products, 17. Textiles, 18. Wearing apparel and Fur articles, 19. Tanning and Dressing of Leather, Manufacture of Luggage and Footwear, 20. Wood andProducts of Wood and Cork, 21. Pulp, Paper and Paper Products, 22. Printing and Reproduction of Recorded Media, 24. Chemicals and chemical products, 25. Rubber and Plastic Products, 26. Other Non-Metallic Mineral Products, 27. Basic Metal Products, 28. Fabricated Metal Products, 29. Other Machinery and Equipment, 30. Office Machinery and Equipment, 31. Other electrical machinery and Equipment, 32 Radio, television and Communication Equipment, 33. Medical, Precision and Optical Instruments, Watches, 34. Motor Vehicles and Trailers, 35. Other Transport Equipment, 36. Furniture and Others, 37. Waste Collection, Disposal and materials Recovery

ID(code)	Fi(CRS)	Fi(NRS)	Fi(VRS)	Si	OBS	Fi ratio
Pulp, Paper (21)	0.0999	0.1193	0.4544	0.2440	415	0.9422
Printing and Reproduction (22)	0.0483	0.0507	0.6080	0.0752	781	0.9936
Chemicals (24)	0.0571	0.0640	0.2986	0.1846	946	0.9736
Rubber (25)	0.0583	0.0672	0.4275	0.1642	1261	0.9785
Other Non-Metallic Mineral (26)	0.1354	0.1520	0.3852	0.4024	538	0.9368
Basic Metal (27)	0.1056	0.1436	0.3840	0.3377	672	0.8943
Fabricated Metal (28)	0.0811	0.0881	0.4536	0.1913	2,237	0.9741
Other Machinery (29)	0.0499	0.0551	0.4670	0.1313	2,351	0.9783
Office Machinery (30)	0.2690	0.2923	0.5753	0.4567	117	0.9316
Other electrical machinery (31)	0.0974	0.1132	0.5024	0.2106	791	0.9482
Radio, television (32)	0.0808	0.0978	0.4571	0.1738	808	0.9480
Medical, Precision (33)	0.1431	0.1548	0.5168	0.2607	390	0.9641
Motor Vehicles (34)	0.1402	0.1544	0.3968	0.3701	749	0.9346
Other Transport (35)	0.2706	0.3299	0.5493	0.4574	121	0.8843
Furniture (36)	0.1235	0.1320	0.5415	0.2390	617	0.9627
Waste Collection (37)	0.2967	0.2967	0.6708	0.3990	39	1
Industry wide	0.1253	0.1405	0.4853	0.2560	17,724	0.9667

Ⅳ. Empirical results

Since this study tests whether there was any improvement in the technical efficiency of industrial water, the technical efficiency of industrial water for each firm was estimated when all inputs, except industrial water input, were fixed at present levels. To estimate the technical efficiency of industrial water input for each firm based on the similar production technology, each firm is categorized in to 21 sub-industries. The estimated average technical efficiency of industrial water input for each sub-industry is summarized in <Table 2>. The industry-wide technical efficiencies of industrial water input relative to variable returns to scale (Fi(VRS)) in 1998 and 2003 are 0.518 and 0.485, respectively. That is, even though the average product per ton of industrial water input increased among these periods, the estimated technical efficiency slightly decreased. The results show that even though there was some improvement of industrial water input productivity, there is still some room for more improvement through the greater technical efficiency of industrial water use. Technical efficiency estimates relative to constant returns to scale (Fi(CRS)) and non-increasing returns to scale (Fi(NRS)) are much less than that relative to variable returns to scale. Technical efficiencies relative to constant returns to scale were 0.154 in 1998 and 0.125 in 2003.

Thus, scale efficiencies (Si) for both years were rather low, i.e., 0.285 in 1998 and 0.256 in 2003. By the technical efficiency estimates relative to non-increasing returns to scale, it is possible to tell whether scale inefficiency is due to the fact that they are producing at decreasing or increasing returns to scale. Technical efficiencies relative to non-increasing returns to scale were 0.174 in 1998 and 0.141 in 2003. Since the industry-wide average technical efficiency estimates relative to non-increasing returns to scale are larger than those relative to constant returns to scale, these results show that scale inefficiency is due to decreasing returns to scale. However, if we focus on the technical efficiency for each firm, we can see that most firms' technical efficiencies relative to constant and non-increasing returns to scale are the same. That is, these estimates (Fi ratio) were the same for 94.28% among all firms in 1998 and 96.67% in 2003. Therefore, most firms were producing at increasing returns to scale. In the case of 37 industries, all firms' technical efficiencies relative to constant and non-increasing returns to scale were the same and thus, all firms were producing at increasing returns to scale in both years.

Even though the average industry-wide productivity of industrial water input increased during that period, technical efficiencies for most sub-industries decreased while those for only two industries (17,18) slightly increased during the period. Therefore, policy for improving technical efficiency of industrial water input is necessary in order to encourage more efficient use of industrial water. In addition, since technical efficiency estimates differ greatly among industries for both years, the policy for improving technical efficiency has to be applied differently for each industry by taking into consideration their current technical efficiency levels.

Previous studies, which assumed all inputs were variable, reported that the technical efficiency was about 0.58~0.85. Those results were a little larger than the estimates in this study. The lower technical efficiency estimates for industrial water input may have resulted from the fact that the cost of industrial water input is lower than that of other inputs and therefore the manager may not be seriously concerned about the cost of industrial water.

Based on the results of this paper, it can be argued that the previous studies based on the assumption that every firm was producing efficiently may result in biased estimates. Therefore, when industrial water input is analyzed, a proper method has to be used in considering the technical inefficiency.

V. Conclusion

This study estimates technical efficiency for each industry in order to give some information on the present technical efficiency level of industrial water input to improve the efficiency of water management policy. To do this, this paper estimates the technical efficiency of industrial water by assuming all other inputs are fixed, except industrial water input. This study estimates the technical efficiency of industrial water and shows that most firms use industrial water inefficiently.

This paper shows that the technical efficiency of industrial water input was 0.518 and 0.485 in 1998 and 2003, respectively. Based on these results, it is possible to say that previous studies that were based on the assumption of efficient use of industrial water input may show biased results. In addition, the technical efficiency of industrial water input is much lower than those of previous papers, assuming that all inputs are variable. This lower technical efficiency level may result from the fact that managers did not pay much attention to the efficient use of industrial water because industrial water represented only a minor portion of their expenses. Thus, there is much room for reducing water use through a more efficient use of industrial water. Even though the productivity of industrial water increased significantly during the past decade, in order to meet the water shortage problem in the near future, policy makers will have to focus on finding ways to use industrial water more efficiently.

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