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Technical Efficiency in the Iron and Steel Industry: A Stochastic Frontier Approach

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A Stochastic Frontier Approach

by

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ABSTRACT

In this paper we examine the technical efficiency of firms in the iron and steel industry and try to identify the factors contributing to the industry's efficiency growth, using a time-varying stochastic frontier model. Based on our findings, which pertain to 52 iron and steel firms over the period of 1978-1997, POSCO and Nippon Steel were the most efficient firms, with their production, on average, exceeding 95 percent of their potential output. Our findings also shed light on possible sources of efficiency growth in the industry. If a firm is government owned, its privatization is likely to improve its technical efficiency to a great extent. A firm's technical efficiency also tends to be positively related to its production level as measured by a share of the total world production of crude steel. Another important source of efficiency growth identified by our empirical findings is adoption of new technologies and equipment. Our findings clearly indicate that continued efforts to update technologies and equipment are critical to the pursuit of efficiency in the iron and steel industry.

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1. Introduction

The iron and steel industry has been traditionally regarded as a key manufacturing industry because of its large linkage effects. Consequently, national governments often try to support the industry explicitly or more often in subtler ways. At the global level, however, firms fiercely compete for a bigger market share to take advantage of economies of scale. As a result, international comparisons of the industry's efficiency have been of great interest to firms in the industry as well as policymakers.

Several studies investigated the efficiency of the iron and steel industry. They include among others: Ray and Kim (1995) for the U.S. steel industry; Jefferson (1990), Kalirajan and Cao (1993), Wu (1996), and Ma et al. (2002) for Chinese iron and steel firms; and Liberman and Johnson (1999) for Japanese and U.S. steel producers. However, most studies examined the issue in the context of a single or two countries, and there is very little systematic evidence available. We try to fill this gap by examining 52 steel firms from 23 countries over the period of 1978-1997.

The paper is organized as follows: Section 2 discusses technical efficiency and introduces stochastic frontier models; Section 3 presents a brief data description and constructs a panel data model to analyze the technical efficiency of iron and steel firms; Section 4 presents estimation results; and Section 5 concludes the paper.

2. Technical Efficiency

Technical efficiency is defined as the ratio of actual output to the maximum output attainable (often called a frontier) with the given amount of inputs. Early studies of

technical efficiency were based on the deterministic frontier model suggested by Aigner and Chu (1968), but this model cannot account for the random factors that may move production off the frontier. Subsequently, various stochastic production frontier models were introduced to take these factors into account.[1] A simple form of the stochastic production frontier is as follows:

(1)

$$\ln y_i = X_i \beta + v_i - u_i$$

where y_i is output of firm i; X_i is a column vector of inputs; v_i is an unrestricted error component; and u_i is a non-negative random variable which captures production inefficiency. Thus, the total error term, $v_i - u_i$, has an asymmetric distribution.

The stochastic frontier model was first extended to cover panel data by assuming time-invariant inefficiency.[2] However, the assumption of time-invariant inefficiency may not be appropriate when the data covers a relatively long period of time. For example, the technical efficiency of a firm can change as the firm acquires new information and technology over time. Several models of time-varying inefficiency were later introduced to take this possibility into consideration.[3]

In this study, we consider time-varying inefficiency, and base our analysis on the model developed by Battesse and Coelli (1995). This model allows for firm-specific patterns of efficiency change[4], and specifies inefficiency as Equation 2.

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[1] For example, see Aigner, Lovell, and Schmidt (1977), and Meeusen and Van den Broeck (1977).
[2] See Schmidt and Sickles (1984).
[3] See Cornwell et al. (1990), Kumbhakar (1990), Battesse and Coelli (1992 and 1995), Lee and Schmidt (1993), and Cuesta (2000) among others.
[4] Alternatively, we can assume the same pattern of efficiency change, monotonic increase or decrease, for all firms. See Battesse and Coelli (1992).

(2) $u_{it} = z_{it}\delta + \varepsilon_{it}$

where z_{it} is a vector of explanatory variables associated with technical inefficiency of firm i at time t, δ is an unknown vector of coefficients, and the random variable, ε_{it}, is defined to have the normal distribution trunctaed at $-z_{it}\delta$.[5]

3. Data Description and Model Specification

We collect data on iron and steel firms from the non-communist countries for the period of 1978-1997. For the twenty-year period, the World Steel Dynamics Core Report (1990 and 1999) has data on 55 firms from 23 non-communist countries, but only 52 firms are finally included in our analysis because of missing data. Appendix A lists all firms included in our study.

Our model consists of two equations, the stochastic production frontier (Equation 3) and inefficiency (Equation 4) equations. We assume a translog production function.

(3)
$$
\begin{aligned}
\ln(y_{it}) = {} & \beta_0 + \beta_1 \ln(L_{it}) + \beta_2 \ln(K_{it}) + \beta_3 \ln(O_{it}) \\
& + \frac{1}{2}\beta_4 (\ln L_{it})^2 + \frac{1}{2}\beta_5 (\ln K_{it})^2 + \frac{1}{2}\beta_6 (\ln O_{it})^2 \\
& + \beta_7 (\ln L_{it})(\ln K_{it}) + \beta_8 (\ln K_{it})(\ln O_{it}) + \beta_9 (\ln L_{it})(\ln O_{it}) \\
& + v_{it} - u_{it}
\end{aligned}
$$

and

(4) $u_{it} = \delta_0 + \delta_1 D_{it} + \delta_2 AGE_{it} + \delta_3 SCALE_{it} + W_{it}$

where y is output (as measured by crude steel production in millions of tons), L is the total

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[5] This definition indicates $\varepsilon_{it} \geq -z_{it}\delta$, and is consistent with the assumption that u_{it} has the truncated normal distribution, $N(z_{it}\delta, \sigma_u^2)$.

number of employees, K is productive capacity of equipment (as measured by crude steel in millions of tons), and O is other material inputs employed (in thousands of U.S. dollars). In our inefficiency equation, D is a dummy variable equaling 1 for a state-owned firm and zero otherwise, AGE is the average age of a firm's plants, and $SCALE$ is a firm's production as a share of the total production in all non-communist countries (in percentages). Table 1 summarizes descriptive statistics of each variable.

Since many studies stress the positive effects of privatization on technical efficiency for various industries, we include D in Equation (4) to see whether it is the case with the iron and steel industry.[6] AGE is included in our inefficiency equation to see whether technical efficiency is related to the age of equipment as measured by the average age of plants. Aged and outdated equipment is likey to drag down productivity.[7] However, the relatively long lead time necessary to bring new equipment on line in the iron and steel industry may suggest the significance of accumulated knowledge through learning-by-doing.[8] Therefore, the expected sign of AGE's coefficient is somewhat ambiguous. Because iron and steel production is believed to show economies of scale,[9] we include $SCALE$ in Equation (4) to test the existence of economies of scale in the industry.

4. Empirical Results

Our model is estimated by the maximum likelihood method using FRONTIER 4.1 (Coelli, 1996). The estimated coefficients of Equations (3) and (4) are presented in Table

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[6] Half of our 52 sample firms started the period covered by our study as government-owned enterprises. Of these 26 firms, 12 firms were privatized during our study period.
[7] Liberman and Johnson (1999) conclude that aggressive investment in new equipment by Japanese steel firms led to a higher level of labor productivity vis-à-vis U.S. firms in the 1980s.
[8] Wu (1996) found some evidence of learning-by-doing in his study of China's iron and steel industry.
[9] For example, see Wu (1996).

2. All estimated coefficients are statistically significant at the 1-percent level except for that of *D,* which is significant at the 5-percent level. The positive estimated coefficient of *D* in the inefficiency equation indicates that an iron and steel firm tends to be less efficient under government ownership than private ownership.   The positive and statistically significant estimate of *AGE*'s coefficient clearly shows that aged equipment negatively affects efficiency in the iron and steel industry, and learning-by-doing has only limited effect. The estimated coefficient of *SCALE* is negative and statistically significant, which is in accord with the proposition that the iron and steel industry tends to show economies of scale.[10]

4.1 Efficiency of Individual Firms

We can evaluate the efficiency of major firms in the iron and steel industry using estimates of technical efficiency based on our model. Table 3 shows the ten most efficient firms in the industry and their average levels of technical efficiency over the period of 1978-1997. According to our estimates, POSCO from South Korea and Nippon Steel from Japan were the most efficient firms, producing on average at around 97 and 96 percent of their potential output, respectively. Usinor (94 percent) from France and China Steel (93 percent) from Taiwan were trailing right behind them in terms of average efficiency over the twenty-year period.

It should be noted that the seven most efficient firms on the list were holding

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[10] If a firm's market share ($SCALE_{it}$) is also influenced by its inefficiency (u_{it}), estimating the model without considering this endogeneity would yield the inconsistent estimate for the coefficient of $SCALE_{it}$. The size of this inconsistency may depend on the slope parameters, δ_3 and γ (the effect of u_{it} on $SCALE_{it}$) as well as the variances of the error terms.

significant market power as a monopoly or a dominant firm in their domestic markets, but competing fiercely at the global level. Three of them also went through privatization during the period this study covers. British Steel from the U.K. was privatized in 1988 as part of a wave of privatization measures under Prime Minister Thatcher. Usinor and China Steel were both privatized in 1995. From the U.S., three firms made the list by ranking eighth through tenth. They include National Steel, Nucor Steel, and Bethlehem Steel, and achieved, on average, around 91 percent of their potential output over the period.

4.2 Sources of Efficiency Growth

4.2.1 Privatization

Our empirical results suggest that privatization should improve the efficiency of iron and steel firms. This is in line with the experience of individual firms that went through privatization during the period this study covers. For example, the British government privatized British Steel through public offerings in 1988. Before its privatization, British Steel was a state-owned monopoly that had been established after merging thirteen private firms and one state-owned enterprise in 1967. Figure 1a clearly shows a change in the trend of British Steel's technical efficiency after privatization in 1988. Its technical efficiency, which fluctuated widely before 1988, remained stable at higher levels after privatization.

Figure 1b plots the efficiency trend of another firm, CSN from Brazil, which was privatized in 1993. We can also see a clear trend of more stable and higher levels of

technical efficiency after the privatization of CSN. In both companies, privatization was immediately followed by significant structural reform within their organizations. Their restructuring efforts are well reflected in a continued decline of their total employee numbers over the five-year period following privatization (Figures 2a and 2b).

4.2.2 Economies of Scale

Our findings confirm the existence of economies of scale in the iron and steel industry. The technical efficiency of iron and steel firms was positively related to their production levels as measured by shares of the total world production of crude steel. A close look at the performance of POSCO clearly shows a strong correlation between its efficiency and production level. POSCO, a relative late-comer to the industry, was established in 1968, but has grown rapidly since then. As it continued to expand its share of world steel production over the period of 1978-1997, its technical efficiency also improved consistently during the same period (Figure 3a). In fact, POSCO was the most efficient of the major firms in our sample in terms of average technical efficiency over the twenty-year period (Table 3).

Based on our estimates, another firm with its margin of inefficiency smaller than 5 percent was Nippon Steel. It has been a formidable player in the industry over the past several decades, and was already the world's largest producer of iron and steel with an annual output of 32 million tons by the late 1970s. If economies of scale become tenuous beyond some significant level of steel production as suggested by Lim (1991), their effects on efficiency will be easily swamped by those from other factors. In fact, Figure 3b shows no clear relationship between its production level and technical efficiency for

Nippon Steel, which started the period covered by our study as the world's largest producer.

4.2.3 Technologies and Equipment

Steel production critically depends on industry-specific technologies and equipment. For example, the production of molten steel involves process heating operations that typically require such equipment as the basic oxygen furnace or the electric arc furnace. Subsequent forming operations require equipment for casting, hot and cold rolling, extrusion, drawing, finishing, and cutting. Consequently, old and outdated equipment is likely to be detrimental to the efficiency of iron and steel firms. Our empirical findings clearly indicate this is the case. That is, efficiency losses from the aging of equipment tend to outweigh any efficiency gains from learning-by-doing associated with the aging.

POSCO and China Steel provide good illustrations of the importance of new and up-to-date equipment in efficiency growth. Among the major firms in our sample, POSCO was the most efficient firm with its production, on the average, approaching 97 percent of its potential output, and China Steel was the fourth most efficient with its average efficiency exceeding 93 percent. However, it should be noted that both companies were under government ownership for most of the period covered by this study.[11] They were also relative late-comers to the industry. POSCO was launched in 1968 and China Steel in 1971. Subsequently, they were clearly at a disadvantage compared to other more established firms in the industry with respect to economies of scale at least for the early part of the study period.

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[11] POSCO was under government ownership during the whole study period (1978-1997), and China Steel was under government ownership as late as in 1995,

In contrast, as relative late-comers, they were able to benefit from comparatively new and up-to-date equipment compared to more established firms. In fact, Figure 4 shows that the average age of plants for both companies was below the industry average. For the first ten years of our study period in particular, POSCO ranked third and China Steel fifth among our sample firms in terms of freshness of equipment (Table 4). Although a relatively long lead time is necessary to bring new equipment on line in the iron and steel industry, aggressive R&D (research and development) investment is likely to expedite the learning-by-doing process. In fact, both companies were very active in R&D during our study period. For example, there was a 15-fold increase in the number of registered patents by POSCO during the period of 1984-1992.

5. Conclusions

As excitement about the so-called "new economy" during the 1990s somewhat subsides, more recently, there are renewed interests in the efficiency of traditional manufacturing industries. Of those industries, the iron and steel industry is of particular interest because of its large linkage effects and fierce competition at the global level. Based on our findings, which pertain to 52 major iron and steel firms over the period of 1978-1997, POSCO and Nippon Steel were the most efficient firms, with their production, on average, exceeding 95 percent of their potential output. When we consider the ten most efficient firms during the twenty-year period, their production was, on average, at least 90 percent of their potential ouput.

Our findings also shed light on the possible source of efficiency growth in the industry. If a firm is government-owned, its privatization is likely to improve its efficiency to a

great extent. Taken at face value, the estimates in Table 2 suggest that, if an iron and steel firm is privatized, its production might increase by 14 percent of its potential output with the same amount of inputs. The experience of individual privatized firms shows a clear trend of more stable and higher levels of estimated efficiency after privatization.

Steel production requires a high level of initial capital investment and thus incurs high fixed costs. The resulting economies of scale in the iron and steel industry are confirmed by our empirical results. A firm's technical efficiency tends to be positively related to the firm's share of the world crude steel production. In fact, we often observe major firms fiercely competing for a larger market share in order to enhance their competitive edge. This may account for the worldwide oversupply that frequently plagues the iron and steel industry.

Another important source of efficiency growth identified by our empirical findings is adoption of new technologies and equipment. Of course, installation of new steelmaking equipment typically requires a relatively long lead time and additional retrofitting of other equipment, which may initially lead to efficiency losses, rather than gains. However, our findings clearly indicate that efficiency gains from new technologies and equipment tend to outweigh any efficiency losses. POSCO and China Steel are telling examples. During the period our study covers, both companies were basically government-owned and initially at a clear disadvantage compared to the industry's more established firms with respect to economies of scale. Nonetheless, they managed to become the most efficient firms in the industry. Figure 4 clearly shows that they benefited from relatively new and up-to-date equipment in achieving efficiency growth. Therefore, continued efforts to update technologies and equipment are critical in pursuit of efficiency in the iron and steel industry.

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Table 1. Descriptive Statistics

Variables	Means	Standard Deviation	
Production (y)	5.67	5.59	Crude steel production (Millions of tons)
Labor (L)	27662.34	31872.53	Total number of employees
Capital (K)	7.82	8.27	Crude steel production capacity of Equipment (Millions of tons)
Other inputs (O)	134.36	137.24	Other material inputs employed (Thousands of US dollars)
Dummy (D)			Private ownership: 0 Government ownership: 1
AGE	11.21	5.58	Average age of plants (Years)
SCALE	1.18	1.16	A firm's share of total production in non-communist countries (%)

Table 2. Estimation Results

Stochastic production frontier			Inefficiency		
	coefficient	t-value		coefficient	t-value
constant	-5.1408	-7.84	*constant*	-0.4366	-4.02
ln (L)	1.0571	7.15	*D*	0.1436	2.28
ln (K)	0.5277	3.80	*AGE*	0.0226	5.56
ln (O)	0.9157	6.61	*SCALE*	-0.4198	-3.72
(ln L)²	-0.0737	-5.90			
(ln K)²	-0.0783	-6.46			
(ln O)²	-0.0450	-4.18			
(lnL)(lnK)	0.1216	4.97			
(lnK)(lnO)	0.0921	4.39			
(lnL)(lnO)	-0.1216	-6.25			

Table 3. Average Technical Efficiency : 1978-1997

(Ten Most Efficient Firms)

Firm (Country)	Average Efficiency
POSCO (Korea)	0.9663
NIPPON STEEL (Japan)	0.9596
USINOR (France)	0.9397
CHINA STEEL (Taiwan)	0.9344
ISCOR (South Africa)	0.9227
BRITISH STEEL (U.K.)	0.9136
ARBED (Luxembourg)	0.9128
NATIONAL STEEL (U.S.)	0.9103
NUCOR STEEL (U.S.)	0.9077
BETHLEHEM STEEL (U.S.)	0.9055

Table 4. Average Age of Plants : 1978-1987

(Ten Firms with Newest Plants)

Firms	Average Age (Years)
MANNESMANN	0.31
CHAPPARAL	3.39
POSCO	3.45
ITALSIDER	4.37
CHINA STEEL	4.77
NUCOR	4.86
BHP	5.07
SVENSKT STAL	5.46
FLORIDA	6.79
HIGHVELD	6.82

Figure 1a. Technical Efficiency of British Steel (1978-1997)
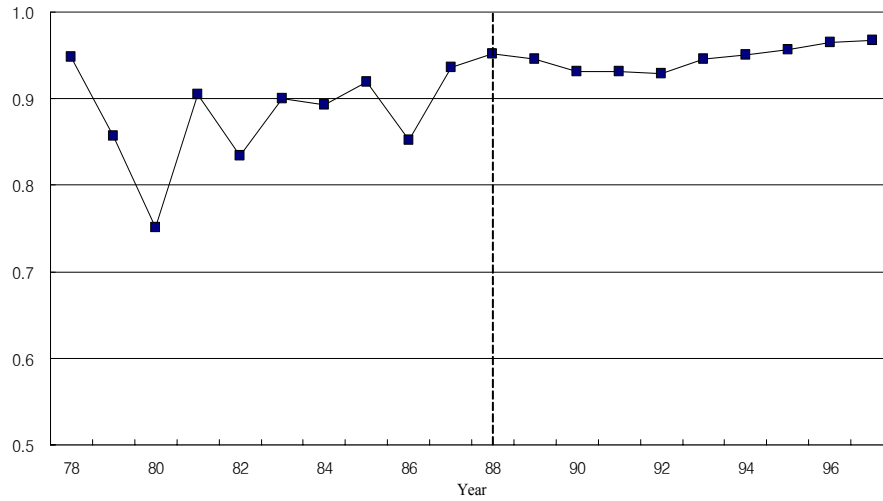
Figure 1b. Technical Efficiency of CSN (1978-1997)
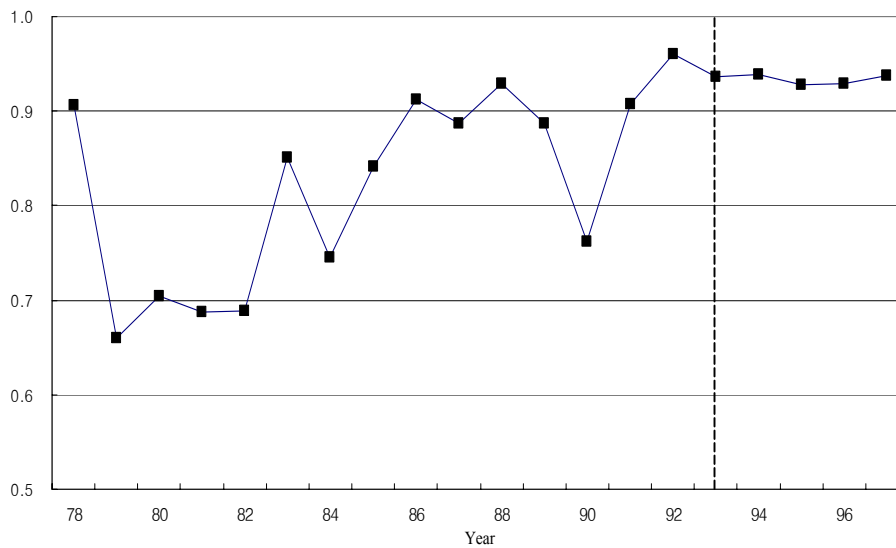
Figure 2a. Total Number of Employees: British Steel
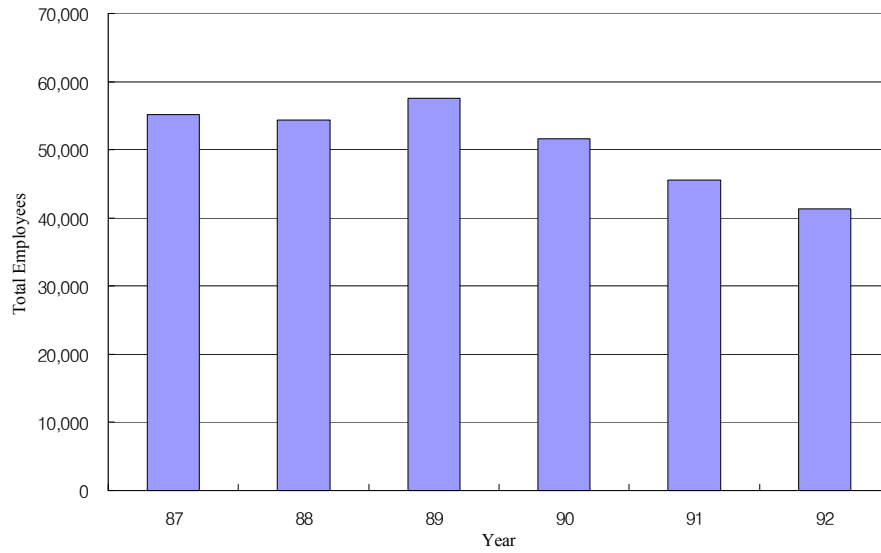
Figure 2b. Total Number of Employees: CSN
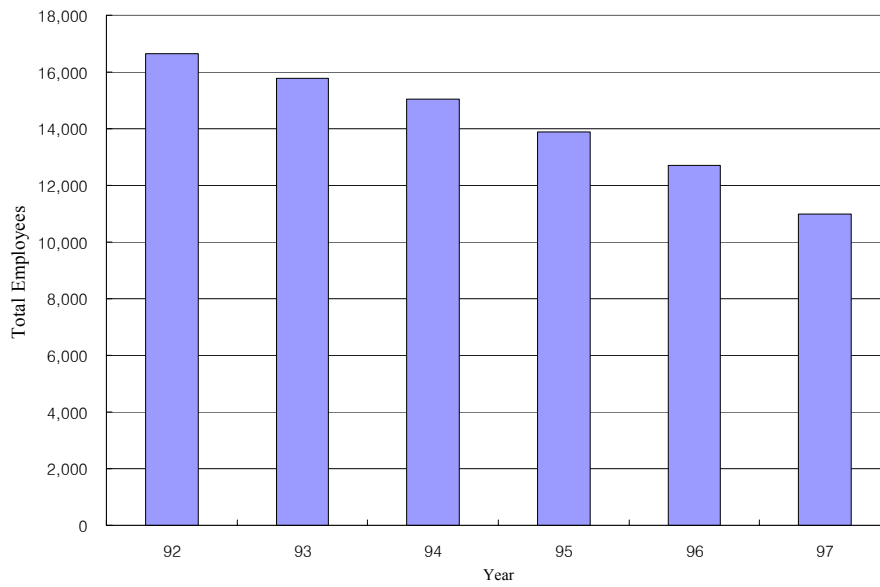
Figure 3a. Technical Efficiency and Scale: POSCO
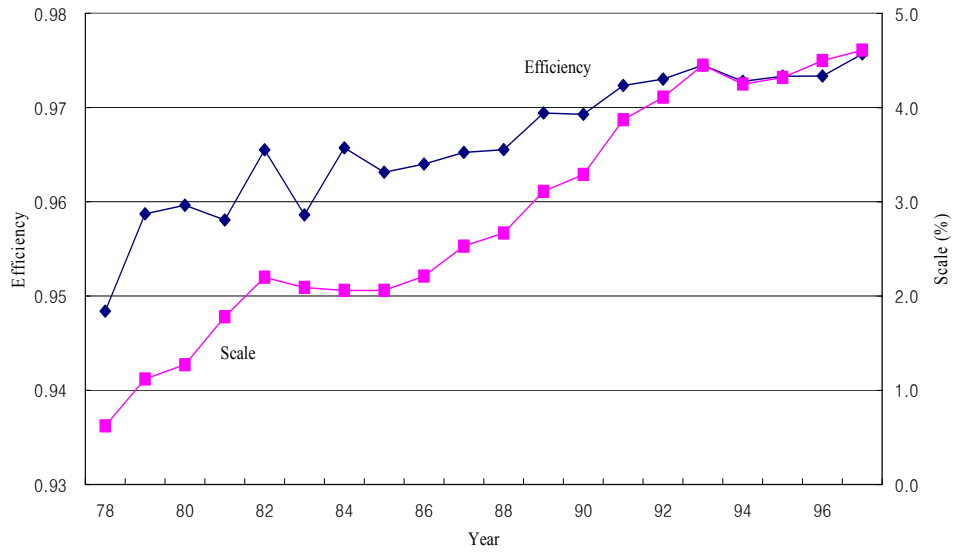
Figure 3b. Technical Efficiency and Scale: Nippon Steel
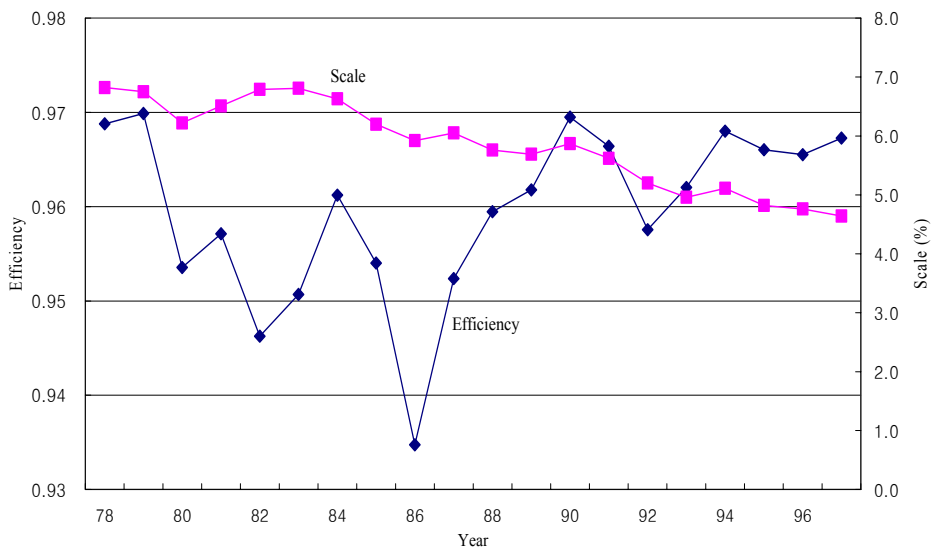
Figure 4. Average Age of Plants: POSCO and CHINA STEEL
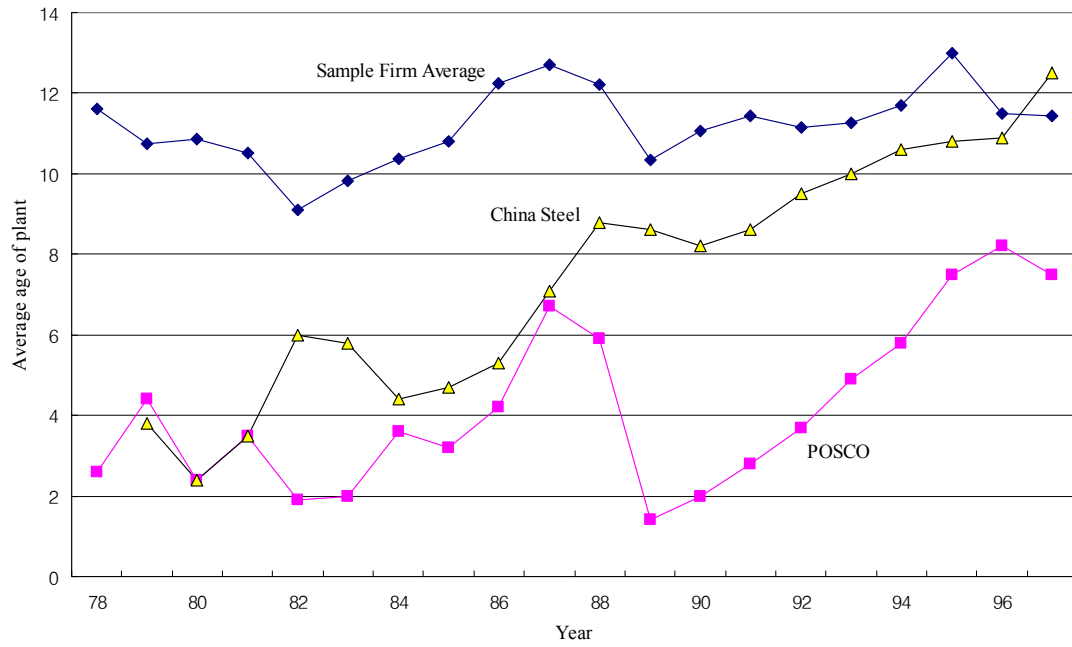
Appendix A: List of Firms

country	firm	country	firm
U.S.	ARMCO STEEL	Germany	KLOCKNER-WERKE
	BETHLEHEM STEEL		KRUPP
	CARPENTER TECH		KRUPP AG HOESCH-RUPP
	CHAPPARAL STEEL		MANNESMANN
	FLORIDA STEEL		PEINE-SALZGITTER
	INLAND STEEL		THYSSEN
	LACLEDE STEEL	Mexico	ALTOS HORNOS
	LTV		TAMSA
	LUKENS STEEL	South Africa	HIGHVELD
	NATIONAL STEEL		ISCOR
	NORTHWESTERN STEEL	Argentina	ACINDAR
	NUCOR STEEL	Australia	BHP
	USX CORP	Austria	VOEST-ALPINE
	WHEELING-PITTSBURGH	Belgium	COCKERILL
Japan	KAWASAKI STEEL	Brazil	CSN
	KOBE STEEL	Finland	RAUTARUUKKI
	NIPPON STEEL	France	USINOR-SACILOR
	NISSHIN STEEL	India	TATA IRON & STEEL
	NKK	Italy	ITALSIDER
	SUMITOMO METALS	Luxembourg	ARBED
	TOA STEEL (TOSHIN)	South Korea	POSCO
	TOKYO STEEL	Sweden	SVENSKT STAL
Canada	ALGOMA	Taiwan	CHINA STEEL
	DOFASCO	The Netherlands	HOOGOVENS
	SIDBEC	U.K.	BRITISH STEEL
	STELCO	Venezuela	SIVENSA

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