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Abstract

This paper comprises two major parts. The first part examines major stages in the historical development of Taiwan's steel industry, with a particular focus on changing production capacity, technological development, and involvement in international trade. Recent trends in production, apparent consumption, and trade are analyzed, including a detailed review in major sub-sectors of the steel industry. The second part of this paper applies data envelopment analysis (DEA) and measures the relative operating efficiency of eight major Taiwan steel-making firms in terms of sales revenues. A single composite output and three inputs (labor, capital, and intermediate materials) are considered, and main sources of production inefficiency are examined. The estimated technical efficiency score was relatively high, 87.3 percent on average. Compared with the scale of production, the pure technical efficiency had less importance as a source of inefficiency. Overall, the application of DEA approach suggests that the development of a more efficient and competitive steel-making sector should be encouraged in Taiwan and that there should be more emphasis on improving scale efficiency, rather than pure technical efficiency.

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1. Introduction

Unlike in Japan and Korea where employment of steel plants contracted sharply between the early 1990s and 2001, employment of steel plants in Taiwan increased throughout the period. If steel production is measured in tonnage, then that in China, Korea and Taiwan grew during this period. While China achieved very rapid growth over the 1991-2001 period, more than doubling its crude steel production in tonnage, Taiwan also achieved 57 percent growth over the same period. Largely because of the rapid growth in China, the share of the four Northeast Asian economies in the global output of crude steel increased from 29.7 percent in 1991 to 37.2 percent in 2001 (International Iron and Steel Institute, various years).[1]

It is generally recognized that the driving forces for changes in the shape of the production map have been the transformation of production technology and trade liberalization. On the one hand, the global production type of crude steel has gradually shifted from the basic oxygen furnace (BOF) method to the electronic arc furnace (EAF) method. In addition, the importance of trade in steel products has been increasing, with the ratio of world exports to world production rising from 27.9 percent in 1991 to 39.8 percent in 2001 (Industrial Technology Information Services, 2001). This reflects continuous improvements in production efficiency, leading to enhancements in international competitiveness. Over the past years, Taiwan's steel industry also followed this trend of increasing productivity and internationalization.

In addition, the estimation of efficiency is quite important because accurate productivity measurement can provide useful information in enhancing competitiveness (Demura, 1995; Ray and Kim, 1995; Grossman, 1980; Hayes and Clark, 1986; Rimmer, 1989). Hence, the second part of this paper applies data envelopment analysis (DEA), a non-parametric, linear programming technique, to measure the technical, allocative, and overall efficiency of eight major Taiwan steel-making firms in terms of their sales revenue. A single composite output and three inputs (labor, capital, and intermediate materials) are considered, and main sources of production inefficiency are examined. Results of this empirical estimation show that the technical efficiency score was relatively high in Taiwanese steel firms, 87.3 percent on average. Compared with the scale of production, the pure technical efficiency was a less important source of inefficiency. Overall, the application of DEA approach suggests that the development of a more efficient and competitive steel-making sector should be encouraged in Taiwan and

[1] The ranking of major steel-producing countries in 2002 (in tonnage) was as follows: China, Japan, the United States, Russia, South Korea, Germany, Ukraine, Brazil, India, Italy, France and Taiwan.

that there should be more emphasis on improving scale efficiency, rather than pure technical efficiency. The next section examines the development and current status of the steel industry in Taiwan, with a particular focus on changing production capacity, technological development, and involvement in international trade. Because improving productivity and efficiency of steel makers is a key factor for the future success of Taiwan's steel industry, in section 3 the relative performance of major steel-making plants/firms is estimated using DEA. Section 4 summarizes the main findings of the paper and provides possible extensions to this study.

2. The Development and Current Status of Taiwan Steel Industry

A. Development Stages

Table 1 summarizes three different development stages of the steel industry in Taiwan. In the mid-1970s, Taiwan's steel industry was still in its incipient stage. Low quality steel bars and rods were major products, and they were produced by numerous local small steel firms. The first integrated steel plant, China Steel, was built in 1974 after Taiwan launched the 'Ten Major Development Projects' to establish heavy industries to stimulate economic growth. At the same time, many local mini-mills (such as Kao Hsing Chang and Yieh Hsing) increased their investment to expand production capacity. In subsequent years, China Steel also started to expand its plant capacity. Taiwan steel industry was relying on both BOF and EAF methods. Because mini-mills generally have the advantage of low level of minimum efficiency scale, their capacity costs and manufacturing costs are typically significantly lower than those of integrated producers.[2] However, the integrated producers shifted to producing more complex steel products, such as flat-rolled, structural, and tubular steel products, and they could meet all product quality requirements. In contrast, mini-mills tended to produce lower quality but specialized shape product, such as bars and structural steel.[3] As a consequence, China Steel was leading Taiwan's steel industry into the growth stage during 1976-1985 (Lee, Jing, and Tien, 1993).

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[2] Integrated steel plants can produce carbon steel sheets at a cost of US$1,000/ton at capacity of 2 million tons per annum. Mini-mills, however, has reduced capacity to 1 million tons per annum. Moreover, the capacity cost of a mini-mill can be as low as a half that of a basic oxygen plant. A modern basic oxygen plant, with an annual production capacity of 3 million tons, could require an investment of up to US$5 billion. For the details, see Crompton (2001).

[3] Mini-mills can easily change the production rates depending on demand and enjoy substantial transport cost advantages due to their proximity to the market. Integrated plants are located away from the markets due to their production size.

Table 1: Different Development Stages of the Steel Industry in Taiwan

Periods	Stages	Steel plants	Main products	Trade orientation
Before 1975	Introductory	EAF Ship Breaking	Bar, Rod	Import Substitution
1976-1985	Growth	EAF/BOF Ship Breaking	Plates, Sheet	Export Orientation
1986-2001	Expansion	EAF BOF	Special Alloy	Direct Exports

Source: Industrial Technology Information Services (2001).

After the mid-1980s, increases in demand for steel both domestically and abroad, particularly in Asia, as well as expansions of downstream industries domestically (such as motorcycles, steel furniture, metal products, and machine tools), further induced the development of the steel industry in Taiwan. Meanwhile, many downstream industries rapidly relocated its production base and increased their investment in Mainland China. As a result, instead of the previous import substitution pattern in the steel industry, many steel firms shifted to exporting their products abroad. However, some inefficient plants with poor management were closed down after the Asian financial crisis of 1997-1998 and the intensifications of dumping investigations abroad, particularly in the United States. Moreover, increases in product varieties have created demand-supply imbalances in the domestic market. About 30-40 percent of domestic demand for carbon and alloy steel relies on imports while Taiwan is almost self-sufficient in stainless steel. One of the challenges faced by Taiwan's steel industry is dealing with excess demand for upstream crude steel products and excess supply of downstream steel products (Tu, Liu and Tien, 2000).

B. Recent Trends in Production, Employment and Trade in Steel

As reported in Table 2, Taiwan's crude steel production increased from 10.5 million tons in the early 1990s to 17.3 million tons in 2001. It thus increased by 65 percent during the decade and Taiwan became the 13th largest steel producer in the world in 2001. At the same time, Taiwan's apparent consumption of finished steel increased steadily from 15.4 million tons in 1990-1992 to 21.0 million tons in 2000 before sharply falling to 17.7 million tons in 2001. In addition, per capita consumption of finished steel in Taiwan is about 900-950 kilograms, which is one of the highest in the world.

Table 2: Annual Indicators for Taiwan's Steel Industry

Indicator	1990-1992	1993-1996	1997	1998	1999	2000	2001
Taiwan Steel and Iron Association Data (million tons)							
Production	10.47	11.88	16.06	16.97	15.44	16.90	17.26
Apparent Consumption	18.52	23.45	21.33	20.63	21.17	21.27	17.82
Imports	8.87	11.06	13.92	12.78	14.86	14.58	9.47
Exports	7.55	3.98	5.13	6.03	7.65	8.28	7.99
Wholesale price index (1995=100)	94.51	94.69	94.71	94.15	85.17	88.63	84.26
Earnings Survey Data							
Number of Employees	72,896	82,064	83,285	83,519	82,357	82,946	80,534
Earnings/Employee (NT$)	422,562	490,314	523,614	529,395	561,316	596,228	613,420
Earnings/Employee (US$)	16,114	18,365	18,243	15,824	17,394	19,088	18,142
Exports (value from Statistics Canada, price from Taiwan Economic Data Center)							
Million current US$	1,162	1,329	3,294	3,630	4,011	5,209	4,426
Quantity (1995=100)	53.13	95.67	161.72	220.11	272.64	312.27	335.77
Export Price in US$ (1995=100)	85.71	89.05	79.80	64.63	57.65	65.36	51.65
Imports (value from Statistics Canada, price from Taiwan Economic Data Center)							
Million current US$	3,104	3,927	3,955	3,297	3,506	3,993	2,562
Quantity (1995=100)	69.11	94.07	90.31	82.13	96.92	103.63	69.71
Import Price in US$ (1995=100)	93.36	93.13	90.38	82.85	74.65	79.52	75.85

Sources: Central Bank of China (various years); Directorate-General of Budget, Accounting and Statistics (various years); Statistics Canada (2003); Taiwan Economic Data Center (2003); Taiwan Steel and Iron Association (2002).

In monetary terms, the gross output in steel firms also increased from 333 billion NT dollars (US$12.4 billion) in 1991 to 523 billion NT dollars (US$15.5 billion) in 2001 (Table 3). Following the same trend, the overall revenue of steel firms increased from 363 billion NT dollars in 1991 to 583 billion NT dollars in 2001. Furthermore, the value added of steel firms in constant 1996 prices was 89 billion NT dollars (US$3.3 billion), accounting for 1.6 percent of GDP in 1991. It increased to 147 billion NT dollars (US$4.3 billion) in 2001, with the GDP share of steel in constant prices remaining at 1.6 percent.

As for the number of employees, it increased from 72,900 in 1990-1992 to 80,500 in 2001 (Table 2). The earnings per employee also increased from US$16,100 in 1990-1992 to US$18,100 in 2001. In addition, the value added per employee in steel firms increased from 1.03 million NT dollars (US$38,500) in 1991 to 1.21 million NT dollars (US$35,900) in 2001 (Table 3). The compensation per employee also climbed from 404,000 NT dollars (US$15,100) to 476,000 NT dollars (US$14,100).

Table 3: Basic Indicators for Taiwan's Steel Industry from the Industrial and Commercial Census

Indicator	1991	1996	2001
Gross output of steel firms, billion current US$	12.428	18.176	15.476
Gross output of steel firms, billion current NT$	333.269	499.087	523.190
Gross output of steel plants, billion current NT$	322.285	497.782	509.380
Revenue of steel firms, billion current NT$	362.751	553.398	583.105
Value added of steel firms, billion current US$	3.406	4.253	3.871
Value added of steel firms, billion current NT$	91.328	116.774	130.878
- % of GDP	1.90	1.52	1.38
Value added of steel firms, billion 1996 NT$	89.367	116.774	146.753
- % of GDP	1.62	1.52	1.57
Employment of steel firms, number	88,531	91,259	107,918
- % of total	1.05	1.01	1.27
Employment of steel plants, number	87,956	92,208	105,649
Value added/employee of steel firms, current US$	38,471	46,601	35,873
Value added/employee of steel firms, current NT$	1,031,588	1,279,584	1,212,754
Value added/employee of steel firms, 1996 NT$	1,009,442	1,279,584	1,359,861
Compensation/employee of steel firms, current US$	15,056	18,863	14,068
Compensation/employee of steel firms, current NT$	403,734	517,935	475,596
Labor compensation of steel firms, % of value added	39.14	40.48	39.22
Depreciation of steel firms, % of value added	17.73	18.07	24.03
Other operating surplus of steel firms, % of value added	12.16	18.87	32.73
Profits of steel firms, % of value added	30.97	22.58	4.02
Profits of steel firms, % of revenue	7.80	4.76	0.90
Foreign sales by steel firms, billion current US$	1.091	2.138	3.015
Foreign sales by steel firms, billion current NT$	29.244	58.712	101.924
- % of total sales	8.85	11.66	20.61

Sources: Central Bank of China (various years); Directorate-General of Budget, Accounting and Statistics (1993, 1998, 2004); Taiwan Economic Data Center (2003).

Among four major components of value added, the share of labor compensation was very stable at 39-40 percent in 1991, 1996, and 2001. The share of depreciation was relatively stable, moving within the 18-24 percent range. By contrast, the shares of profits and other operating surplus fluctuated substantially. For example, the shares of profits dropped from 31 percent in 1991 to 4 percent in 2001 (Table 3). This might be largely explained by a substantial fall in demand for steel in 2001 as Taiwan experienced –2.2 percent growth in real GDP, the first time it registered a negative growth rate since official statistics became available in 1952 (Council for Economic Planning and Development, 2003).

The import and export volume of steel were 8.9 million tons and 7.6 million tons, respectively, in 1990-1992 and then rose to 9.5 million tons and 8.0 million tons in 2001 (Table 2). Overall, the volume of steel trade of Taiwan varied substantially and did not always exhibit an increasing trend. Similar trends are evident in Taiwan's trade figures in monetary units, as reported in the bottom half of Table 2. In 1991, the foreign sales by steel firms was 29.2 billion NT dollars (US$1.1 billion), representing 8.9 percent of total sales (Table 3). In 2001, the foreign sales increased to 102 billion NT dollars (US$3.0 billion), accounting for 20.6 percent of total sales.

As shown in Table 4, the value of Taiwan's steel exports increased sharply from US$1.2 billion in 1990-1992 to US$4.4 billion in 2001. The value of imports increased moderately from US$3.1 billion in 1990-1992 to US$4.0 billion in 2000, before falling to US$2.6 billion in 2001 because of the recession (Table 5). Asia became the largest export destination for Taiwanese steel producers, accounting for about 75 percent of total exports in recent years, and the Asian share in total imports to Taiwan was also quite high, about 65 percent. Corresponding to the rapid increase in Taiwan's investment to China, China has become one of the most important exporting partners for Taiwan. For example, in 2001 Taiwan exported US$2.2 billion of steel products to China, representing more than 40-fold increase during the decade of 1991-2001. On the import side, Japan has remained the leading source country for Taiwan. Taiwan's steel imports from Japan were between US$1.4 billion and US$1.7 billion during the early 1990s to 2000, but fell to $1.1 billion in 2001 as Taiwan's recession caused imports to fall sharply that year.

In addition to changing geographical distribution of trade in total steel (classified by Standard Industrial Trade Classification as SITC 67), there were various changes in major sub-categories of steel products. SITC 674, containing steel products of universals, plates and shapes, accounted for about 75 percent of total Taiwanese steel exports in 1999-2001 (Table 4). Although SITC 674 was an important import category as well (Table 5), its share in imports was nearly matched by SITC 672 (consisting largely of ingots) in recent years. As for other major steel categories at the 3-digit SITC level, the export values of both SITC 671 (consisting of pig iron and sponge iron) and SITC 672 were significantly lower than their import values. In 2001, the export value of pig iron and sponge iron was about US$19 million, far less than the corresponding import figure (US$365 million). Similarly, the exports value of ingots was US$37 million in 2001, whilst the imports were US$706 million. Taiwan was a net of importer of SITC 673 (bars, rods, angles and shapes) in 1990-1992 but became a net export of these steel products after 1999. For SITC 674 and 678 (tubes, pipes and fittings), exports were significantly

Table 4: The Value of Taiwan's Steel Exports by Commodity and Destination (US$ millions)

Indicator	1990-1992	1993-1996	1997	1998	1999	2000	2001
All Steel (SITC 67)	1,162	2,168	3,294	3,630	4,011	5,209	4,426
Asia	846	1,782	2,767	2,650	3,089	3,889	3,657
China	51	415	888	1,059	1,467	2,004	2,244
Japan	347	408	458	356	372	438	301
Korea	63	64	70	30	90	129	81
Europe	112	127	113	466	244	343	200
North America	169	207	308	414	591	851	459
United States	152	186	271	364	502	713	396
Pig iron, sponge iron, etc. (SITC 671)	17	20	7	6	9	9	19
Asia	17	19	6	5	8	8	19
China	0	2	1	2	2	3	5
Japan	1	0	0	1	1	0	2
Korea	3	0	0	0	0	0	6
Europe	0	0	0	0	1	0	0
North America	0	0	0	1	0	0	0
United States	0	0	0	1	0	0	0
Ingots, primary forms, etc. (SITC 672)	112	129	57	16	33	78	37
Asia	24	45	16	14	31	76	35
China	2	7	8	10	27	66	33
Japan	4	26	0	0	0	0	0
Korea	3	3	0	0	0	3	0
Europe	83	84	40	2	0	1	0
North America	1	0	0	1	1	1	2
United States	1	0	0	1	1	1	2
Bars, rods, angles, shapes (SITC 673)	91	259	383	376	390	443	414
Asia	82	214	280	266	292	291	316
China	4	53	85	107	136	140	162
Japan	6	3	4	4	8	7	7
Korea	8	22	28	12	26	33	26
Europe	1	7	14	28	20	26	20
North America	3	34	77	70	65	106	62
United States	3	33	69	64	58	94	55
Universals, plates, sheets (SITC 674)	624	1,263	2,233	2,571	2,972	3,923	3,316
Asia	576	1,191	2,084	1,959	2,401	3,073	2,914
China	33	243	649	780	1,125	1,566	1,844
Japan	278	316	389	303	317	371	245
Korea	47	38	40	15	63	91	48
Europe	1	5	8	375	169	261	122
North America	38	58	105	201	369	538	240
United States	37	56	98	181	310	442	212
Tubes, pipes, fittings (SITC 678)	214	329	405	463	399	498	416
Asia	79	187	224	271	207	251	213
China	7	68	84	94	98	126	109
Japan	32	31	36	28	24	34	30
Korea	1	0	0	1	1	1	1
Europe	24	25	37	44	41	40	36
North America	98	83	94	102	116	159	119
United States	84	68	77	85	100	137	96

Source: Statistics Canada (2003).

Table 5: The Value of Taiwan's Steel Imports by Commodity and Source (US$ millions)

Indicator	1990-1992	1993-1996	1997	1998	1999	2000	2001
All Steel (SITC 67)	3,104	4,255	3,955	3,297	3,506	3,993	2,562
Asia	1,917	2,476	2,361	2,417	2,216	2,449	1,697
China	75	207	329	405	365	572	306
Japan	1,450	1,720	1,611	1,473	1,417	1,461	1,071
Korea	201	256	224	336	264	235	201
Europe	424	776	712	345	343	394	303
North America	146	148	122	77	49	111	73
United States	79	123	73	52	45	67	67
Pig iron, sponge iron, etc. (SITC 671)	153	294	344	299	449	567	365
Asia	44	139	205	218	231	296	198
China	12	42	85	90	87	112	82
Japan	9	62	79	104	122	148	98
Korea	0	0	4	5	4	3	4
Europe	27	21	13	9	6	8	7
North America	5	13	34	10	2	6	7
United States	5	13	34	10	2	6	7
Ingots, primary forms, etc. (SITC 672)	451	874	836	812	999	1,287	706
Asia	173	330	268	441	393	488	358
China	37	123	155	226	209	378	159
Japan	28	52	33	117	90	48	149
Korea	8	13	21	44	10	3	1
Europe	52	171	136	30	54	99	49
North America	26	22	37	21	3	40	7
United States	17	17	3	1	3	2	4
Bars, rods, angles, shapes (SITC 673)	735	742	571	394	343	380	273
Asia	468	466	377	305	254	261	197
China	14	7	14	9	6	6	3
Japan	354	341	274	229	176	188	145
Korea	61	55	38	55	37	37	27
Europe	100	166	138	59	55	74	49
North America	15	16	9	9	7	9	8
United States	9	11	5	6	4	5	7
Universals, plates, sheets (SITC 674)	1,465	1,953	1,748	1,259	1,324	1,343	884
Asia	1,009	1,256	1,166	1,030	1,035	1,083	694
China	5	2	2	6	3	7	2
Japan	878	1,060	998	819	847	892	549
Korea	114	163	138	193	172	146	124
Europe	197	351	348	169	170	168	156
North America	82	78	19	11	11	13	11
United States	32	65	9	9	11	12	10
Tubes, pipes, fittings (SITC 678)	218	256	318	415	267	284	208
Asia	166	199	241	333	200	221	158
China	3	18	47	50	36	43	39
Japan	142	156	171	162	133	142	98
Korea	5	10	9	22	24	25	14
Europe	31	35	54	60	46	33	26
North America	13	12	17	17	17	28	22
United States	13	11	16	17	16	28	22

Source: Statistics Canada (2003).

greater than imports in recent years. Substantial portions of trade in these products were intraregional (exported to and imported from Asia).

3. An Estimation of Efficiency of Taiwan Steel-Making Firms

A. Data Envelopment Analysis

There are generally three main approaches to measuring productivity: index number approach, linear programming method, and econometric estimation (Sudit, 1995). Data envelopment analysis (DEA) is a non-parametric linear programming approach to frontier estimation that measures the relative performance of organizational units with multiple inputs and outputs (Bowling, 1998; Boussofiane, Dyson, and Thannsoulis, 1991).

The basic idea of DEA is to identify the most efficient decision-making unit (DMU) among all DMUs. In an input-oriented model, the most efficient DMU produces a given amount of output with the smallest possible amount of inputs. By constructing a piecewise linear convex isoquant benchmark, all observed data points that lie either on or below the production frontier can be compared. Efficient DMUs are identified by efficiency scores that equal to unity, whereas inefficient DMUs have DEA scores less than unity.

The DEA approach is used in this paper because of its several advantages. First of all, the DEA approach is a non-parametric method that does not require an explicit specification of functional forms that relates inputs to outputs (in contrast, regression-based methods require postulating a specific functional form for a production function). Moreover, the DEA allows more than one production functions, and its solution can be interpreted as a local approximation to whatever function is applicable in the neighborhood of the coordinate values formed from the outputs and inputs of examined DMUs. No matter what production technology is used (such as basic oxygen furnace and electronic arc furnace in steel making), the DEA approach can estimate and compare relative efficiencies of DMUs. Secondly, unlike the conventional management accounting and production methods, the construction of production frontiers by the linear programming method does not require price data (Sudit, 1995). Finally, DEA is a procedure that fits a curve to the convex hull of the data points and estimates the maximal outputs for given levels of inputs. Firms that produce the maximal outputs are defined as efficient while those with lower outputs (for identical levels of inputs) are relatively inefficient. However, even though the DEA method can be applied to analyzing small samples of steel-making firms, its results can be very sensitive to outlying observations that could bias estimates of efficiency scores (Sudit, 1995).

Farrell (1957) proposed that firm's efficiency contains two components: technical efficiency (TE), which reflects the ability to obtain maximal output from a given set of inputs, and allocative efficiency (AE), which reflects the ability to use the inputs in optimal proportions, given their respective prices. These two measures are combined to provide a measure of overall efficiency EE, with $EE = TE \cdot AE$. Following this idea, Charnes, Cooper, and Rhodes (1978) suggested an input orientation model to measure the technical efficiency frontier, assuming constant returns to scale (CRS model). Banker, Charnes, and Cooper (1984) developed a variable returns to scale (VRS) model to measure not only pure technical efficiency, but also scale efficiency, when some DMUs are operating at an optimal scale of production. Since the technical efficiency (TE_{CRS}) score is equal to the multiplication of pure technical efficiency (TE_{VRS}) and scale efficiency (SE), the scale efficiency score can be easily derived as $SE = TE_{CRS} / TE_{VRS}$.

This DEA methodology can be formulated as a fractional linear programming problem. For each DMU_j, the efficiency measure E_j is the ratio of a weighted sum of outputs Y_{jn} to a weighted sum of inputs X_{jm}. If a DMU uses M inputs to produce N outputs, with U_n and V_m representing the weights associated with each output and input, the CRS DEA model is specified by:

$$\underset{U_n V_m}{Max}\ E_j = \frac{\sum_{n=1}^{N} U_n Y_{jn}}{\sum_{m=1}^{M} V_m X_{jn}} \qquad m = 1, 2, ..., M; n = 1, 2, ..., N$$

$$s.t.\ \frac{\sum_{n=1}^{N} U_n Y_m}{\sum_{m=1}^{M} V_m X_{rm}} \leq 1 \quad U_n, V_m \geq 0$$

This implies that estimated values for U_n and V_m has two properties: first, the efficiency measure of the jth DMU is maximized; second, all efficiency measures must be less than or equal to one. The optimal input and output weights that maximize efficiency scores are determined for each DMU. However, since this formulation has an infinite number of solutions, it is typically modified to the following multiplier form:

$$\underset{U_n V_m}{Max}\ E_j = \sum_{n=1}^{N} U_n Y_{jn}$$

$$s.t.\ \sum_{n=1}^{N} U_n Y_m - \sum_{m=1}^{M} V_m X_{rm} \leq 0$$

$$\sum_{m=1}^{M} V_m X_{jm} = 1$$

As long as the number of constrained equations exceeds the number of variables in the primal linear programming problem, this problem can be solved by the following dual form:

$$Min\ TE = \theta_0 - \varepsilon(\sum_{m=1}^{M} S_{jn}^{-} + \sum_{n=1}^{N} S_{jn}^{+})$$

$$s.t. \sum_{r=1}^{R} \lambda_r X_{rm} - \theta X_{jm} + S_{jn}^{-} = 0$$

$$\sum_{r=1}^{R} \lambda_r Y_{rn} - Y_{jn} - S_{jn}^{+} = 0$$

$$\lambda_r \geq 0, S_{jn}^{+} \geq 0, S_{jn}^{-} \geq 0$$

where θ_0 represents the maximum proportion of input levels which can be employed to produce output levels for the unit r_0, ε is a non-archimedean quantity, the value of which is very minute, and S_{jn}^{+} and S_{jn}^{-} are the input slacks and the output slacks, respectively. Note that for the *j*th DMU, the output slacks will be equal to zero only if $\sum_{r=1}^{R} \lambda_r Y_{rn} - Y_{jn} = 0$, while the input slacks will be equal to zero only if $\sum_{r=1}^{R} \lambda_r X_{rm} - \theta X_{jm} = 0$ for the given optimal values of θ and λ. Furthermore, the pure technical efficiency can be derived by adding constraint $\sum_{r=1}^{R} \lambda_r = 1$, which turns the CRS model into the VRS model.

B. Empirical Results

This study uses annual data on outputs and inputs of Taiwan's steel industry from 200 plant-level compilations in the industrial and commercial census for 4-digit classes: iron and steel refining manufacturing (C2311) and steel rolling manufacturing (C2313). The eight largest steel plants/firms in terms of sales revenue were selected to analyze and compare their relative performance.[4] A single composite output and three inputs—labor, capital and materials—were considered. All variables were provided by the Directorate-General of Budget, Accounting and Statistics. The labor input was measured by the number of workers. The capital input was the fixed capital of individual steel plants. The material input was measured by direct charges paid for intermediate materials consumed during the year. The output quantity was a weighted index of shipped quantities of different steel products.

Table 6: Empirical Results of Efficiency Scores for Steel Refining Units (C2311)

Name	*TE*	*PE*	*SE*	Scale Type
Unit 1	0.886	1.000	0.886	DRS
Unit 2	0.899	1.000	0.899	DRS
Unit 3	0.551	0.722	0.763	DRS
Unit 4	1.000	1.000	1.000	
Unit 5	0.748	0.805	0.930	IRS
Unit 6	0.897	1.000	0.897	IRS
Unit 7	1.000	1.000	1.000	
Unit 8	1.000	1.000	1.000	
Mean	0.873	0.941	0.922	

Note: *TE* = technical efficiency from CRS DEA

PE = technical efficiency from VRS DEA

SE = scale efficiency = *TE* / *PE*

Table 6 reports the technical, pure technical, and scale efficiency scores for the largest eight steel-making units of C2311. In this group, the mean technical efficiency score was quite high (0.873), implying that these steel-making firms could have produced the same level of output using of 87.3 percent of the input actually used. The efficiency differences among the eight units were not too large and all the efficiency scores

[4] It was impossible to identify steel firm (plant) in this data set, so that no panel data could be constructed to compare their productivity changes over time.

exceeded 0.5. Among these units, three were categorized as fully efficient, while five were categorized as inefficient. As discussed above, the technical efficiency is the product of the pure technical efficiency and the scale efficiency. Therefore, the relative magnitudes of these scores provided evidence about efficiency sources. The mean of scale efficiency was 0.922 and was slightly lower than the mean of technical efficiency from variable returns to scale (*PE* = 0.941), suggesting that the pure technical efficiency was less important than scale efficiency in determining inefficiency among the steel-making firms. In other words, inefficiency in steel-making firms was more due to inappropriate returns of scale rather than to over-utilization of inputs or the incorrect selection of input combinations. These results suggest that the scales of investments in these steel-making firms need to be reexamined.

Table 7: Empirical Results of Efficiency Scores for Steel Rolling Units (C2313)

Name	*TE*	*PE*	*SE*	Scale Type
Unit 1	0.016	0.065	0.240	IRS
Unit 2	0.056	0.793	0.070	IRS
Unit 3	0.134	0.543	0.248	IRS
Unit 4	1.000	1.000	1.000	
Unit 5	0.083	0.996	0.083	IRS
Unit 6	0.378	1.000	0.378	IRS
Unit 7	0.142	0.184	0.775	IRS
Unit 8	0.067	1.000	0.067	IRS
Mean	0.235	0.698	0.358	

Note: *TE* = technical efficiency from CRS DEA

PE = technical efficiency from VRS DEA

SE = scale efficiency = *TE* / *PE*

Table 7 reports the technical, pure technical, and scale efficiency scores of the C2313 sample group. Under the assumption of constant returns to scale, the mean technical efficiency score for the eight largest plants/firms in this group was quite low (0.235). This implies that these firms could have produced the same level of output using only 23.5 percent of the inputs they actually used. The technical efficiency ranged between rather low levels of 0.016 and 0.378. Among these steel-making units, only one was categorized as efficient while the other seven were categorized as inefficient. In addition, the mean of scale efficiency (*SE* = 0.358) was lower than the mean of technical efficiency under the assumption of variable returns to scale (*PE* = 0.698), indicating that the scale inefficiency was a very important source of inefficiency of these steel-making plants/firms. In order to improve their performance, the scale of investment among the steel-making plants needs to be reexamined.

4. Concluding Remarks

This paper dealt with two major topics. The first part of the paper examined the historical development and current status of the steel industry in Taiwan, pointing out that the production volume of both integrated mills and mini-mills have increased rapidly, while the production types of crude steel have gradually shifted toward electronic arc furnaces, reaching the current market share of around 41 percent. Moreover, the ratio of world exports to world production for steel products has also increased. At the same time, the industry has been affected by imbalances between supply and demand (including excess demand in the upstream crude steel market and excess supply in the downstream steel market), and these imbalances continue to be significant at present. This problem could be solved by improving productivity and efficiency of Taiwanese steel-making firms. Therefore, the second part of the paper applied the DEA approach to estimate the relative performance of two groups of major steel-making plants/firms in Taiwan. The empirical results suggests that the development of a more efficient and competitive steel industry should be encouraged in Taiwan and that inefficient steel-making plants/firms should make an effort to improve their performance, focusing especially on their scale efficiency, rather than pure technical efficiency.

There are several limitations and possible extensions for this study. First, only major steel-making plants/firms were included in the efficiency analysis. To provide a more complete picture of Taiwan's steel industry, the research could be extended to include estimations of the relative efficiency of all firms by the stochastic frontier approach. Second, future evaluation of productivity performance could be approached using more detailed characteristics of data. For example, the labor input might be distinguished by the type of employees (such as contractors, maintenance personnel, and non-production employees). Similarly, the future analysis could make distinctions in the degree of vertical integration and product range of examined companies. Finally, since DEA does not suggest causes or remedies of identified inefficiency, internal audit or follow-up reviews would be needed to define the types of operating changes that could improve estimated inefficiencies.

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