Estimation of Production-factor Redundancy of Manufacturing Industries in Japan

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ABSTRACT: We investigated the production-factor redundancy of 24 manufacturing industries in Japan using Data Envelopment Analysis (DEA) with prefectural data. First, we estimated the returns-to-scale of production by industry and selected the most suitable DEA model for each industry. Next, we implemented DEA on prefectural economies by industry and learned the following: 1) large redundancies provably exist in key industries (including various processing and assembly ones) ; 2) the total estimated redundancy on the size of the workforce is 2.5 million persons or more, and it is 13 trillion yen or more for the capital equipment amount.

Keywords: Manufacturing Industries, Production Function, DEA, Productive Efficiency, Production-factor Redundancy.
JEL Classification Numbers: P47, R11, R30.

1. Introduction: background and purpose

Currently, the Japanese economy is in the process of making macro changes in its industrial structure. However, since this conversion is not being efficiently conducted, it is greatly decreasing the workforce, fueling unemployment, and lowering the operation status of manufacturing facilities. In the following, we examine the Japanese economy's current situation using related economic indexes.

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First, in Table 1, the numbers of employed, unemployed, and the unemployment rate chronologically indicate the following: 1) the employment condition improved in the mid-2000s but it has worsened recently, 2) a decrease of over 1 million employed persons occurred, 3) the total number of unemployed exceeds 3 million, 4) the index for those 15 to 64 years old (core of labor force) has especially worsened.[1] Next, the size of the workforce in the major divisions of the Japan Standard Industry Classification (JSIC)[2] is chronologically indicated in Table 2. However, the table consists of agriculture, forestry, and those industries whose workforce share exceeds 5% of the economy's total amount. This table shows the following: 1) manufacturing, wholesale/retail, and service industries are the three major industries for employment, 2) there are notable decreases in the manufacturing, service, and construction industries in recent years, but limited increases in the medical, health care, and welfare fields. Next, the size of the workforce and the unemployment rate of each region in recent years are indicated (Table 3). The unemployment rate is soaring in the Hokkaido, Tohoku, Kinki, Shikoku, Kyushu, and Okinawa regions, and the employment situation is worsening in all other regions. Last, we indicate the chronological change of the real capacity utilization ratio of manufacturing facilities (estimation) in Figure 1. The ratio peaked at 80% in the 2000s and has declined to about 60%.

Based on the above background, we research and analyze the employment core in the Japanese economy, that is, its manufacturing industry (Table 2), to acquire the basic data for future industrial employment policies. First, we estimate each production function of 24 industries based on the medium divisions of JSIC. Next, with our estimation results, we implement a Data Envelopment Analysis (DEA)[3] for the regional economies of 47 prefectures and evaluate the efficiency by prefecture and industry. Also, we quantitatively clarified the size of the workforce and the amount of capital equipment that are considered redundant. Although the results of this study may be viewed critical about the Japanese economy and its manufacturing industries, we believe that this knowledge will provide quantitative benchmarks for industrial employment policies and contribute to the effective conversion of its industrial structure.

The rest of this paper is organized as follows. In Section 2, we explain previous examples with DEA and the DEA models used in our analysis.

In Section 3, we explain the 24 industry divisions, number the prefectures, and show the ten regional divisions. In Section 4, the production function is estimated by industry. In Section 5, we implement DEA by industry based on the estimated production function. In Section 6, we provide concluding remarks and future works.

Table 1 Changes in Work force Size, Number of Unemployed, and Unemployment Rate

(ten thousand persons ((1), (3)); % ((2), (4)))

	Actual figures						Change from previous year					
	Unemployed persons (1)			Unemployment rate (2)			Unemployed persons (3)			Unemployment rate (4)		
Year	Total	15-64	65-	Total	15-64	65-	Total	15-64	65-	Total	15-64	65-
2000	320	308	11	4.7	4.9	2.2	3	2	0	0.0	0.0	0.0
2001	340	327	12	5.0	5.2	2.4	20	19	1	0.3	0.3	0.2
2002	359	348	11	5.4	5.6	2.3	19	21	−1	0.4	0.4	−0.1
2003	350	338	12	5.3	5.5	2.5	−9	−10	1	−0.1	−0.1	0.2
2004	313	304	10	4.7	4.9	2.0	−37	−34	−2	−0.6	−0.6	−0.5
2005	294	284	10	4.4	4.6	2.0	−19	−20	0	−0.3	−0.3	0.0
2006	275	264	11	4.1	4.3	2.1	−19	−20	1	−0.3	−0.3	0.1
2007	257	246	10	3.9	4.0	1.8	−18	−18	−1	−0.2	−0.3	−0.3
2008	265	253	12	4.0	4.2	2.1	8	7	2	0.1	0.2	0.3
2009	336	321	15	5.1	5.3	2.6	71	68	3	1.1	1.1	0.5

Note: "15-64" and "65-" denote 15-64 years old and 65 years old or more.
Source: Labor force survey: Ministry of Internal affairs and Communications.

Table 2 Changes in Workforce Size by Main Industries

(Both genders)

Year	Total	AF	Const	Manu	Trans	WR	EDA	MC	Ser
	Actual figures (ten thousand persons)								
2002	6,330	268	618	1,202	324	1,145	358	474	844
2009	6,282	242	517	1,073	326	1,097	338	621	923
	Percentage by industry (%)								
2002	100.0	4.2	9.8	19.0	5.1	18.1	5.7	7.5	13.3
2009	100.0	3.9	8.2	17.1	5.2	17.5	5.4	9.9	14.7

Note: AF, Const, Manu, Trans, WR, EDA, MC, and Serv denote agriculture and forestry, construction, manufacturing, transport, wholesale and retail trade, eating, drinking, and accommodations, medical, health care and welfare, and others.
Source: Labor force survey: Ministry of Internal affairs and Communications.

Table 3 Changes in Workforce Size and the Unemployment Rate by Regions

(Both genders)

Region	1	2	3	4	5	6	7	8	9	10
Year	Hokkaido	Tohoku	Southern-Kanto	Northern-Kanto, Koshin	Hokuriku	Tokai	Kinki	Chugoku	Shikoku	Kyushu, Okinawa
	Employed persons (ten thousand persons)									
2007	264	469	1816	520	283	796	998	376	197	693
2008	263	462	1820	517	281	794	995	370	193	691
2009	260	451	1798	507	275	776	977	367	189	681
	Unemployment rate (%)									
2007	5.0	4.7	3.6	3.2	3.4	2.7	4.4	3.6	3.9	4.7
2008	5.1	4.7	3.8	3.5	3.4	2.9	4.5	3.6	4.5	4.6
2009	5.5	6.0	4.8	4.7	4.5	4.6	5.7	4.7	5.0	5.4

Source: Labor force survey: Ministry of Internal affairs and Communications.

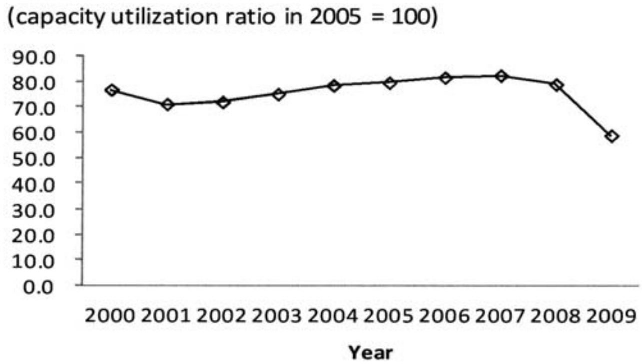


Figure 1 Changes in Real Capacity Utilization Ratio: manufacturing

Note: Our estimate used "Index of Capacity Utilization Ratio (manufacturing)" and "Real Capacity Utilization Ratio (estimation value)."
Sources: Indexes of Business Conditions (Cabinet Office) and http://www.meti.go.jp/statistics/tyo/iip/qa.html.

2. Explanation of DEA model

2.1 Comparison of this study's position with previous researches

The following analyses evaluated the efficiencies of some industries in some countries by DEA. Cooper *et al.* (1995) implemented DEA on textile, chemical, and metallurgical industries in China using data from 1966-1988. Yamada *et al.* (1995) used the data from 1976-1991 in Japan to investigate the total of manufacturing industries, electrical machinery, precision machinery, textiles, iron and steel, and chemical industries. However, to the best of our knowledge, only Yoshida (2012) comprehensively analyzed the state of a country's entire economy and each region by DEA (details explained in Section 2.2). Using the data of 1990, 1995, and 2000, he implemented DEA on 12 industries, including all industries (except for public service) based on the major divisions of JSIC. Hence, we overcame the problems in that analysis and studied the state of Japan's entire manufacturing industry of each region as comprehensively as possible. This study directly follows Yoshida (2012) and implements DEA on more detailed categories:[4] 24 manufacturing industries based on the medium divisions of JSIC. Therefore, based on Yoshida (2012), the rest of this section describes our basic concept of DEA, the utilization examples, the DEA models, and the productive efficiency.

2.2 Basic concept and utilization examples of DEA

First, we explain the basic concept of DEA. If several decision making units (DMUs) have similar inputs and outputs, we compare the efficiency among them by the ratio scale of each one. The ratio scale is defined as the weighted sum of the outputs divided by the weighted sum of the inputs,[5] assuming that their activities are efficient and yield larger output with less input. Second, we link the activities of the most efficient DMUs to introduce the *efficient frontier*. Based on it, we evaluate the performances of the other DMUs. The above is the basic principle of DEA. In other words, although the parametric analyses are based on an average image of the objectives, DEA, which is a non-parametric analysis based on improved DMUs, produces two analysis results of each DMU using the efficient frontier. One is the efficiency[6] (called the Defficiency value) on the activity, and the other is its improvement measure.

Next, we explain DEA's merits and demerits, as shown in Okuda and Take (2006) and Viton (1997). DEA does not demand that researchers specify the function form between inputs and outputs in advance, unlike other parametric analyses. Therefore, the arbitrariness of this point cannot be avoided. Moreover, DEA has no statistical process, which allows analysis without a large sample. Since DEA does not predict a sample's observational errors, when a sample includes inappropriate observations, the DEA results are inevitably and largely distorted. Additionally, researchers who use DEA also risk selecting input and output variables that are theoretically and statistically inappropriate, because DEA does not theoretically assume a relation between the input and output variables or test them statistically.[7]

Finally, we explain the preceding analyses by DEA. Despite its above imperfections, it has been used to evaluate various DMUs, ranging from private enterprises to public institutions, because it can deterministically evaluate the efficiency of each one and show an improvement measure for it. The following analyses are examples of DEA implementation: Ferrier and Lovell (1990) on 575 American financial institutes in 1984; Viton (1996) on 217 American bus services (both private and public) in 1990; Drake and Simper (2000) on the English and Welsh police forces between 1992 and 1996; Ueda (2006) on Japanese paper manufacturing companies between 1990 and 2004; Miyara and Fukushige (2002a) on 48 Japanese public bus services in 1999; Miyara and Fukushige (2002b) on police forces in 47 Japanese prefectures between 1975 and 1999; Nozao (2007) on 606 regional Japanese public hospitals in 2001. Moreover, XU (2005) used DEA to measure the total factor productivity (TFP) and the technical and efficiency manufacturing changes between 1993 and 2002 in 25 prefectures in China. Finally, Yoshida (2012) implemented DEA on 12 industries in Japan, which are based on the major divisions of JSIC, with the estimation results of 12 production functions using data of 1990, 1995, and 2000. His analysis investigated nine prefectures from such productive areas in the Japanese economy as Tokyo, Aichi, and Osaka.

The following are the main contributions of our study in comparison with Yoshida (2012) :

1) We estimated the production function of each industry and modified the data.
2) We disregarded the assumption that the depreciation rate for capital equipment through all industries is consistent.
3) Since we analyzed 24 manufacturing industries based on the medium divisions of JSIC, our analysis is more detailed and more suitable for the DEA characteristics.
4) We expanded our analysis subjects to all 47 Japanese prefectures.
5) We could more easily examine the economic conditions throughout Japan, because our analysis results are totaled by region, such as Southern Kanto

and Kinki.

2.3 DEA models used in this study

First, we explain the CCR model (input-oriented model),[8] which is a basic model of DEA, assuming constant returns-to-scale (CRS) on returns-to-scale (RTS). If we are concerned about DMU O, we can denote this model as the following two-phase linear programming problem:

First objective function $\quad \min \quad \theta$ (1)

Second objective function $\quad \min \quad -\mathbf{es_x} - \mathbf{es_y}$ (2)

$$s.t. \quad \theta \mathbf{x_o} = \mathbf{X\lambda} + \mathbf{s_x}, \tag{3}$$

$$\mathbf{y_o} = \mathbf{Y\lambda} - \mathbf{s_y}, \tag{4}$$

$$\theta \geq 0, \boldsymbol{\lambda} \geq 0, 0 \leq \mathbf{e\lambda} \leq \infty, \mathbf{S_x} \geq 0, \mathbf{S_y} \geq 0, \tag{5}$$

where the $\mathbf{e}$ s are the vectors of (1, … , 1) : their dimensions are m(number of inputs), s (number of outputs), and n (number of DMUs) in order of appearance, $s_x = (s_x^1, \cdots, s_x^m)^T$ denotes an input slack vector whose every element shows the excess on every input, $s_y = (s_y^1, \cdots, s_y^s)^T$ denotes an output slack vector whose every element shows the shortfall on every output, $\theta \in [0,1]$ denotes a variable showing the Defficiency value of DMU O (lesser θ means lesser efficiency), $x_o = (x_o^1, \cdots, x_o^m)^T$ is the input vector of DMU O, X is a $m \times n$ matrix composed of the input vectors of all DMUs, $\lambda = (\lambda_1, \cdots, \lambda_n)^T$ is a non-negative vector for creating a non-negative linear combination of the activities of the referred DMUs, $y_o = (y_o^1, \cdots, y_o^s)^T$ is the output vector of DMU O, and Y is a $s \times n$ matrix composed of the output vectors of all DMUs.

The solution of this model relating to DMU O is (θ^*, λ^*, s_x^*, s_y^*), which is obtained by solving the above problem. If $\theta^* = 1$ and without slack ($s_x^* = 0$, $s_y^* = 0$), such a DMU is efficient, otherwise it is inefficient. If DMU O is inefficient,

$$E_o = \{ j \mid \lambda_j > 0, j = 1, \ldots, n \} \tag{6}$$

is its reference set. In addition, after solving the above problem, an improvement measure of DMU O is finally as follows:

$$\mathbf{x_o} \Rightarrow \theta^* \mathbf{x_o} - \mathbf{s_x^*}, \mathbf{y_o} \Rightarrow \mathbf{y_o} + \mathbf{S_y^*}. \tag{7}$$

Next, we account for the decreasing returns-to-scale (the DRS) and increasing returns-to-scale (the IRS) models. In them, the range of $\mathbf{e}\boldsymbol{\lambda}$ is changed as follows:

$$0 \le \mathbf{e\lambda} \le 1, \text{for DRS model}; 1 \le \mathbf{e\lambda} \le \infty, \text{for IRS model} . \tag{8}$$

Since the upper bound in this inequality is 1 for the DRS model, the scaling up of DMUs is not allowed in the assumed production possibility set; however, scaling down is free. On the other hand, since the lower bound in this inequality is 1 for the IRS model, scaling down is not allowed; scaling up is free.[9]

2.4 Productive efficiency

Taking account of the unit cost of each production factor (each input) and the manufacturing cost, and following Yoshida (2012),[10] we disintegrate the productive efficiency:

$$PE = AE \times TE = AE \times [SE \times PTE],$$

where PE, AE, TE, SE, and PTE respectively denote productive, allocation, technical, scale, and pure technical efficiencies.

Certainly, if the DMUs with which we are concerned are enterprises, researchers cannot ignore AE to minimize their production costs.[11] However, we analyze the efficiency of the technique that produces macro output (value added) from inputs (labor and capital equipment) in each industry in each prefecture (Section 3). Therefore, we define TE in the above equation as the productive efficiency,[12] as Yoshida (2012).

3. Industry divisions, numbering prefectures, and region divisions

3.1 Industry divisions

The following are the industry divisions in our analysis. We used 24 industries based on the medium divisions in the manufacturing group of JSIC (Table 4).

Table 4 24 manufacturing industries

Type No.	No.	Industry
3	1	Food
3	2	Beverages, tobacco, and food
3	3	Textile mill products, except apparel and other finished products made from fabrics and
3	4	Apparel and other finished products made from fabrics and similar materials
1	5	Lumber and Wood products, except furniture
3	6	Furniture and fixtures
1	7	Pulp, paper, and paper products
3	8	Printing and allied industries
1	9	Chemical and allied products
1	10	Petroleum and coal products
1	11	Plastic products, except otherwise classified
1	12	Rubber products
3	13	Leather tanning, leather products, and fur skins
1	14	Ceramic, stone, and clay products
1	15	Iron and steel
1	16	Non-ferrous metals and products
1	17	Fabricated metal
2	18	General machinery
2	19	Electrical machinery, equipment, and supplies
2	20	Information and communication electronics equipment
2	21	Electronic parts and devices
2	22	Transportation
2	23	Precision instruments and machinery
3	24	Miscellaneous manufacturing

Note: Type 1, 2, and 3 denote primary materials, processing and assembly, and livelihood industries, respectively.
Source: JSIC (the 11th revised edition), Manufacturing Census: Ministry of International Trade and Industry, 1996.

3.2 Numbering prefectures and region divisions

Next, we number the prefectures and show the region divisions in Tables 5 and 6.

Table 5 Numbering Prefectures

1	Hokkaido	11	Saitama	21	Gifu	31	Tottori	41	Saga
2	Aomori	12	Chiba	22	Shizuoka	32	Shimane	42	Nagasaki
3	Iwate	13	Tokyo	23	Aichi	33	Okayama	43	Kumamoto
4	Miyagi	14	Kanagawa	24	Mie	34	Hiroshima	44	Oita
5	Akita	15	Niigata	25	Shiga	35	Yamaguchi	45	Miyazaki
6	Yamagata	16	Toyama	26	Kyoto	36	Tokushima	46	Kagoshima
7	Fukushima	17	Ishikawa	27	Osaka	37	Kagawa	47	Okinawa
8	Ibaraki	18	Fukui	28	Hyogo	38	Ehime		
9	Tochigi	19	Yamanashi	29	Nara	39	Kochi		
10	Gumma	20	Nagano	30	Wakayama	40	Fukuoka		

Table 6 Region Divisions

No.	Region	Prefecture
1	Hokkaido	1
2	Tohoku	2, 3, 4, 5, 6, 7
3	Southern Kanto	11, 12, 13, 14
4	Northern Kanto, Koshin	8, 9, 10, 19, 20
5	Hokuriku	15, 16, 17, 18
6	Tokai	21, 22, 23, 24
7	Kinki	25, 26, 27, 28, 29, 30
8	Chugoku	31, 32, 33, 34, 35
9	Shikoku	36, 37, 38, 39
10	Kyushu, Okinawa	40, 41, 42, 43, 44, 45, 46, 47, 48

Note: The above classification follows "Labor force survey."

4. Estimation of production function and selection of DEA model

4.1 Estimation method for production function

The selection of DEA models depends on which relationship is assumed among CRS, DRS, and IRS on RTS between inputs and output. This selection is critical because it affects the DEA results. However, we cannot determine which relationship is statistically adequate in DEA. Many previous DEA researches have been concurrently conducted under each assumption (see, e.g., Miyara and Fukushige, 2002a, b; Nozao, 2007). But in this case, it remains unclear under which assumption efficiency the improvement measures of DMUs should be considered. Moreover, as pointed out in Okuda and Take (2006), the significance of the input variables cannot be statistically tested. As a result, researchers might use variables with a theoretical problem.

Therefore we estimated the production function[13] in each industry and determined the RTS state to select an adequate model among CCR, DRS, and

IRS, following Yoshida (2012)'s procedure. The following are the contents:

(1) We analyzed regression model A (Model A) using the workforce (Labor) and the amount of capital equipment (Capital) as independent variables that represent production factors and the amount of value added (Value) as a dependent variable.
(2) We analyzed regression model B (Model B) using Capital divided by Labor as an independent variable and Value divided by Labor as a dependent variable.
(3) Using the residual sum of squares (RSS) obtained from the results of (1) and (2), the homogeneity of degree one (this equals CRS) of each production function was tested with F statistic.[14]
(4) When the homogeneity of degree one was accepted in (3), we adopted CRS on RTS. When it was rejected, the sum of the coefficient estimates on Labor and Capital was adopted as RTS. That is, the type of DEA model used in Section 5 was determined.

4.2 Regression model

Next we explain the above two regression models. First, we start with Model A. Assuming the Cobb-Douglas production function for each industry, Model A is obtained by logarithmic conversion:

$$\log Y_t^{ji} = C^j + \alpha \log L_t^{ji} + \beta \log K_t^{ji} + u_t^{ji}, \text{for } j = 1,\ldots,24, i = 1,\ldots,47, \quad (9)$$

where Y denotes Value, L denotes Labor, K denotes Capital, and C is a constant term indicating the level of technology. In addition, j, i, and t denote the industry, the prefecture, and the year index, respectively, and u denotes an error term satisfying the standard assumption[15] of the linear regression model.

Next, we explain Model B, which is based on the assumption of the homogeneity of degree one: $\alpha + \beta = 1$ in Equation (9). Under this assumption, we divide each dependent and independent variable of Equation (9) by L and obtain this model:

$$\log\left(Y_t^{ji} / L_t^{ji}\right) = C^j + \beta \log\left(D_t^{ji} / L_t^{ji}\right) + u_t^{ji}. \quad (10)$$

Since Yoshida (2012) failed to acquire the data for the capital equipment for industries that are based on the major divisions of JSIC and his analysis subjects, he assumed that capital equipment is a function of the depreciation rate, which is consistent throughout all industries. As a result, there is a probability that a discrepancy occurred between the actual production function and his estimation. On the other hand, since our analysis subjects are the industries based on the medium divisions of JSIC, we can use the data for the capital equipment itself, as explained in Section 4.3. Therefore, our analysis avoids the problem encountered by Yoshida (2012).

4.3 Data used for estimation of production functions

We obtained the estimation data from the "Manufacturing census: Report by Industry."[16] Table 7 shows descriptive statistics for each indicator by industry:

(1) The data are annual for the sample years of 2002-2007.
(2) We used data from establishments with 30 or more employees, because the data for the capital equipment amount are not reported for those with fewer than 30 employees.
(3) The data for the added value and capital equipment amounts are adjusted for the changes in the price level by GDP deflator (2000 year = 100) (reported by Japanese National Economic Accounting, Cabinet Office).
(4) In Table 8, the number of observations differs by industry, because some of the yearly and prefecture/industry data are missing from the "Manufacturing census."[17]

Table 7 Descriptive Sample Statistics

Industry	Variable	Mean	Std. Dev.	Min	Max	No. of obs.	Industry	Variable	Mean	Std. Dev.	Min	Max	No. of obs.
1	Labor	17,187	13,975	2,630	62,152	275	13	Labor	619	476	115	2,473	97
	Capital	120,551	128,275	436	900,725			Capital	54,432	381,075	71	3,763,718	
	Value	156,910	144,251	13,925	554,935			Value	4,655	4,429	271	20,134	
2	Labor	1,421	1,124	159	5,808	262	14	Labor	3,439	3,426	219	19,584	281
	Capital	46,862	52,084	523	368,094			Capital	92,352	242,789	1,944	3,790,326	
	Value	64,631	73,696	809	413,586			Value	54,406	64,046	611	392,591	
3	Labor	1,806	2,063	133	10,807	241	15	Labor	3,978	5,030	179	25,374	257
	Capital	48,813	243,101	1,154	3,424,844			Capital	137,734	213,280	169	879,632	
	Value	16,001	19,280	807	96,321			Value	111,467	159,211	373	734,432	
4	Labor	2,650	1,830	153	8,600	265	16	Labor	2,784	2,512	259	11,457	217
	Capital	37,572	168,657	233	1,996,524			Capital	65,959	99,542	1,107	656,865	
	Value	12,592	10,604	541	74,904			Value	47,825	54,747	1,176	405,847	
5	Labor	1,041	837	109	4,789	254	17	Labor	7,276	6,999	152	33,155	276
	Capital	52,723	305,091	328	3,749,588			Capital	94,073	193,398	1,001	2,494,893	
	Value	10,971	9,920	325	47,392			Value	82,772	83,883	992	377,704	
6	Labor	1,415	1,419	111	8,443	236	18	Labor	15,007	14,621	1,217	74,291	270
	Capital	57,182	347,775	504	4,912,849			Capital	141,110	177,561	775	1,522,677	
	Value	13,992	13,330	481	70,645			Value	213,907	237,484	6,486	1,320,430	
7	Labor	3,074	3,159	202	18,048	278	19	Labor	9,839	9,752	152	43,986	274
	Capital	94,339	156,819	921	1,480,453			Capital	78,599	104,076	1,145	1,091,927	
	Value	48,405	54,866	376	290,317			Value	130,879	152,100	641	733,595	
8	Labor	3,990	6,644	254	46,117	276	20	Labor	5,278	5,688	138	27,246	220
	Capital	44,283	82,099	690	640,905			Capital	35,162	41,658	166	209,647	
	Value	47,770	87,211	1,878	548,921			Value	88,758	104,967	305	495,186	
9	Labor	6,941	7,160	178	33,907	258	21	Labor	10,048	5,354	758	29,680	268
	Capital	168,363	190,890	934	783,096			Capital	120,981	102,085	214	793,550	
	Value	252,872	296,234	1,215	1,281,714			Value	147,777	114,643	845	1,019,793	
10	Labor	956	676	163	2,551	83	22	Labor	17,981	35,994	210	282,665	261
	Capital	112,884	103,501	657	480,286			Capital	209,060	460,451	858	3,468,018	
	Value	49,822	58,262	376	257,648			Value	335,478	823,513	422	7,405,132	
11	Labor	6,122	6,549	202	40,988	276	23	Labor	3,070	2,878	110	11,265	219
	Capital	118,931	513,064	1,253	7,633,079			Capital	26,296	44,951	242	411,369	
	Value	73,661	90,392	469	512,026			Value	39,650	41,895	496	174,613	
12	Labor	2,516	2,066	127	9,956	219	24	Labor	1,893	1,921	179	10,825	174
	Capital	71,727	285,204	490	3,003,378			Capital	19,286	24,984	551	166,529	
	Value	34,291	34,277	372	175,697			Value	26,073	32,490	107	200,942	

Note: The Labor unit is a person. The unit for Capital and Value is one million yen.
Source: Manufacturing census (report by industry) : Ministry of Economy, Trade and Industry and Japanese National Economic Accounting: Cabinet Office.

4.4 Estimation results and selection of DEA model

Table 8 shows the OLS estimation results using the pooled data from the sample years of 2002-2007. We utilized the White estimator[18] as the true variance estimator of the least squares estimator when the assumption of homoscedasticity was statistically rejected at the 5% significance level. This table shows the following facts.

(1) In the regressions of industries 3, 5, 6, 9, 10, 13, 15, 16, 18, 20, and 21, the significance of capital is not accepted, even at the 10% level. From the viewpoint of econometrics, capital should not be used as a DEA input in Section 5 concerning these industries.

(2) For all the industries except 4, 13, 16, and 21, the RTS is IRS; for industry 4, it is DRS; for industries 13, 16, and 21, it is CRS. Hence, the IRS model is

used in Section 5 for all industries except 4, 13, 16, and 21; we used the DRS model for industry 4 and the CCR model for industries 13, 16, and 21.

Table 8 Estimation Results of Production Functions

Model	Industry Number	1	2	3	4	5	6	7	8	9	10	11	12
A	Constant term	0.109	0.595	1.211***	2.416***	1.159***	1.361***	1.130***	0.917***	1.305***	−0.069	0.656***	0.093
		(0.066)	(1.302)	(6.244)	(7.687)	(4.941)	(6.634)	(4.853)	(7.985)	(4.698)	(−0.070)	(3.781)	(0.456)
	Ln (Labor) (1)	1.123***	0.932***	1.079***	0.752***	1.084***	1.071***	1.061***	1.124***	1.219***	1.521***	1.086***	1.240***
		(39.520)	(8.797)	(38.387)	(18.380)	(20.107)	(29.492)	(29.655)	(44.578)	(30.928)	(7.108)	(34.114)	(27.326)
	Ln (Capital) (2)	0.073***	0.327***	0.032	0.112***	0.056	0.038	0.094***	0.042*	0.018	0.002	0.088***	0.051*
		(3.751)	(4.866)	(1.281)	(4.440)	(1.572)	(1.567)	(3.308)	(1.973)	(0.576)	(0.022)	(3.586)	(1.775)
	Adj.R^2	0.938	0.637	0.916	0.712	0.860	0.879	0.863	0.964	0.901	0.562	0.949	0.897
	LM het.	4.723	13.631	23.617	0.033	8.776	6.839	1.374	0.139	47.656	0.059	30.231	8.304
B	Constant term	1.977***	2.405***	2.034***	1.349***	2.102***	2.119***	2.405***	2.178***	3.347***	2.899***	2.107***	2.211***
		(49.220)	(9.923)	(30.947)	(37.897)	(22.280)	(33.319)	(24.888)	(35.937)	(26.437)	(5.902)	(26.802)	(24.196)
	Ln (Capital/Labor)	0.061***	0.329***	0.010***	0.133***	0.052	0.032	0.064**	0.043	−0.010	0.114	0.076**	0.073*
		(2.889)	(4.560)	(0.415)	(5.068)	(1.414)	(1.214)	(2.169)	(1.636)	(−0.249)	(1.045)	(2.415)	(1.916)
	Adj.R^2	0.034	0.127	−0.003	0.155	0.022	0.005	0.013	0.006	−0.004	0.001	0.029	0.024
	LM het.	0.005	5.035	0.070	50.423	15.813	4.866	2.724	0.054	0.265	0.069	0.060	0.255
	White	yes	yes	yes		yes	yes			yes		yes	yes
	No. of Obs.	275	262	241	265	254	236	278	276	258	83	276	219
	F statistics	110.871	17.778	25.244	16.128	23.561	16.462	31.201	148.021	86.365	11.602	110.783	95.230
	H_0: CRS	rejected	rejected	rejected	rejected	rejected	rejected	rejected	rejected	rejected	rejected	rejected	rejected
RTS	(1)+(2)	1.196	1.260	1.110	0.865	1.140	1.109	1.155	1.165	1.238	1.523	1.174	1.291
	Type	IRS	IRS	IRS	DRS	IRS	IRS	IRS	IRS	IRS	IRS	IRS	IRS

Model	Industry Number	13	14	15	16	17	18	19	20	21	22	23	24
A	Constant term	1.535***	0.234	0.795***	2.886***	1.314***	1.127***	0.224	0.447	1.970***	1.274***	1.257***	0.194
		(3.270)	(0.873)	(3.978)	(6.791)	(10.331)	(6.804)	(1.340)	(1.432)	(3.483)	(6.820)	(5.532)	(0.683)
	Ln (Labor) (1)	1.014***	1.093***	1.245***	0.806***	1.049***	1.138***	1.150***	1.233***	1.023***	1.092***	1.053***	0.995***
		(10.729)	(22.831)	(26.008)	(6.870)	(30.824)	(34.012)	(34.849)	(21.395)	(12.393)	(30.240)	(22.479)	(12.787)
	Ln (Capital) (2)	0.035	0.151***	0.024	0.122	0.057*	0.011	0.078***	0.018	0.035	0.048	0.076**	0.237***
		(0.851)	(4.825)	(0.745)	(1.214)	(1.911)	(0.431)	(2.733)	(0.402)	(0.986)	(1.539)	(1.976)	(4.037)
	Adj.R^2	0.733	0.881	0.881	0.607	0.956	0.927	0.922	0.838	0.642	0.937	0.881	0.845
	LM het.	18.949	7.798	2.719	0.006	21.098	8.614	7.353	0.910	12.268	6.059	0.341	2.755
B	Constant term	1.839***	2.230***	2.835***	2.369***	2.235***	2.511***	2.280***	2.472***	2.493***	2.552***	2.237**	1.721***
		(24.834)	(17.836)	(24.167)	(9.332)	(27.948)	(46.073)	(30.851)	(25.884)	(34.408)	(32.012)	(27.126)	(12.677)
	Ln (Capital/Labor)	0.035	0.112***	0.026	0.112	0.046	0.002	0.035	0.006	0.036	0.025	0.069*	0.293***
		(0.831)	(2.658)	(0.620)	(1.129)	(1.340)	(0.085)	(0.915)	(0.126)	(1.002)	(0.739)	(1.716)	(4.676)
	Adj.R^2	0.001	0.044	−0.002	0.013	0.012	−0.004	0.001	−0.005	0.001	−0.001	0.009	0.108
	LM het.	7.174	0.575	8.291	20.782	0.257	1.055	2.698	1.619	3.583	0.164	0.000	3.491
	White	yes	yes	yes	yes	yes	yes	yes		yes	yes		
	No. of Obs.	97	281	257	217	276	270	274	220	268	261	219	174
	F statistics	0.587	79.597	85.500	1.925	54.803	56.946	110.096	45.977	1.448	57.679	21.270	30.721
	H_0: CRS		rejected	rejected		rejected	rejected	rejected	rejected		rejected	rejected	rejected
RTS	(1)+(2)	1.049	1.244	1.269	0.928	1.106	1.149	1.228	1.252	1.058	1.140	1.129	1.232
	Type	CRS	IRS	IRS	CRS	IRS	IRS	IRS	IRS	CRS	IRS	IRS	IRS

Note: (1) The t-statistics are reported in parentheses. LM het indicates the value of the homoscedasticity test statistic. White means using the White heteroscedasticity consistent estimator. H_0 indicates the null hypothesis.

(2) *** and ** indicate statistical significance at 1% and 5% levels, respectively.

5. Implementation of DEA and the results

5.1 Productive efficiency (Defficiency)

Based on the results in Section 4, we implemented DEA for 47 prefectures by industry. However, note the following:

(1) Since our aim is to provide quantitative benchmarks for planning the

macro conversion of the industrial structure, our main subject is the most current year of 2007.

(2) Table 9 indicates the prefectures removed from our analysis because of missing data and the percentage distribution of each variable for each industry. Although this table shows that some industries have many prefectures removed from the analysis, the share of these industries is only about 10% of the whole concerning Labor on which we are focusing. Therefore, considering the data constraint, we think that we can qualitatively and quantitatively examine almost all Japanese manufacturing industries with the data in our study.

(3) We indicate the DEA results using the ten regional divisions shown in Table 6. We used this indication method for the following reasons: 1) Due to space constraints, it is difficult to show all of the results for 47 prefectures; 2) however, to understand the economic situation throughout the country and compare regions, it is more beneficial to indicate the results at the region level than the prefecture one

First, we consider efficiency. The productive efficiency of each region and industry is indicated in Table 10. However, note that each figure here is the average of the prefectures belonging to each region. It is difficult to see more than the properties of each industry from this table. Therefore, in Figure 2, we indicate the productive efficiency of each region by industry type in 2002 and 2007, and, from this figure, the following nationwide and chronological tendencies are observed:

(1) Throughout all industry types, western Japan is more efficient than eastern Japan.

(2) The comparative positions among regions in 2002 and 2007 are maintained except for some regions.

(3) In Type 1 industries (basic material), Shikoku, Kyushu, Okinawa, Southern Kanto, and Koshin regions, in Type 2 industries (processing and assembly), Shikoku, Kyushu, Okinawa, and Kinki regions, and, in Type 3 industries (livelihood), Shikoku, Southern Kanto, and Kinki regions have high efficiency.

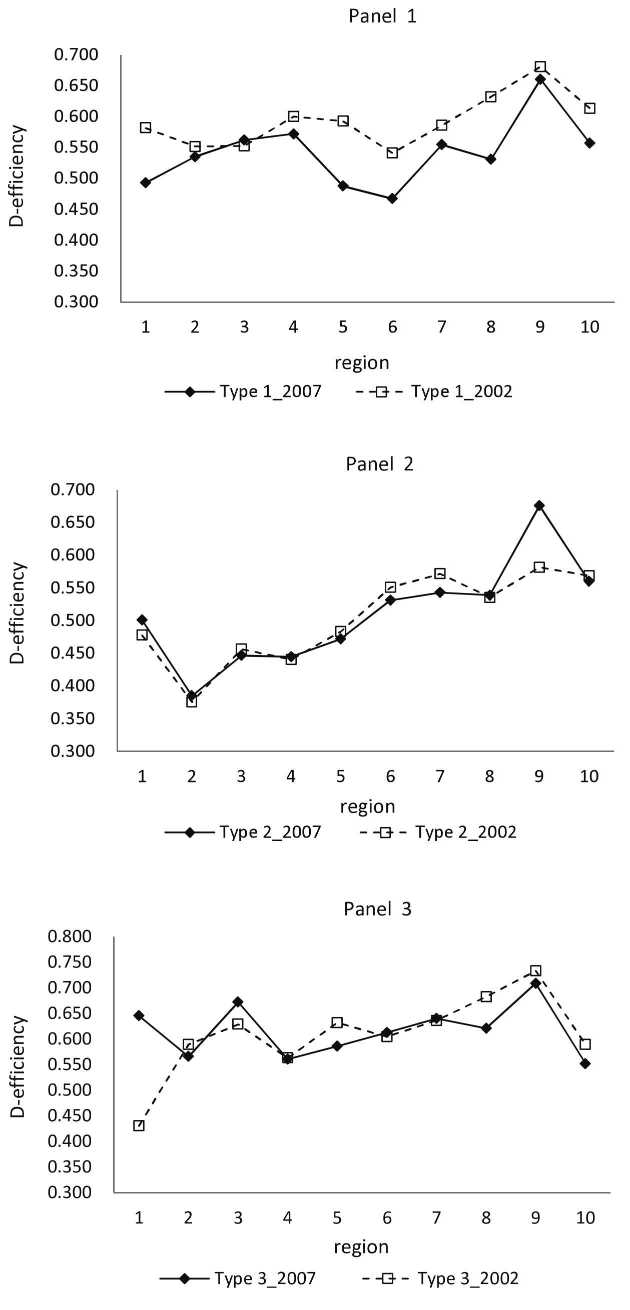
Table 9 Omitted Prefectures and Percentage Distribution of Variables by Industry (2007)

Industry	Omitted prefectures due to lack of data	Percentage distribution		
		Labor	Capital	Value
1		13.5%	8.0%	7.7%
2	18, 19	1.0%	2.8%	2.9%
3	2–4, 12, 31, 41, 47	1.1%	0.9%	0.6%
4		1.7%	0.5%	0.5%
5	2, 19, 39, 42, 47	0.7%	0.7%	0.5%
6	2, 3, 42, 43, 45–47	0.9%	0.6%	0.6%
7		2.3%	4.4%	2.2%
8		3.1%	2.5%	2.3%
9	31, 39	5.1%	10.7%	11.2%
10	2–7, 9–11, 15–22, 26, 29, 31–34, 36–39, 41–47	0.3%	2.6%	0.7%
11		5.1%	4.3%	3.8%
12	2, 17–19, 26, 31, 36, 39 ,42, 46, 47	1.7%	1.2%	1.4%
13	2, 4, 8–10, 14–19, 21, 22, 24, 25, 30–36, 38–40, 42–47	0.2%	0.1%	0.1%
14		2.7%	3.8%	2.8%
15	18, 45, 46	3.0%	8.5%	5.4%
16	30–32, 36, 39, 41, 42, 45–47	2.1%	3.5%	2.5%
17		5.7%	4.7%	3.9%
18	5, 47	12.3%	9.0%	11.6%
19		7.6%	4.7%	6.7%
20	30, 35–39, 41, 42, 44, 46, 47	3.4%	1.5%	3.9%
21	37, 47	7.8%	8.2%	7.4%
22	30, 47	15.2%	14.6%	18.5%
23	16, 24, 31, 35, 36, 38, 41, 42, 47	2.0%	1.1%	1.7%
24	2, 5, 8, 11, 12, 14, 16, 17, 20, 24, 26, 31, 32, 36–38, 40–43, 46, 47	1.4%	1.1%	1.4%
Sum		100.0%	100.0%	100.0%

Table 10 Productive Efficiency (D-efficiency) of Each Industry (2007)

Type	Industry	DEA model	Region 1	2	3	4	5	6	7	8	9	10
1	5	IRS	0.329	0.521	***0.718***	0.594	0.467	0.522	0.574	0.574	0.745	0.609
	7	IRS	0.840	0.816	0.831	0.716	0.836	0.657	***0.900***	0.583	0.675	0.820
	9	IRS	0.193	0.492	0.459	0.469	0.494	0.418	0.361	0.475	0.381	***0.558***
	10	IRS	0.274	—	0.923	***1.000***	—	0.419	0.467	0.428	—	0.412
	11	IRS	***0.955***	0.741	0.719	0.672	0.671	0.793	0.697	0.833	0.713	0.798
	12	IRS	***0.922***	0.655	0.551	0.589	0.495	0.467	0.566	0.579	0.855	0.636
	14	IRS	0.393	0.456	0.387	0.463	0.418	0.416	***0.613***	0.606	0.446	0.450
	15	IRS	0.301	0.347	0.250	0.400	0.262	0.190	***0.448***	0.355	0.467	0.451
	16	CCR	0.035	0.114	0.064	0.065	0.065	0.070	0.078	0.097	***0.733***	0.090
	17	IRS	0.687	0.673	0.719	0.753	0.681	0.720	0.840	0.780	***0.928***	0.748
2	18	IRS	0.560	0.378	0.433	0.381	0.443	0.440	***0.631***	0.598	0.568	0.554
	19	IRS	0.542	0.569	0.629	***0.756***	0.685	0.657	0.694	0.607	0.693	0.627
	20	IRS	***0.614***	0.192	0.355	0.283	0.529	0.342	0.415	0.408	—	0.536
	21	CCR	0.281	0.222	0.288	0.255	0.291	***0.561***	0.284	0.389	0.342	0.365
	22	IRS	0.432	0.505	0.680	0.559	0.419	0.722	0.703	0.687	***1.000***	0.743
	23	IRS	***0.578***	0.446	0.297	0.434	0.465	0.465	0.531	0.544	0.775	0.536
3	1	IRS	0.655	0.777	0.801	0.821	***0.910***	0.816	0.852	0.811	0.871	0.732
	2	IRS	0.191	0.450	0.320	0.331	0.467	0.407	0.570	0.592	***0.682***	0.338
	3	IRS	***1.000***	0.404	0.740	0.501	0.309	0.490	0.410	0.505	0.383	0.457
	4	DRS	***0.849***	0.696	0.741	0.450	0.510	0.690	0.608	0.550	0.723	0.563
	6	IRS	0.350	0.364	0.524	0.490	***0.624***	0.415	0.492	0.549	0.616	0.428
	8	IRS	***0.861***	0.714	0.789	0.678	0.594	0.771	0.773	0.757	0.696	0.744
	13	CCR	0.292	0.332	0.551	0.414	—	0.502	0.639	—	***1.000***	0.301
	24	IRS	***0.965***	0.790	0.910	0.801	0.688	0.813	0.777	0.583	0.698	0.851

Notes: (1) The value of efficiency is the average for all prefectures belonging to the region.
(2) The value of the region, whose efficiency is the highest, is in bold italics. The region, whose efficiency is the lowest, is underlined.



Note: The value of efficiency is the average for all industries belonging to the industry type and all prefectures belonging to the region.

Figure 2 Changes in Productive Efficiency of Each Industry Type (2002-2007)

5.2 Differences of each input

As in Section 4, the production-factor redundancies for each industry and region are indicated in Tables 11 (industries with labor and capital as inputs) and 12 (those with labor). However, note the following: 1) production-factor redundancy in DEA is the difference between the effective production-factor amount calculated by Equation (7) and the actual one; 2) each figure indicated in the tables is the sum of the redundancy of the prefectures belonging to each region; 3) these tables show the total figure of each production factor in all of Japan to help readers understand the severity level of the production-factor redundancy. These tables provide the following facts:

(1) Examining the situation by industry, we recognize a large labor redundancy of over 150,000 workers in industriy 1, 9, 18, 19, 21, and 22, which originally had many workers, and a large capital equipment redundancy over 1 trillion yen in industry 1, 2, 7, 14, 19, and 22, which originally had a large scale of capital equipment. These analysis results show that the redundancies have become more significant in Japan' s following main industries: food and beverage, paper and pulp, chemical engineering, steel, and machinery/appliance manufacturing.

(2) Examining the situation by region, we recognize a large redundancy in Southern and Northern Kanto, Koshin, Tokai, and Kinki regions, which originally had larger scale industries than the others. The total redundancy of labor is around 400,000 workers, and that of the capital equipment amount exceeds 2 trillion yen in each above region.

(3) In the grand total of all the industries, the labor redundancy exceeds 2.5 million workers and that of capital equipment exceeds 13 trillion yen. Considering the current unemployment condition and the real capacity utilization ratio of the manufacturing facilities reported in Tables 1-3 and Figure 1, these figures suggest that the Japanese economy must drastically convert its industrial structure.

Table 11 Difference on Each Input (2007) : 2 inputs (Labor and Capital)

(one thousand persons (Laber), one billion yen (Capital))

Region	Industry	1	2	4	7	8	11	12	14	17	19	22	23	24	Sum	Input Sum
1	Labor	−2	−2	−1	−1	−1	0	0	−1	−2	−1	−4	0	0	−35	98
2		−26	−3	−21	−2	−3	−6	−4	−10	−9	−20	−18	−14	−1	−137	296
3		−30	−6	−1	−5	−20	−11	−8	−13	−15	−20	−48	−21	0	−197	632
4		−16	−7	−3	−4	−4	−18	−5	−9	−10	−20	−40	−17	−2	−156	463
5		−3	−1	−7	−1	−4	−7	−1	−5	−14	−8	−11	−5	0	−68	182
6		−16	−6	−2	−12	−6	−19	−13	−26	−18	−35	−48	−11	−3	−213	973
7		−22	−5	−5	−2	−9	−14	−7	−11	−14	−29	−26	−12	−3	−158	542
8		−11	−2	−5	−3	−2	−2	−6	−6	−5	−9	−27	−2	−1	−79	250
9		−4	−1	−2	−5	−2	−2	0	−3	−1	−5	0	0	0	−25	98
10		−29	−8	−11	−2	−5	−6	−5	−18	−12	−23	−15	−2	0	−136	342
1	Capital	−140	−78	0	−105	−4	−1	0	−41	−15	−7	−73	−1	−1	−466	1, 097
2		−104	−98	−15	−61	−32	−33	−53	−142	−75	−121	−188	−46	−23	−990	2, 452
3		−308	−193	−4	−82	−232	−120	−99	−272	−227	−184	−677	−164	−3	−2, 564	7, 279
4		−185	−285	−10	−66	−47	−200	−57	−224	−136	−227	−499	−132	−23	−2, 091	5, 531
5		−13	−39	−20	−44	−55	−61	−9	−83	−95	−54	−89	−26	−3	−590	1, 604
6		−132	−157	−7	−390	−52	−202	−163	−461	−171	−225	−418	−48	−65	−2, 489	10, 700
7		−186	−267	−40	−28	−112	−221	−82	−305	−141	−246	−266	−81	−35	−2, 010	5, 992
8		−77	−43	−12	−119	−19	−17	−55	−130	−42	−46	−466	−9	−13	−1, 049	2, 834
9		−27	−33	−7	−114	−20	−32	−3	−121	−12	−32	0	−2	−1	−402	1, 363
10		−159	−230	−15	−40	−43	−48	−56	−270	−71	−103	−140	−21	−1	−1, 197	3, 134
Sum	Labor	−178	−40	−58	−36	−56	−85	−48	−102	−100	−168	−236	−85	−11	−1, 204	3, 876
	Capital	−1, 332	−1, 423	−129	−1, 048	−615	−934	−577	−2, 048	−985	−1, 244	−2, 817	−529	−166	−13, 847	41, 984
Input	Labor	839	63	107	142	193	318	101	164	355	473	944	122	54	3, 876	
Sum	Capital	6, 314	2, 197	359	3, 498	1, 965	3, 409	931	3, 021	3, 694	3, 717	11, 500	857	522	41, 984	

Note: The value of difference in each industry and each region is the sum for all prefectures belonging to the region. Input Sum shows the total number or amount of each input existing in all of Japan.

Table 12 Difference on Input (2007) : 1 input (Labor)

(one thousand persons)

Region	Industry	3	5	6	9	10	13	15	16	18	20	21	Sum	Input Sum
1	Labor	0	−3	−1	−3	−1	0	−3	−1	−2	−1	−5	−18	27
2		−1	−3	−3	−9	0	−2	−6	−11	−29	−28	−68	−158	221
3		−1	−1	−3	−36	−1	−1	−22	−19	−65	−41	−40	−230	370
4		−2	−2	−3	−14	0	0	−13	−22	−74	−30	−52	−213	312
5		−12	−1	−1	−13	0	0	−7	−9	−35	−6	−35	−120	178
6		−9	−4	−7	−32	−1	0	−27	−22	−81	−13	−20	−215	375
7		−9	−2	−9	−39	−2	−1	−25	−16	−74	−20	−33	−230	388
8		−3	−2	−2	−14	−1	0	−18	−7	−25	−4	−21	−98	177
9		−2	0	−1	−9	0	0	−1	−1	−10	0	−5	−29	56
10		−2	−2	−2	−10	0	0	−9	−4	−27	−2	−38	−97	160
Sum	Labor	−39	−21	−33	−178	−6	−5	−132	−111	−422	−144	−317	−1, 407	2, 265
Input Sum	Labor	67	45	56	317	14	10	185	123	757	208	482	2, 265	

Note: See note for Table 11.

6. Concluding remarks

In this study, we analyzed the production status of 24 manufacturing industries for 47 Japanese prefectures and acquired the following:

(1) IRS is recognized in 20 industries by estimating the production function.

(2) Each region in Western Japan shows relatively high performance through all industries. In basic material industries Shikoku, Kyushu,

Okinawa, Northern Kanto, and Koshin regions have high efficiency; in the processing and assembly ones, Shikoku, Kyushu, Okinawa and Kinki have high efficiency; and in the livelihood industries, Shikoku, Southern Kanto, and Kinki have high efficiency.

(3) Large production factor redundancies are found in such main industries as food and beverage, paper and pulp, chemical engineering, steel, machines, and appliances and in regions with large scale industries, such as Southern and Northern Kanto, Koshin, Tokai, and Kinki.

(4) Through all the industries, the total estimated redundancy on the size of workforce is 2.5 million persons or more, and that of capital equipment is 13 trillion yen or more.

Finally, the following are our future works. First, in DEA, each DMU is evaluated based on the efficiency frontier, which is determined by the DMUs that are regarded as the most effective under the relation of the inputs and outputs used in the analysis. Therefore, we must consider the factors that were not considered in our analysis to judge whether our production factor redundancies are appropriate. Next, to expand our analysis, data must also be acquired for regions and industries that were removed from our study and for establishments with fewer than 30 employees. Accomplishing these tasks will advance both industrial structure and employment policies in Japan.

1 15-24 years old workers are facing the worst conditions.

2 JSIC is defined by Ministry of Internal Affair and Communication, Government of Japan.

3 This method was developed by A. Charnes and W. W. Cooper who implemented an efficiency analysis by exchanging the process from inputs to outputs (Charnes *et al.*, 1978).

4 This detailed analysis is one future task pointed out in Yoshida (2012).

5 In DEA, the set of weights can vary with each DMU and the most favorable one can be applied to the concerned DMU. Larger weight can be applied to the items at which the DMU is good and less weight to those at which it is not good. However, the ratio scales of other DMUs must be calculated by the same weight set. After that, the efficiency of each DMU is relatively evaluated by the results.

6 We quote "Stochastic Frontier Analysis" as a parametric analysis to evaluate the efficiency of each object. For reference, see Aigner *et al.* (1977), Battese and Coelli (1995), etc.

7 Chalos and Cherian (1995) statistically checked the causality between inputs and output by regression analysis before implementing DEA.

8 In this analysis, we use not an output-oriented model but an input-oriented model to grasp the redundancies concerning inputs: labor and capital equipment. Moreover, see Cooper *et al.* (1978), Cooper *et al.* (2000) chs. 2 and 3, Tone (1993) chs. 2 and 3, etc. for the details of the CCR and output-oriented models.

9 See Cooper *et al.* (2000) chs. 4 and 5, Tone (1993) ch. 4, and Banker *et al.* (1984) for the details of these models and the BCC model: the basic one of these.

10 The disintegration of Yoshida (2012) follows Farell (1957), Viton (1997), and Drake and Simper (2000).

11 See Tone (1993) ch. 8 for an DEA model that minimizes production cost.

12 In addition, in this study, DEA is implemented by specifying RTS by industry. Therefore, we follow Yoshida (2012) and assume that the scale efficiency is 1: $TE = 1 \times PTE$.

13 Note that we regard a "production technique" as one that includes all production and management activities: from preparing production factors to sales of goods and services.

14 See Green (1997) ch. 6 and others for details of F statistic and F tests.

15 The following is the assumption: $E(u_t^{ji}) = 0, E((u_t^{ji})^2) = (\sigma_u^j)^2, E(u_t^{ji} u_s^{jl}) = 0$ *for* $i \neq l, t \neq s$.

16 This is published by Ministry of Economy, Trade and Industry, Government of Japan.

17 The "Manufacturing census" data are missing in the following cases: 1) no applicable data, 2) since there are only a few establishments that are applicable as a research subject, the data concerning them are closed to the public to protect privacy.

18 See Green (1997) ch. 12 and others for the details.

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