Dynamic Network DEA and An application to Japanese Prefectures

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Abstract: The purpose of this paper is twofold. First, we develop a multi-period dynamic multi-process network DEA (data envelopment analysis) model. Second, we apply this methodology to Japanese prefectural time series data. In this framework, we specify that prefectural technology consists of two sectors, called the human capital generating sector and the physical capital formation sector. Each sector has its own exogenous inputs, and carry-overs in preceding and subsequent periods as well as final output. We assume that the final output is jointly produced by the two sectors.
Keyword: Dynamic DEA, network DEA, weighted dynamic network model

1. INTRODUCTION

In this paper, we develop a multi-period dynamic multi-process network DEA (data envelopment analysis) model and apply it to Japanese prefectural time series data. We first provide a general model for incorporating the structure of networks and dynamics. Färe and Grosskopf (1996) presented a dynamic methodology that comprises a sequence of technologies, which are connected by storable inputs and carry-over outputs from individual periods. Based on the Färe-Grosskopf setting, Nemoto and Goto (2003) studied the impact of quasi-fixed inputs and Emrouznejad and Thanassoulis (2005) assessed the efficiency of dynamic processes by assuming that there is correspondence between carry-over products. Bogetoft et al. (2009) and Chen and van Dalen (2010) provided discussions on the incorporation of lagged effects of input consumption into a DEA framework. Tone and Tsutsui (2010) developed a dynamic slack-based measure by classifying carry-over activities into four kinds: good, bad, free and fixed. Tone and Tsutsui (2012) presented a slacks-based dynamic DEA model with network structure by combining their previous studies.

Building on these contributions, we develop a weighted dynamic network model (WDNM). By adopting slacks-based form similar to Tone and Tsutsui (2010, 2012), WDNM focuses on the following respects. First, WDNM does not include slacks of divisions or sub-processes in the objective function of the

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optimization problem. That is, the efficiency status of the evaluated DMU (decision making unit) is identified by only the slacks associated with exogenous inputs and final outputs. See Fukuyama and Mirdehghan (2012) for a discussion on the identification of divisional efficiency. Second, WDNM allows for joint outputs produced by more than one division. Third, WDNM incorporates lagged variables in each period.

As an illustration, we assess the dynamic efficiency/productivity performance of Japanese prefectures. This framework specifies that a prefecture's production process is expressed as a two parallel network system that allows resources to be reallocated between periods so that larger final outputs can be achieved through inter-temporal optimization.

2. MULTI-PERIOD DYNAMIC MULTI-PROCESS NETWORK

In this section, we define a multi-period dynamic multi-process network model called WDNM. We first introduce relevant notations and define production technologies. In time period t $(t = 1,...,T)$, consider a set of K divisions (sub-processes), $k = 1,...,K$, of decision making units (DMUs), each of which coverts its carry-over products produced at the preceding periods as well as the exogenous inputs, the intermediate inputs from other processes to produce not only final outputs and intermediate outputs but also carry-over products to the subsequent periods. For DMU_j, let us first define the following:

x_{nj}^{kt}: exogenous input n consumed by division k in time period t.

$z_{qj}^{(kt,ht)}$: intermediate product (input) q produced by division k in time period t and consumed by division h in time period t.

y_{mj}^{kt}: final output m produced by process k in time period t.

$c_{rj}^{(g'\tau',kt)}$: carryover product r produced by division k in time period t and consumed by division g' in time period $\tau' < t$.

$c_{rj}^{(kt,g\tau)}$: carry-over product r leaving division k in time period t to division g in time period $\tau > t$.

$\overline{c}_{\overline{r}j}^{(\overline{\tau},kt)}$: lagged carryover product $\overline{r}$ coming from finitely many time periods $\overline{\tau}$ and entering division k in time period t.

where t, τ, $\overline{\tau}$ are the index sets of relevant time periods and t^0 is the length of time lag. Here we denote intermediate input q entering division k in time t from division h' in time t by $(h't,kt)$ and the set by $\overline{\mathbf{L}}$. Similarly, the intermediate output leaving division k in time period t to division h in t by (kt,ht) and the set of intermediate outputs by $\overline{\overline{\mathbf{L}}}$. We also denote the inflow connecting division g' in time period τ' and division k in t by $(g'\tau',kt)$, and the index set of inflows by $\overline{\mathbf{F}}$. Similarly, the outflow from division k in t to division g in t by $(kt,g\tau)$ and the set of out-flows by $\overline{\overline{\mathbf{F}}}$. That is, $(h't,kt) \in \overline{\mathbf{L}}$, $(kt,ht) \in \overline{\overline{\mathbf{L}}}$, $(g'\tau',kt) \in \overline{\mathbf{F}}$ and $(kt,g\tau) \in \overline{\overline{\mathbf{F}}}$. Armed with these notations, we make the following assumptions.

- Assumption 1: The objective function of our framework includes slacks of exogenous inputs but does not include slacks associated with intermediate products and carry-overs.
- Assumption 2: We allow for lagged carry-over products that are independent of where they come from, and divisions of the DMU can be constrained by the amounts of carry-overs that were produced in finitely many preceding periods $\overline{\tau}$.
- Assumption 3: Final outputs can be produced jointly by several divisions.

Assumption 1 is consistent with the two-stage procedures of Kao and Hwang (2010), Chen, Liang and Zhu (2009) and Fukuyama and Weber (2010) in the sense that slacks

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associated with intermediate products are not included in the objective function. In Assumption 2 means that $\bar{\tau} = t-1, t-2, ..., t-t^0$ where $t \geq t^0$ and t^0 is predetermined constant. Hence, the dynamic production systems are subject to lagged effects, which can be modeled by t^0–period lags (Chen and van Dalen 2010). For example, bad loans are used as a carry-over output in a bank efficiency context by Akther et al. (2013) and Fukuyama and Weber (2013), where carry-over inputs negatively affects production in later periods. Regarding Assumption 3, some final outputs can be produced by combining several sub-technologies or sub-processes.

We define a production possibility set T^{kt} for division k in time period t by

$$\left\{ \left(\begin{array}{l} \left\{ \sum_{\bar{\tau}=t-t^0}^{t-1} \bar{c}_{\bar{r}}^{(\bar{\tau},kt)} \right\}, \left\{ x_n^{kt} \right\}, \left\{ z_q^{(h't,kt)} \Big|_{(k't,kt)\in \bar{\mathbf{L}}} \right\}, \\ \left\{ z_q^{(kt,ht)} \Big|_{(kt,ht)\in \bar{\bar{\mathbf{L}}}} \right\}, \left\{ \sum_{\tau'=t}^{T} c_r^{(g'\tau',kt)} \Big|_{(g'\tau',kt)\in \bar{\mathbf{F}}} \right\}, \\ \left\{ \sum_{\tau=t}^{T} c_r^{(kt,g\tau)} \Big|_{(kt,g\tau)\in \bar{\bar{\mathbf{F}}}} \right\}, \ \left\{ y_m^{kt} \right\} \end{array} \right) \text{ is feasible} \right\} \quad (1)$$

where

$$\sum_{\bar{\tau}=t-t^0}^{t-1} \bar{c}_{\bar{r}}^{(\bar{\tau},kt)} \geq \sum_{\bar{\tau}=t-t^0}^{t-1} \sum_{j=1}^{J} \bar{c}_{\bar{r}j}^{(\bar{\tau},k)} \lambda_j^{kt} \qquad (\bar{r}=1,...,\bar{R}^k)$$

$$x_n^{kt} \geq \sum_{j=1}^{J} x_{nj}^{kt} \lambda_j^{kt} \qquad (n=1,...,N^k)$$

$$y_m^{kt} \leq \sum_{j=1}^{J} y_{mj}^{kt} \lambda_j^{kt} \qquad (m=1,...,M^k)$$

$$z_q^{(h't,kt)} \geq \sum_{j=1}^{J} z_q^{(h't,kt)} \lambda_j^{kt} \qquad ((h't,kt)\in \bar{\mathbf{L}}, \forall h't;\ q=1,...,\bar{Q}^k)$$

$$z_q^{(kt,ht)} \leq \sum_{j=1}^{J} z_q^{(kt,ht)} \lambda_j^{kt} \qquad ((kt,ht)\in \bar{\bar{\mathbf{L}}}, \forall ht;\ q=1,...,\bar{\bar{Q}}^k)$$

$$\sum_{\tau'=t}^{T} c_r^{(g'\tau',k\tau)} \geq \sum_{\tau'=t}^{T} \sum_{j=1}^{J} c_{rj}^{(g'\tau',k\tau)} \lambda_j^{kt} \qquad ((g'\tau',kt)\in \bar{\mathbf{F}};\quad r=1,...,\bar{R}^k)$$

$$\sum_{\tau=t}^{T} c_r^{(kt,g\tau)} \leq \sum_{\tau=t}^{T} \sum_{j=1}^{J} c_{rj}^{(kt,g\tau)} \lambda_j^{kt} \qquad ((kt,g\tau)\in \bar{\bar{\mathbf{F}}};\quad r=1,...,\bar{\bar{R}}^k)$$

Using (1), we denote a network production possibility set NT^t as

$$\left\{ \left(\begin{array}{l} \left\{ \sum_{\bar{\tau}=t-t_0}^{t-1} \bar{c}_{\bar{r}}^{(\bar{\tau},kt)} \right\}, \left\{ x_n^{kt} \right\}, \left\{ z_q^{(h't,kt)} \Big|_{(h't,kt)\in \bar{\mathbf{L}}} \right\}, \\ \left\{ z_q^{(kt,ht)} \Big|_{(kt,ht)\in \bar{\bar{\mathbf{L}}}} \right\}, \left\{ \sum_{\tau'=t}^{T} c_r^{(g'\tau',kt)} \Big|_{(g'\tau',kt)\in \bar{\mathbf{F}}} \right\}, \\ \left\{ \sum_{\tau=t}^{T} c_r^{(kt,g\tau)} \Big|_{(kt,g\tau)\in \bar{\bar{\mathbf{F}}}} \right\}, \left\{ y_m^{kt} \right\} \end{array} \right) \in T^{kt} \ (\forall k) \right\} \quad (2)$$

This network technology is illustrated in Figure 1.

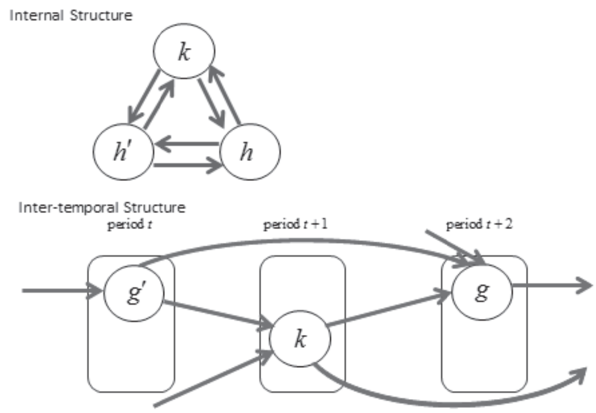

Figure 1: Dynamic Network Structure

A general multi-period dynamic multi-process network technology takes the form:

$$\left\{ \left(\begin{array}{l} \bar{\mathbf{c}}^t,\ \mathbf{x}^t,\ \mathbf{z}^t(\bar{\mathbf{L}}), \mathbf{z}^t(\bar{\bar{\mathbf{L}}}), \\ \mathbf{c}^t(\bar{\mathbf{F}}),\ \mathbf{c}^t(\bar{\bar{\mathbf{F}}}),\ \mathbf{y}^t \end{array} \right) \in NT^t \quad \forall t=1,...T \right\} \quad (3)$$

where

$$\begin{array}{l} \bar{\mathbf{c}}^t = \left\{ \sum_{\bar{\tau}=t-t_0}^{t-1} \sum_{k=1}^{K} \bar{c}_r^{(\bar{\tau},kt)} \right\}, \mathbf{x}^t = \left\{ \sum_{k=1}^{K} x_n^{kt} \right\}, \\ \mathbf{z}^t(\bar{\mathbf{L}}) = \left\{ \sum_{(h't,kt)\in \bar{\mathbf{L}}} z_q^{(h't,kt)} \right\}, \mathbf{z}^t(\bar{\bar{\mathbf{L}}}) = \left\{ \sum_{(kt,ht)\in \bar{\bar{\mathbf{L}}}} z_q^{(kt,ht)} \right\}, \\ \mathbf{c}^t(\bar{\mathbf{F}}) = \left\{ \sum_{\tau'=t}^{T} \sum_{(g'\tau',kt)\in \bar{\mathbf{F}}} c_r^{(g'\tau',kt)} \right\}, \\ \mathbf{c}^t(\bar{\bar{\mathbf{F}}}) = \left\{ \sum_{\tau=t}^{T} \sum_{(kt,g\tau)\in \bar{\bar{\mathbf{F}}}} c_r^{(kt,g\tau)} \right\}, \mathbf{y}^t = \left\{ \sum_{k=1}^{K} y_m^{kt} \right\} \end{array} \quad (4)$$

3. EFFICIENCY/PRODUCTIVITY MEASUREMEMT

Using (3) as the dynamic technology, we define a weighted multi-period dynamic multi-division network model (WDNM) by

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$$\theta_{o,non} = \min \frac{\sum_{t=1}^{T} W^t \sum_{k=1}^{K} w^k \left\{ 1 - \frac{1}{N^k} \times \left(\sum_{n=1}^{N^k} \frac{s_n^{kt-}}{x_{no}^{kt}} \right) \right\}}{\sum_{t=1}^{T} W^t \sum_{k=1}^{K} w^k \left\{ 1 + \frac{1}{M^k} \times \left(\sum_{m=1}^{M^k} \frac{s_m^{kt+}}{y_{mo}^{kt}} \right) \right\}} \quad (5)$$

subject to:

$$\begin{aligned}
&\sum_{\bar{\tau}=t-t^0}^{t-1} \sum_{j=1}^{J} c_{\bar{r}j}^{(\bar{\tau},kt)} \lambda_j^{kt} \le \sum_{\bar{\tau}=t-t^0}^{t-1} c_{\bar{r}o}^{(\bar{\tau},kt)} \quad (\bar{r} = 1,\dots,\bar{R}^k) \\
&\sum_{j=1}^{J} x_{nj}^{kt} \lambda_j^{kt} = x_{no}^{kt} - s_n^{kt-} \quad (k = 1,\dots,K \; ; \; n = 1,\dots,N^k) \\
&\sum_{j=1}^{J} y_{mj}^{kt} \lambda_j^{kt} = y_{mo}^{kt} + s_m^{kt+} \quad (k = 1,\dots,K \; ; \; m = 1,\dots,M^k) \\
&\sum_{j=1}^{J} z_{qj}^{(h't,kt)} \lambda_j^{kt} = z_q^{(h't,kt)} - s_q^{z(h't,kt)-} \quad ((h't,kt) \in \bar{\mathbf{L}}; q = 1,\dots,\bar{Q}^k) \\
&\sum_{j=1}^{J} z_{qj}^{(kt,ht)} \lambda_j^{ht} = z_q^{(kt,ht)} + s_q^{z(kt,ht)+} \quad ((kt,ht) \in \bar{\bar{\mathbf{L}}}; \; q = 1,\dots,\bar{\bar{Q}}^k) \qquad (6) \\
&\sum_{\tau'=t}^{T} \sum_{j=1}^{J} c_{rj}^{(g'\tau',kt)} \lambda_j^{kt} = c_{ro}^{(g'\tau',kt)} - s_r^{c(h'\tau,kt)-} \quad ((g'\tau',kt) \in \bar{\mathbf{F}}; r = 1,\dots,\bar{R}^k) \\
&\sum_{\tau=t}^{T} \sum_{j=1}^{J} c_{rj}^{(kt,g\tau)} \lambda_j^{kt} = c_{ro}^{(kt,h\tau)} + s_r^{c(kt,h\tau)+} \quad ((kt,g\tau) \in \bar{\bar{\mathbf{F}}}; \; r = 1,\dots,\bar{\bar{R}}^k) \\
&s_n^{kt-} \ge 0 \;\; (\forall n,k,t); \quad s_m^{kt+} \ge 0 \;\; (\forall m,k,t), \\
&s_q^{z(h't,kt)-} \ge 0 \;\; (\forall (h't,kt) \in \bar{\mathbf{L}}, \forall q); \\
&s_q^{z(kt,ht)+} \ge 0 \;\; (\forall (kt,ht) \in \bar{\bar{\mathbf{L}}}, \forall q) \\
&s_r^{c(g'\tau',kt)-} \ge 0 \;\; (\forall (g'\tau',kt) \in \bar{\mathbf{F}}, \forall r); \\
&s_r^{c(kt,g\tau)+} \ge 0 \;\; (\forall (kt,g\tau) \in \bar{\bar{\mathbf{F}}}, \forall r)
\end{aligned}$$

where w^k $(\forall k)$ are exogenous weights attached to division k and W^t $(\forall t)$ are exogenous weights associated with time *t*. The input- and output-oriented models can be defined as

$$\theta_{o,inp} = \min \sum_{t=1}^{T} W^t \sum_{k=1}^{K} w^k \left\{ 1 - \frac{1}{N^k} \times \left(\sum_{n=1}^{N^k} \frac{s_n^{kt-}}{x_{no}^{kt}} \right) \right\} \quad (7)$$

$$\theta_{o,out} = \min \frac{1}{\sum_{t=1}^{T} W^t \sum_{k=1}^{K} w^k \left\{ 1 + \frac{1}{M^k} \times \left(\sum_{m=1}^{M^k} \frac{s_m^{kt+}}{y_{mo}^{kt}} \right) \right\}} \quad (8)$$

Each of the overall efficiency measures ($\theta_{o,non}$, $\theta_{o,inp}$ and $\theta_{o,out}$) is (dynamically) overall efficient if it is equal to unity; it is inefficient if it is less than one. Each ratio-form programming problem (after applying the Charnes-Cooper transformation) is solved *J* times, once for each DMU in the sample.

4. EMPIRICAL APPLICATION

4.1. Prefectural Production and Data

In traditional growth theory, it is common to assume that a single product is produced by labor and physical capital. Employing this framework, we assume that the output is prefectural GDP (gross domestic product), the labor input is human capital, and the physical capital input is public and private infrastructure capital. We regard these sub-processes as two distinct sub-units (sectors): the human capital generating sector and the physical capital formation sector. Figure 2 shows prefectural production structure.

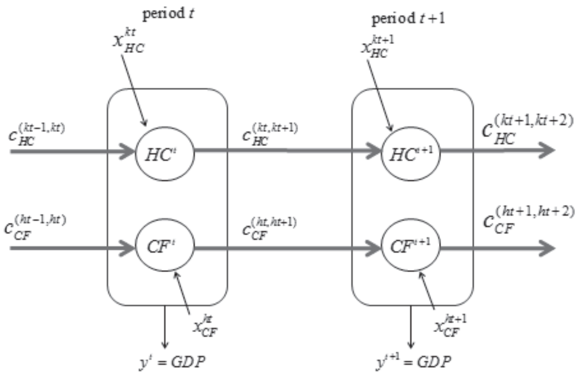

Figure 2: Prefectural Production

Human capital consisting of general education and training investments is an important factor of economic growth at the macro-economic or micro-economic level. In our study, the data on human capital is constructed according to the procedure of Fukao and Yue (2000), who developed a 47 prefectural human resource index for the years 1955-1995. For a complete account of their calculation procedure, see http://www.ier.hit-u.ac.jp/~fukao/japanese/data/fuken2000/datamaking.pdf.

Physical capital includes the basic infrastructure and producer goods needed to support various economic activities. As a proxy of this input, we use prefectural capital formation (Cabinet Office, Government of Japan).

While we set up a model with the two sectors, each of which is assumed to have its own exogenous inputs. The human capital generating sector transforms education-related input to produce new human capital (human capital carry-over), while being constrained by the previous human capital. The physical capital formation sector employs public investment to produce new capital formation (capital formation carry-over), while being constrained by the capital stock in the preceding period $t-1$. The final product of GDP is jointly produced by these sectors, i.e., GDP is a joint final output. Similarly, the human capital sector uses educational inputs to produce the carry-over of human capital and the joint output of GDP.

Formally, the exogenous inputs, carry-overs and output are defined as follows:

x^t_{HC} = educational (school) expenses in the human capital sector

x^t_{CF} = public investment in the human capital sector

$c^{(t-1,t)}_{HC}, c^{(t,t+1)}_{HC}$ = human capital carry-over within the human capital sector

$c^{(t-1,t)}_{CF}, c^{(t,t+1)}_{CF}$ = capital formation carry-over within the capital formation sector

y^t = gross domestic product (GDP)

The data set consists of 47 prefectures over the period 2007-2009. The yen values are deflated by 2005 GDP deflator. The descriptive statistics are given in Table 1.

4.2. Efficiency estimates and their determinants

Table 2 reports the estimates of overall efficiency, and Figure 3 compares the overall prefectural efficiencies calculated by using the non-oriented, input-oriented and output-oriented measures. We can identify four best efficiency performers. Tokyo is the only efficient prefecture, and the remaining three are Osaka, Aichi and Kanagawa. Japan's four biggest cities (Tokyo, Yokohama, Osaka and Nagoya) belong to these prefectures. Overall efficiency is much higher in these urbanized and industrialized prefectures than it is in rural agricultural prefectures. This evidence may show that there are important relationships among overall efficiency and agglomeration economies (benefits that firms obtain by the clustering of activities external to the firms).

Table 1: Data Description (inputs, output, carry-overs)

Period		Educational Expenses (Mill. Yen)	Public Investment (Mill. Yen)	GDP (Mill. Yen)	Human Captial	Capital Formation (Mill. Yen)
2007-2009	mean	19,922	389,803	11,820,143	1.2368	2,389,120
	std dev	14,121	305,119	15,303,072	0.0682	2,819,822
	max	85,403	1,757,011	100,207,872	1.6053	18,554,609
	min	5,885	93,363	2,236,416	1.1327	437,647
2007	mean	19,923	373,113	12,226,245	1.2205	2,602,720
	std dev	13,689	276,407	15,992,193	0.0608	3,090,101
	max	77,045	1,493,109	100,207,872	1.5177	18,554,609
	min	6,896	93,363	2,351,641	1.1327	487,244
2008	mean	19,989	385,049	11,816,519	1.2367	2,445,562
	std dev	14,543	317,020	15,173,019	0.0665	2,805,869
	max	85,403	1,757,011	94,733,969	1.5608	16,687,683
	min	6,600	93,542	2,303,782	1.1393	465,140
2009	mean	19,854	411,247	11,417,666	1.2533	2,119,078
	std dev	14,116	318,793	14,705,590	0.0727	2,512,138
	max	81,734	1,686,854	92,254,693	1.6053	15,384,099
	min	5,885	108,793	2,236,416	1.1459	437,647

Therefore, it is of great interest to examine sources of prefectural overall inefficiency and its determinants in relation to prefectural locations and characteristics. Otsuka et al. (2010) examined whether or not market access (MA), population density (DEN), and public fiscal transfer (FT) have impact on the efficiency of Japanese regional industries. Employing Otsukai et al.'s (2010) idea into account, we estimate the following:

$$\mathit{Overall\ Efficiency} = f(\mathrm{MA, DEN, FT, REG})$$

where REG is the regional dummy. MA and DEN are considered to be proxy variables of agglomeration economies by Otsuka et al. (2010). While Otsuka et al. (2010) constructed a market accessibility index based on automobile travel time and the size of prefectural production market, we use Nakamura et al.'s (2010) estimates that are based on Redding and Venables' (2004) supplier access index. We use the estimates as the indexes of MA for agriculture, manufacturing and service industries because the estimation procedure is closely related to the theoretical structure of the trade and geography model.

In addition to these two proxy variables of agglomeration economies, we also include FT defined as the national tax revenue allocated to local governments (prefectures) as Otsuka et al. (2010) did. To analyze drivers of overall efficiency, we adopt the two-stage approach by regressing the overall efficiency scores against a set of environmental variables that are discretionary in nature. However, the estimates obtained in the first stage are correlated with the explanatory variables used in the second stage. Simar and Wilson (2007) proposed bootstrap truncated regression analysis to overcome this problem.

We employ Simar and Wilson's (2007) approach to generate a set of bias-corrected overall efficiency estimates $\hat{\theta}$ and confidence intervals. Once bias-corrected overall efficiency scores are obtained from the bootstrap algorithm, they are then regressed on a set of hypothesized environmental factors using the following regression

$$\begin{aligned}\hat{\theta} = \alpha + \alpha_1 \cdot DEN + \alpha_2 \cdot FT + \delta_1 \cdot AGR + \delta_2 \cdot MAN \\ + \delta_3 \cdot SER + \sum_i \beta_i \cdot dummy_i + \varepsilon\end{aligned} \tag{9}$$

where $\alpha, \alpha_1, \alpha_2, \delta_1, \delta_2, \delta_3, \beta_i$ are parameters to be estimated. AGR, MAN and SER indicate supplier access indexes of agriculture, manufacturing and service industries, respectively. These variables are used as proxies of MA for the industries. $dummy_i$ is the dummy variable which is unity if the prefecture belongs to region i. Since the market accessibility index is not available for Okinawa, we delete Okinawa from the regression (9). Kyushu region is the region for which we do not create a dummy in the regression analysis.

Table 3 gives the bootstrap regression results based on two models. For model 1, the coefficients of DEN and MAN are statistically significant. This result is consistent with that of Otsuka et al. (2010). FT has a negative sign but not statistically significant in contrast to the result of Otsuka et al. (2010). All region dummy coefficients are insignificant, showing the location of prefectures does not significantly affect overall efficiency. So, we estimate model 2 by dividing the sample into two groups: the group of the most overall efficient four prefectures (the urbanized industrial prefectures), and the rest of the prefectures. The coefficient of the urbanized industrial prefectures is statistically insignificant. Evidence from models 1 and 2 in Table 3 shows that the location factors are not significant contributors to overall efficiency.

Table 2: Two-period Efficiency Estimates

Prefectures		Non- oriented	Input- oriented	Output- oriented
All	mean	0.450	0.543	0.706
	std dev	0.152	0.114	0.158
	max	1	1	1
	min	0.220	0.402	0.394
Hokkaido- Tohoku	mean	0.364	0.435	0.413
	Std dev	0.087	0.089	0.088
Kanto	mean	0.586	0.640	0.623
	Std dev	0.184	0.169	0.162
Hokuriku- Tokai	mean	0.488	0.558	0.557
	Std dev	0.144	0.129	0.123
Kansai	mean	0.567	0.653	0.596
	Std dev	0.170	0.139	0.156
Chugoku- Shikoku	mean	0.429	0.508	0.486
	Std dev	0.123	0.108	0.115
Kyushu	mean	0.358	0.434	0.420
	Std dev	0.103	0.099	0.098
Okinawa	mean	0.239	0.329	0.287
	Std dev	0	0	0
Urbanized industrial prefecture	mean	0.855	0.889	0.860
(Tokyo, Kanagawa, Osaka, Aichi)	Std dev	0.088	0.066	0.084
Other prefectures	mean	0.426	0.502	0.481
	Std dev	0.120	0.113	0.112

Table 3: Bootstrap Regression Results

				supplier access			area dummy A					area dummy B
	coefficient	population density	fiscal transfer	agriculture	manufacture	service	Hokkaido–Tohoku	Kanto	Hokuriku–Tokai	Kansai	Chugoku–Shikoku	urbanized industrial prefectures (Tokyo, Kanagawa, Osaka,
model 1	0.03771*	0.00198***	−0.00131	−0.00913	0.04762***	−0.00358	0.00502	−0.01116	−0.00796	−0.00563	0.00153	
model 2	0.01414	0.00103	−0.00194	−0.00779	.04390***	0.013						0.02133

Legend: * significant at 10% level; ** significant at 5% level; *** significant at 1% level

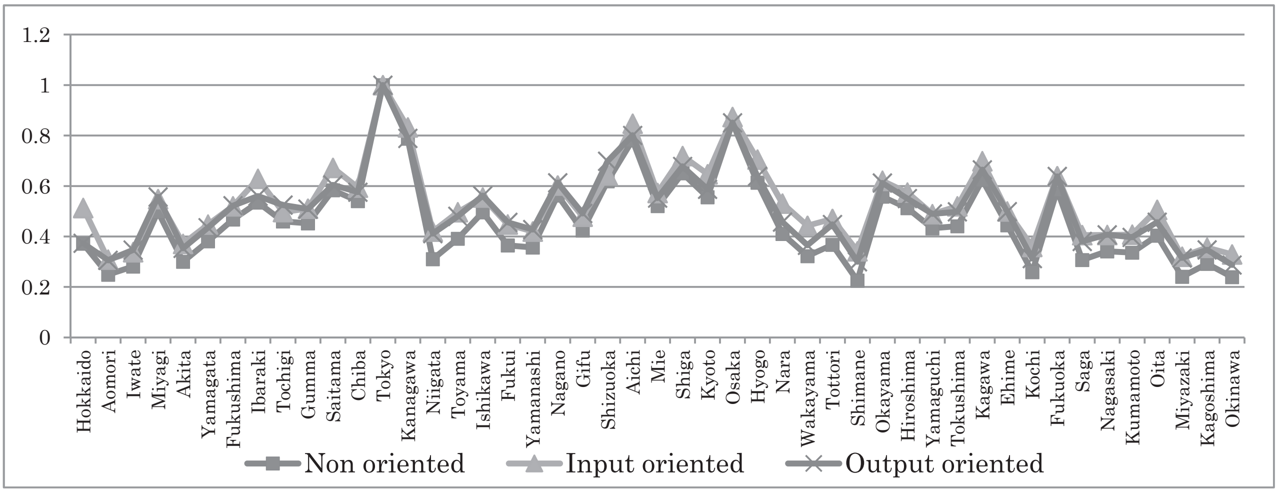

Figure 3: Prefectural Efficiencies

5. Conclusions

We have dealt with the assessment of the overall efficiency performance of DMUs, some of whose inputs and outputs are internally or inter-temporarily dependent. We developed a DEA model for assessing the performance of DMUs where panel data are available. An application of our developed model to Japanese prefectures investigated how prefectural GDP can be enhanced. Empirical evidence indicates that agglomeration economies are important factors that determine overall efficiency.

We have developed the non-oriented, input-oriented and output-oriented models by only assuming that all intensity variables are non-negative constraints. It is possible to append $\sum_{j=1}^{J} \lambda_j^{kt} = 1 \; (\forall k, \forall t)$ to our framework in order to impose some kind of variable returns to scale. In this paper, however, we did not add these constraints since it is not very clear about exactly what kind of returns to scale structure is imposed to each division with the implementations (Chen et al. 2012). This is an important theoretical issue of future study.

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