Dynamic and static productivity measurements of Japanese airlines: can they really compete through the liberalization in Asian aviation industry? *

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Abstract

Objective of this paper is twofold. First is to provide a methodological framework called dynamic TFP. In this parametric method, the optimal choice of the levels of quasi-fixed inputs in a dynamic optimization problem conforms the benchmark, relative to which dynamic efficiency is measured. As its second objective, the paper applies the dynamic TFP method to the efficiency measurement of Japanese airlines. The results show that the overall and dynamic efficiency is the highest for JAL, followed by ANA then by JAS. The paper also discusses about the implications of the results on Japanese aviation industry and its policy.

Key words: Japanese airlines, dynamic efficiency, total factor productivity

1 Introduction

Airline industry is one of those industries that are particularly dynamic and ever-changing. In the last few decades it went through drastic changes in regulation regimes while being washed in a series of macroeconomic shocks and political instabilities. Japanese aviation industry is not an exception. The sun used to be shining high is now quickly setting; Japan Airlines (JAL), the Japanese flag carrier which used to be leading the industry

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in the dawn of deregulation in the late 80’s is now facing the deep bottom. One of many reasons behind this is the merger of Japan Air System (JAS) into JAL in 2002. In turn, All Nippon Airways (ANA) that now seems to have gained its solid position in the market was clearly the follower in the late 80’s. This paper introduces a dynamic productivity measurement methodology and adopts it to investigate the dynamic change of the productive efficiencies of these three airline companies in Japan during this period of change, up to the point when JAS has been merged into JAL in 2002.

The last two decades were indeed tempestuous for the Japanese airlines. According to Oum and Yu [5] and Oum and Yu [6], in the early 1990’s Japanese airlines’ productivity was considerably lower than other major airlines in the world. But how well did they manage since then? There were three major forces of dynamism in Japanese air transport market during the past two decades, namely, domestic competition, international competition, and macro-economic factors. Regarding domestic competition, before mid-1980’s there was a regime under which markets were divided into trunk and regional routes. JAL would operate on trunk routes, ANA on trunk and regional routes, and JAS on regional routes. In those days route structure and entry of airlines were carefully coordinated by the aeronautical authorities. In 1986, the government decided to rescind the old regime so that multiple airlines could enter and operate. In the domestic market, threshold in passenger volume was initially set for multiple operations to be applicable. The threshold was subsequently reduced and abolished by 1998. In 2000 the remaining route license and airfare regulations were revised from approval-based to report-based.

As to the international competition, before 1986 JAL was the sole Japanese airline that provided international scheduled service. Since 1986, multiple designations in international routes have been adopted. Today there are 28 international routes on which multiple Japanese airlines operate.

Macro-economic factors played an important role on Japanese aviation industry. After a period of economic boom in late 1980’s, the Japanese economy entered into a prolonged stagnation. Also affecting the economy was the appreciation of Japanese currency. Strong Yen induced overseas travel by Japanese residents: a tail wind for the Japanese airline industry. Soon, however, they were encountered by price under-cut by foreign carriers.
Coupled with deflation, average yield plunged.

Have they improved the productivity drastically? Are they ready for further steps of liberalization, particularly in the growing market of East Asia? This paper tries to provide a stepping stone to answer to these questions by analyzing recent trends in the productivity of Japanese airlines taking into account the dynamic efficiency of their decision making.

In pursuing the ultimate goal as mentioned as above, this paper achieves two objectives. The first is to provide a parametric method of measuring productive efficiency which takes into account the dynamic nature of firms’ decision. The paper considers a situation where a decision making unit such as a firm employs quasi-fixed inputs as part of its production factors. The firm uses stock of quasi-fixed inputs from the previous period as well as other variable inputs in the current period to produce outputs jointly with the new levels of quasi-fixed inputs. The choice of the levels of quasi-fixed inputs over time thus becomes the problem of dynamic optimization. Solution to this optimization problem given the production technology and factor prices conforms the benchmark, relative to which dynamic productive efficiency of each firm is measured.


The use of DEA as a measurement method of the production frontier, however, implies the multiplicity of best performers and the sensitivity to outliers. The natural alternative is to measure the production frontier through a parametric approach, which we call the dynamic total-factor productivity approach, (or dynamic TFP in short.) The paper suggests to estimate the production transformation function after specifying it as an appropriate functional form. Then the estimated production transformation function is
corrected by shifting above as much as the largest positive deviation in the sample to produce the production possibility frontier.\(^1\) Using this production possibility frontier, optimal (cost-minimizing) paths of quasi-fixed inputs and the corresponding minimum total cost of fulfilling the actual demand over the observation period are obtained. Finally, dynamic efficiency is measured by taking a ratio between the actual and the minimum possible costs measured as above.

As its second objective, the paper applies the above-mentioned method to the dynamic productive efficiency measurement of Japanese airlines. Dynamic TFP is then computed for three Japanese airlines over the period of 1986 – 2002, to evaluate the efficiency in their investment and production behavior. The results show that JAL’s overall and dynamic efficiency is the highest, followed by ANA then by JAS. In the background of lower efficiency for ANA and JAS there seems to be over-investment in aircraft stock, and for the case of JAS, there is excessive use of labor as well.

The paper also spends an independent section in analyzing and interpreting the obtained results in the background of Japanese aviation industry and policy. It argues that JAL’s higher productivity is attributable to the fact that it has been facing international competition and tightening macroeconomic environment both in Japan and in the world. ANA was in a better situation owing to its favorable position in the domestic market, which in turn could have lowered its productivity and efficiency relative to JAL. However, not only international but domestic market is also getting more competitive since the mid to late 90’s, which induced ANA to strive for enhancing operation efficiency. JAS however, did not have such advantage that ANA used to have in domestic market. Besides, JAS has been struggling with the over-investment and excessive use of labor input throughout our observation period.

The paper is composed as follows. The following section discusses the methodology of dynamic productivity measurement through the dynamic TFP. Section three adopts the dynamic TFP method to the case of Japanese airlines. Section four interprets the obtained results in the background of Japanese aviation industry and its policy. Finally, section five concludes.

\(^1\)The idea is similar to the corrected ordinary least squares by Coelli and Perelman [1].
2 Dynamic TFP

2.1 Basic Structure

Proposed method of this paper shares the basic structure with that of Nemoto and Goto [4]. This section briefly reviews their setup with slight modifications in assumptions and notations. Define $x_t$ as a $l \times 1$ vector of variable inputs and $k_t$ as an $m \times 1$ vector of quasi-fixed inputs such as capital stock in period $t$. A firm uses variable inputs $x_t$ and capital stock in the end of the last period $k_{t-1}$ to produce a $n \times 1$ vector of outputs $y_t$ and the capital stock in the end of current period, $k_t$. Naturally, an input vector $(x_t, k_{t-1})$ lies in $l + m$ dimensional space of non-negative real numbers $\mathbb{R}^{l+m}_+$ and similarly, an output vector $(y_t, k_t)$ lies in $\mathbb{R}^{n+m}_+$. Let $\Phi_t$ denote the production possibility set in period $t$ which satisfies the standard properties such as disposability and monotonicity.\(^2\) That is

$$\Phi_t = \left\{(x_t, k_{t-1}, y_t, k_t) \in \mathbb{R}^{l+m}_+ \times \mathbb{R}^{n+m}_+ \mid (x_t, k_{t-1}) \text{ can produce } (y_t, k_t)\right\}, \quad (1)$$

where

1. if $\left(\tilde{x}_t, \tilde{k}_{t-1}, \tilde{y}_t, \tilde{k}_t\right) \in \Phi_t$ and $\left(\tilde{x}_t, \tilde{k}_{t-1}\right) \leq (x_t, k_{t-1})$, then $(x_t, k_{t-1}, y_t, k_t) \in \Phi_t$; and

2. if $\left(x_t, k_{t-1}, \tilde{y}_t, \tilde{k}_t\right) \in \Phi_t$ and $\left(\tilde{y}_t, \tilde{k}_t\right) \geq (y_t, k_t)$, then $(x_t, k_{t-1}, y_t, k_t) \in \Phi_t$.

The dynamically efficient paths of variable and quasi-fixed inputs are defined as the solution of the following minimization problem, given demand for outputs as $\tilde{y}_t$ and factor prices:

$$C(\tilde{k}_0) = \min_{\{x_t, y_t\}_{t=1}^T} \left\{\sum_{t=1}^T \gamma^t (w_t'x_t + v_t'y_t, k_t)_{t=1}^T \in \times_{t=1}^T \Phi_t, k_0 = \tilde{k}_0\right\} \quad (2)$$

where $\gamma$ is a constant discount factor, $w_t$ is a $l \times 1$ price vector for variable inputs in period $t$, $v_t$ is an $m \times 1$ price vector for quasi-fixed inputs in period $t$, and a bar (\(\bar{\cdot}\)) indicates the actual value. Initial amount of capital stock is exogenously given as $\tilde{k}_0$. The terminal time $T$ is given but $k_T$ can be either free or given as the actual value $\tilde{k}_T$.

Overall efficiency (denoted by $OE$) is then defined as the ratio between the minimum

\(^2\)Since we allow the possibility of increasing return, unlike Nemoto and Goto [4], we do not assume $\Phi_t$ to be convex.
cost $C(\bar{k}_0)$ and the actual cost $\bar{C}$:

$$OE = \frac{C(\bar{k}_0)}{\bar{C}}. \quad (3)$$

Next we decompose the overall efficiency $OE$ into static efficiency $SE$ and dynamic efficiency $DE$. Define the static efficiency $SE$ as the following:

$$SE = \frac{C^{SE}}{\bar{C}} \quad (4)$$

where

$$C^{SE} = \min_{\{x_t\}_{t=1}^T} \left\{ \sum_{t=1}^{T} \gamma^t \left( w_t' x_t + v_t' \bar{k}_{t-1} \right) \mid (x_t, \bar{k}_{t-1}, \bar{y}_t, \bar{k}_t)_{t=1}^T \in \times_{t=1}^{T} \Phi_t, k_0 = \bar{k}_0 \right\}. \quad (5)$$

The above equation says that $C^{SE}$ is the minimum cost a firm can achieve by adjusting the levels of variable inputs only, while the levels of quasi-fixed inputs are fixed at actual values. Then by definition, dynamic efficiency $DE$ is computed as the residual of overall efficiency $OE$ after taking out the static efficiency $SE$:

$$DE = \frac{OE}{SE}. \quad (6)$$

Static efficiency $SE$ can be further decomposed into technical efficiency $TE$ and the allocative efficiency $AE$. Technical efficiency $TE$ is defined as

$$TE = \frac{C^{TE}}{\bar{C}} \quad (7)$$

where

$$C^{TE} = \min_{\{\phi_t\}_{t=1}^T} \left\{ \sum_{t=1}^{T} \gamma^t \left( \phi_t w_t' \bar{x}_t + v_t' \bar{k}_{t-1} \right) \mid (\phi_t \bar{x}_t, \bar{k}_{t-1}, \bar{y}_t, \bar{k}_t)_{t=1}^T \in \times_{t=1}^{T} \Phi_t, k_0 = \bar{k}_0 \right\} \quad (8)$$

for some positive scaler $\phi_t \in [0, 1]$ for $t = 1, \cdots, T$. The scaler $\phi_t$ “shrinks” the variable input vector $x_t$ so that $\phi_t x_t$ lies exactly on the production possibility frontier, or equivalently, at the boundary of the production possibility set at time $t$. Then the allocative efficiency $AE$ is defined as the residual after extracting $TE$ out of static efficiency $SE$:

$$AE = \frac{SE}{TE}. \quad (9)$$

Note that combining above we have the following:

$$OE = DE \cdot SE \quad (10)$$

$$= DE \cdot TE \cdot AE. \quad (11)$$
2.2 Parametric Approach of Measuring Dynamic Efficiency

One can take either parametric or non-parametric approach in estimating the production possibility set $\Phi_t$. Nemoto and Goto [3] and Nemoto and Goto [4] took the latter by using DEA, which they called dynamic DEA. Dynamic DEA transforms the cost-minimization problem described in (2) into a linear programming problem, and by solving it they obtained the production possibility set and the minimum cost at the same time. Use of DEA, however, implies that obtained results are more sensitive to outliers, and there are multiple best performers.\(^3\) Here instead, we take the parametric approach in estimating the production possibility set, which we call dynamic TFP in contrast to dynamic DEA. Instead of solving for the production possibility set and the minimum cost in the same one step as in the dynamic DEA, dynamic TFP divides the entire process into two stages. In the first stage, it specifies and estimates a production possibility set. In the second, cost-minimization problems are solved. Dynamic TFP transforms the overall cost-minimization problem in the second stage into an optimal control problem.\(^4\)

Let us now discuss the first stage. Production possibility set is obtained by specifying the production possibility frontier as an appropriate functional form and estimating it from the data. Therefore in our case, the production possibility set is expressed as

$$\Phi_t = \left\{ (x_t, k_{t-1}, y_t, k_t) \in \mathbb{R}^{l+m}_+ \times \mathbb{R}^{n+m}_+ \right\}$$

such that, for some production possibility frontier $f(x_t, k_{t-1}, y_t, k_t, t) = 0$,

1. if $f\left(\hat{x}_t, \hat{k}_{t-1}, y_t, k_t, t\right) = 0$ and $\left(\hat{x}_t, \hat{k}_{t-1}\right) \leq (x_t, k_{t-1})$, then $(x_t, k_{t-1}, y_t, k_t) \in \Phi_t$; and

2. if $f\left(\bar{x}_t, \bar{k}_{t-1}, \bar{y}_t, \bar{k}_t, t\right) = 0$ and $\left(\bar{y}_t, \bar{k}_t\right) \geq (y_t, k_t)$, then $(x_t, k_{t-1}, y_t, k_t) \in \Phi_t$.

\(^3\)Nemoto and Goto [4] showed that, with variable-return assumption, seven out of nine Japanese electric utility companies are assigned unity for their static efficiency, i.e., seven out of nine have full efficiency score for both technical and allocative efficiencies. Among those seven companies, two have the full efficiency score for overall and dynamic efficiencies as well.

\(^4\)This dichotomy between the first stage of production technology estimation and the second stage of computation of minimum cost and efficiency enhances the applicability of the dynamic TFP. Dynamic TFP can be applied into cases where the availability of cost data is limited to a subset of the firms. Computation of the efficiency in the second stage depends only on each firm's cost data availability, and estimation of the production possibility set in the first stage only requires the physical data. If the cost data is available for all firms, then one can alternatively estimate dynamic cost functions or Euler equations as derived factor demand functions through generalized method of moments.
We now turn to the second stage. Using the estimated production possibility set \( \hat{\Phi}_t \) obtained above in the cost-minimization problem in (2) yields the following (discrete-time) optimal-control problem. Let \( u_t \) be an \( m \times 1 \) vector of investment in period \( t \) such that \( k_t = k_{t-1} + u_t \), then the problem can be expressed as:

\[
\hat{C} (\hat{k}_0) = \min_{\{x_t, u_t\}^T} \sum_{t=1}^{T} \gamma^t (w_t'x_t + v_t'k_{t-1})
\]

s.t. \( k_t = k_{t-1} + u_t \),

\[
f (x_t, k_{t-1}, k_t, \tilde{y}_t, t) = 0
\]

for all \( t \in \{1, \cdots, T\} \) with \( \hat{k}_0 \) being given as \( \hat{k}_0 \) and \( k_T \) being free or given as \( \tilde{k}_T \). Then the Lagrangian to this minimization problem is

\[
L = \sum_{t=1}^{T} \left[ \gamma^t (w_t'x_t + v_t'k_{t-1}) + \lambda_t' (k_t - k_{t-1} + u_t) + \mu_t f (x_t, k_{t-1}, u_t, \tilde{y}_t, t) \right]
\]

where \( \lambda_t \) is a \( m \times 1 \) vector of costate variables. The corresponding first-order conditions are

\[
\frac{\partial L}{\partial x_{tj}} = \gamma^t w_{tj} + \mu_t \frac{\partial \hat{f} (t)}{\partial x_{tj}} = 0, \quad \forall j = \{1, \cdots, l\}
\]

\[
\frac{\partial L}{\partial u_{tj}} = \lambda_{tj} + \mu_t \frac{\partial \hat{f} (t)}{\partial u_{tj}} = 0, \quad \forall j = \{1, \cdots, m\}
\]

\[
\frac{\partial L}{\partial k_{tj}} = \gamma^{t+1} v_{t+1,j} + \lambda_{tj} - \lambda_{t+1,j} + \mu_{t+1} \frac{\partial \hat{f} (t + 1)}{\partial k_{tj}} = 0, \forall j = \{1, \cdots, m\}
\]

for \( t = \{1, \cdots, T\} \), where \( \hat{f} (t) = f (x_t, k_{t-1}, u_t, \tilde{y}_t, t) \) and the subscript \( j \) denotes the \( j \)th element of each vector. Solving the above first-order conditions together with constraints in the problem yields the optimal paths for the variable inputs and investment \( x_t^* \) and \( u_t^* \). This then gives the corresponding optimal path of capital stock \( k_t^* \) and the resulting optimal value function \( \hat{C} (\hat{k}_0) \).

In finding \( \hat{C} (\hat{k}_0) \) above, it is useful and illustrative to convert the above optimal control problem into a dynamic programming problem. The problem at time \( t \) then
becomes

\[
\begin{align*}
\min_{x_t, k_t} & \quad \gamma^t \left( w_t^i x_t + v_t^i k_{t-1} \right) + J(k_t, t) \\
\text{s.t.} & \quad f(x_t, k_{t-1}, k_t, \bar{y}_t, t) = 0 \\
& \quad k_t = g(x_t, k_{t-1}, u_t, \bar{y}_t, t) \\
& \quad g = k_{t-1} + u_t
\end{align*}
\]

(20) (21) (22) (23)

where \( J \) is the Belman value function and \( J(k_T, T) = 0 \). The Lagrangian is

\[
L_t = \gamma^t \left( w_t^i x_t + v_t^i k_{t-1} \right) + J(k_t, t) + \mu_t f(x_t, k_{t-1}, k_t, \bar{y}_t, t),
\]

(24)

and the corresponding first-order conditions are

\[
\frac{\partial L}{\partial x_{tj}} = \gamma^t w_{tj} + \mu_t \frac{\partial f}{\partial x_{tj}} = 0, \quad \forall j = \{1, \cdots, l\}
\]

(25)

\[
\frac{\partial L}{\partial u_{tj}} = \frac{\partial J}{\partial g_j} + \mu_t \frac{\partial f}{\partial u_{tj}} = 0, \quad \forall j = \{1, \cdots, l\}
\]

(26)

for all \( t \in \{1, \cdots, T\} \) where the subscript \( j \) denotes the \( j \)-th element of each vector, and the second line uses the fact that \( \partial g_j/\partial u_{tj} = 1 \). The implication of the first-order conditions are

\[
\frac{f_{x_{tj}}}{f_{x_{ti}}} = \frac{w_{tj}}{w_{ti}}, \quad \forall i, j \in \{1, \cdots, l\}
\]

(27)

where \( f_{x_{tj}} = \partial f/\partial x_{tj} \); and

\[
\frac{\partial J}{\partial u_{tj}} = \gamma^t w_{tj} \frac{f_{u_{tj}}}{f_{x_{ti}}}, \quad \forall j \in \{1, \cdots, l\}
\]

(28)

where \( f_{u_{tj}} = \partial f/\partial u_{tj} \). Solving backward from \( t = T \), \( \hat{C}(k_0) \) is obtained as \( J(k_0, 0) \). Note here that \( \partial J/\partial u_{tj} \) coincides with \( \lambda_{tj} \) in the optimal control problem.

As mentioned earlier, overall efficiency \( OE \) is computed as the ratio between \( \hat{C}(k_0) \) and the actual cost \( \bar{C} \). In turn, static and technical efficiencies are obtained by solving the following two static minimization problems. As to static efficiency, the minimization problem is

\[
\hat{C}^{SE} = \min_{\{x_t\}_{t=1}^T} \sum_{t=1}^T \gamma^t \left( w_t^i x_t + v_t^i \bar{k}_{t-1} \right)
\]

s.t. \( f(x_t, \bar{k}_{t-1}, k_t, \bar{y}_t, t) = 0, \)

(29) (30)
and for technical efficiency, it is

$$\hat{C}^{TE} = \min_{\{\phi_t\}_{t=1}^T} \sum_{t=1}^T \gamma_t (w'_{it} \phi_{ix_t} + \nu_{it} \tilde{k}_{i(t-1)})$$

subject to

$$f(\phi_t \bar{x}_t, \tilde{k}_{t-1}, \tilde{k}_t, y_t, t) = 0.$$  \hfill (32)

Thus we can compute efficiency measures as

$$OE = \hat{C}(\bar{k}_0) / \bar{C}$$ \hfill (33)
$$SE = \hat{C}_{SE} / \bar{C}$$ \hfill (34)
$$DE = OE / SE$$ \hfill (35)
$$TE = \hat{C}^{TE} / \bar{C}$$ \hfill (36)
$$AE = SE / TE.$$ \hfill (37)

3 Dynamic Efficiency Measurement of Japanese Airlines

3.1 The Data

Our data set includes two variable inputs, one quasi-fixed input, and two outputs for three Japanese airlines, namely, Japan Airlines (JAL), All Nippon Airways (ANA), and Japan Air System (JAS), for the years from 1986 to 2002 (for quasi-fixed input, data start from 1985.) Two variable inputs are materials and labor, which we label as $x_1$ and $x_2$ respectively. Materials includes all the variable inputs except labor, fuel, and aircraft maintenance. Labor is the number of employees, including foreign and contract-based flight crews. One of the two outputs is primary (or “air-side”) output which we denote as $y_1$ and is the geometric mean of the paid passenger and cargo volumes, while another is secondary (or “land-side”) output which is incidentals and denoted by $y_2$. Stock of aircraft measured by the number of seats available is treated as a quasi-fixed input and denoted by $k$. All the data are normalized such that values for JAL in 1986 is one.

Cost data for each of these variables are also included as well as GDP deflator. Material input index and incidental output index are obtained through dividing material costs and incidental revenue by GDP deflator in each year, respectively. Total cost and expenditure on each input including aircraft stock is normalized by GDP deflator and
hence these are measured in real terms. This implies that the material input serves as a numeraire in our following analysis of efficiency measurements.

3.2 Dynamic TFP Measurements

3.2.1 Estimation of Production Possibility Set

To identify the production possibility set, we first specify and then estimate a production transformation function. Second, we shift it upward as much as the maximum positive error to make it the production possibility frontier. This idea of shifting the estimated production transformation function to yield the production possibility frontier is analogous to that of the corrected ordinary-least-square (or COLS) method presented by Coelli and Perelman [1].

In estimating the production transformation function, we employ the following non-autonomous specification, which is essentially nested CES functions.\(^6\)

\[
O_{it} = e^{\beta + At} I_{it}^\delta
\]

(38)

where

\[
O_{it} = \left[ \alpha_{11} Y_{it}^{\rho_{11}} + (1 - \alpha_{11}) k_{it}^{\rho_{11}} \right]^{-\frac{1}{\rho_{11}}}
\]

(39)

\[
I_{it} = \left[ \alpha_{21} X_{it}^{\rho_{21}} + (1 - \alpha_{21}) k_{i,t-1}^{\rho_{21}} \right]^{-\frac{1}{\rho_{21}}}
\]

(40)

and

\[
Y_{it} = \left[ \alpha_{12} Y_{it}^{\rho_{12}} + (1 - \alpha_{12}) Y_{2it}^{\rho_{12}} \right]^{-\frac{1}{\rho_{12}}}
\]

(41)

\[
X_{it} = \left[ \alpha_{22} X_{it}^{\rho_{22}} + (1 - \alpha_{22}) X_{2it}^{\rho_{22}} \right]^{-\frac{1}{\rho_{22}}}
\]

(42)

In the above specification, \(O_{it}\) and \(I_{it}\) are considered to be output and input indices respectively, and \(Y_{it}\) and \(X_{it}\) are variable-input and variable-output indices. Parameter \(A\) captures the technological advance while \(\delta\) is the return-to-scale parameter. Subscript

\(^5\)By doing this, absolute levels of efficiency measures is not efficient, however, relative relationships among the measured efficiencies are still efficient unlike DEA, as it utilizes all available information in estimating the shape of the production possibility frontier.

\(^6\)The most conventional approach to specify the production transformation function would be to use the translog functions. However, it involves a large number of parameters while we do not have enough data points to retain sufficient degrees of freedom. Also it is hard to interpret the estimated parameters with translog functions as it is a second-order approximation of an anonymous function around unity.
$i$ stands for company $i$ and thus $i \in \{\text{JAL, ANA, JAS}\}$. That is, we estimate a common but non-autonomous production transformation function for three airline companies.

We take the log of both sides of (38) and assume that their difference follows a symmetric error distribution.\(^7\) Thus we estimate the parameters by minimizing the sum of squared errors:

$$
\min_{a^s, \beta, \delta, \rho, \rho^s, A} \sum_i \sum_t \varepsilon^2_{it} \quad (43)
$$

where

$$
\varepsilon_{it} = \ln O_{it} - \beta - At - \delta \ln I_{it}. \quad (44)
$$

After estimating the parameters, we find the maximum positive error $\varepsilon_{\text{max}} = \max \{\varepsilon_{it}\}$, and “shift-up” the production transformation function as much as $\varepsilon_{\text{max}}$, a-la Coelli and Perelman. Finally we obtain the production possibility frontier $f(x_t, k_{t-1}, k_t, y_t, t)$ as

$$
O_{it} = e^{\beta + At - \varepsilon_{\text{max}} \rho^s \delta} f^s_{it} \quad (45)
$$

where $O_{it}$ and $I_{it}$ are defined as above.

Parameters are estimated as follows (values in parentheses are standard errors):

<table>
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<tr>
<th>Parameter</th>
<th>Value</th>
<th>Standard Error</th>
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<td>$a_{12}$</td>
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<td>(0.1725)</td>
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<td>(3.7112)</td>
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<tr>
<td>$A$</td>
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<td>(0.0041)</td>
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</tbody>
</table>

The result indicates that production possibility frontier is concave in variable output index $Y_t$ and stock of aircraft $k_t$ with $\rho_{11}$ being $-4.3871$. Also, the fact that $\rho_{21}$ is 6.6818 indicates low elasticity of substitution between the variable inputs $X_t$ and aircraft stock $k_{t-1}$. Return-to-scale parameter $\delta$ is slightly smaller than one, thus indicating a weak decreasing return to scale. Estimate for $A$ being 0.0124 implies that there is a technological advance about 1.2% per year through the observed period.

\(^7\) An alternative of estimating the production transformation function is to assume an error distribution consisted of white noise and inefficiency as in the stochastic frontier approach, and then to use maximum-likelihood method.
3.2.2 Measurement Results of Static and Dynamic Efficiencies

Next, we compute the overall and static efficiencies and obtain dynamic efficiency, by solving two cost-minimization problems in (2) and (5) respectively. Static efficiency is decomposed into technical and allocative efficiencies by solving another cost-minimization problem as described in (8). In the cost-minimization problem finding the overall efficiency in (2), \(k_T\) can be either free or given as the actual value \(\bar{k}_T\) as mentioned earlier. In our computation, we take the latter option by setting \(k_T = \bar{k}_T\) to avoid \(k_T\) being extremely small in the optimal path, which can result from the firm’s incentive to save variable inputs in time \(T\).\(^8\) Discount rate of 4% is used for the value of \(\gamma\).

**Dynamic Efficiency and Over-investment in Aircraft Stock** Table 1. presents the computation results of efficiency measures. The results show that overall efficiency is the highest for JAL and lowest for JAS, while ANA being in the middle. At the same time, all three airlines achieved similar scores for static efficiencies, resulting in stark differences in dynamic efficiencies. Dynamic efficiency for JAL is as high as 0.9681 while that for JAS is as low as 0.6406, and ANA being again in the middle at 0.8241. These results suggest JAL’s competitive advantage over other two airlines, and for ANA and JAS (especially for JAS) over-investment for aircraft stock is suspected. Indeed, as Figure 1 and Figure 2 show, the deviation of the actual aircraft stock \(k\) from the optimal value \(k^*\) is the largest for JAS and then for ANA.

**Adjustment Costs and Lumpy Investment** Figure 3 presents the actual and optimal investment in aircraft stock for three airlines. Optimal paths are in general much smoother than the actual path, indicating the existence of adjustment costs in reality, which is not incorporated in our model this time.\(^9\) This applies more to the case of JAL, followed by ANA, and less to the case of JAS. This is partly due to that JAL flies internationally and thus uses larger aircrafts compared to other two airlines, and that airlines typically order aircraft in certain bulk.

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\(^8\) Alternatively, one can add a salvage (residual) value term to the objective function to avoid such behavior of \(k_T\) if the market value of the capital stock at time \(T\) is known.

\(^9\) Nemoto and Goto [3] discussed about the adjustment costs in the context of dynamic DEA.
Allocation between Materials and Labor  Figures 4 and 5 give the comparison of actual and optimal paths of both variable inputs, namely materials and labor. Relative to the shape of estimated isoquant curves and the relative prices of these inputs, all three companies are employing too much materials and too little labor. As materials include outsourcing of labor, this result seems to contradict with the common belief of efficiency gains through outsourcing. Figure 6 shows the ratio between actual and optimal proportions of material and labor inputs for three airlines. It indicates that for JAL, actual ratio is the closest to the optimum, while ANA is the farthest, and JAS being in the middle. This ranking is compatible with our allocation efficiency measures. Given that static efficiencies are almost the same for these three airlines, ranking for technical efficiency is just the reverse of that for allocative efficiency, i.e., it is the highest for ANA.

Excessive Labor Input for JAS  Figure 7 presents the comparison of optimal and actual paths for variable input indices, and Figure 8 takes the ratio of them. It shows that deviation from optimal path is discretely large for JAS, relative to JAL and ANA for whom extent of deviation is similar. This lowers JAS’s overall efficiency even more than that of ANA who shares the over-investment inefficiency mentioned earlier. Figures 9 and 10 decomposes such deviation into materials and labor. It is evident that JAS is using consistently more labor than other two airlines through the observation period. As to the deviation in materials, JAS is the highest throughout the period, while ANA seems to be successfully lowering such deviation, and getting closer to the level of JAL toward the end of the period.

Transition of Overall Efficiencies  Figure 11 contrasts the transition of three airlines’ overall efficiencies over time. In early 90’s both JAL and ANA lowered their efficiencies while JAS did to a much lesser extent. This is clearly the impact of Gulf war, as JAS was mostly flying domestic routes. After ’93, however, JAL and ANA successfully reverses the downward trend to upward rather sharply, while again JAS could not quite follow these two. Also, it is in a contrast that, toward the late 90’s ANA managed to improve
its efficiency, while JAS’s efficiency remained low.\footnote{We should note that values for ANA in 2002 and JAS between 2000 and 2002 is overestimated due to the boundary condition that the optimal value of $k_T$ must come back to its actual value $k_T$.}

**Stage Length** Lastly, it is worth noting that the data used for output are the passenger and cargo volumes which do not take into account the distance flown. As JAL mainly flies internationally while ANA and JAS fly domestically, the obtained results would be even more distinct and unambiguous, once we take into account these differences in the stage lengths.

4 Japanese Aviation Policy and Implications of Results

4.1 Japanese Aviation Policy and its Background

4.1.1 Air Transport Industry in its Primary Stage

In 1951, Japan’s aviation industry was allowed to resume its service and in 1953, Japan Air Lines (JAL) was set up through government funding and special legal status. JAL was designated to operate international and domestic trunk routes, while a number of other airlines were allowed to operate only on domestic local routes. As the demand for air transport increased, competition in the domestic market became severe. This called for establishment of a framework under which fair and moderate competition could be achieved. Recommendation of 1970 by the Transport Policy Council under the Ministry of Transport\footnote{As of January 2001, Ministry of Transport was integrated with Ministry of Construction etc., into Ministry of Land, Infrastructure and Transport (MLIT).} and the Ministerial Order of 1972 stipulated area of operation for the three major carriers: JAL on international and domestic trunk routes, All Nippon Airways (ANA) on domestic trunk and local routes, and Japan Air Systems (JAS, ex-Toa Domestic Airlines (TDA)) on domestic local routes. This consisted a part of so-called 45/47 regime, which had strongly regulated Japanese aviation industry until mid-1980’s.\footnote{45/47 stands for 1970 and 1972 in Japan’s Showa era. This regime is often referred to as “aviation constitution” in the literature including Yamauchi and Ito [8].}

4.1.2 Pro-Competitive Air Transport Policy since Mid-1980’s

**Promotion of Multiple Airline Operation in Domestic Air Transport Market**

In 1985, after the 45/47 regime had been in effect for more than 10 years, Transport
Policy Council reviewed this framework and was subsequently abolished by the Cabinet. New policy was introduced to promote multiple numbers of airlines operating in routes with large volume. Ministry of Transport set the level of passengers for a route in which two airlines (double tracking) or three airlines (triple tracking) could operate. Initially, threshold was set at 700 thousand and one million annual passengers respectively, i.e., in routes with annual passengers of more than 700 thousand, two airlines were allowed to operate; and in routes with more than one million, three airlines were allowed. The threshold was reduced twice, once in 1992 and again in 1996 to promote competition. In 1998, the rule itself was abolished so that airlines could enter into any route under their initiative. As a consequence, the ratio of available seats in routes with multiple airlines against total available seats in the domestic aviation market rose from 53% in 1985 to 80% in 1999.

In addition to pro-competitive reform in the domestic market, multiple designations in international air transport market was introduced. Also JAL was completely privatized in 1987.

**Regulatory Reform of Domestic Airfare** Domestic airfare regulation in Japan was designed to check and control fare raise. When the airlines applied for a permission to increase their airfares due to inflation or upspring in fuel price, aggregate cost of airline was reviewed by the Civil Aviation Bureau. Airfare was only allowed to increase upto the level justifiable by the cost under efficient operation. This was the rule in most public utilities back then.

In the mid-1990’s, regulatory reform of public utilities became a keen political agenda. In domestic airfare, “zone” for normal fare was set allowing airlines to set airfares freely between the cap and 25% below it. The cap was set from the cost of competitive routes, i.e., double- or triple-tracking routes. Incumbent airlines, however, took advantage of this reform and while introducing various discount fares such as advance booking discounts and improved frequent flyer programs (FFPs), they increased the normal fares in trunk routes such as Tokyo-Fukuoka and Tokyo-Sapporo. Price hikes in routes with two of the world’s heaviest traffic such as Tokyo-Fukuoka and Tokyo-Sapporo triggered severe criticism from Fukuoka and Sapporo regions.
Entry of New Airlines  Meanwhile, airport capacity expansion of highly congested Haneda Airport\textsuperscript{13} – the domestic hub airport located in Tokyo – was proceeding in due course. In March 1997, a new runway was opened which made it possible to increase landing slots for additional 40 flights per day. These slots were allocated to airlines in two stages: July 1997 and April 1998. At that time, there were six projects launched to raise new airlines and the first two to be in the market was Skymark Airlines in September 1998 on Tokyo-Fukuoka, and Hokkaido International Airlines (AIR DO) in December 1998 on Tokyo-Sapporo; new entry since 35 years ago. Incumbent carriers matched to the low airfares of these new entrants, and as a result passengers increased by 16.3\% on Tokyo – Fukuoka route, and 9.4\% on Tokyo – Sapporo route\textsuperscript{14}.

In order to accelerate deregulation in various transportation sectors, in December 1996 Ministry of Transport decided to abolish supply/demand test in the transport sector by the end of the century.\textsuperscript{15} As for air transport Civil Aeronautics Law was amended and put into effect on February 2000 and the supply/demand regulation policy was abolished. Since then, pro-competitive slot allocation policy at congested airports has been introduced. Allocated landing slots are reviewed every five years. Also, airfare change is only subject to notification by airlines to the Ministry in advance.

Market Performance  Between 1980 and 2000, the number of passengers in domestic market has more than doubled and average airfare decreased by one third. International market grew faster, and the number of passengers grew by four-fold. In its background, Japanese Yen appreciated against US\$ as much as 2.5 time between 1985 and 1995, which gave rise to a rapid increase in international air transport demand for Japanese travellers. However, the appreciation of yen resulted in high-cost structure of Japanese air carriers, while they faced severe competition against foreign carriers in the international aviation market. As a result, foreign airlines outgrew Japanese airlines, and market share of Japanese airlines dropped from 40\% to 37\%. Also, the average yield per passenger has been pulled downward, as its transition almost completely coincides with that of foreign

\textsuperscript{13}Tokyo International Airport (Haneda) has basically served as a domestic airport after Narita International Airport opened in 1978.
\textsuperscript{14}The numbers are average rates during the period.
\textsuperscript{15}This regulation required sufficient level of demand to be expected on each route in order to enter the market.
exchange rate due to international competition. Average airfare of Japanese international services decreased to less than half of what it was twenty years ago.

4.2 Interpreting Dynamic TFP of Japanese Air Carriers

Since 1986, when regulatory regime was replaced by pro-competitive policy, Japanese airlines went through a process of reform. The strongest impetus that forced Japanese airlines to improve their productive efficiency came from the international market. As mentioned earlier, Japanese Yen appreciated during this period, and this was a source of relatively high costs for Japanese airlines as well as for Japanese industry in general. Macroeconomic depression also served as a severe deflationary force. Coupled with competition from other domestic airlines, JAL was confronted with unprecedented difficulty in the international market. JAL’s revenue share from the international market was 70% of the total. In 1991 JAL plunged into the red with 97 million US$ operating loss. Until then JAL had enjoyed ten years of moderate gains. Operating loss expanded to 388 and 273 million US$ in 1992 and 1993, respectively. Faced with this crisis, JAL established a Corporate Restructuring Committee in 1992 and put together the so-called “Survival Plan” in which investment in fleets was slashed and cost-cuts undertaken to restore productivity. By 1995 JAL’s balance returned to black. Hence, JAL’s higher productivity is attributable to the fact that it has been facing international competition and tightening macroeconomic environment both in Japan and in the world.

ANA’s position, on the other hand, was relatively secured due to its advantageous position in the domestic market with its market share being around 50%. Leveraged by this advantage in domestic market, ANA gradually penetrated into the international market. It was not until 1998 when two new airlines entered the most lucrative routes in Japan such as Tokyo-Fukuoka and Tokyo-Sapporo, that ANA posted operating loss of 102 million US$. The fact that ANA was in a better situation owing to its favorable position in the domestic market, in turn could have weakened its incentive to improve productivity and efficiency relative to JAL. However, concord in 1998 Japan-US aviation talks expanding opportunities across the Pacific allowing ANA to operate in the same liberal status as the incumbents also put pressure on the company. It is not only international but also domestic market that is getting more competitive since the mid to
late 90’s, which induced ANA to strive for enhancing operation efficiency during the last decade.

JAS however, did not have any particular competitive edge in either international or domestic market. JAS did not have such advantage that ANA used to have in the domestic market, nor did it have any opportunity to operate in international market unlike JAL. Besides, JAS has been struggling with over-investment and excessive use of labor input through its history. This vulnerable company struggled to compete with the two mega-carriers without much success. It may have been a destiny for JAS to merge with JAL in 2002.

The question now is whether new JAL could overcome the heritage of over-investment and low labor productivity from JAS, as well as to revive from devastating damage from 9.11 and Iraq/SARS that shook the airline industry at the wake of 21st Century. We should note here that JAL is the most efficient among three Japanese airlines only historically, and that having done well in the last 20 years does not automatically mean that they will do the same in the next 20 years. In fact, if we look only at the current picture without the past 20 years in our scope, the ranking may well be already reversed for JAL and ANA.

What is important for Japanese airlines is to look at the next 20 years and do it right, and indeed opportunities are there for them. By 2009 a new runway will open at Haneda Airport, adding 50% more slots for domestic and short international routes in East Asia. Narita’s second runway will be extended to 2,500 meters by 2010, and the maximum number of aircraft landings will increase by 30,000. Expansion of these capacity-constrained airports in Tokyo will open a window of opportunity for Japanese airlines. Time is running out, however. They need to go though the second phase of productivity improvement quite swiftly to be prepared for a new competitive environment in and around east Asia.

\[16\text{It is planned to increase from about 260,000 to 400,000 landings per year.}\]
5 Conclusions

The main contribution of this paper is twofold. First it has provided a methodological framework called dynamic TFP which is a parametric method of measuring dynamic productive efficiency. The paper has considered a situation where a decision making unit employs quasi-fixed inputs as part of its production factors and produces new levels of quasi-fixed inputs jointly with other outputs. The choice of the levels of quasi-fixed inputs over time thus becomes the problem of dynamic optimization in the cost-minimization problem. Solution to this optimization problem given the production technology and factor prices conforms the benchmark, relative to which dynamic productive efficiency of each firm is measured. The idea of dynamic efficiency described above is first introduced in the framework of DEA, however, the use of DEA, implies the sensitivity to outliers and multiplicity of best performers. As a natural alternative, the paper has suggested to estimate the production transformation function after specifying it as an appropriate functional form, then to correct it by shifting above as much as the largest positive error to yield the production possibility frontier. Using this production possibility frontier, dynamic efficiency is measured as a ratio between the actual and the minimum possible costs given the output levels and prices.

As its second objective, the paper has applied the above-mentioned method to the dynamic productive efficiency measurement of Japanese airlines. The results have shown that the overall and dynamic efficiency is the highest for JAL, followed by ANA then by JAS. Lower dynamic efficiency for ANA and JAS is attributable to over-investment in aircraft stock. Overall efficiency is the lowest for JAS due to excessive use of variable inputs, especially labor, relative to other two airlines. The paper also discussed in detail about the interpretation of the results and its implications on Japanese aviation industry and its policy. It has argued that heightened international competition has triggered the efficiency improvement of Japanese airlines, especially for JAL, followed by ANA, who are now facing rapid deregulation in the domestic market as well.

One immediate extension of the paper would be to incorporate adjustment costs of quasi-fixed inputs, as suggested by the data. Another will be the inclusion of foreign airlines in the data set with longer observation period, to answer to the ultimate questions
mentioned in the beginning: are the Japanese airlines ready for further steps of global liberalization, particularly in the growing market of East Asia?

References


Table 1. Overall efficiency and its decompositions

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<th>JAL</th>
<th>ANA</th>
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<td>0.9154</td>
</tr>
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<td>AE</td>
<td>0.8528</td>
<td>0.7863</td>
<td>0.8017</td>
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Note:
OE: overall efficiency
DE: dynamic efficiency (computed as OE/SE)
SE: static efficiency
TE: technical efficiency
AE: allocative efficiency (computed as SE/TE)
Figure 1. Optimal and actual paths of aircraft stock measured in the number of seats available for (a) JAL, (b) ANA, and (c) JAS.
Figure 2. Ratios of actual and optimal paths of aircraft stocks for JAL, ANA, and JAS.
Figure 3. Optimal and actual paths of investment in aircraft stock measured in the number of seats available for (a) JAL, (b) ANA, and (c) JAS.
Figure 4. Optimal and actual paths of materials for (a) JAL, (b) ANA, and (c) JAS.
Figure 5. Optimal and actual paths of labor input for (a) JAL, (b) ANA, and (c) JAS.
Figure 6. Ratios of actual and optimal proportions of materials and labor inputs for JAL, ANA, and JAS.
Figure 7. Optimal and actual paths of variable-input indices for (a) JAL, (b) ANA, and (c) JAS.
Figure 8. Ratios of actual and optimal paths of variable-input indices for JAL, ANA, and JAS.
Figure 9. Ratios of actual and optimal paths of materials for JAL, ANA, and JAS.
Figure 10. Ratios of actual and optimal paths of labor inputs for JAL, ANA, and JAS.
Figure 11. Transition of overall efficiencies over time for JAL, ANA, and JAS.