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A COMPARATIVE STUDY OF TOTAL FACTOR PRODUCTIVITY OF THE WORLD'S MAJOR AIRLINES

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Abstract

This paper measures and compares the productive efficiency and unit cost competitiveness of the world's major airlines. Yearly panel data for the world's 36 major airlines is used to measure and compare the total factor productivity (TFP) and unit costs. Since the 'gross' TFP and unit cost measures are influenced by network and output attributes, a 'residual' TFP index is computed after removing the effects of the network and output attributes.

INTRODUCTION

Although the airline industry is characterized by increasing returns to traffic density and generally growing demand over time, profitability of the airline industry world-wide has been marginal. Beginning with deregulation in US domestic markets in 1978, many countries adopted pro-competitive policies in their approach to bilateral air treaties with other countries as well as in their domestic markets. This has intensified competition in both domestic and international markets. As the market becomes more competitive, the ultimate ability of a carrier to survive and prosper depends greatly on improvements in its efficiency and productivity. The issue of efficiency and productivity will become increasingly important for the airline industry, since the importance of input cost differences, including labour costs, are likely to diminish over time, as more and more airlines practice global sourcing of their flight crews, maintenance work, and other inputs.

There have been a number of studies on airline productivity and efficiency. Caves et al. (1987) compares the productivity performance of a sample of US and non-US airlines over the 1970-1983 period. Specifically, they computed the growth rate of total factor productivity (TFP) with an emphasis on measuring the effects of US deregulation on airline productivity. Gillen et al. (1985, 1990) measures and compares the productive performance of seven Canadian air carriers for the 1964-81 period by analyzing TFP and total cost functions. Bauer (1990) examines the relationship between TFP growth and changes in returns to scale, cost efficiency, and technology using quarterly panel data of 12 US airlines over the period 1971-1981. Encaoua (1991) examines cost and productivity differences among European carriers, and finds that the gap in productivity measures between the carriers has shrunk during the 1981-86 period. Using the stochastic frontier method, Good et al. (1993) compares technical efficiency and productivity growth for the four largest European carriers and eight US carriers during the 1976-86 period. They predict the potential efficiency gains of the European aviation liberalization by comparing efficiency differences between the two carrier groups. Ehrlich et al. (1994) examines the effects of state versus private ownership on rates of firm-specific productivity growth and cost decline, based on panel data of 23 international airlines during the period 1973-1983. Distexhe and Perelman (1993) uses the DEA method to measure technical efficiency and productivity gains for 33 airlines during 1977-1988. They find technological progress as a major source of productivity growth. The Bureau of Industry Economics (1994) study (Appendix D) has also applied the DEA method to one-year (1992) data to measure 'operating efficiency' of 28 world's airlines.

Except the BIE study, all other studies are based on data prior to the mid 1980s. The latest data used in other studies is for 1988. However, significant structural, institutional and regulatory changes have occurred in the airline industry since the mid-1980s. Consolidation of US airlines into six or seven major carriers began in the mid 1980s, and privatization of some major airlines began after the mid 1980s: JAL and British Airways in 1987, Air Canada in 1989, partial privatization of Qantas in 1992, etc. The European Commission introduced three packages of liberalization measures in 1987, 1990 and 1993. Therefore, it would be of interest to see if there are any significant changes in the relative ranking of airlines' productive efficiency because of these structural, regulatory and institutional changes in the airline industry.

This paper attempts to measure and compare productivity and efficiency of 23 of the world's major airlines using recent data (1986-93 period). We focus our analysis on identifying the factors which influence observed productivity differentials across airlines. A total factor productivity (TFP) index is computed to compare the observed or 'gross' measure of productivity across airlines, and over time. 'Gross' TFP index is influenced by variations in network, operating and market conditions, regulatory and institutional environment, variations over which airlines have limited control. A TFP regression, therefore, is used to identify the effects of these variations on the 'gross' TFP level, and to compute residual TFP after removing the effects of variations beyond managerial control.

The paper is organized as follows: the next section gives a brief description of the data base and the variables. The TFP results are presented in the following section. Then the sources of TFP differentials are examined. Summary and concluding remarks are given in the final section.

DATA

Our sample data consists of annual observations on 23 major international airlines over the 1986-93 period. The airlines in our sample are chosen mainly on the basis of availability of consistent time-series data. The data is compiled mainly from the *Digest of Statistics* series published by the International Civil Aviation Organization (ICAO). Additional data was obtained directly from airline companies. Annual reports of the carriers were used to supplement, cross-check with, and correct errors in the ICAO data. We contacted the airline companies for clarification when the two sources of data could not be reconciled.

Measurement of productivity requires detailed data on outputs, inputs, and network and output attributes. Four categories of output data were collected from ICAO's annual publication series *Commercial Traffic*: scheduled passenger service (measured in Revenue-Passenger-Kilometres or RPK), scheduled freight service (measured in Revenue-Tonne-Kilometres or RTK), mail service (measured in RTK), and non-scheduled passenger and freight services (measured in RTK). In addition, revenues from a fifth output category, the incidental services, were collected from ICAO's annual series *Financial Data.*

Incidental services refer to a carrier's non-airline businesses including catering services, ground handling, aircraft maintenance and reservation services for other airlines, sales of technology, consulting services, hotel business, etc. These are non-core activities of an airline, but use up part of the inputs reported in data sources most researchers rely on. Most previous researchers have ignored the presence of incidental services, and thus, failed to account for incidental outputs. Our data shows that the revenues from incidental services account for up to 30 percent of total operating revenues for some airlines, with an average of 8 percent for the airlines included in this study. Therefore, omission of the incidental services output without excluding the inputs used to produce them, would bias productivity measures in favour of the airlines who do little non-core businesses. An incidental output quantity index is constructed by deflating incidental revenue by the Purchasing Power Parity (PPP) index for GDP obtained from the Penn World Table (Mark 5.6, see Summers and Heston 1991, for description) and by the US GDP deflator.

Five categories of inputs are included: labour, fuel, materials, flight equipment, and ground property and equipment (GPE). Labour input is measured by total number of employees. Both the total number of employees and corresponding labour compensation are collected from ICAO's annual series *Fleet and Personnel,* and supplemented by data obtained directly from airline companies and from their annual reports. Fuel input is measured in gallons of fuel consumed. Fuel consumption data for a number of airlines was provided by the airlines upon request. Fuel consumption for US carriers for 1992 and 1993 are collected from the *Airline Monitor.* Fuel quantity data for Canadian carriers are collected from *Statistics Canada* 51-002 and 51-206. As was done in Caves et al. (1987), a fuel quantity regression model was used to estimate fuel consumption for those airlines whose fuel consumption data were not available to us. The regression included available tonne-kilometres, aircraft kilometres, load factor, aircraft hours, aircraft departure, aircraft type and year effects.

For flight equipment, a fleet quantity index is constructed by aggregating 14 types of aircraft using the translog multilateral index procedure proposed by Caves, Christensen, and Diewert (1982). The number of aircraft by type is collected from ICAO's annual series *Fleet and Personnel.* The leasing price series for these aircraft types was kindly supplied to us by Avmark, Inc., and is used as the weights in the aggregation. The stock of ground properties and equipment (GPE) is estimated using the perpetual inventory method. Data on the 1986 benchmark capital stock and the net investment series is compiled from ICAO's annual series *Financial Data.* Since the GPE costs are small relative to the costs of flight equipment, these two categories of capital inputs are further aggregated into a single capital stock series using the translog multilateral index procedure.

The last category of inputs is materials. The materials input contains all other inputs, not included in any of the categories discussed above. As such, materials cost is the catch-all cost category, and thus includes numerous items including airport fees, sales commissions, passenger meals, employee travel, consultants, non-labour repair and maintenance expenses, stationery, and other purchased goods and services. To compute the materials cost we take the total operating cost reported in ICAO's *Financial Data,* and subtract labour, fuel and capital related costs. A materials input quantity index is constructed by dividing materials costs by country-specific materials input price index. The construction of the country-specific materials price index starts with the intercountry purchasing power parity index for GDP, obtained from the Penn World Table 5.6 (Summers and Heston 1991), for each of the eight years during our sample period. The US GDP deflator is then applied to form a complete cross-sectional and time series materials price index. It is worthwhile to note that many studies on airline productivity, for example Distexhe and Perelman (1993), have excluded the materials input presumably because the materials input is difficult to measure. Since the materials cost accounts for 35%-50% of the total cost depending on airlines, the exclusion of such an important input will obviously bias the empirical findings on the relative efficiency of airlines.

Seven network, operating and output characteristics variables are compiled: average stage length, average load factor, revenue shares of freight and mail, non-scheduled services, and incidental services, aircraft utilization rate (based on aircraft hours), and government ownership status (use of a dummy variable for majority government ownership where government owns more than 50 percent). The effects of these variables are to be examined in order to make proper inferences about productive efficiency.

The 1993 key statistics for the 23 sample airlines are reported in Table 1. The list is organized by continent and by revenue size. It shows, among other things, that Qantas, Singapore, Cathay, JAL and KLM are long-haul carriers. Korean Air has heavy emphasis on freight services and non-airline businesses. Overall, many Asian carriers and some European carriers generate relatively high proportions of their revenues from freight services compared to US carriers. European carriers (except BA) have heavy emphasis on non-airline businesses as well. US carriers, on the other hand, primarily provide scheduled passenger services.

TOTAL FACTOR PRODUCTIVITY ANALYSIS

Total factor productivity (TFP) is defined as the amount of aggregate output produced by a unit of aggregate input. The following multilateral index procedure for making time series and cross section comparisons proposed by Caves et al. (1982) are used to compute TFP index:

$$\begin{aligned}\ln TFP_k-\ln TFP_j&=(\ln Y_k-\ln Y_j)-(\ln X_k-\ln X_j)\\ &=\sum_i \frac{R_{ik}+\overline{R}_i}{2}\ln\frac{Y_{ik}}{\tilde{Y}_i}-\sum_i \frac{R_{ij}-\overline{R}_i}{2}\ln\frac{Y_{ij}}{\tilde{Y}_i}\\ &-\sum_i \frac{W_{ik}+\overline{W}_i}{2}\ln\frac{X_{ik}}{\tilde{X}_i}+\sum_i \frac{W_{ij}+\overline{W}_i}{2}\ln\frac{X_{ij}}{\tilde{X}_i}\end{aligned} \quad (1)$$

where Y_{ik} is the output i for observation k, R_{ik} is the revenue share of output i for observation k, $\overline{R}_i$ is the arithmetic mean of the revenue share of output i over all observations in the sample, and $\tilde{Y}_i$ is the geometric mean of output i over all observations, X_{ik} are the input quantities, and W_{ik} are the input cost shares. This multilateral TFP index procedure is applied to panel data of 23 airlines for the 1986-93 period to measure and compare 'gross' TFP levels across airlines and over time.

Table 1 Descriptive statistics of the sample airlines, 1993

	Rev. (Mill US$)	No. of emp.	Av. Wage ('000 US$)	Stage Length (km)	Load Factor (%)	%Pax Rev[1] (%)	%Fre Rev[1] (%)	%Inc Rev[1] (%)	Rev/Exp[2]
North America									
American	14737	91773	56	1566	60	88	3	8	1.04
United	14354	78105	62	1631	67	88	5	6	1.02
Delta	12375	69537	70	1206	62	92	4	2	0.98
Northwest	8448	42439	63	1395	67	87	7	4	1.04
US Air	6624	45986	61	866	59	92	1	5	0.98
Continental	5086	36191	39	1360	63	90	3	6	0.99
Air Canada	2099	18184	36	1459	64	85	9	3	0.97
Canadian	1947	15208	36	1630	68	85	8	3	0.94
Australasia									
Japan Airl.	8591	22008	107	2396	65	79	13	5	0.97
All Nippon	7226	13870	94	1034	62	89	5	5	1.01
Singapore	3482	14664	25	4214	71	77	19	3	1.09
Korean Air	3342	15398	31	1617	65	58	20	18	1.09
Cathay	2957	13483	52	2990	70	75	17	5	1.10
Qantas	2688	15475	39	4257	70	77	10	6	1.06
Thai	2311	19247	19	1524	67	73	12	14	1.09
Europe									
Lufthansa	9532	46338	57	1071	66	65	13	18	0.999
British Air	8694	47705	35	1712	71	89	7	0.2	1.09
Air France	6826	43258	47	1637	68	65	14	20	0.92
Alitalia	3527	17212	70	1248	65	68	8	22	0.99
SAS	3623	19439	63	702	63	77	5	17	0.99
KLM	4321	26859	52	1856	67	64	18	17	1.06
Swissair	3540	19788	67	1243	60	66	10	23	1.01
Iberia	2745	25676	48	1196	67	85	7	7	0.96

Notes:

1. Revenue shares for passenger, freight and incidental
2. Ratio of operating revenue over operating expenses based on ICAO data

Table 2 reports the TFP index and average annual growth rate. The TFP index is normalized at American Airlines 1990. This TFP index is referred to as 'gross' TFP index because it includes the effects of variations in the variables (network, operating and market conditions, etc.) which are largely beyond managerial control. It merely shows how efficiently the given outputs, measured in revenue-passenger-kms, revenue-tonne-kms, etc., are produced without questioning, for example, how long the stage length of the flight is, or whether or not the government helps the airline to achieve high load factor by reducing competition. Therefore, one should refrain from making inferences on productive efficiency from the 'gross' TFP results. However, given that there tends to be less variations in network and other uncontrollable variables within a firm over time than across different firms, the 'gross' TFP may be used legitimately to identify general trends of productivity change over time. Also, it may be used to compare the productive efficiency across airlines with similar network and market conditions. Even these limited inferences should be made subject to revision when the results are changed after removing the effects of uncontrollable variables. With this note of caution, the gross TFP results in Table 2 can be summarized as below:

- There is a general trend that most airlines' gross TFP levels have improved during the 1986-1993 period. European carriers, on average, have achieved higher rate of productivity growth (3.3%) than North American carriers (0.7%). This may be, to a large extent, accountable by the major regulatory and institutional changes that have occurred in the European aviation market since 1986. Among Asian carriers, Korean Air (KAL) has had consistent improvement in its gross TFP throughout our sample period. Qantas and Thai International have also improved their productivity substantially, with average annual growth rates at 5.5% and 4.4%, respectively. Delta has achieved the highest productivity growth rate among the North

American carriers at an average of 2.3% per year, which is below the average for carriers outside North America.

Table 2 Gross TFP Index (normalized at American Airline 1990)

	1986	1987	1988	1989	1990	1991	1992	1993	%chg*
North America									
American	1.064	1.042	1.037	1.045	1.000	0.982	1.050	1.088	0.32
United	1.057	1.096	1.107	1.046	1.039	1.031	1.064	1.145	1.14
Delta	0.881	0.967	0.955	0.982	0.940	0.946	0.957	1.031	2.25
Northwest	1.086	0.997	1.017	1.040	1.040	1.083	1.122	1.170	1.06
US Air	0.757	0.791	0.755	0.739	0.738	0.753	0.775	0.799	0.77
Continental	1.179	1.110	1.053	1.046	1.027	1.042	1.090	1.086	-1.17
Air Canada	0.829	0.811	0.819	0.825	0.835	0.762	0.786	0.850	0.36
Canadian	0.910	0.833	0.927	0.924	0.937	0.840	0.855	0.956	0.70
Australasia									
Japan Airl.	1.081	1.169	1.286	1.264	1.144	1.131	1.105	1.029	-0.70
All Nippon			0.729	0.736	0.778	0.799	0.794	0.725	-0.01
Singapore	1.184	1.160	1.210	1.266	1.240	1.254	1.341	1.274	1.05
Korean Air	0.768	0.768	0.758	0.846	0.865	0.895	1.002	1.136	5.59
Cathay			1.180	1.150	1.132	1.148	1.188	1.235	0.91
Qantas	0.880	0.921	0.996	1.008	0.931	1.070	1.185	1.295	5.52
Thai	0.526	0.609	0.652	0.698	0.688	0.656	0.669	0.715	4.39
Europe									
Lufthansa	0.827	0.909	0.911	0.908	0.913	0.850	0.864	1.002	2.74
British Air	0.632	0.654	0.717	0.790	0.710	0.734	0.836	0.870	4.57
Air France	0.748	0.806	0.828	0.843	0.813	0.847	0.953	0.993	4.05
Alitalia	0.754	0.735	0.697	0.725	0.905	0.883	1.005	1.189	6.51
SAS	0.652	0.649	0.667	0.688	0.741	0.668	0.724	0.774	2.45
KLM	0.975	1.043	1.082	1.087	1.053	1.063	1.095		1.93
Swissair	0.846	0.895	0.913	0.943	0.929	0.925	1.013		3.00
Iberia	0.748	0.757	0.767	0.747	0.712	0.684	0.764	0.828	1.45

Note:
* average annual productivity growth rate during the 1986-1993 period.

- Observed TFP growth is closely associated with output growth which is easy to observe. Table 3 lists the multilateral output and input indices constructed using the translog multilateral index procedure proposed by Caves, Christensen and Diewert (1982). Both series are normalized at American Airlines 1990. Table 3 shows that most of the carriers had strong output growth during the 1986-1993 period, except for Air Canada and IBERIA. US Air and Delta achieved the highest rate of output growth, 18% and 14%, respectively, mostly because of the mergers with other carriers (US Air-PSA-Piedmont; Delta-Western). Korean Air, All Nippon, and Thai International are the fastest growing carriers in Asia with average annual output growth rates at 11%, 10% and 14%, respectively. Among the European carriers, Air France (10%) and Alitalia (11%) are leaders in output growth, closely followed by British Airways (9%) and Lufthansa (9%). It is noted that airlines which had high output growth also experienced strong TFP growth. For example, Alitalia's gross TFP had improved dramatically since 1990, in line with its strong output growth. Similarly, Korean Air's continuous TFP growth was matched by its continuous strong output growth. Air France improved its TFP substantially since its merger with UTA in 1992, as a result of both output growth and changes in output mix.
- Many airlines experienced a reduction of TFP during 1990-1992, mostly due to reductions in demand caused by the Gulf war and economic recession. Continental and Japan Airlines (JAL) have experienced slight declines in their gross TFP over the sample period, with average annual TFP diminution -1.1% and -0.7%, respectively.
- In 1993, the following carriers had high gross TFP levels relative to other carriers:

North America	Northwest (1.17), United (1.15), Continental (1.09), American (1.09)
Asia	Singapore (1.27), Qantas (1.29), Cathay (1.24), Korean Air (1.14)
Europe	KLM (1.09 in 1992), Swissair (1.01 in 1992), Alitalia (1.19), Lufthansa (1.002)

- US Air, All Nippon, Thai, and SAS have had considerably lower gross TFP than other carriers throughout our sample period.

Table 3 Output and Input Indices (normalized at American Airline 1990)

	Multilateral Output Index				Multilateral Input Index			
	1986	1990	1993	%chg*	1986	1990	1993	%chg*
North America								
American	0.631	1.000	1.288	10.19%	0.593	1.000	1.184	9.88%
United	0.754	1.005	1.308	7.87	0.713	0.967	1.142	6.73
Delta	0.375	0.705	1.004	14.07	0.426	0.750	0.974	11.81
Northwest	0.381	0.691	0.792	10.45	0.351	0.664	0.677	9.38
US Air	0.127	0.416	0.438	17.69	0.167	0.564	0.548	16.98
Continental	0.265	0.523	0.510	9.35	0.225	0.509	0.470	10.52
Air Canada	0.194	0.225	0.184	-0.97	0.233	0.269	0.216	-1.08
Canadian	0.096	0.193	0.177	8.74	0.105	0.206	0.185	8.09
Australasia								
Japan Airl.	0.387	0.486	0.520	4.22	0.358	0.425	0.505	4.91
All Nippon	0.180[1]	0.240	0.296	9.95	0.246[1]	0.309	0.408	10.12
Singapore	0.223	0.288	0.410	8.70	0.188	0.232	0.322	7.69
Korean Air	0.174	0.246	0.385	11.35	0.226	0.284	0.339	5.79
Cathay	0.198[1]	0.245	0.293	7.84	0.168[1]	0.216	0.237	6.88
Qantas	0.183	0.238	0.298	6.97	0.209	0.256	0.230	1.37
Thai	0.089	0.199	0.242	14.29	0.168	0.289	0.339	10.03
Europe								
Lufthansa	0.362	0.533	0.658	8.54	0.437	0.584	0.656	5.80
British Air	0.343	0.521	0.622	8.50	0.543	0.734	0.715	3.93
Air France	0.282	0.354	0.570	10.05	0.378	0.435	0.574	5.97
Alitalia	0.127	0.215	0.273	10.93	0.168	0.237	0.230	4.49
SAS	0.138	0.179	0.179	3.72	0.212	0.242	0.232	1.29
KLM	0.235	0.304	0.357[2]	6.97	0.242	0.289	0.326[2]	4.97
Swissair	0.161	0.192	0.202[2]	3.78	0.190	0.207	0.200[2]	0.85
Iberia	0.192	0.193	0.196	0.29	0.257	0.271	0.237	-1.16

Notes:
* average annual growth rate over the sample period.
1. 1988; 2. 1992

IDENTIFYING SOURCES OF TFP DIFFERENTIALS

As stated previously, the gross TFP levels are affected by the variables beyond managerial control, such as variations in network, operating and market conditions. Therefore, they should not be used to make inferences about productive efficiency of airlines. Earlier studies, such as Caves et al. (1981) and Ehrlich et al. (1994), have used regression analysis to decompose TFP differentials into various sources. Following a similar procedure, we ran a set of log-linear regressions of TFP and TFP growth on a number of factors, including output and network variables. This regression analysis has two objectives: to identify the potential effects of these variables on gross TFP levels and growth rates, and to compute a residual TFP index after removing the effects of 'uncontrollable' variables.

In this paper the following variables are treated as being beyond managerial control:

- average stage length: This variable depends on the route and market structure of the network which depends largely on geographic location of the home country, and regulatory control on market access (except in the deregulated domestic markets such as in the US), including the governments' attitude toward bilateral air treaties.
- composition of airline outputs: This is also greatly influenced by geographic location of the airline, and regulatory control on the airline industry. For example, air cargo businesses of many Asian and European carriers based in export-oriented countries, such as Lufthansa, Korean Air, KLM, Air France, JAL, Singapore, and Cathay, account for a large portion of total outputs because they were economically induced to develop air cargo businesses early on. On the other hand, US carriers have traditionally focused on passenger business.

Some researchers argue that load factor is also largely determined by the type of markets an airline is allowed to enter, as well as the extent of control on choice of aircraft and flight frequencies. Others argue that airline management can manage load factor by adjusting flight frequency and aircraft size to changing demand. Obviously, whether or not the load factor can be managed depends largely on regulatory conditions of a specific market. Most airlines have two types of markets: flight frequency and choice of aircraft are regulated and unregulated. When a system-wide load factor is used, therefore, it can be regarded either as a controllable or uncontrollable variable. In this study, load factor is regarded as being controllable.

In order to reflect the effect of disequilibrium adjustments in aircraft fleet, a capital stock variable is often included in the TFP regression (see, for example, Gillen et al. 1989). In addition, Oum and Zhang (1991) proposes to modify the capital stock variable by multiplying its utilization rate when the sample includes firms with varying utilization rates. Following the Oum-Zhang framework, we construct a utilization rate based on hours flown by aircraft to modify the capital stock. The effects of this modified capital stock are examined in the regression analysis. In addition to these "economic" variables, a set of dummy variables are created to examine year-specific effects and firm-specific effects.

In TFP level regressions, the natural logarithm of 'gross' TFP is the dependent variable with all the right-hand-side explanatory variables except dummy variables being transformed to natural logarithmic form as well. In TFP growth regressions, the difference in logarithm of gross TFP between two consecutive years is defined as the growth rates of TFP, and used as the dependent variable. The explanatory variables are also defined as the growth rates.

Table 4 reports four alternative sets of TFP level and growth regressions. Models (1), (3), (5), and (7) include the modified capital stock variable, while Models (2), (4), (6), and (8) do not. Models (3), (4), (7), and (8) include dummies for firm specific effects, but not the other four models. It should be noted that the parameter estimates for the firm dummy variables in Models (3), (4), (7) and (8) are not presented here due to space limitations. It should also be noted that the two TFP growth regressions with firm dummies, Models (7) and (8), theoretically correspond to TFP level regressions with firm specific time trend variables.

Comparison of the alternative regression models shows that inclusion of the capital stock variable increases the coefficients for output and decreases the coefficients for %Incidental for both level and growth regressions. When capital stock is included such as in Models (1), (3), (5) and (7), the output coefficients appear to be overestimated since these two variables are highly correlated, but work in opposite directions in the regression. Inclusion of firm dummies has substantial effects on the level regressions, while it does not have any significant effect on the growth regressions except for some increases in the coefficients for stage length, and some decreases in the coefficients for %Freight.

In the level regressions, for example, stage length and capital stock are both highly significant when firm dummy variables are not included, but they are no longer significant once firm dummies enter the regressions. This is because there are large variations in average stage length and the size of capital stock between carriers while variations in these variables over time within a carrier are relatively small. In such a case, the firm dummy variables explains some of the variations in TFP which can be legitimately explained stage length. Therefore, stage length coefficient is being under-estimated.

Table 4 TFP regression results*

	Level: Dep = LTFP=log(TFP)				Growth: Dep=LTFP$_t$-LTFP$_{t-1}$			
Parameter	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Constant	-1.301	-1.991	-2.856	-2.972				
	(1.70)	(2.45)	(4.25)	(4.44)				
Output	0.407	0.156	0.130	0.071	0.216	0.112	0.268	0.151
	(8.16)	(8.76)	(2.33)	(2.03)	(3.36)	(2.59)	(3.82)	(3.17)
Stage Length	0.257	0.273	0.067	0.065	0.196	0.208	0.257	0.277
	(9.52)	(9.38)	(1.18)	(1.14)	(2.85)	(3.01)	(3.40)	(3.65)
Load Factor	-0.176	0.012	0.396	0.446	0.372	0.412	0.368	0.408
	(0.93)	(0.06)	(3.07)	(3.60)	(3.48)	(3.87)	(3.46)	(3.83)
%Freight	-0.006	-0.042	-0.227	-0.225	-0.091	-0.083	-0.061	-0.053
	(0.26)	(1.85)	(4.65)	(4.58)	(1.77)	(1.59)	(1.12)	(0.97)
%Non-Sch.	0.007	0.018	-0.0004	0.002	-0.002	-0.001	-0.002	-0.002
	(0.90)	(2.12)	(0.06)	(0.24)	(0.28)	(0.17)	(0.33)	(0.32)
%Incidental	0.030	0.047	0.029	0.035	0.015	0.024	0.010	0.020
	(3.37)	(5.34)	(3.39)	(4.55)	(1.80)	(3.35)	(1.26)	(2.80)
Capital	-0.282		-0.071		-0.110		-0.117	
	(5.33)		(1.36)		(2.17)		(2.24)	
1987	0.015	-0.002	-0.024	-0.028	-0.014	-0.016	-0.032	-0.034
	(0.41)	(0.06)	(1.26)	(1.49)	(1.06)	(1.19)	(1.52)	(1.56)
1988	0.046	0.019	-0.008	-0.015	0.013	0.009	-0.006	-0.010
	(1.27)	(0.48)	(0.36)	(0.72)	(1.11)	(0.82)	(0.31)	(0.47)
1989	0.047	0.014	-0.013	-0.021	-0.006	-0.007	-0.023	-0.024
	(1.25)	(0.35)	(0 .52)	(0.89)	(0.53)	(0.61)	(1.15)	(1.18)
1990	0.022	-0.029	-0.035	-0.048	-0.021	-0.027	-0.037	-0.043
	(0.57)	(0.72)	(1.30)	(1.90)	(1.94)	(2.54)	(1.85)	(2.14)
1991	-0.0002	-0.053	-0.032	-0.046	0.0005	-0.002	-0.015	-0.018
	(0.005)	(1.39)	(1.23)	(1.88)	(0.05)	(0.20)	(0.73)	(0.87)
1992	0.033	-0.026	0.006	-0.009	0.033	0.032	0.014	0.013
	(0.87)	(0.66)	(0.20)	(0.32)	(3.05)	(2.88)	(0.71)	(0.63)
1993	0.060	0.001	0.045	0.030	0.042	0.041	0.028	0.027
	(1.55)	(0.02)	(1.42)	(1.01)	(4.06)	(3.95)	(1.44)	(1.37)
No. of Obs.	178	178	178	178	155	155	155	155
R-Square	0.666	0.620	0.944	0.943	0.438	0.419	0.553	0.535

Notes:
* T-values in parentheses
- all variables except dummies are in natural log;
- Capital is Capital stock multiplied by utilization rate.
- Models (3), (4), (7), (8) include firm dummy variables; the parameter estimates for the firm dummies are not reported here due to space limitation.

It appears that the growth regressions are more robust with respect to inclusion of different explanatory variables than the level regressions. However, both sets of regressions appear to be biased in one way or another, and to different degrees. In the following discussions about the effects of these variables on TFP and TFP growth, we try to reconcile results from the alternative models in order to provide a reasonable summary.

The results from the growth regressions indicate that there is a strong positive relationship between output growth and TFP growth. Growth in stage length and load factor made significant contributions to TFP growth. Growth in incidental services also contributed to TFP growth. On the other hand, the continuous existence of excess capacity slows TFP growth. The results on the time dummies show relatively strong TFP growth over the 1992-93 period, which is not explained by growth in other explanatory variables, and TFP decrease in 1990 due to Gulf War and recession.

In contrast to the growth regressions, we observe noticeable differences among the TFP level regressions. The results from the four level regressions are summarized below.

- Output level, stage length and load factor appear to have strong positive effects on the observed TFP level. %Incidental is significant and has a positive coefficient in all four regressions, indicating that there is a strong positive relationship between %Incidental and the observed TFP level, which is not attributable to any other factor. %Freight has a negative effect on TFP, which is contrary to the common intuition that freight services require less input than passenger services. This result is plausible, however, for the following reasons. Since cargo yields per RTK are far lower than passenger yield per RTK (average yield for our sample is US$1.03 per RTK for passenger vs US$0.33 per RTK for freight), cargo output receives very low weight in aggregating outputs. Therefore, the amount of increase in output index caused by cargo output may be relatively small as compared to the amount of increase in input index caused by cargo output. If this is the case, %Freight variable would have a negative coefficient as in our case. %Non-schedule is not significant in any of the regressions, since it represents a very small percentage of carriers' output in our sample. Capital stock has negative coefficients in both Models (1) and (3), indicating the potential negative effects of excess capacity on the observed TFP. The coefficients for year dummies indicate an industry-wide residual productivity improvement by about 3-6% between 1986 and 1993.

- Airlines with longer stage length or heavier concentration on incidental services are expected to have high 'gross' TFP than other airlines. This implies that as long as some of these variables are beyond an airline's control, the 'gross' TFP index can not be used to make inferences about productive efficiency.

In order to compare pure productive efficiency of the airlines, a 'residual' TFP index is computed after removing the effects of uncontrollable variables from the 'gross' TFP values reported in Table 2. Since the firm dummies in Models (3) and (4) take away the effects of stage length which is an important network variable, especially for an international comparison, we use Models (1) and (2) to compute the residual TFP index. Specifically, we removed the effects of the average stage length and output mix. It is believed that airlines at least have partial control over output expansion, load factor, and capital deployment. Therefore, the effects of output, load factor, and capital stock are not removed in computing the residual TFP. The two sets of residual TFP indices are very similar. Table 5 reports the residual TFP indices for selected years and average annual growth rates. The results are summarized as follows:

- Comparing the gross TFP and the residual TFP, it is noted that in some cases the effects of stage length and output characteristics on productivity are not large. However, the effects of these variables are substantial for the airlines at extreme ends of the scale in terms of stage length and/or output mix. There appear to be some over-adjustments for the effects of average stage length and output mix variables. Therefore, we need to be cautious in interpreting the residual TFP measures involving long-haul carriers. For example, Qantas, Singapore Air, and Cathay have very long stage length, and thus their residual TFPs are considerably reduced from their gross TFPs. On the other hand, US Air and SAS have short stage length, and thus their residual TFPs are consequently improved. Nevertheless, it is apparent that there are some substantial differences in productivity between airlines, although the differences are not as large as indicated by gross TFP.
- After removing the effects of the changes (and differences) in stage length and output mix, residual TFP has much smaller spread than the gross TFP. Moreover, about one third of the sample carriers have experienced slight declines in residual TFP. These imply that changes in airlines' network and output characteristics account for large portion of TFP growth over time. This is consistent with the findings of earlier studies, such as Bauer (1990).
- All the European carriers in our sample have improved their productive efficiency in terms of the residual TFP index, and achieved much higher growth rates than North American carriers. In particular, British Airways (4% per year), Alitalia (4%) and Swissair (3%) achieved the most significant growth. The Asian carriers, however, are divided into two groups. One group, including Korean Air (5%), Qantas (5%), and Thai (4%), achieved high growth rates, while the other group experienced declines in their residual TFPs. Among the North American carriers, Delta and Canadian achieved modest growth, while Continental experienced a noticeable decline in its performance. There is little change in the rest of North American carriers' relative performance. It should be noted that some European and Asian carriers, such as Alitalia and Korean Air, were able to improve their residual TFP (productive efficiency) more than others because of their high output growth.

Table 5 Residual TFP indices (normalized at American Airline 1990)

	Using Model (1): with capital stock				Using Model (2): without capital stock			
	1986	1990	1993	%chg*	1986	1990	1993	%chg*
North America								
American	1.083	1.000	1.066	-0.23%	1.094	1.000	1.080	-0.14%
United	1.089	1.025	1.110	0.27	1.111	1.029	1.129	0.23
Delta	1.011	1.054	1.112	1.36	1.054	1.096	1.155	1.31
Northwest	1.138	1.089	1.187	0.60	1.187	1.121	1.214	0.32
US Air	0.936	0.887	0.906	-0.46	0.940	0.893	0.897	-0.67
Continental	1.205	1.036	1.094	-1.38	1.226	1.020	1.086	-1.73
Air Canada	0.864	0.832	0.853	-0.18	0.894	0.845	0.871	-0.37
Canadian	0.856	0.934	0.924	1.09	0.864	0.938	0.929	1.04
Australasia								
Japan Airl.	0.946	0.995	0.900	-0.71	0.979	1.026	0.919	-0.90
All Nippon	0.868[1]	0.910	0.804	-1.53	0.917[1]	0.949	0.839	-1.78
Singapore	1.007	0.993	0.987	-0.29	1.059	1.049	1.035	-0.33
Korean Air	0.745	0.843	1.054	4.96	0.787	0.872	1.067	4.35
Cathay	1.038[1]	0.970	1.021	-0.33	1.074[1]	0.994	1.047	-0.51
Qantas	0.679	0.708	0.959	4.93	0.698	0.719	0.945	4.33
Thai	0.492	0.670	0.686	4.75	0.538	0.682	0.699	3.74
Europe								
Lufthansa	0.866	0.929	1.030	2.48	0.903	0.961	1.032	1.91
British Air	0.697	0.765	0.910	3.81	0.734	0.807	0.964	3.89
Air France	0.770	0.857	0.927	2.65	0.818	0.914	0.945	2.06
Alitalia	0.846	0.933	1.178	4.73	0.901	0.938	1.173	3.77
SAS	0.763	0.835	0.901	2.37	0.784	0.838	0.905	2.05
KLM	0.890	0.957	0.997[2]	1.89	0.916	0.991	1.022[2]	1.83
Swissair	0.854	0.952	1.012[2]	2.83	0.859	0.964	1.026[2]	2.96
Iberia	0.807	0.787	0.873	1.12	0.814	0.826	0.907	1.55

Notes:
* average annual growth rate over the sample period.
1. 1988; 2. 1992

- Among the North American carriers, Northwest is the most efficient airline, followed closely by Delta, United, American, and Continental. It is noted, however, that the efficiency level of the three mega carriers, American, United, and Delta, are very similar. US Air, Air Canada, and Canadian are about 10-25% less efficient than the mega carriers. The major Asian carriers, SIA, Korean Air, and Cathay, had converged to basically the same efficiency level in 1993, although there were substantial differences in their performance at the beginning of our sample period. Qantas performed relatively well in 1993 after making substantial improvements, especially since 1991 when Australia started the process of deregulation and privatization. On the other hand, JAL and ANA were not able to improve their productive efficiency despite their efforts. Thai is the least efficient carrier among the Asian carriers, but is improving quickly. Lufthansa, Alitalia, KLM, and Swissair are among the most efficient carriers in Europe. SAS and Iberia are the least efficient carriers in Europe. In the past, European carriers were considered as being inefficient. Although there is still a considerable gap between the performance of the major European carriers and that of US major carriers, significant improvements have been made since the European aviation liberalization process started in 1987. For example, British Airways has consistently improved its performance since privatization in 1987, and Lufthansa dramatically improved its performance in 1992/93 through its aggressive restructuring measures. We were able to observe and measure these improvements because of the use of more recent data than in previous studies.
- Overall, the major European carriers are about 5% - 20% less efficient than the mega carriers in the US, but they are catching up. In this respect, this study confirms the view which has resulted from some earlier studies of airline productivity.

- On average, major US carriers perform well relative to major carriers in Asia. While the major Asian carriers were much more efficient than the major European carriers at the beginning of our study period, the gap is becoming very small.

It should be noted that our results concern airlines' productive efficiency. The results on efficiency are not necessarily consistent with airlines' profitability. The most noticeable case is British Airways. While British Airways is among the most profitable airlines in the World, it appears to be relatively inefficient. This result is consistent with the findings of some of the previous studies, such as Distexhe and Perelman (1993) and Forsyth et al. (1986).

SUMMARY AND CONCLUDING REMARKS

This study measures and compares the total factor productivity for 23 major international airlines. It is noted that stage length and output mix have substantial effects on airlines' observed productivity. Therefore, their effects must be removed from the 'gross' measures of TFP in order to make meaningful comparisons across firms and/or over time within a firm. We measure the 'residual' TFP index after removing the effects of stage length and output composition variables. This 'residual TFP is used to compare productive efficiencies across firms and over time.

Although several Asian carriers (Singapore, Cathay and Qantas) have higher 'gross' TFPs than the major US carriers, the result is reversed in terms of the 'residual' TFP, a better indicator for productive efficiency. In 1993, Northwest, American, United, Continental and Delta, enjoyed higher productive efficiency than Cathay, KAL, Singapore or Qantas, the most efficient carriers in Asia. KLM, Alitalia, Swissair, and Lufthansa were the most efficient carriers among European carriers in 1993. Although there are some exceptional airlines, overall the US carriers enjoy higher productive efficiency, followed by Asian carriers and then by the European carriers. However, European carriers have significantly improved their performance since the aviation liberalization process began in 1987. As a result, the initial gap which existed between productivity performances of major European carriers and that of the major US carriers (and some major Asian carriers), is noticeably shrinking.

Our results also indicate that the performance of the major carriers which are competing in the same or similar markets is converging. For example, in 1993 there was little difference between the efficiency levels of American, United, and Delta in North America—the three mega carriers. This is also the case for Singapore, Korean Air, and Cathay in Asia. Similar trends can be seen in Europe, although there are still substantial differences in efficiency performance among the European carriers.

This study primarily concerns airlines' productive efficiency, which is not necessarily strongly correlated with airlines' profitability and financial well-being. Further study is necessary to examine the effects of efficiency and input prices, among other factors, on carriers' cost competitiveness which is vital for a carrier to survive and prosper in an increasingly competitive global market.

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