Integrated Air Freight Cost Structure: The Case of Federal Express

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PREFACE AND ACKNOWLEDGMENTS

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TABLE OF CONTENTS

Page

Preface and Acknowledgments ii
Table of Contents iii
Abstract iv

Introduction 1
Comparison of Passenger and Integrated Air Freight Industries 2
A Priori Expectations About Network Growth 3
History and Growth of Federal Express, 1986-1992 4
Data Collection and Reduction 7
Total Cost Model Methodology 10
Conclusions 16
Appendix A - Data Correction Procedure 18
References 20

ABSTRACT

This paper analyzes the economic structure of the integrated air freight industry. We evaluate a total cost model for Federal Express, Inc. by analyzing quarterly time-series data from 1986-1992. We find that Federal Express, and arguably all dedicated air freight carriers, exhibit diseconomies of scale and significant economies of density. We show that these two economic concepts can be restrictive, however, and introduce a third aspect of the integrated air freight industry's economic structure that combines the effects of economies of density and economies of scale. We call it economies of size, and show that Federal Express exhibits approximately constant economies of size. The conditions under which these findings hold are discussed.

INTEGRATED AIR FREIGHT COST STRUCTURE: THE CASE OF FEDERAL EXPRESS

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INTRODUCTION

Since deregulation, a large body of literature has emerged analyzing the performance of the passenger airline industry. By comparison, a paucity of literature exists analyzing the performance of the air freight industry, due in part to a lack of air freight industry performance statistics. Furthermore, the highly visible, cut-throat nature of passenger airline competition and the enormous revenues generated by the passenger carrier industry have attracted more attention from industry analysts. Consequently, we have only a limited knowledge of the air freight industry's economic structure, and an equally poor understanding of the emergence and success of the air freight industry as we know it today: highly concentrated and consisting primarily of integrated door-to-door delivery services with networks covering the United States and extending to many international markets.

The paucity of literature concerning the air freight industry's cost structure suggests that, as a point of departure, we borrow from the passenger industry literature, according to which costs are characterized by economies of scale at the segment level and constant returns to scale at the network level. In other words, if output is increased while the set of links served is held constant, unit costs decrease, while if a proportional change in output is achieved by a proportional change in network size, no change in unit costs is expected. We cannot, however, simply assume that the air freight industry is characterized by the same features as the air passenger industry because although the two are similar in many respects, they also have significant differences that may substantially influence their cost structures. Thus, there is a clear need for empirical study of the air freight industry's economic structure.

In this paper, we analyze the cost structure of the integrated air freight industry. (Integrated air freight carriers coordinate and execute the services of air carrier, freight forwarder, and ground handling.) Toward that end, we evaluate a total cost model for the largest express carrier in the industry (Federal Express) by analyzing quarterly time-series data from 1986-1992. We find that Federal Express, and arguably all dedicated air freight carriers in the industry, exhibit diseconomies of scale and significant economies of density. We also introduce the concept of

economies of size and show that Federal Express exhibits approximately constant economies of size. Possible restrictions in the conditions under which these findings hold are also discussed.

COMPARISON OF PASSENGER AND INTEGRATED AIR FREIGHT INDUSTRIES

As mentioned, there are two widely held beliefs about the structure of costs in the passenger airline industry. Caves, Christensen, and Tretheway (1984), Gillen, Oum, and Tretheway (1985 and 1990), and Hansen and Kanafani (1989) among others indicate that there are declining unit costs of service within any city-pair segment, and second, that there are approximately constant returns to scale for airline systems that have reached the size of U.S. trunk carriers. To assess the applicability of these findings to the air freight industry, it is useful to compare some of the qualitative features of each industry's technology.

The industries have some clear similarities. Both involve the operation and maintenance of large commercial aircraft. The aircraft fleets are very similar except that many freight industry aircraft are older, having been used in the passenger industry first and later converted for all-cargo use. In both industries, aircraft are flown on regular routes and according to regular schedules. Finally, airline companies in both industries make considerable use of hub-and-spoke routing strategies.

On the other hand, there are several significant differences between the industries. First, the nature of the hub-and-spoke systems are different. Air freight carriers employ fewer hubs, and route higher percentages of traffic through them than the passenger industry. In other words, the air freight industry relies on a purer application of the hub-and-spoke strategy, primarily because the passenger of a commercial airline carrier is unwilling to travel a circuitous route, whereas freight shippers are indifferent to circuity. Second, since the frequency of service is not as important to the freight customer as it is to the passenger, we rarely see more than one flight per day on a given segment in the air freight industry. Furthermore, since next day rather than same day service is needed, flights can leave in the evening when passenger activity is generally low and few congestion problems exist. Third, there are differences in airport ground access practices. The air freight industry includes ground access as part of its service, and is able to consolidate much of their loads before arriving at, or departing from, the airport. There are economies in freight collection and distribution since as density of shipments increase, vehicles need to travel short distances between pickup and delivery points. Fourth, freight requires considerably more ground handling than passengers. While passengers can transport themselves to the hub and "sort themselves" at the hub, this is a complex, labor intensive, and error prone process for freight shippers. Moreover, there is reason to believe that freight sorting is subject to diseconomies of scale since the complexity of the sort increases with the number of spokes.

A PRIORI EXPECTATIONS ABOUT NETWORK GROWTH

Drawing from the previous section, we can speculate on three aspects of the air freight industry's economic structure -- economies of density, economies of scale, and economies of size. We informally define the first two concepts below. (Formal definitions are provided in the methodology section later in this paper.)

- Economies (diseconomies) of density - a decrease (increase) of unit costs of production resulting from an increase in output, holding the number of points served, average stage length, average load factor, and input prices constant (i.e. constant network size).
- Economies (diseconomies) of scale - a decrease (increase) of unit costs of production resulting from an increase in output and the number of points served, holding density (i.e. output per point), average stage length, average load factor, and input prices constant.

These two economic concepts (particularly scale economies) are restrictive, however, in that as a company expands, its output is increased by adding points to the network, which changes the density. Thus, we should evaluate a third aspect of the economic structure of the air freight industry that combines the effects of economies of density and economies of scale. We call it economies of size, which is defined as follows:

- Economies (diseconomies) of size - a decrease (increase) of unit costs of production resulting from an increase in output and the number of points served, where it is assumed that output and the number of points served are functionally related.

Arguably, it is the economies of size that determines if it is beneficial for a company to expand its network. If, for example, strong economies of density exist coincident to diseconomies of scale, it may still be economically beneficial to expand the network.

Having defined these terms, and in light of the previous discussions, what do we expect concerning the structural properties of the air freight industry? First, we expect strong economies of density, since, for a given network, additional output should have little effect on system costs. This is particularly true in air freight since additional traffic is normally accommodated on existing flights rather than through adding additional flights, and since unit ground distribution costs decrease with traffic density. Second, we expect constant or decreasing economies of scale. Expansion of the system will generally involve replication of operations such as ground access and flying, but certain hub operations, such as sorting, may become more complicated and expensive. Finally, we expect that for a mature network, such as that of Federal Express during the period of our analysis, there will be approximately constant economies of size. Otherwise, the airline would have incentives to either expand or contract its network to reduce unit costs. By the same token, we would expect increasing economies of size when the

network is less mature. In other words, when the network is growing, additional traffic generated by increasing the set of origin-destination markets served more than compensates for the additional costs of adding these points, while in the mature network these effects largely counteract each other.

HISTORY AND GROWTH OF FEDERAL EXPRESS, 1986-1992

Because of the scarcity of economic and operational statistics of carriers in the dedicated freight industry, we can analyze the performance of only one carrier - Federal Express. While the performance of passenger carriers under deregulation is well documented by statistics reported to the Federal Aviation Administration (FAA), the same is not true for the air freight industry. Dedicated freight carriers have avoided reporting detailed operating statistics to the FAA for most of deregulation by not attaining certificated airline status or by operating only domestic flights. UPS did not begin reporting detailed statistics until 1990, nor did Emery until 1991. DHL and Airborne Express still do not report detailed statistics. The exception is Federal Express, who has reported detailed operating statistics since 1986.

Federal Express is the brainchild of Frederick Smith, who was convinced that it was possible to provide next day, door-to-door delivery of freight if the hub-and-spoke network concept were properly utilized, and that the demand for overnight delivery was sufficient to justify pursuing the concept. According to Federal Express (1992) fact sheets and Form 10-K reports, Smith incorporated Federal Express in Delaware in 1971, and officially began operations in 1973 with a fleet of only 33 Falcon 20's, serving only 25 cities. A total of 186 packages were shipped the first night. Initially, Federal Express' growth was only moderate, due in part to the company's newness, and later to federal regulations that severely constrained operations. After the freight industry was deregulated in 1977, Federal Express grew rapidly, creating a nationwide network seemingly "overnight". Federal Express moved over 1 million packages system-wide in a single night for the first time in November, 1988.

In 1989, Federal Express gained access to the international market by acquiring Flying Tigers and more than 20 other air freight transportation companies. Sigafoos (1988) and Trimble (1993) indicate that the primary motivation for the merger was to gain landing rights overseas. Nonetheless, the merger significantly affected domestic operations, particularly in heavier freight markets. (Generally, the term "freight" refers to parcels weighing between zero and 70 pounds. Shipments weighing more than 70 pounds are referred to as "heavy freight.") Figures 1 and 2 illustrate the increase in domestic freight and mail tonnage, and operating revenues, respectively, induced by the Flying Tigers acquisition in the latter half of 1989. (The acquisition was made in February of that year, and operations were merged six months later.) More specifically, the merger's most immediate impact on domestic operations was a fifty percent increase in freight

and mail tonnage which, interestingly, only resulted in a twenty percent increase in domestic revenues. The drastic decrease in reported "mail and freight", and increase in "other revenues" occurring in 1990-Q1 (Figure 2) is analyzed and explained in detail later in the report. For now, it is sufficient to note that there was a major change in the federal reporting standards implemented that year.

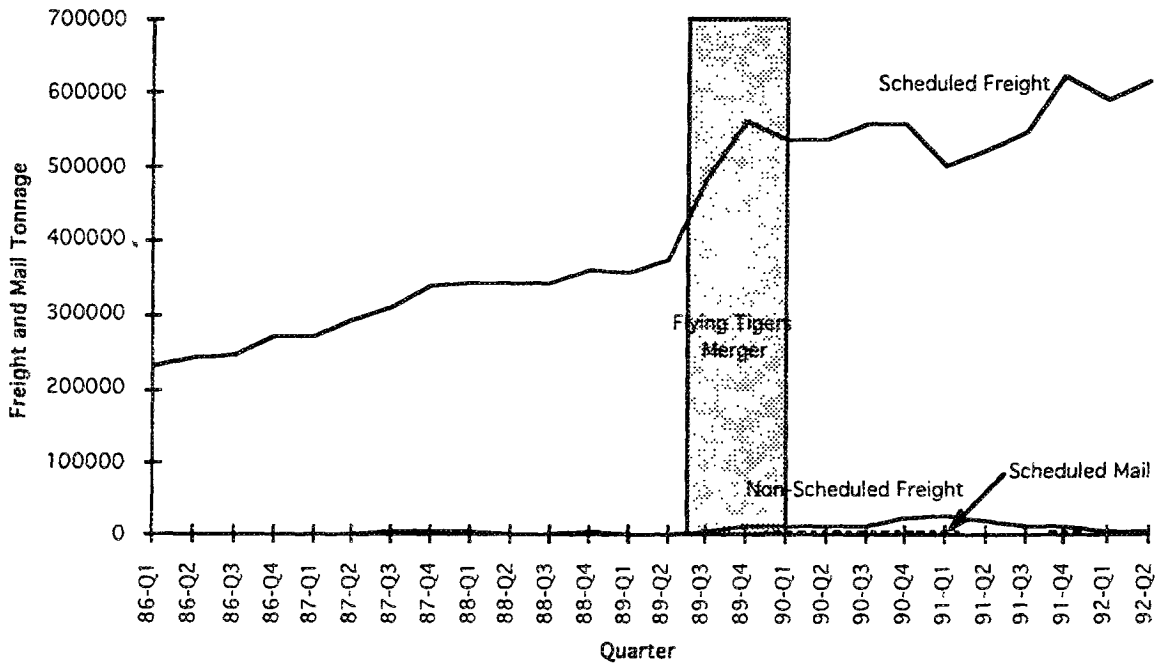

FIGURE 1 - FEDERAL EXPRESS DOMESTIC FREIGHT AND MAIL TONNAGE

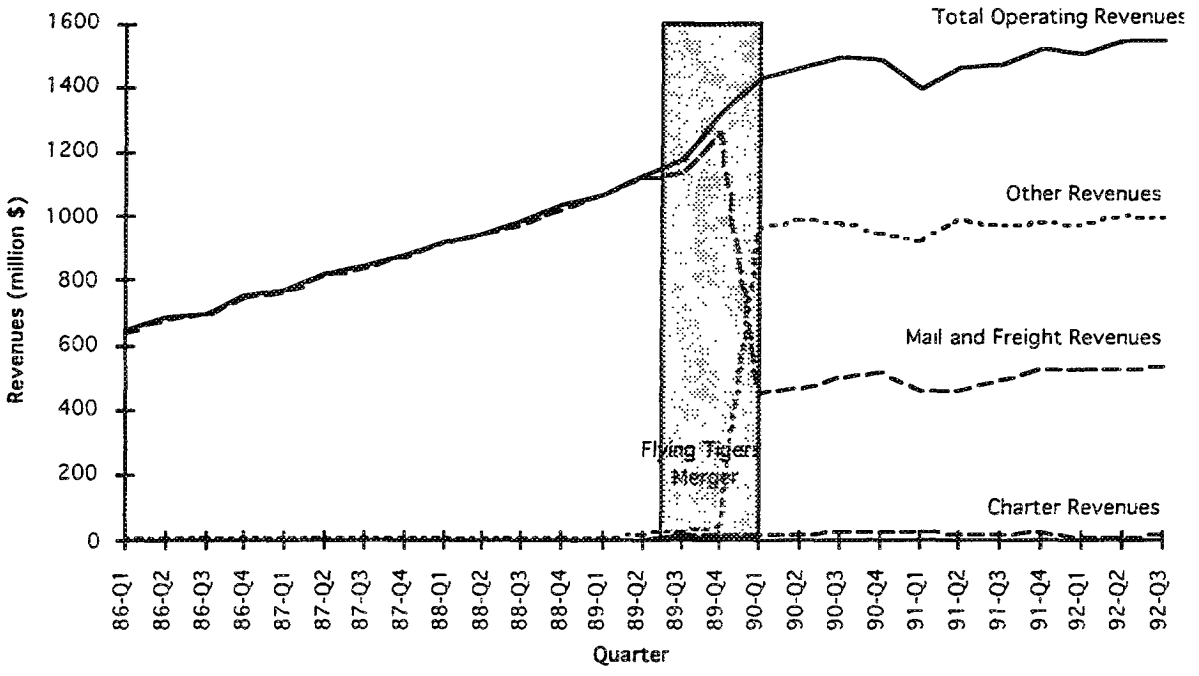

FIGURE 2 - FEDERAL EXPRESS FREIGHT AND MAIL REVENUES

From Figures 1 and 2, we see that the majority of Federal Express' revenue was generated by the movement of common carrier freight as opposed to mail or charter services. Throughout the period of observation (1986-1992), several different freight services were offered, illustrated in Figure 3. The company's mainstay has been the priority overnight service, which guarantees delivery by 10:30 a.m. the following business day, generating anywhere from 60 to 85 percent of the company's revenue from 1986 to 1992. For less urgent shipments, Federal Express offers a lower cost service, called the standard overnight service, which provides delivery by 4:30 p.m. the following business day. This service was introduced in 1990, and by 1992 accounted for 16 percent of the company's freight revenue. The third domestic service is the standard air, or 2-day service, which provides delivery of items by 4:30 p.m. two business days after the item is shipped. It has consistently generated from 10 to 15 percent of the company's freight revenue.

In addition to these delivery services, Federal Express generates revenue through freight charter services, heavy freight air services, and business logistics services. At the beginning of the facsimile revolution, Federal Express even experimented with Zap Mail, a combination of facsimile and document delivery services. The serviced was quickly discontinued when it became apparent that facsimile machines were destined to become standard operating equipment for businesses.

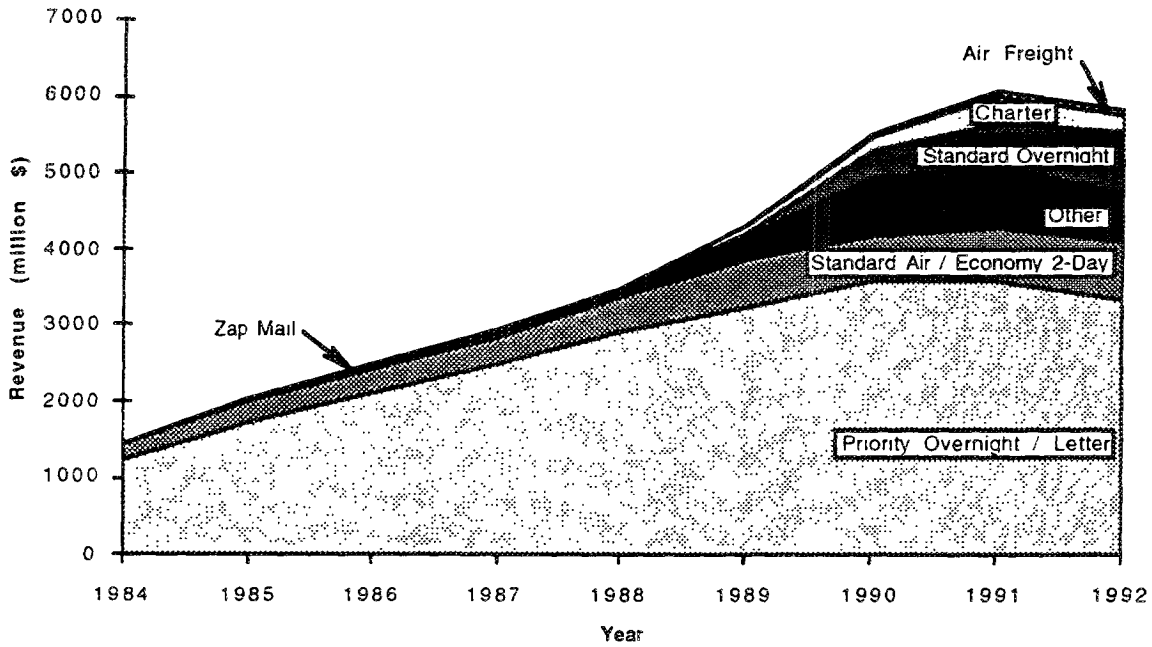

FIGURE 3 - REVENUE GROWTH OF FEDERAL EXPRESS SERVICES

Initially, Federal Express relied completely on the Memphis, TN, hub where all freight and mail items were shipped before final delivery. Over the years, Federal Express relaxed this constraint by developing a hub in Indianapolis (opened in 1988), and regional hubs in Los Angeles, Chicago, Oakland, and Newark. They also implemented operational innovations such as bleed-off operations which allow for direct delivery of freight (either by air or land) between two relatively close cities that have a high demand.

DATA COLLECTION AND REDUCTION

The first step toward developing the total cost model required to characterize the economic structure is to develop the data set. As previously discussed we analyze only Federal Express' performance. Furthermore, we consider only domestic operations since Federal Express' experience in international operations -- dating essentially from the Flying Tigers merger -- does not span a sufficient time period and, thus, does not result in a large enough data set to estimate an adequate international model.

We collected FAA Form 41 statistics (see USDOT (1986)) from the first quarter of 1986 (1986-Q1) to 1992-Q3 using a CD-ROM created and maintained by Data Base Products, Inc., to

develop our data set. This resulted in 27 observations, which are summarized in Table 1. We also obtained aggregated cost and price indices from the Air Transport Association of America.

TABLE 1 - SUMMARY OF QUARTERLY STATISTICS, 1986-Q1 TO 1992-Q3

	Mean	Standard Deviation
Total Cost of Operations ($)	618,101,508	196,802,500
Output (revenue ton-miles)	396,080,259	160,879,037
Fuel Price ($ per gallon)	0.63	0.12
Fuel Cost ($)	40,430,444	18,248,056
Labor Price ($ per employee)	2,531	410
Labor Cost ($)	134,014,325	44,717,590
Materials and Service Cost ($)	106,887,399	27,266,761
Available Line Haul (Available ton-miles per departure)	14,657	2,705
Number of Aircraft	210	89
Load Factor	0.57	0.03
Number of Points Served	212	20

The original data set had several problems, the most significant of which was that in 1990-Q1, the reported employment cost dropped approximately 75 percent while most other Federal Express statistics remained unaffected. While the absolute magnitude changed substantially, the trends before and after the discontinuities were consistent with each respective half of the data. Figure 4 illustrates that the employment cost increases steadily for the first twelve quarters of the data set. After the drop, it again increases steadily but at a lower magnitude. The dashed line in the figure was constructed by first extrapolating the 1990-Q1 employment cost datum from the 1986-Q1 to 1989-Q4 series, then estimating the 1990-Q2 to 1992-Q3 data based on growth rates calculated from the original statistics, and illustrates the consistency of growth trends before and after 1991-Q1. This procedure is described further in Appendix A.

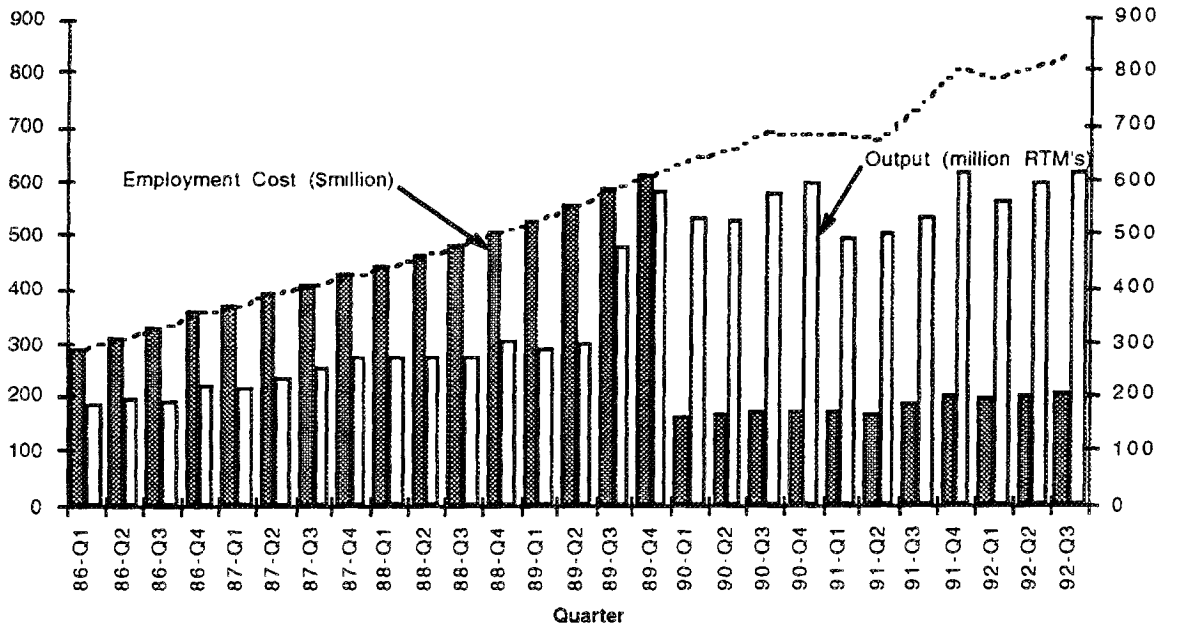

FIGURE 4 - CHANGES IN THE REPORTING OF OPERATIONAL STATISTICS

The original data set included several outlier fuel observations. Specifically, very high fuel prices were reported in 1986-Q1, 1990-Q4 (due to the Gulf War), 1992-Q2, and 1992-Q3, and very low fuel usage statistics were reported in 1992-Q2 and 1992-Q3. To explain how we controlled for the outliers, it is necessary to understand how Federal Express purchases fuel. Most vehicle fuel is purchased through local retailers at a small discount. Vehicle fuel accounts for less than 2 percent of the company's total operating expense each year. Aircraft fuel, which accounts for a much higher percentage of operating cost, is purchased through contracts with suppliers or is included in wet lease agreements. The contracts typically range from 3 to 18 months in length, and normally provide for specific amounts of fuel to be delivered. Up to 40 percent of the fuel represented by these contracts is prepriced, whereas the remainder of the required aircraft fuel is purchased at market price with the exception of that included in wet-lease agreements. These various methods of purchasing fuel allow Federal Express to avoid excessive hardship from short term fuel price increases. As a result, we "smooth" the reported fuel prices in 1986-Q1 and 1990-Q4 by replacing the reported price with three month averages.

Form 41 fuel prices for 1992-Q2 and 1992-Q3 were deemed unreliable and replaced by data from the Air Transport Association (ATA). The Form 41 prices in these quarters -- $0.99 per gallon -- were much higher than all quarters except that at the beginning of the Gulf War. Also,

the Form 41 prices for these quarters were substantially different from ATA prices, while all other data from these sources were in close agreement.

TOTAL COST MODEL METHODOLOGY

To analyze the cost structure of the air freight industry, we estimate a total cost model which includes input prices of factors used in production (fuel, labor, materials and services, and flight capital), a measure of output, and a set of other operating characteristics expected to influence the production technology.

We specify the general total cost function as:

$$TC = f(Q, FP, LP, PTS, ALH, LF, FT, Q1, Q2, Q3)$$

where

- Output, Q - the total revenue ton-miles (RTM) of freight and mail,
- Fuel price, FP - the fuel cost per gallon, normalized on the 1986-Q1 price,
- Labor price, LP - the salary and benefits per full-time equivalent employees, normalized on the 1986-Q1 price,
- Available Line Haul, ALH - the available ton-miles *(ATM)* divided by the total number of departures,
- Load Factor, LF - the actual revenue ton-miles divided by the available ton-miles,
- Points Served, PTS - the total number of airports served,
- Flying Tiger dummy variable, FT - 0 if 1986-Q1 to 1989-Q2 and 1 if 1989-Q3 to 1992-Q3, representing the merger of Federal Express with Flying Tigers, and
- Quarterly dummy variables, $Q1$, $Q2$, $Q3$ - representing the first three quarters of each year.

We define the total cost of operations, TC, as the sum of operating expenses and the opportunity cost of working capital. Based on the categories of information reported to FAA, we calculate the operating expenses as the sum of the total costs of materials and services, fuel and oil, labor, landing fees, and rental costs. We estimate the opportunity cost of working capital as 15% of the stated total value of operating property and equipment, plus current assets, minus current liabilities.

We adopt the Cobb-Douglas functional form to specify the total cost function, necessitated by the fact that there are only 27 observations in our data set. Estimating a translog functional form that captures second order effects, albeit preferred, would yield more variables in the formulation than there are observations in the data set. In other words, there are not enough

degrees of freedom to estimate the model. Furthermore, the presence of only moderate variation in the sample data suggests that the second order effects on the coefficient estimates are small. The Cobb-Douglas functional form, then, which is commonly assumed as a first order approximation, is appropriate.

If we let α denote an estimated constant, δ_i denote estimated dummy variable coefficients, D_i denote dummy variable i, and β_i denote estimated coefficients of the remaining variables, then we can specify the Cobb-Douglas total cost model:

$$TC = Q^{\beta_Q} FP^{\beta_{FP}} LP^{\beta_{LP}} ALH^{\beta_{ALH}} LF^{\beta_{LF}} PTS^{\beta_{PTS}} e^{\Sigma\delta_i D_i + \alpha}$$

Shephard's (1953) lemma implies that input i's share of the total cost is equivalent to the elasticity of the cost function with respect to the input price in question. The log transformed total cost function allows us to calculate the input share which, because of the simplicity of the Cobb-Douglas function, is simply the model's estimated coefficient for that input:

$$\begin{aligned} lnTC = \alpha + \beta_Q lnQ + \beta_{FP} lnFP + \beta_{LP} lnLP + \beta_{PTS} lnPTS + \\ + \beta_{ALH} lnALH + \beta_{LF} lnLF + \sum \delta_i D_i \end{aligned}$$

$$S_i = \frac{\partial lnTC(\cdot)}{\partial lnW_i} = \beta_i$$

It has become standard practice to specify classical disturbances for the above two equations and to estimate the parameters of the cost function by treating them as a simultaneous regression (see Gillen, Oum, and Tretheway (1985)). Applied to a Cobb-Douglas technology, this approach constrains cross-price elasticities, which are assumed to be constant, to equal mean total cost shares.

The inclusion of the *PTS* variable in the total cost function along with output is very important in that it allows us to distinguish between economies of density *(EOD)* and economies of scale *(EOS)* in air freight operations. Caves, Christensen, and Tretheway (1984) define returns to density as "the proportional increase in output made possible by a proportional increase in all inputs" holding all other factors constant. (Caves, Christensen, and Tretheway uses the terms returns to density and economies of density interchangeably. However, since we are considering a cost model, we will adhere to the latter terminology.) This is equivalent to the inverse of the elasticity of total cost with respect to output:

$$EOD = \frac{1}{\beta_Q}$$

We say there are economies of density if *EOD* is greater than unity, and diseconomies of density if it is less than unity. Economies of density would exist if unit costs decline as air freight carriers add flights or increase the capacity of existing flights (for example, through larger aircraft), with no change in the number of points served or the network configuration. Thus, it is critical that we include the *PTS* variable in the total cost model.

Caves, Christensen, and Tretheway (1984) and others also define returns to scale as "the proportional increase in output and points served made possible by a proportional increase in all inputs" holding all other factors constant. The same definition also applies directly to the freight industry. Again, because we are using a cost function, we prefer the terminology of economies of scale, which are equivalent to the inverse of the sum of the elasticities of total cost with respect to output and points served:

$$EOS = \frac{1}{\beta_Q + \beta_{PTS}}$$

We say there are economies of scale if *EOS* is greater than unity, and diseconomies of scale if it is less than unity. Economies of scale exist only if unit costs decline when points are added to the network, given that the additional service causes no change in load factor, stage length, or output per points served (i.e. density).

Whereas economies of density is defined as a reduction of unit cost from an increase in output over a fixed network, and economies of scale is defined as a reduction in unit cost from a proportional increase in output and points served, we define economies of size as the proportional increase of output, points served, <u>and density</u> made possible by a proportional increase in all inputs, with average stage length, and input prices held fixed. To formalize the definition, we express total costs of production as a function of the number of points served, output, and other descriptive variables (represented as *OTHER* for simplicity):

$$TC = Q^{\beta_Q} PTS^{\beta_{PTS}} OTHER$$

Assuming that the number of points served is closely correlated to the output, we can approximate the number of points served from the output:

$$PTS \approx Q^{\beta_{PTS\,Q}}$$

We can then substitute the *PTS* approximation into the original equation, and obtain the formal definition of economies of size *(EOSz)*:

$$TC \approx Q^{\beta_{PTS}\,\beta_{PTS\,Q}}\,Q^{\beta_Q}\,OTHER$$

$$EOSz \approx \frac{1}{\beta_Q + \beta_{PTS\cdot Q}\beta_{PTS}}$$

We say there are economies of size if *EOSz* is greater than unity, and diseconomies of size if *EOSz* is less than unity. *EOSz* is estimated by dropping *PTS*, which is assumed endogenous, from the cost model.

Since our model consists of a time series for a single carrier, we must consider the appropriateness of modelling it with a long-run cost function. Such a model assumes that all input quantities are variable, whereas, in practice, certain input quantities -- particularly capital -- may not be fully variable from one quarter to the next. Fortunately, however, the data show that capital is highly correlated with output throughout this period (r=0.982). Since Federal Express is able to vary the amount of working capital as output varies, we conclude that the long-run cost model presented above is appropriate. Estimation results are summarized in Table 2.

TABLE 2 - TOTAL COST MODEL RESULTS

Coefficient	Variable	Model 1	Model 2	Model 3
α	Intercept	8.847 (1.720)	6.711 (0.712)	11.558 (1.252)
β_Q	Output	0.424 (0.161)	0.246 (0.069)	0.965 (0.051)
β_{FP}	Fuel Price	0.064 (0.003)	0.064 (0.002)	0.064 (0.002)
β_{LP}	Labor Price	0.216 (0.002)	0.216 (0.002)	0.216 (0.002)
β_{ALH}	Available Line Haul	-0.372 (0.281)	—	-1.130 (0.156)
β_{LF}	Load Factor	-0.151 (0.192)	—	-0.540 (0.179)
β_{PTS}	Number of Points Served	1.192 (0.360)	1.600 (0.172)	—
δ_F	First quarter dummy	-0.008 (0.017)	—	—
δ_S	Second quarter dummy	-0.033 (0.017)	-0.032 (0.012)	—
δ_T	Third quarter dummy	-0.039 (0.016)	-0.036 (0.012)	—
δ_{FT}	Dummy variable for Flying Tiger merger	0.154 (0.059)	0.100 (0.037)	0.180 (0.054)
	Adj. R-Square	0.994	0.994	0.989
	D-W Statistic	1.84	2.03	1.40
	Economies of Scale	0.62	0.54	—
	Economies of Density	2.36	4.07	—
	Economies of Size	—	—	1.04
	F-statistic for H_o: $\beta_Q=1$	12.82	117.91	0.47
	F-statistic for H_o: $\beta_Q+\beta_{PTS}=1$	8.73	52.54	—
	Test statistic	3.98	3.98	3.98

The first model includes all of the previously defined variables. All coefficients have the expected signs, and most are highly significant. Recalling Shephard's lemma, we see that fuel accounts for approximately six percent of Federal Express' operating costs, while labor accounts for approximately 21 percent. The load factor coefficient tells us that a one percent increase in load factor implies that costs decrease approximately 0.15 percent, *ceteris paribus*. Specifically, we see that a one percent increase in output leads to approximately a 0.42 percent increase in cost. According to the above definition of economies of density, we see that *EOD* is 2.36 which, since it is significantly greater than unity, means there are strong economies of density. The F-statistic shows that we can reject the null hypothesis, H_0: $\beta_Q=1$ at a 95 percent confidence level. We also see that there are diseconomies of scale since $1/(\beta_Q+\beta_{PTS})<1$. The F-test reveals that we can reject the null hypothesis: $\beta_Q+\beta_{PTS}=1$ at a 95 percent confidence level. The estimated *EOS* for model one is 0.619.

Model two is a simplified version of model one in that it drops the first quarter dummy variable, and the available line haul *(ALH)* and load factor *(LF)* variables due to their statistical insignificance. The estimate of β_{PTS} in model two is considerably larger than the model one estimate because of the exclusion of *ALH* and *LF* from the model. Part of the density economies captured in model two derive from the increases in available line haul and load factor associated with increased density. Since model one controls for these effects, it only captures those density economies derived from other sources, namely complexity of traffic handling and scale economies of ground access. It is somewhat surprising that "most" of the density economies derive from these other sources (i.e. that the β_{PTS} coefficient in model one is well over half the value in model two). These modifications have little impact on the key results that there are significant economies of density (*EOD*=4.07) and diseconomies of scale (*EOS*=0.54). In both cases, the results are statistically significant in the sense that both of the previously defined null hypotheses can be rejected.

The most surprising aspect of models one and two is the finding of strong diseconomies of scale. As noted above, some such diseconomies are possible. For example, unit costs for sorting would be expected to increase with the number of points served (holding density constant) since this makes sorting operations more complicated. However, sorting is not a sufficiently large component of Federal Express' operations to, by itself, account for the strength of the diseconomies observed here. (Only about 24 percent of the labor cost is attributed to traffic and handling personnel.) We have not been able to identify any other plausible explanation for diseconomies of this magnitude. We can report, however, that our results proved quite robust to variations in model specification and estimation technique.

In model three, we drop the *PTS* variable, so that *EOSz* can be determined. By so doing, the output elasticity increases substantially to 0.97. We see that the inverse of this coefficient is

approximately unity, implying approximately constant economies of size. We cannot reject H_0: $\beta_Q=1$. Thus, as expected in a mature network, the increase in output generated by adding marginal points is just sufficient to counteract the cost penalty for doing so.

CONCLUSIONS

In this paper, we have analyzed the cost structure of Federal Express. We find that over the time period analyzed, Federal Express has a cost structure characterized by strong economies of density and diseconomies of scale. We also find that the carrier has constant economies of size, meaning that the increase in output resulting from expanding the network is such that unit costs are essentially unchanged.

Our findings suggest that freight carriers have cost structures with properties qualitatively similar, but considerably stronger, than those of passenger carriers. Caves, Christensen, and Tretheway (1984), for example, report economies of density of approximately 1.25 for passenger carriers, while we find economies of density much greater than 2.0 for dedicated freight carriers. These authors also report constant economies of scale for passenger airlines, while we find strong and statistically significant diseconomies of scale. The first of these findings is consistent with expectation, since we expect a large fraction of the costs associated with operating an air freight network to be fixed. The latter finding is unexpected, and, in our view, lacks a convincing explanation. We can only conjecture that future analyses will justify the presence of diseconomies of scale, or show that this result is a statistical anomaly.

We have shown that the concepts of scale and density economies do not adequately describe the structural properties of an air freight network. The former concept concerns the impact of output variation proportional to variation in the size (number of points) of the network, while the latter concerns output variation for a fixed network. While the concepts are useful, they overlook the fact that network growth -- particularly in the context of a hub-and-spoke network -- can result in supra-proportional output growth, since the number of origin-destination markets served is quadratically related to the number of points served. We believe that our concept of economies of size, by assuming a structural relation between output and network size, fills this gap.

Our results have strong implications for industry structure. In light of the strong economies of density, the industry is a natural monopoly, in the sense that a given set of points is most efficiently served by a single carrier. Federal Express' dominant position among domestic all-freight carriers, while falling short of complete monopolization, is generally consistent with this finding. Indeed, Federal Express' main competitors are not other freight airlines, but rather multimodal companies such as United Parcel Service and the U.S. Post Office. These companies offer services competitive to those of Federal Express as part of a much broader service mix.

This suggests that economies of scope between air express and other freight services, which we could not observe from the Federal Express data alone, may exert a considerable influence on the future development of the air express industry.

APPENDIX A - DATA CORRECTION PROCEDURE

We accounted for the drop in the data by adjusting the 1986-Q1 to 1989-Q4 data downward to coincide with the 1990-Q1 to 1992-Q3 data. This negated the need for including another dummy variable, which in turn, increased the performance of the model and made it simpler to work with.

To adjust the data, we first identified the categories of data that were affected by the reporting change. In the case of labor expenditures, we see that the total expenditure is comprised of 5 different categories of labor (general management personnel, flight personnel, maintenance, aircraft and traffic handling, and other personnel), only 2 of which are affected (aircraft and traffic handling, and other personnel). To adjust the 1986-Q1 to 1989-Q4 portion of the data set, we combine information from both the affected and unaffected categories. Extending the above example, we consider two categories of labor - aircraft and traffic handling salary (which drops in 1990-Q1) and flight personnel salary (which does not drop). The 1989-Q4 aircraft and traffic handling observation (ATH_{894}) was estimated by decreasing the 1990-Q1 observation (ATH_{901}) by the same percentage that the flight personnel (FP) salary changed in that period, as shown below. We denote an estimate with an overstrike.

$$\overline{ATH}_{894} = ATH_{901} \frac{FP_{894}}{FP_{901}}$$

The unaffected category from which the estimate is based was chosen because of its highly linear fit to the affected data. We then calculated the 1989-Q3 observation by decreasing the 1989-Q4 observation by the same percentage that it (aircraft and traffic handling) decreased from 1989-Q4 to 1989-Q3 in the original data:

$$\overline{ATH}_{893} = \overline{ATH}_{894} \frac{ATH_{894}}{ATH_{893}}$$

The remaining observations (1986-Q1 to 1989-Q2) where adjusted in this same way. We adjusted the 1986-1989 observations as opposed to the 1990-1992 observations because the latter half consistently reports only airside related operations whereas the former includes groundside related operations. This means that the latter is more consistent with all other categories of the data set. Finally, we calculated the sum of all labor categories to determine the revised total labor expenditure. We are essentially estimating only one observation for each affected category -- we use all of the information from the original data to adjust the remainder of the observations.

There is only one exception to the aforementioned procedure. The "aircraft rentals" cost category had no reasonably linear fit to another category. To compensate, the 1989-Q4 observation was estimated using a three month average of the post-1990 data. Then, the remainder of the observations were revised based on the 1989-Q4 estimate. A total of eight categories were adjusted in one of the aforementioned ways.

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