WCTR 2013 RIO

SELECTED PROCEEDINGS

THE COST STRUCTURE OF THE INTEGRATED AIR FREIGHT BUSINESS:THE CASE OF FEDEX AND UPS

EVY ONGHENA,DEPARTMENT OF TRANSPORT AND REGIONAL ECONOMICS – UNIVERSITY OF ANTWERP
HILDE MEERSMAN,DEPARTMENT OF TRANSPORT AND REGIONAL ECONOMICS – UNIVERSITY OF ANTWERP
VAN DE VOORDE,DEPARTMENT OF TRANSPORT AND REGIONAL ECONOMICS – UNIVERSITY OF ANTWERP

This is an abridged version of the paper presented at the conference. The full version is being submitted elsewhere. Details on the full paper can be obtained from the author.

ISBN: 978-85-285-0232-9

13th World Conference on Transport Research

www.wctr2013rio.com

15-18 JULY 2013
Rio de Janeiro, Brazil

THE COST STRUCTURE OF THE INTEGRATED AIR FREIGHT BUSINESS: THE CASE OF FEDEX AND UPS

Evy Onghena, Hilde Meersman and Eddy Van de Voorde
Department of Transport and Regional Economics – University of Antwerp
Prinsstraat 13
2000 Antwerp
Belgium
Tel. -32-3 265 43 96
Fax -32-3 265 43 95
{evy.onghena; hilde.meersman; eddy.vandevoorde}@ua.ac.be

ABSTRACT

This paper intends to deeply analyze the cost structure of the integrated air freight business by means of a translog cost function. This analysis makes it possible to better understand the supply side of the integrated air freight business and the industrial-economic relationships within the business. The cost function is based on quarterly time-series data from 1990 to 2010 of the airline operations of FedEx and UPS. A total as well as a variable model is estimated. In case of the total cost function, a dynamic approach is added to the static one. The results indicate that both integrators exhibit strong scale and density economies. This important result is in line with the current consolidation trend in the industry, of which the acquisition of TNT Express by UPS in 2012 is a clear sign. In addition, the model shows that the total and variable costs of FedEx and UPS depend mostly on the labor input price. For UPS, fuel seems to have the second-largest impact on its total and variable costs, while for FedEx it is the capital input price that has the second-largest impact on its total costs. The use of a translog cost function makes it also possible to calculate the substitution and price elasticities based on the different models. The findings of this paper are useful, not only for academics, but also for industry actors and policy makers since integrators play a significant role in the air freight industry and moreover, the integrated air freight business is of strategic importance for many other industries.

Keywords: integrators, air freight, translog cost model, economies of scale and density

1. INTRODUCTION

In our global, speed-driven economy with an increasing share of high-value goods, air cargo is very important for shippers, airlines, forwarders, airports, economic regions and governments. The air cargo market is a heterogeneous market in which the following three sub-markets can be distinguished: the general air freight market, the air express market and the postal services market. Integrators are situated at the intersection of all three sub-markets. In this paper, an integrator is defined as 'a vertically integrated express company that provides time-definite, door-to-door services and, for that purpose, performs its own[1] pick-up and delivery services, operates its own fleet of aircraft and trucks and ties it all together with advanced information and communication technologies'. (Zondag, 2006)

Until now, four large companies dominate the integrator market, namely FedEx, UPS, DHL and TNT Express. However, the acquisition of TNT Express by UPS increases the consolidation in this oligopolistic industry even further. Despite the dominant presence of integrators in the air cargo industry and their relationships with many actors in the air cargo chain, the know-how about the integrators' cost structure is very limited. This contrasts highly with the air passenger market, of which cost characteristics were studied much more frequently by means of estimating cost functions.

This paper intends to deeply analyze the cost structure of the integrated air freight industry. This includes the examination of the industry's cost characteristics, such as the existence of scale and density economies and the calculation of substitution and price elasticities between different inputs. This information allows us to better understand the integrators' strategies and the industrial-economic relationships in the market.

FedEx and UPS are respectively the numbers 1 and 2 in the IATA top 50 rankings of 2010 concerning both total (i.e. international and domestic combined) scheduled freight tonnes and freight tonne-kilometres carried (IATA, 2011, p. 88 and p. 90). These rankings show that FedEx and UPS have a dominant position in the air cargo industry. Moreover, they both are related to many other players in the air transport field by means of different types of business economic relationships. Hence, information about their cost structure is very useful, not only for academics but also for industry players and governments.

The cost functions in this paper are single-output cost functions since the data are from the air cargo carriers FedEx and UPS, not from the entire companies. Thus, this research provides an insight into the cost structure of the air cargo operations of FedEx and UPS, transporting both express parcels and heavy air freight in their aircraft[2]. However, in the case of integrators, cost interactions exist between their air and ground operations. These cost

[1] Next to their own pick-up and delivery services and the use of their own fleet, integrators make use of subcontractors.
[2] Even though the air cargo is listed on an air waybill, it is 'trucked' in some cases, especially for domestic US air cargo.

interactions are not taken into account in this paper because of two main reasons. Firstly, there is a data problem which makes it impossible to build a multi-output translog cost model for these companies. Secondly, this paper aims at modeling the cost structure of the air cargo operations of FedEx and UPS in order to be able to compare them with non-integrated air carriers.

This paper is structured as follows. Section 2 provides a brief overview of previous research dedicated to the cost structure of airlines and airports. Section 3 contains the model specification. The data used to estimate the cost models are described in section 4. In section 5, the concepts 'economies of scale' and 'economies of density' are defined and it is explained how these cost characteristics are calculated in the case of a total and variable translog cost function. Section 6 presents and analyzes the estimation results and cost characteristics. In the last section, the overall conclusions are summarized and the agenda for further research is set up.

2. PREVIOUS RESEARCH

The cost structure of the passenger airline industry has been the subject of many studies. In general, these studies agree on two important conclusions. The first conclusion is that there are declining unit costs of service within any city-pair segment. (Keeler, 1978; White, 1979; Bailey and Panzar, 1981, and Caves, Christensen and Tretheway, 1984). Secondly, they conclude that there are approximately constant returns to scale for airline systems that have reached the size of US trunk carriers. (Caves, 1962; Douglas and Miller, 1974; Keeler, 1978; White, 1979; Caves, Christensen and Tretheway, 1984). The know-how on airline cost structure was extended to small carriers and multiple outputs by, among others, Gillen, Oum and Tretheway (1990). In most of these studies, a total and/or variable translog cost function is applied to a panel data set.

A variable cost function is estimated by a growing number of economists in order to avoid the problems related to the correct approximation of the unit cost of capital. In a variable cost function the capital stock is treated as exogenously given. One of the main studies on variable translog cost functions is that of Caves, Christensen and Swanson (1981) which focuses on the US railroad sector. They derived the formulae for measuring returns to scale from a variable cost function. Oum, Tretheway and Zhang (1990) introduced an alternative specification for the calculation of returns to scale. In Oum and Zhang (1991), the impact of the utilization rate upon the shape of the cost function and the derived values of returns to scale and density are discussed. A study that focused on airline cost competitiveness by means of a variable translog cost function was that of Oum and Yu (1998). In Martín, Nombela and Romero (1999), the impact of the EU liberalization process on the cost structure of airlines and on their productive efficiency was analyzed. A recent study in which a variable translog cost function is estimated is that of Zou and Hansen (2010). They used the translog function to examine the relationship between airline operational performance and cost.

A good overview of developments in aggregate cost function research is that of Oum and Waters (1996). They show how cost functions are mostly used to infer cost characteristics of the industry and to measure productive efficiency across firms and/or over time.

Next to the passenger airline industry, the translog cost function has been applied to the airport industry as well. One of the studies in which a translog cost function is estimated in order to examine economies of output scale for airports is that of Jeong (2005). In Martín and Voltes-Dorta (2008), the returns to scale and marginal costs of 41 airports are estimated using single- and multi-product translog specifications of a long-run cost function.

As mentioned in the introduction, the research dedicated to cost structure analysis of the air cargo industry is very limited. This is mainly due to the scarcity of structured cost data about cargo carriers and, more specifically, about integrators. Kiesling and Hansen (1993) are, according to our literature study, the only authors that examined the cost structure of the integrated air freight industry. They estimated a total, Cobb-Douglas cost model for FedEx based on quarterly time-series data from 1986 to 1992. They concluded that this integrator exhibited diseconomies of scale and significant economies of density. They also introduced a new concept, namely economies of size. A more recent paper in which an adjusted translog model is applied to data on US air cargo carriers is that of Lijesen (2010). His objective is to measure the competition intensity through the use of cost data.

3. MODEL SPECIFICATION

A transcendental logarithmic (translog) specification is chosen for the cost function to be estimated. This functional form is very common in the analysis of cost structures across industries. The main reason for the use of a translog function in this paper is its flexibility, providing a second-order Taylor's series approximation in logarithms to an arbitrary cost function around a certain point. In addition, the translog specification allows for both positive and negative scale effects and makes it possible to capture the effects of varying elasticities of substitution between various inputs. (Christensen and Greene, 1976)

In this paper, a total as well as a variable cost function approach is used. Regarding the total translog cost function, a static as well as a dynamic specification is estimated. In the static (long-run) models, it is assumed that variable factors adjust instantaneously to changes in factor prices. However, this kind of models show significant autocorrelation in the error terms, suggesting that additional information may be obtained from the data with an improved model specification. Therefore, a dynamic, first-order autoregressive error process model is estimated, based on Seldon et al. (2000). The total cost function approach is explained in section 3.1, while section 3.2 deals with the variable approach.

3.1. Total translog cost function

3.1.1. Static approach

The most general form of a total translog cost function is written as follows (Berndt, 1991):

$$LNC = \ln\alpha_0 + \sum_{i=1}^{n}\alpha_i\, lnP_i + {}^1\!/_2 \sum_{i=1}^{n}\sum_{j=1}^{n}\gamma_{ij}\, lnP_i\, lnP_j + \alpha_y lnY + {}^1\!/_2\, \gamma_{YY}\,(lnY)^2 + \sum_{i=1}^{n}\gamma_{iY}\, lnP_i\, lnY \tag{1}$$

where
C: total cost
P_i and P_j: input prices
Y: output

The symmetry condition implies that $\gamma_{ij} = \gamma_{ji}$. Another restriction on the parameter estimates is that the cost function must be homogeneous of degree 1 in input prices, given Y. This implies the following restrictions on equation (1):

$$\sum_{i=1}^{n}\alpha_i = 1, \sum_{i=1}^{n}\gamma_{ij} = \sum_{j=1}^{n}\gamma_{ji} = \sum_{i=1}^{n}\gamma_{iY} = 0$$

The translog cost function can be estimated directly, but according to Berndt (1991), gains in efficiency can be obtained by estimating the optimal, cost-minimizing input demand equations, transformed into cost share equations. By logarithmically differentiating equation (1) with respect to input prices and employing Shephard's Lemma (duality between production and cost functions), the following cost share equations are obtained:

$$\frac{\partial lnC}{\partial lnP_i} = \frac{P_i}{C}.\frac{\partial C}{\partial P_i} = \frac{P_i}{C}X_i = \alpha_i + \sum_{j=1}^{n}\gamma_{ij}\, lnP_j + \gamma_{iY} lnY$$

where $\sum_{i=1}^{n} P_i\ X_i = C$. Defining the cost shares $S_i \equiv P_i\, X_i/C$, it follows that

$$\sum_{i=1}^{n} S_i = 1$$

This is the adding-up condition of the share equation system, which has several econometric implications. In this paper, only one of the implications is mentioned, namely the fact that one of the share equations has to be dropped to avoid a singularity problem when estimating by Maximum Likelihood (ML). The remaining n-1 share equations are then estimated by ML.

In order to be able to estimate returns to scale, it is necessary to add the translog cost function to the share equation system to be estimated (Berndt, 1991). Therefore, we estimated the translog function and the share equations jointly.

In this paper, we estimate a total translog cost function with four inputs: labor (UC_LABOR), fuel (UC_FUEL), capital (UC_DAR) and materials (UC_MAT). We opted for a cost function with one output variable, namely Revenue Tonne Kilometers (RTKs) since the available data did not allow us to estimate a multi-output translog cost function for the integrators. Moreover, FedEx and UPS are considered in this research as all-cargo airlines, only producing one output. In this paper, we focus specifically on the air cargo activities of FedEx and UPS. Both integrators' remaining activities (e.g. road transport, warehousing, forwarding, logistics, etc.) are beyond the scope of this paper.

In order to be able to distinguish between economies of scale (EOS) and economies of density (EOD), two network characteristics were incorporated in the model, namely the number of points served (N1) and the average stage length (N2). These variables are a measure for the network size of FedEx and UPS. The distinction between EOS and EOD is discussed in section 5.

A time trend variable (T), representing technical change over time, was also added to the model. It is often introduced when working with time-series data in order to capture output changes that are due to technological change. In addition, a dummy variable for the fourth quarter of each year was included but seemed to be insignificant.

The total cost function was estimated by means of two different estimation methods, namely Maximum Likelihood (ML) as well as Seemingly Unrelated Regressions (SUR). The econometric details of both methods are beyond the scope of this paper. The coefficient estimates, standard errors and probabilities were similar. Therefore, only the ML results are presented in section 6.

3.1.2. Dynamic approach

Since the static models show significant autocorrelation in the error terms, a first-order autoregressive error process model is used, based on Seldon et al. (2000). These authors applied the method developed by Berndt and Savin (1975). As pointed out by Seldon et al. (2000), one must be careful when correcting for autocorrelation in the share equations because of two reasons. First, the lagged error term associated with one equation may affect other equations. Second, the shares have to sum to one (adding-up restriction). In this paper, the cost function is included in the system of equations. In this case , the error terms of the cost function and the two remaining cost shares in case of a basic, three-input (labor, fuel and capital) model can be written as:

$$U_{c,t} = \rho_{c,c}U_{c,t-1} + (\rho_{c,dar}-\rho_{c,labor})U_{dar,t-1} + (\rho_{c,fuel}-\rho_{c,labor})U_{fuel,t-1} + V_{c,t} \quad (8)$$

$$U_{dar,t} = \rho_{dar,c}U_{c,t-1} + (\rho_{dar,dar}-\rho_{dar,labor})U_{dar,t-1} + (\rho_{dar,fuel}-\rho_{dar,labor})U_{fuel,t-1} + V_{dar,t} \quad (9)$$

$$U_{fuel,t} = \rho_{fuel,c}U_{c,t-1} + (\rho_{fuel,dar}-\rho_{fuel,labor})U_{dar,t-1} + (\rho_{fuel,dar}-\rho_{fuel,fuel})U_{fuel,t-1} + V_{fuel,t} \quad (10)$$

The v-terms are well-behaved error terms. The ρ-coefficients are the autocorrelation coefficients and the terms for the ρ-differences are estimated as one parameter since we are not interested in, and cannot estimate, these ρ_s individually. This involves that, compared to the static model, 9 extra coefficients have to be estimated. Equations (8) to (10) can be written as:

$$U_{c,t} = C(17)U_{c,t-1} + C(18)U_{dar,t-1} + C(19)U_{fuel,t-1} + V_{c,t} \quad (11)$$
$$U_{dar,t} = C(20)U_{c,t-1} + C(21)U_{dar,t-1} + C(22)U_{fuel,t-1} + V_{dar,t} \quad (12)$$
$$U_{fuel,t} = C(23)U_{c,t-1} + C(24)U_{dar,t-1} + C(25)U_{fuel,t-1} + V_{fuel,t} \quad (13)$$

The lagged error terms are specified as follows:

$U_{c,t-1}$ =
*LNTC_SUM(-1)-(C(1)+C(2)*LNY(-1)+(1-C(4)-C(5))*LNUC_LABOR(-1)+C(4)*
LNUC_FUEL(-1)+C(5)*LNUC_DAR(-1)+ 0.5*C(6)*
(LNY(-1))^2+0.5*(C(8)+C(9)+2*C(12))*(LNUC_LABOR(-1))^2+0.5*C(8)*
(LNUC_FUEL(-1))^2+0.5*C(9)*(LNUC_DAR(-1))^2-(C(8)+C(12))*LNUC_LABOR(-1)*LNUC_FUEL(-1)-
(C(9)+C(12))*LNUC_LABOR(-1)*LNUC_DAR(-1)+C(12)*LNUC_FUEL(-1)*LNUC_DAR(-1)-
(C(14)+C(15))*LNY(-1)*LNUC_LABOR(-1)+C(14)*LNY(-1)*LNUC_FUEL(-1)+C(15)*
LNY(-1)*LNUC_DAR(-1)+C(16)*LNT(-1))* (14)

$U_{dar,t-1}$ =
S_DAR(-1)-(C(5)+C(9)(LNUC_DAR(-1)-LNUC_LABOR(-1))+C(12)*(LNUC_FUEL(-1)-
LNUC_LABOR(-1))+C(15)*LNY(-1))* (15)

$U_{fuel,t-1}$ =
S_FUEL(-1)-(C(4)+C(8)(LNUC_FUEL(-1)-LNUC_LABOR(-1))+C(12)*(LNUC_DAR(-1)-
LNUC_LABOR(-1))+C(14)*LNY(-1))* (16)

The final dynamic specification is obtained by replacing equations (14) to (16) in equations (11) to (13) and by adding equation (11) to the static cost function (2) and equation (12) and (13) to the remaining capital (6) and fuel (7) cost shares. The adding-up restrictions in this system are written as:

C(3)=1-C(4)-C(5)
*C(7)=C(8)+C(9)+2*C(12)*
C(10)=-C(8)-C(12)
C(11)=-C(9)-C(12)
C(13)=-C(14)-C(15)

In section 6 only the results of the dynamic version of the four-input model are presented. The specification of this model can be derived from the static four-input model in a way that corresponds to the method described above for the three-input model. However, since the theoretical specification of this model is very complex, it is not included in this paper.

3.2. Variable translog cost function

We use the variable cost function approach next to the total cost function approach. The main reason for this is the difficulty to calculate an exact unit price of capital input for FedEx and UPS. In addition, various authors showed that firms, and more specifically, airlines, are not able to adjust their capacity instantaneously to the optimal, equilibrium level. Therefore, a distinction can be made between variable and quasi-fixed inputs, where the latter adjust only partially to their full equilibrium levels within one time period. The variable cost function reflects the short-run minimization process. (Caves, Christensen and Swanson, 1981; Caves, Christensen and Tretheway, 1984; Gillen, Oum and Tretheway, 1990)

The variable translog cost function for FedEx and UPS includes three variable inputs (labor, fuel and materials) and one fixed input (capital). Contrary to the total translog cost function, the variable cost function does not include the unit price of capital as a right-hand variable, but the quantity of the fixed capital amount. According to Zou and Hansen (2010), the capital quantity is called 'capital input' (S). The capital input is calculated by multiplying the capital stock with the utilization rate, for which the load factor is used as a proxy. The capital stock is calculated as the asset values plus investment. The following four types of assets are included: flight equipment, ground property and equipment, capital leases and land. A time trend variable T is included in the variable cost function.

The variable cost function is specified as follows:

*LNVC = C(1) + C(2)*LNY + C(3)*LNUC_LABOR + C(4)*LNUC_FUEL + C(5)*LNUC_MAT + C(6)*LNT + C(7)*LNS + 0.5*C(8)*(LNY)^2 + 0.5*C(9)*(LNUC_LABOR)^2 + 0.5*C(10)*(LNUC_FUEL)^2 + 0.5*C(11)*(LNUC_MAT)^2 + 0.5*C(12)*(LNS)^2 + C(13)*LNUC_LABOR*LNUC_FUEL + C(14)*LNUC_LABOR*LNUC_MAT+ C(15)*LNUC_FUEL*LNUC_MAT + C(16)*LNY*LNUC_LABOR + C(17)*LNY*LNUC_FUEL + C(18)*LNY*LNUC_MAT + C(19)*LNY*LNS + C(20)*LNUC_LABOR*LNS + C(21)*LNUC_FUEL*LNS + C(22)*LNUC_MAT*LNS*

with

VC	variable cost = labor cost + fuel cost + materials cost
Y	output (RTKs)
UC_LABOR	input price of labor (cost per unit of labor used)
UC_FUEL	input price of fuel (cost per unit of fuel used)
UC_MAT	input price of materials
S	capital input (capital stock * load factor)
S_LABOR	share of labor cost in variable cost
S_FUEL	share of fuel cost in variable cost
S_MAT	share of materials cost in variable cost
T	time trend variable
C(1),…,C(22)	coefficients to be estimated

In analogy with the total cost function, the share equations for the variable inputs are written as:

$$S\_MAT = \frac{\partial lnVC}{\partial lnUC\ MAT}$$

*S_MAT = C(5) + C(11)*LNUC_MAT + C(14)*LNUC_LABOR + C(15)*LNUC_FUEL + C(18)*LNY + C(22)*LNS*

$$S\_LABOR = \frac{\partial lnVC}{\partial lnUC\ LABOR}$$

*S_LABOR = C(3) + C(9)*LNUC_LABOR + C(13)*LNUC_FUEL + C(14)*LNUC_MAT + C(16)*LNY + C(20)*LNS*

$$S\_FUEL = \frac{\partial lnVC}{\partial lnUC\ FUEL}$$

*S_FUEL = C(4) + C(10)*LNUC_FUEL + C(13)*LNUC_LABOR + C(15)*LNUC_MAT + C(17)*LNY + C(21)*LNS*

The variable cost function has to be homogeneous of degree 1 in variable input prices, given S and Y. In addition, the adding-up condition is valid for the variable translog cost function as well, so one of the share equations has to be omitted. The results are invariant to which share equation is deleted.

As indicated by Oum and Zhang (1991) and Oum and Yu (1998), the estimation efficiency can further be increased by imposing an additional equation for the shadow value of capital input. Berndt (1991) defines the shadow value of the fixed capital input as the one-period reduction in variable costs attainable if, holding output quantity and variable input prices constant, the quantity of capital services were increased by one unit. In this paper, the additional equation is specified as follows:

$$-C_k/VC = \frac{\partial lnVC}{\partial lnS} =$$

*C(7)+C(12)*LNS+C(19)*LNY+C(20)*LNUC_LABOR+C(21)*LNUC_FUEL+C(22)*LNUC_MAT*

where C_k is the depreciated capital cost, which is approximated by the total capital cost multiplied by the utilization rate (load factor). In this paper, the total capital cost is calculated as the sum of depreciation, amortization and rentals (DAR).

In a next step, the variable cost function was estimated with the network characteristics N1 and N2 included. These variables are calculated in the same way as in case of the total cost function. The results shown in section 6 are the results from a variable cost model that includes the network characteristics N1 and N2.

4. DATA

The cost function in this paper is based on quarterly time-series data from the first quarter of 1990 (1990Q1) to the second quarter of 2010 (2010Q2) of FedEx and UPS, provided by US Department of Transportation - Bureau of Transportation Statistics (BTS). The databases that were used are Form 41 Air Carrier Financial Data, Form 41 Air Carrier Traffic Data and T1 Traffic and Capacity Summary Data by Service Class. Domestic as well as international operations are considered. International operations involve Atlantic, Pacific and Latin operations, so only operations to/from the US. This means that e.g. flights from Europe to Asia or flights within Asia are not included in the dataset. All cost statistics are calculated in constant prices (2005=100).

4.1. Total translog cost function

Total costs (TC_SUM) are calculated as the sum of Salaries and Related Fringe Benefits (labor cost), Aircraft Fuel and Oil (fuel cost) and Depreciation, Amortization and Rentals (capital cost). In the case of a fourth input variable (Materials), also the Total Materials cost (without fuel) is included.

As discussed, Revenue Tonne Kilometers (RTKs) is used as a single output variable (Y). It is calculated based on T1 Traffic Summary Data by Service Class. The labor input price (UC_LABOR) is calculated as the total labor cost divided by the number of full time equivalents (FTEs). The input price of fuel is calculated as the total fuel cost divided by the total consumption (in gallons).

In case of a fourth input variable (materials), the materials input price (UC_MAT) is proxied by the producer price index (PPI), according to what was done in Zou and Hansen (2010). This index varies by quarter but not by airline and is collected from the US Bureau of Labor Statistics.

The input price of capital (UC_DAR) is calculated as the total cost of depreciation, amortization and rentals (DAR) per Available Tonne Kilometer (ATK). It was difficult to find a correct measure for the cost of capital. A calculation of the Weighted Average Cost of Capital (WACC) was considered but seemed to be impossible due to the lack of data on the market value of equity for the airline operations of FedEx and UPS. It was also impossible to calculate an annuity since information about the purchase price, scrap value and life span of each aircraft of FedEx and UPS was unavailable. The option to work with an opportunity cost of capital, namely the real interest rate, was also considered. Estimations with the real interest rate as a proxy for the input capital price were done. However, the results were worse than when DAR per ATK was used. Therefore, the best possible way to calculate the input price of capital was by using the three elements mentioned above, namely depreciation, amortization and rentals. Since we recognize that also this option is not a perfect measure for the unit cost of capital of FedEx and UPS, the variable translog cost function was estimated as well.

The network variable N1 is calculated as the number of airports served, based on T-100 Segment Traffic Data provided by BTS, while N2 is calculated as the total distance flown divided by the total number of departures performed and is based on T-1 Traffic Summary provided by BTS.

The sample consists of 82 observations. The descriptive statistics of the key variables for FedEx and UPS are presented in table I. These variables are used in the static as well as the dynamic specification.

Table I – Descriptive Statistics of Key Variables (in constant prices) of Total Translog Cost Function – FedEx and UPS

	Mean	Std. Dev.	Minimum	Maximum
		FedEx		
Total Cost (excl. materials) ($)	1.34E+09	3.89E+08	8.07E+08	2.20E+09
Total Cost (incl. materials) ($)	1.49E+09	4.47E+08	8.78E+08	2.46E+09
Output (RTKs)	2.47E+09	8.27E+08	1.15E+09	3.76E+09
Labor price ($ per FTE)	22130.15	2641.01	18616.37	31086.36
Fuel price ($ per gallon)	1.15	0.58	0.53	3.24
Capital price ($ per ATK)	0.11	0.03	0.07	0.16
Materials price (index)	142.98	14.58	114.90	170.80
Number of points served	47.84	10.85	28.00	79.00
Average stage length (kilometers)	922.94	122.23	743.08	1130.86
		UPS		
Total Cost (excl. materials) ($)	4.84E+08	2.12E+08	1.93E+08	1.06E+09
Total Cost (incl. materials) ($)	5.34E+08	2.39E+08	2.17E+08	1.14E+09
Output (RTKs)	1.43E+09	5.49E+08	4.84E+08	2.44E+09
Labor price ($ per FTE)	39228.01	6848.61	23873.22	52072.31
Fuel price ($ per gallon)	1.17	0.59	0.53	3.35
Capital price ($ per ATK)	0.05	0.01	0.02	0.08
Materials price (index)	142.98	14.58	114.90	170.80
Number of points served	31.37	12.53	9.00	65.00
Average stage length (kilometers)	1423.64	160.20	1144.27	1760.41

4.2. Variable translog cost function

Variable operating costs (VC) are calculated as the sum of Salaries and Related Fringe Benefits (labor cost), Aircraft Fuel and Oil (fuel cost) and Total Materials cost (without fuel).

The output variable, Y, represents Revenue Tonne Kilometers (RTKs) of FedEx and UPS and is the same variable as in case of the total translog cost function.

The unit price of labor (UC_LABOR) and the unit price of fuel (UC_FUEL) are the same variables as those used for the total cost function. With regard to the input price of materials, the Producer Price Index is used as a proxy variable in the estimations of the variable cost function.

Regarding capital, the capital input S is used in the variable cost function. It is explained in section 3.2 how this capital input variable is calculated. Also the calculation of C_k, the depreciated capital cost, is explained in section 3.2.

Table II provides an overview of the descriptive statistics of the key variables of the variable translog cost function of FedEx and UPS.

Table II – Descriptive Statistics of Key Variables (in constant prices) of Variable Translog Cost Function – FedEx and UPS

	Mean	**Std. Dev.**	**Minimum**	**Maximum**
	FedEx			
Variable Cost (incl. materials) ($)	1.10E+09	4.08E+08	6.10E+08	2.05E+09
Output (RTKs)	2.47E+09	8.27E+08	1.15E+09	3.76E+09
Capital input S ($)	7.79E+09	1.83E+09	4.32E+09	1.10E+10
Labor price ($ per FTE)	22130.15	2641.01	18616.37	31086.36
Fuel price ($ per gallon)	1.15	0.58	0.53	3.24
Materials price UC_MAT (index)	142.98	14.58	114.90	170.80
Number of points served	47.84	10.85	28	79
Average stage length (kilometers)	922.94	122.23	743.08	1130.86
Depreciated capital cost C_k ($)	2.45E+08	40972632	1.58E+08	3.20E+08
	UPS			
Variable Cost (incl. materials) ($)	4.29E+08	2.23E+08	1.54E+08	1.02E+09
Output (RTKs)	1.43E+09	5.49E+08	4.84E+08	2.44E+09
Capital input S ($)	4.72E+09	2.05E+09	1.42E+09	7.70E+09
Labor price ($ per FTE)	39228.01	6848.61	23873.22	52072.31
Fuel price ($ per gallon)	1.17	0.59	0.53	3.35
Materials price UC_MAT (index)	142.98	14.58	114.90	170.80
Number of points served	31.37	12.53	9.00	65.00
Average stage length (kilometers)	1423.64	160.20	1144.27	1760.41
Depreciated capital cost C_k ($)	60576613	15307336	15833786	84404562

5. ECONOMIES OF SCALE AND ECONOMIES OF DENSITY

By introducing the number of points served in the cost function next to the output variable, it is possible to distinguish between EOD and EOS in airline operations. This is confirmed by Caves et al. (1984). They define EOD as 'the proportional increase in output made possible by a proportional increase in all inputs, with points served, average stage length, average load factor, and input prices held constant'. Thus, EOD exist in case of a reduction of unit cost made possible by an increase in output over a fixed network. Or in other words, EOD exist if unit costs decrease as cargo airlines add flights (to destinations that are already served) or as they add freight on existing flights (through larger aircraft or a denser loading scheme).

EOS are defined as 'the proportional increase in output and points served made possible by a proportional increase in all inputs, with average stage length, average load factor, and input prices held fixed. Scale economies exist if unit costs decline when a cargo airline adds flights to an airport it had not been serving before, and the additional flights cause no change in load factor, stage length, or output per point served (density).

In section 5.1 and 5.2 it is explained how EOD and EOS are calculated in case of a total and variable translog cost function.

5.1. Total translog cost function

In case of a total translog cost function in which the number of points served is not included, the EOS are calculated as the inverse of the elasticity of costs with respect to output. The elasticity of costs with respect to output is the ratio of marginal to average costs. If marginal is above average, average is rising and there are diseconomies of scale (EOS<1). If marginal lies below, average is falling and there are economies of scale (EOS>1) (Berndt, 1991, p. 476). More specifically,

$$EOS=1/\varepsilon_{CY}=\left(\frac{\partial lnTC}{\partial lnY}\right)^{-1} \quad where \quad \varepsilon_{CY}=\frac{\partial lnTC}{\partial lnY}={MC}/{AC}$$

However, when the number of points served is included in the cost function, there is a distinction between EOS and EOD. The EOD are calculated as the inverse of the elasticity of total costs with respect to output, similar to the EOS for a cost function without number of points served. The EOS are calculated as the inverse of the sum of the elasticities of total cost with respect to output (Y) and points served (N1) (Gillen, Oum and Tretheway, 1990). Thus,

$$EOD=\left(\frac{\partial lnTC}{\partial lnY}\right)^{-1}$$

$$EOS=\left(\frac{\partial lnTC}{\partial lnY}+\frac{\partial lnTC}{\partial lnN1}\right)^{-1}$$

5.2. Variable translog cost function

In case of a variable translog cost function in which the number of points served is not included, the EOS are calculated as the inverse of the elasticity of variable costs with respect to output. If the number of points served is included, the EOD and EOS are calculated as follows (Caves, Christensen and Swanson, 1981):

$$EOD=(1-ELAST_{VCS})/ELAST_{VCY}=\left(1-\frac{\partial lnVC}{\partial lnS}\right)/\frac{\partial lnVC}{\partial lnY}$$

$$EOS=(1-ELAST_{VCS})/(ELAST_{VCY}+ELAST_{VCN1})=\left(1-\frac{\partial lnVC}{\partial lnS}\right)/\left(\frac{\partial lnVC}{\partial lnY}+\frac{\partial lnVC}{\partial lnN1}\right)$$

6. ESTIMATION RESULTS AND COST CHARACTERISTICS

6.1. Total translog cost function

6.1.1. Static approach

Table III reports the estimation results and cost characteristics for the total, long-run translog cost function of FedEx and UPS. This model includes four inputs (labor, fuel, capital and materials) and two network variables. Only the first-order coefficients are mentioned in table III. The second-order coefficients are available upon request. Two different estimation techniques are used: Full Information Maximum Likelihood – BHHH (ML) and Seemingly Unrelated Regressions (SUR). Since the results are very similar, only the ML results are presented. All explanatory variables are normalized around the means by dividing the observed values by their mean value. This is done since the translog cost function is an approximation of an unknown cost function around a certain point, as was explained in section 3. It is necessary to specify this approximation point. In this paper, analogous to most of the literature, we assume that this point is the mean[3].

Table III – Total Static Translog Cost Function – Model 1 Results

	Model 1 FedEx			**Model 1 UPS**		
	Coeff.	**Std.Err.**	**Prob.**	**Coeff.**	**Std.Err.**	**Prob.**
Output	0.572	0.043	0.000	0.486	0.055	0.000
Labor price	0.431	0.003	0.000	0.364	0.002	0.000
Fuel price	0.189	0.002	0.000	0.322	0.003	0.000
Capital price	0.277	0.002	0.000	0.215	0.002	0.000
Materials price	0.103	0.002	0.000	0.099	0.003	0.000
Trend	0.028	0.015	0.067	0.105	0.034	0.002
Number of points served	0.120	0.044	0.006	0.004	0.027	0.891
Average stage length	-0.242	0.110	0.028	-0.460	0.078	0.000
EOS at sample mean		1.445			2.043	
EOD at sample mean		1.749			2.059	
EOS in 1990Q1		1.210			4.547	
EOS in 2010Q2		1.659			1.629	
EOD in 1990Q1		1.441			6.546	
EOD in 2010Q2		2.050			1.914	

Since all regressions are normalized at the mean data point, the first-order coefficients reflect the sensitivity of total costs to various regressors at the sample mean. In other words, the first-order coefficients can be interpreted as cost elasticities evaluated at the sample mean.

In model 1 for FedEx, all coefficients are statistically significant. The coefficients also have the expected sign, except that of the trend variable. In the case of UPS, the coefficient of the number of points served is not significant. With regard to the output cost elasticity, the value for FedEx is larger than that of UPS. The input cost elasticities of FedEx indicate that the input shares of labor, fuel, capital and materials are respectively 43%, 19%, 28% and 10%. In the case of UPS, the cost elasticities for labor, fuel, capital and materials are respectively

[3] It is shown by Gillen, Oum and Thretheway (1990) that the same estimates of, e.g. economies of scale, would be obtained if the data would be normalized at any other point than the mean.

36%, 32%, 22% and 10%. The results show that the total cost of both integrators depends mostly on the labor input price. The effect of labor on FedEx's total cost is higher than on that of UPS. A possible explanation for this is that FedEx has a higher share of pilots in its total number of employees than UPS. For UPS, the effect of the fuel input price is larger than for FedEx. For FedEx, the capital input price has the second-largest impact on its total cost. In addition, the impact of the capital input price on the integrators' total costs is larger for FedEx than for UPS. A potential explanation for this is the fact that between 1993 and 2002, rentals constituted the largest expense category in FedEx's total operating costs, while for UPS fuel has the largest share in its operating cost over the observed period 1990Q1-2010Q2. This suggests that FedEx outsourced more of its operations compared to its rival. In addition, the aircraft fleet of FedEx is larger than that of UPS. Concerning the materials input price, the effect on total cost is similar for both integrators.

The coefficients of number of points served and average stage length are significant for FedEx and have the expected sign. The coefficient of number of points served, about 0.12, suggests that a 1% increase in network size, holding constant the level of output, causes an increase in total cost of about 0.12% at the sample mean. For UPS, this coefficient is statistically insignificant. The coefficient of average stage length for FedEx, about -0.242, indicates that a 1% increase in average stage length, holding the level of output constant, leads to a decrease in total cost of about 0.24%. This can be interpreted as the cost saving effect of flying less cargo over a longer segment to obtain the same level of output. In the case of UPS, this effect is much larger, namely 0.46%.

The cost characteristics calculated at the sample means for both FedEx and UPS show that both integrators exhibit EOD and EOS. Important to mention is that the EOS of UPS based on model 1 are calculated including the coefficient of the number of points served, but that this coefficient is statistically insignificant. At the sample means and in 1990Q1, the EOS and EOD of UPS are larger than those of FedEx. In 2010Q2, the EOD and EOS of both carriers are similar. A possible reason for this is that UPS Airlines was founded in 1988, while FedEx Express began operations in 1973, which involves that UPS had a less mature network in 1990Q1 compared to FedEx. This could lead to larger EOS at that moment. A final observation is that the EOD and EOS of UPS in 1990Q1 are much larger than in 2010Q2 so, according to this model, there are decreasing scale and density economies. FedEx, in contrast, shows increasing scale and density economies. This result indicates that the network of UPS becomes more saturated than that of FedEx over the observed period.

Table IV shows the Allen partial substitution elasticities and Hicks price elasticities in case of the four-input model. The elasticities are calculated at the mean values of the independent variables. The Allen substitution elasticities are symmetric. The substitution and price elasticities show that, for both FedEx and UPS, labor and fuel are complements. The values of the substitution and price elasticities between labor and fuel are larger for UPS than for FedEx. This could be explained by the fact that the fuel input price has a larger effect on UPS' total costs compared to the case of FedEx. Capital and labor are substitutes for both integrators. For both integrators, the substitution and price elasticities between materials and the remaining inputs are larger compared to the elasticities between the other inputs. The own-price elasticities for FedEx and UPS are all negative and quite small, except that of materials. This shows that materials is only input factor that is price elastic, especially in the case of UPS.

Table IV –Substitution and Price Elasticities between Inputs calculated at mean values – Model 1

	Model 1 FedEx				**Model 1 UPS**			
	j=labor	**j=fuel**	**j=dar**	**j=mat**	**j=labor**	**j=fuel**	**j=dar**	**j=mat**
SUBSTITUTION ELASTICITIES								
i=labor		-0.06	0.23	1.36		-0.30	0.04	2.82
i=fuel	-0.06		0.07	0.74	-0.30		-0.21	2.93
i=dar	0.23	0.07		1.32	0.04	-0.21		2.90
i=mat	1.36	0.74	1.32		2.82	2.93	2.90	
PRICE ELASTICITIES								
i=labor	*-0.17*	-0.01	0.06	0.14	*-0.19*	-0.10	0.01	0.28
i=fuel	-0.03	*-0.03*	0.02	0.08	-0.11	*-0.14*	-0.04	0.29
i=dar	0.10	0.01	*-0.25*	0.14	0.01	-0.07	*-0.24*	0.29
i=mat	0.59	0.14	0.37	*-1.09*	1.03	0.94	0.62	*-2.59*

6.1.2. Dynamic approach

Table V contains the estimation results of model 1D: the dynamic version of the four-input model 1 for FedEx and UPS. Only the first-order and autocorrelation coefficients are mentioned in this table. The second-order coefficients are available upon request. Model 1D is estimated by ML-BHHH.

Table V – Total Dynamic Translog Cost Function – Model 1D Results

	Model 1D FedEx			Model 1D UPS		
	Coeff.	**Std.Err.**	**Prob.**	**Coeff.**	**Std.Err.**	**Prob.**
Output	0.318	0.087	0.000	0.326	0.089	0.000
Labor price	0.444	0.020	0.000	0.376	0.015	0.000
Fuel price	0.175	0.021	0.000	0.316	0.030	0.000
Capital price	0.260	0.028	0.000	0.215	0.028	0.000
Materials price	0.121	0.033	0.000	0.092	0.048	0.056
Trend	0.118	0.069	0.088	-0.016	0.091	0.857
Number of points served	0.050	0.050	0.326	-0.037	0.055	0.504
Average stage length	-0.064	0.133	0.629	0.109	0.265	0.680
C(30)	0.651	0.126	0.000	1.022	0.103	0.000
C(31)	-1.092	0.513	0.033	-0.008	0.732	0.991
C(32)	0.093	0.382	0.807	-34.654	3124.261	0.991
C(33)	0.018	0.046	0.689	4.055	368.153	0.991
C(34)	-0.002	0.043	0.967	-0.072	0.038	0.060
C(35)	0.666	0.269	0.013	0.517	0.277	0.063
C(36)	0.022	0.089	0.804	0.197	0.189	0.296
C(37)	-0.256	0.200	0.201	0.113	0.168	0.502
C(38)	0.008	0.062	0.898	-0.105	0.094	0.260
C(39)	0.251	0.289	0.384	0.318	0.423	0.452
C(40)	0.818	0.152	0.000	0.494	0.397	0.214
C(41)	0.126	0.314	0.687	0.243	0.252	0.334
C(42)	-0.019	0.049	0.694	0.209	0.113	0.065
C(43)	-0.075	0.222	0.737	0.062	0.706	0.930
C(44)	-0.056	0.141	0.692	0.178	0.620	0.775
C(45)	0.902	0.199	0.000	0.363	0.294	0.217
EOS at sample mean		2.723			3.455	
EOD at sample mean		3.148			3.067	
EOS in 1990Q1		4.241			3.181	
EOS in 2010Q2		2.326			3.407	
EOD in 1990Q1		4.725			2.739	
EOD in 2010Q2		3.036			3.006	

For both FedEx and UPS, the model 1D coefficients of the number of points served and average stage length variables are statistically insignificant. In addition, the results suggests that a more complex dynamic specification, e.g. a first-difference model or error correction model should be used. Concerning the input cost elasticities for both integrators, the results are similar to the static model 1. The EOD calculated at the sample mean are similar for both integrators. The values are larger than the EOD based on the static model 1. The EOS calculations based on model 1D are not discussed since they are based on the coefficient of number of points served, which is not significant. The substitution and price elasticities based on model 1D are not included in this paper.

6.2. Variable translog cost function

Table VI presents the estimation results and cost characteristics for the variable translog cost function of FedEx and UPS. The variable model includes three variable inputs (labor, fuel and materials), one quasi-fixed input (capital) and two network characteristics. The table only reports the first-order coefficients. The second-order coefficients are available upon request. For the variable cost function estimations, the SUR estimation technique is used.

Table VI – Variable Translog Cost Function – Model 2 Results

	Model 2 FedEx			Model 2 UPS		
	Coeff.	**Std.Err.**	**Prob.**	**Coeff.**	**Std.Err.**	**Prob.**
Output	0.487	0.029	0.000	0.566	0.059	0.000
Labor price	0.603	0.002	0.000	0.475	0.003	0.000
Fuel price	0.257	0.002	0.000	0.412	0.004	0.000
Materials price	0.140	0.002	0.000	0.113	0.004	0.000
Trend	0.099	0.012	0.000	0.119	0.037	0.001
Capital input	-0.229	0.002	0.000	-0.153	0.003	0.000
Number of points served	0.147	0.043	0.001	0.022	0.029	0.450
Average stage length	-0.494	0.089	0.000	-0.616	0.082	0.000
EOS at sample mean		1.940			1.961	
EOD at sample mean		2.524			2.036	
EOS in 1990Q1		1.647			5.219	
EOS in 2010Q2		1.771			1.524	
EOD in 1990Q1		1.755			5.604	
EOD in 2010Q2		3.505			1.818	

The coefficients of model 2 are statistically significant in the case of FedEx. In the case of UPS, the coefficient of the number of points served is statistically insignificant. Similar to the previous models, all coefficients, except that of both integrators' trend variable, have the expected sign. Concerning the share of the various inputs in the integrators' variable cost at the sample mean, the results lead to the same conclusions as those obtained for the total cost function (model 1). For FedEx, the labor input price has the largest impact (60%) on its variable cost, followed by the fuel (26%) and the materials input price (14%). In the case of UPS, the impact of the fuel input price on its variable cost (41%) is much higher than for FedEx, while the effect of the labor input price (48%) is much lower than for FedEx. The materials input price has an impact of 11% on its variable cost. The coefficient of the capital input price is negative for FedEx and UPS. This implies a positive shadow value of capital input. According to model 2, both integrators realize EOS and EOD over the observed period. At the sample means, FedEx has larger EOD than UPS, while the EOS are similar. In addition, model 2 shows that UPS exhibits larger EOS and EOD in 1990Q1 than FedEx, while the situation is vice versa in 2010Q2. Similar to what was observed in model 1, the EOS and EOD of UPS are decreasing over the observed period, while those of FedEx are increasing. However, it should be noted again that the EOS for UPS are calculated based on a coefficient that is insignificant.

Table VII shows the substitution and price elasticities based on model 2. For both FedEx and UPS, labor and fuel are complements. Labor and materials, as well as fuel and materials, are substitutes. In the case of UPS, the substitution elasticities between labor and materials and between fuel and materials are very large. In addition, the price elasticity between materials and labor in the case of UPS is positive and larger than one. The own-price elasticity of materials is also larger than one in the case of UPS. This was also the case in model 1.

Table VII –Substitution and Price Elasticities between Inputs calculated at mean values – Model 2

	Model 2 FedEx			**Model 2 UPS**		
	j=labor	**j=fuel**	**j=mat**	**j=labor**	**j=fuel**	**j=mat**
SUBSTITUTION ELASTICITIES						
i=labor		-0.16	0.99		-0.22	2.70
i=fuel	-0.16		0.21	-0.22		2.09
i=mat	0.99	0.21		2.70	2.09	
PRICE ELASTICITIES						
i=labor	*-0.13*	-0.04	0.14	*-0.22*	-0.09	0.31
i=fuel	-0.10	*-0.01*	0.03	-0.10	*-0.13*	0.24
i=mat	0.59	0.05	*-0.65*	1.28	0.86	*-2.14*

7. CONCLUSIONS AND FURTHER RESEARCH

In this paper, a total and variable translog cost function of FedEx and UPS was estimated. By introducing the number of points served in our models, we were able to make a distinction between EOS and EOD. The results show that both integrators exhibit strong EOD and EOS. This indicates that their expansion and cooperation strategies are in close relation to their cost structures. In addition, the existence of EOS and EOD are an important barrier to entry in this oligopolistic industry. We expect the integrators to continue developing strategies that will allow them to fully exploit the available EOD and EOS. Therefore, it is very likely that the concentration in the integrated air freight industry will continue. This knowledge is important for industry actors but also for regulatory agencies.

Concerning the input shares in the integrators' total and variable costs, all models indicate that the labor input price has the largest impact on both integrators' total and variable costs. In addition, the total cost models show that capital has the second-largest impact on FedEx's total cost, while for UPS this is the fuel input price. This could partly be explained by the fact that FedEx has a larger aircraft fleet than UPS. In addition, over the observed period, rentals constituted the largest expense category in FedEx's operating costs, while for UPS this was fuel. It also means that the strong rise of kerosene prices during the last 10 years has a larger impact on UPS' total costs than on those of FedEx. This implies that UPS' incentive to improve fuel efficiency, to apply a fuel-hedging strategy or to add a fuel surcharge is even larger than in the case of FedEx. The static and dynamic version of the total cost model show that the input share of materials is around 10%, a value that is similar for both integrators. The variable cost model shows a materials' input share of 14% for FedEx and 11% for UPS.

The substitution and price elasticities based on the total and variable models lead to similar conclusions. For both integrators, fuel and labor are complements, while fuel and materials, labor and capital and labor and materials are substitutes. Fuel and capital are substitutes in the case of FedEx and complements in the case of UPS. The elasticities between materials and the remaining inputs, as well as the own-price elasticity of materials, have the largest value.

This paper is subject to some limitations. The first one is related to the dynamic model specification. The results of the dynamic models suggest that a more complex specification such as a first-difference model or error-correction model could be used to further improve the results. For the error-correction model, the approach developed by Urga and Walters (2003) could be followed. Secondly, the variable translog cost function approach applied in this paper is a static one. It could be investigated whether a dynamic, variable model could improve the results. Thirdly, it would be worthwhile in further research to use a panel approach. The panel could include non-integrated air freight carriers as well, which would make it possible to compare their cost structure with that of integrated air freight carriers. Since this paper aimed at analysing the cost structure of FedEx and UPS and a panel should include more than two companies, the panel approach was not followed in this paper. A final limitation is that a single-output cost function is estimated in this paper. However, a lack of structured air cargo data and the focus on the air cargo operations of FedEx and UPS is an explanation for this.

ACKNOWLEDGEMENT

We would like to express our gratitude to Prof. dr. Martin Dresner for his constructive comments on an earlier draft and particularly for his suggestions related to the dynamic model specification. In addition, the discussion we had with Prof. dr. Tae Oum and Prof. dr. Juan-Carlos Martín on the concepts of economies of scale and economies of density in air transport research highly contributed to the quality of this paper.

REFERENCES

Air Cargo Management Group, 2006. International Air Freight and Express Industry Performance Analysis 2006. Washington.

Bailey, E.E., Panzar, J.C., 1981. The Contestability of Airline Markets during the Transition to Deregulation. Law Contemp. Prob. 44, 125-145.

Berndt, E., 1991. The Practice of Econometrics: Classic and Contemporary. Addison-Wesley Publishing Company, Massachusetts.

Berndt, E., Savin, N.E., 1975. Estimation and Hypothesis Testing in Singular Equation Systems with Autoregressive Disturbances. Econometrica. 43, 937-958.

Caves, R.E., 1962. Air Transport and its Regulators. Harvard University Press, Cambridge, MA.

Caves, D.W., Christensen, L.R., Swanson, J.A., 1981. Productivity Growth, Scale Economies, and Capacity Utilization in U.S. Railroads, 1955-74. Amer. Econ. Rev. 71, 994-1002.

Caves, D.W., Christensen, L.R., Tretheway, M.W., 1984. Economies of Density versus Economies of Scale: Why Trunk and Local Service Airline Costs Differ. RAND J. Econ. 15, 471-489.

Christensen, L.R., Greene, W.H., 1976. Economies of Scale in U.S. Electric Power Generation. J. Polit. Economy. 84, 655-676.

Douglas, G.W., Miller III, J.C., 1974. Economic Regulation of Domestic Air Transport: Theory and Policy. Brookings Institution, Washington, D. C.

Duponselle, D., Meersman, H., Van de Voorde, E., Vanelslander, T., 2005. Air Transport Colloquium: Critical Issues in Air Transport Economics, Universiteit Antwerpen, Antwerpen.

Gillen, D.W., Oum, T.H., Tretheway, M.W., 1990. Airline Cost Structure and Policy Implications – A Multi-Product Approach for Canadian Airlines. J. Transp. Econ. Pol. 14, 9-34.

International Air Transport Association (IATA), 2011. World Air Transport Statistics 2010. 55th ed., Geneva.

Jeong, J., 2005. An Investigation of Operating Cost of Airports: Focus on the Effect of Output Scale. University of British Columbia, Vancouver.

Keeler, T.E., 1978. Domestic Trunk Airline Regulation: An Economic Evaluation. Study on Federal Regulation. US Government Printing Office, Washington, D.C.

Kiesling, M.K. and Hansen, M., 1993. Integrated Air Freight Cost Structure: The Case of Federal Express, Berkeley, University of California.

Lijesen, M.G., 2010. Measuring Competition Intensity through Cost Data. Proceedings of the 14th Air Transport Research Society World Conference, Porto.

Martín, J.C., Nombela, G., Romero, M., 1999. European Airline Industry: a Cost Analysis and Economic Performance Evaluation. Selected Proceedings of the 8th World Conference on Transport Research. 1, 211-223.

Martín, J.C., Voltes-Dorta, A., 2008. International Airports: Economies of Scale and Marginal Costs. Journal of the Transportation Research Forum, 47, 5-22.

Oum, T.H., Tretheway, M.W., Zhang, Y., 1990. A Note on Capacity Utilization and Measurement of Scale Economies. J. Bus. Econ. Statist., 9, 119-123.

Oum, T.H., Waters, W.G., 1996. A Survey of Recent Developments in Transportation Cost Function Research. Logist. Transp. Rev. 32, 423-463.

Oum, T. H., Yu, C., 1998. Cost Competitiveness of Major Airlines: an International Comparison. Transp. Res.: Part A: Pol. Practice. 32, 407-422.

Oum, T.H., Zhang, Y., 1991. Utilisation of Quasi-Fixed Inputs and Estimation of Cost Functions: An Application to Airline Costs. J. Transp. Econ. Pol. 25, 121-134.

Seldon, B.J., Jewell, R.T., O'Brien, D.M., 2000. Media substitution and economies of scale in advertising. Int. J. Ind. Organ. 18, 1153-1180.

Urga, G., Walters, C., 2003. Dynamic translog and linear logit models: a factor demand analysis of interfuel substitution in US industrial energy demand. Energ. Econ. 25, 1-21.

White, L.J., 1979. Economies of Scale and the Question of 'Natural Monopoly' in the Airline Industry. J. Air Law Commerce. 44, 545-573.

Zondag, W.J., 2006. Competing for Air Cargo, A Qualitative Analysis of Competitive Rivalry in the Air Cargo Industry. Master of Science Thesis, Free University Amsterdam, Amsterdam.

Zou, B., Hansen, M., 2010. Impact of Operational Performance on Air Carrier Cost Structure: evidence from US Airlines. Proceedings of the 12th World Conference on Transport Research, Lisbon.