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HIGHLIGHTS

- We study the efficiency of integrated and non-integrated cargo carriers.
- We use Stochastic Frontier Analysis to disentangle random shocks from inefficiencies.
- Integrators UPS and FedEx have a lower efficiency than the non-integrated carriers when analysed jointly.
- Comparing integrators with non-integrators is complicated by their different business models.
- Smaller carriers react in a more flexible way to crisis periods.

US all-cargo carriers' cost structure and efficiency: A stochastic frontier analysis

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ABSTRACT

In this paper, the efficiency of the major US all-cargo carriers, both integrated and non-integrated, is measured and compared through a stochastic frontier analysis based on a translog cost function. Because of the high volatility of all-cargo traffic, especially since the 2008 economic crisis, and the increasing market share of integrators, this industry requires more detailed analysis. By using stochastic frontier analysis in this study, a distinction between random deviations from the production frontier and actual differences in technical efficiency is made. We find that smaller carriers react more flexible to a crisis and that non-integrated carriers are more efficient than the integrators when they are analysed jointly, which is however complicated by their different business models. These findings are not only useful for academics and industry actors, but also for policy makers, since air cargo contributes significantly to the profitability of airlines and airports.

Keywords: Air cargo, Efficiency, Stochastic frontier analysis.

1. Introduction

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Air cargo plays a crucial role in the business models of most airlines and airports. Moreover, since approximately 35% of world trade by value (IATA, 2014) is transported by air cargo, it is a key facilitator for international trade. The air cargo industry is a growing industry with an average annual growth rate of 2.6% expressed in Revenue Tonne Kilometres (RTKs) between 2003 and 2013. The outlook is positive too, with an average annual growth rate of 4.7% forecasted by Boeing and 4.4% by Airbus between 2014 and 2034 (Boeing, 2014; Airbus, 2014). For the short term (2014-2018), IATA forecasted an average annual growth of 4.1% (IATA, 2014). According to a model developed by Kupfer et al. (2017), air cargo is expected to grow by a yearly average rate of 3.5% between 2014 and 2023. However, despite this positive outlook, the air cargo industry has been experiencing difficulties since the economic crisis of 2008 with slowing traffic growth and declining revenues. The main reasons for this underperformance are weak trade growth in the US, Europe and Asia Pacific, combined with slower growth in high-value commodities commonly shipped by air. According to IATA (2016), efficiency gains are crucial to survive, due to shortening global supply chains and more competitive pressure.

Nevertheless, when analysing the air cargo industry, the heterogeneity of this industry needs to be considered. A first necessary distinction is the one between all-cargo traffic and combi (or belly-hold) traffic. All-cargo traffic is more vulnerable to crisis periods than combi traffic, which led to a decreasing share of all-cargo traffic since 2008. Moreover, most bankruptcies and capacity reductions during the last years took place in the all-cargo segment (Kupfer et al., 2011). Another distinction is the integrated versus non-integrated business model of all-cargo carriers. The largest integrators, FedEx, UPS and DHL, are capturing an increasing market share and are performing better than non-integrated all-cargo carriers and most combination carriers in terms of profitability (IATA, 2015a). FedEx and UPS are the largest cargo airlines in terms of total scheduled FTKs (IATA, 2015b). DHL, through many cooperation agreements with other air cargo carriers operating on behalf of the integrator, is also an important market player.

Most existing studies look at the cost structure and efficiency of combination carriers. Therefore, by focusing on and comparing the efficiency of both the more volatile non-integrated all-cargo carriers and the dominant integrators, this research aims at filling this gap in the literature. Next to contributing to the literature, also industry stakeholders may benefit from the results of this research since efficiency is key to survive in the competitive air cargo industry. Finally, this research may be of interest for policy makers because of the crucial role air cargo plays in creating economic welfare and enhancing the profitability of airlines and airports.

The remainder of this paper is organised as follows. Section 2 provides an overview of previous studies in the field of airline and airport efficiency and cost structure analysis. The model specification and methodology are explained in Section 3. Section 4 includes a description of the data used in this research. The results are presented in Section 5. Section 6 contains the conclusions and some suggestions for further research.

2. Literature review

Most of the existing cost structure, productivity and efficiency analyses in the air transport business focus on combination carriers and airports. Moreover, in many cases, the analysis is done using total factor productivity (TFP) or data envelopment analysis (DEA). Examples concerning airline performance include Windle and Dresner (1992), Oum and Yu (1995, 1998a,b), Forsyth (2001), Oum et al. (2005), Barbot et al. (2008), Powell (2012), Wang et al. (2014), Merkert and Pearson (2015), Li et al. (2015) and Choi (2017). Homsombat et al. (2010) examined the productivity and cost competitiveness of nine major US airlines in the period 1990 to 2007 using TFP and a translog variable cost function in which the calculated TFP index is subsequently used as an explanatory variable. They showed that the airlines realised productivity gains during the observed period but that this was partly offset by the increase in fuel prices.

Concerning airport productivity and efficiency, there is also a large body of literature. As in the airline case, also many airport studies use DEA, partial productivity measures or TFP. Examples are Hooper and Hensher (1997) who applied the TFP approach to six Australian airports for four financial years starting from 1988-1989. Gillen and Lall (1997, 2001) used DEA to measure US airport productivity and performance in the period 1989 to 1993. Martín and Román (2001) investigated the efficiency of Spanish airports prior to privatisation by means of DEA. Pels et al. (2001) applied DEA to measure the efficiency of European airports. Authors who applied stochastic frontier analysis (SFA) for efficiency measurement include Pels et al. (2003), who measured efficiency and scale economies of European airports. Oum et al. (2008) assessed the impact of ownership structure on airport efficiency using SFA. Martín et al. (2009) estimated the relative efficiency of Spanish airports by SFA. Scotti (2011) applied a stochastic production frontier model with time-dependent inefficiency components to measure the technical efficiency of Italian airports.

The literature review shows that studies analysing the cost structure and especially the performance of all-cargo carriers are scarce. Moreover, existing research focuses on integrators. Examples are Kiesling and Hansen (1993) who investigated the cost characteristics of the airline operations of FedEx and UPS by means of a Cobb-Douglas cost function. More recently, Onghena et al. (2014) conducted a translog cost function analysis to examine the cost structure of the two US integrators FedEx Express and UPS Airlines based on time-series data per firm, without measuring the efficiency of these airlines. Lakew (2014) focused on scale and density economies for the domestic operations of FedEx and UPS by using a Cobb-Douglas cost function approach. Roberts (2014) investigated the efficiency in the US airline industry. Regarding air cargo, the efficiency of FedEx Express and UPS was measured and compared by means of an SFA. Balliauw et al. (2016) was the first to benchmark the productivity and cost competitiveness of US integrated and non-integrated all-cargo carriers by means of TFP. However, a weakness of the non-parametric TFP methodology compared to the parametric SFA methodology is that it does not allow to differentiate between actual differences in technical efficiency of a firm and stochastic deviations from the production frontier. This means that TFP ignores the possibility of a firm's performance being affected by factors both within and outside its control. In contrast, SFA acknowledges the presence of measurement errors and other sources of statistical noise and enables a distinction between these error components and the technical inefficiencies (Coelli et al., 2005).

This paper aims to examine and compare the efficiency of eight US all-cargo carriers, both integrated and non-integrated ones, by means of SFA applied to panel data for the period 1990 to 2014. Next to efficiency measurement, also the cost structure and cost characteristics of the sample airlines are investigated. The main contribution of this research is the use of SFA to compare the efficiencies of two main business models in the air cargo industry: the integrators and the non-integrated all-cargo carriers. Firm-specific efficiency coefficients are included in the methodology. This allows disentangling random shocks from inefficiencies, which do not necessarily follow the same evolution for each firm.

3. Methodology and model specification

Cost functions provide a good insight into the cost structure of a company. Different cost function specifications are possible, such as a Cobb-Douglas, Constant Elasticity of Substitution (CES) or translog model. In this paper, we opt for a translog cost function specification, since it is the most general form with the lowest number of restrictions imposed. Its data intensity can be remediated by including sufficient observations in the data set, cf. the panel data used in this paper. For a description of the data set, we refer to the next section.

We start from a cost function for company *i* at time *t* with Hicks-neutral technical change[2]

$$lnTC_{it} = A(t) + \ln B(Y_{it}, P_{1,it}, \ldots, P_{n,it}) + C(X_{1,it}, \ldots, X_{m,it}) + \varepsilon_{it} \quad (1)$$

with *TC* the total cost, $A(t)$ a function of the time trend *t* as a proxy for technical change, $B(.)$ a function of the output Y_{it} and the n input prices P_{it}, $C(.)$ a function of m additional characteristics X_{it} which may have an impact on the general cost function, and ε_{it} the random error term.

We assume that $A(t)$ is a polynomial function in *t* of order *r* and $B(Y_{it}, P_{it})$ is a translog function

$$lnTC_{it} = \alpha_0 + \sum_{j=1}^{r} \alpha_j t^j + \beta_Y \ln Y_{it} + \sum_{k=1}^{n} \beta_k \ln P_{k,it} + \frac{1}{2}\gamma_{YY} \ln Y_{it}^2 + \frac{1}{2}\sum_{k=1}^{n}\sum_{j=1}^{n} \gamma_{kj} \ln P_{k,it} \ln P_{j,it} + \sum_{k=1}^{n} \gamma_{kY} \ln P_{k,it} \ln Y_{it} + \sum_{j=1}^{m} \theta_j X_{j,it} + \varepsilon_{it} \quad (2)$$

Some additional conditions are imposed. Symmetry implies that $\gamma_{kj} = \gamma_{jk}$. To guarantee linear homogeneity of the cost function, it should hold that $\sum_{k=1}^{n} \beta_k = 1$, $\sum_{k=1}^{n} \gamma_{kj} = 0\ (\forall j)$ and $\sum_{k=1}^{n} \gamma_{kY} = 0$. The first condition is also known as the adding-up condition, which allows to interpret each β_k as the production factor cost share in the total cost. In order to be able to interpret estimated first-order coefficients as total cost elasticities with respect to the independent variables, all quantitative variables should be normalised at a certain point. According to Gillen et al. (1990) the estimates are invariant to the chosen normalisation point. We normalised the variables at the sample mean.

Firms may face allocative and technical inefficiencies. If we assume that they minimise their costs and that they are actually operating at the lowest costs, we can assume that the allocative inefficiencies are zero (Schmidt and Lovell, 1979). When using a stochastic frontier approach, the deviations from the frontier can be due to technical inefficiencies and random deviations. So the error term ε_{it} can be split up into a random part (v_{it}) and an inefficiency term (u_{it}), leading to $\varepsilon_{it} = u_{it} + v_{it}$. All v_{it} are independently and identically normally distributed with zero mean and variance σ^2. u_{it} is assumed to be distributed independently from v_{it}, and comes from a positively truncated $N(0, \sigma^2)$ distribution (Aigner, Lovell and Schmidt, 1977). It has often been assumed that the inefficiencies are time-invariant, but this is a strong assumption that should be tested. There have been different ways in which u_{it} has been made time dependent. Cornwell, Schmidt, and Sickles (1990) assumed that

[2] In order to reduce the number of coefficients and increase the degrees of freedom of the model, Hicks-neutral technical change is assumed, as was also done by Aigner, Lovell and Schmidt (1977) and Meeusen and Van den Broeck (1977). This assumption was tested statistically on the model reported in Appendix A (see e.g. Kuroda, 1987). A Wald test resulted in a *p*-value of 0.17, leading to the acceptance of the null hypothesis of Hicks-neutral technical change.

$$u_{it} = \theta_{i0} + \theta_{i1}t + \theta_{i2}t^2 \quad (3)$$

whereas Kumbhakar (1990) proposes

$$u_{it} = u_i\,[1 + \exp(\theta_{i1}t + \theta_{i2}t^2)]^{-1} \quad (4)$$

One can even go for a more general form as used by Battese and Coelli (1995) where the technical inefficiencies are related to a set of explanatory variables $z_{j,it}$ and random variables w_{it} such that

$$u_{it} = \sum_j \theta_j z_{j,it} + w_{it} \quad (5)$$

where the coefficients θ_j have to be estimated.

We will assume that

$$u_{it} = u_i \cdot \exp(-\eta_{1i}(t-T) - \eta_{2i}(t-T)^2) \quad (6)$$

with T the number of periods included in the study and $t \in \vartheta(i); i = 1, 2, \ldots, N$ while $\vartheta(i)$ being the set of T_i time periods containing observations for firm i[3]. Cost efficiency of firm *i* at time *t* is then calculated as

$$CE_{it} = \exp(-u_{it}) \quad (7)$$

(Battese and Coelli, 1988).

We chose for firm-specific coefficients η to model the evolution of the efficiency over time since a positive efficiency evolution over time in one firm should not prevent negative or level evolutions in other firms. Moreover, we opt for a second-degree time dependency, because the financial crisis of 2008 took place in the middle of our dataset. As a result, a dip in the results should be allowed for, but not necessarily forced. This is only possible with a second-degree specification or higher. Using panel data, sufficient observations are at hand for this specification. Moreover, this approach guarantees a good balance between randomness and the actual inefficiency.

[3] In case of a balanced panel T_i=T; $\forall$i.

Estimates are obtained using full-information maximum likelihood (ML) estimations. With the estimated coefficients at hand, it is possible to calculate and plot efficiency scores for each firm at each point in time. Additionally, economies of density (EOD) and economies of scale (EOS) can be calculated on an industry level as follows (Caves et al., 1984):

$$EOD = \frac{1}{\epsilon_Y} \quad (8),$$

$$EOS = \frac{1}{\epsilon_Y + \epsilon_S} \quad (9),$$

with ϵ_Y and ϵ_S being the total cost elasticity with respect to output and size of the operations respectively. In this model, the number of points served is chosen as a proxy for the size of the operations. As a result of the normalised data, the elasticities can be obtained directly from the estimated first-order coefficients.

An additional advantage of a general translog specification is that it allows to test for the proper functional specification of the cost function. To test whether a translog specification is better suited than a Cobb-Douglas specification, the test statistic $L = 2(LLF_{CD} - LLF_{TL})$ is compared to a χ_n^2-distribution, with LLF_{CD} the log likelihood of a Cobb-Douglas estimation (setting the coefficients of the second order terms to zero) and LLF_{TL} the log likelihood of a translog function. The chi-squared distribution has n degrees of freedom, with n the number of coefficients to be estimated under the Cobb-Douglas specification (Kuroda, 1987).

The translog model is specified as follows[4]:

$$lnTC_{it} = \alpha_1 t + \alpha_1 t^2 + \beta_Y \ln Y_{it} + \sum_{k=1}^{n} \beta_k \ln P_{k,it} + \frac{1}{2}\gamma_{YY} \ln Y_{it}^2 + \frac{1}{2}\sum_{k=1}^{n}\sum_{j=1}^{n} \gamma_{kj} \ln P_{k,it} \ln P_{j,it} + \sum_{k=1}^{n} \gamma_{kY} \ln P_{k,it} \ln Y_{it} + \sum_{j=1}^{m} \theta_j X_{j,it} + u_i \cdot \exp(-\eta_{1i}(t-T) - \eta_{2i}(t-T)^2) + v_{it}, \quad (10)$$

with $\gamma_{kj} = \gamma_{jk}$, $\sum_{k=1}^{n} \beta_k = 1$, $\sum_{k=1}^{n} \gamma_{kj} = 0$ $(\forall j)$ and $\sum_{k=1}^{n} \gamma_{kY} = 0$
and

[4] The intercept α_0 is omitted, because the four quarterly dummies are included in the specification.

t time,
Y output,
P_1 unit cost of labour,
P_2 unit cost of fuel,
P_3 unit cost of capital,
P_4 unit cost of materials,
n total number of inputs (i.c. 4),
X_1 ln(points served),
X_2 ln(stage length),
X_3 ln(load factor),
X_4 vector of four quarterly dummy variables (q1, q2, q3 and q4),
u_i $= \sum_{j=1}^{N} a_j * F_j$ with $F_j = 1 : j = i$ and $F_j = 0 : j \neq i$,
N total number of firms.

According to Pavelescu (2011), an often encountered problem in translog cost or production functions involving multiple input factors is multicollinearity, as a result of the high number of cross-products in the specification. Multicollinearity poses a problem to the interpretation of the individual coefficients. To this end, two actions are undertaken to reduce the multicollinearity in our estimated models to a minimum. First, the correlations between the dependent variables included in each model are checked. When an independent variable is correlated with too many other independent variables, it is decided to leave it out from the analysis. Subsequently, the estimated coefficients are compared to the correlations of each independent variable with the dependent variable. When the signs of the coefficients and the correlations are equal, it is assumed that the multicollinearity does not pose a too big problem to the validity of the estimations.

4. Data description

The SFA is applied to an unbalanced panel of eight US all-cargo carriers observed over the period 1990 until 2014. Quarterly time series data from US Department of Transportation – Bureau of Transportation Statistics were used (BTS, 2015). Domestic as well as international operations are considered. International operations involve Atlantic, Pacific and Latin operations to or from the US. The panel only consists of US airlines because of limited availability of data on European and Asian airlines. Two integrators (FedEx and UPS) and six non-integrated all-cargo carriers are studied. Regarding the integrators, only their airport-to-airport air cargo operations are considered. The non-integrated all-cargo carriers belonging to the sample are Polar Air Cargo Airways, Atlas Air, Southern Air, ABX Air, Evergreen International Airlines and Kalitta Air. A number of these non-integrated all-cargo carriers operate flights on behalf of integrators, e.g. Polar Air Cargo, Atlas Air and Southern Air for DHL.

4.1. Profile of sample airlines

FedEx and UPS, two US integrators, are the two largest cargo airlines in terms of total (domestic and international) freight tonnes carried according to the IATA rankings for 2014 (IATA, 2015b). In terms of total (domestic and international) Freight Tonne Kilometres (FTKs), FedEx is number one and UPS number three. Both FedEx and UPS have large US domestic airfreight volumes next to their international traffic. The fleet of FedEx in 2014 consisted of 650 aircraft, of which 587 were owned and 63 leased, while the fleet of UPS included 649 aircraft. Of these 649 aircraft, 237 were owned or capital leased and 412 short-term leased or chartered from others (FedEx, 2014; UPS, 2014). Despite the similar business model and same type of products offered by FedEx and UPS, Onghena et al. (2014) discovered large differences between both US rivals regarding their cost structure and strategies.

Polar Air Cargo is a US all-cargo carrier providing scheduled services and a subsidiary of Atlas Air Worldwide Holdings (AAWW) since 2001. Next to Polar, AAWH also owns Atlas Air, another carrier in our sample. Polar is 49% owned by DHL Express since 2007, for which it operates B747-400Fs transpacific services. Polar had a fleet of 11 B747Fs and 2 B767Fs in 2014 (Polar Air Cargo, 2008).

Atlas Air, a sister company of Polar Air Cargo, is the largest ACMI-provider[5] worldwide, so it wet leases its B747-400, B747-8 and B767 freighter aircraft to other airlines, forwarders or integrators against a fixed rate per block hour. Its other services include dry leasing (aircraft only leasing), CMI services[6] and charter services (Atlas Air, 2015).

In January 2016, AAWW signed an agreement to acquire Southern Air Holdings, which includes two airline subsidiaries: Southern Air (included in our sample) and Florida West International Airways. As Southern Air is operating flights for DHL Express on a CMI basis, this deal will

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[5] An ACMI-provider provides Aircraft, Crew, Maintenance and Insurance freighter leasing services to other airlines, freight forwarders or integrators. This service is also called 'wet leasing'.
[6] By this service, Atlas Air crews, maintains and insures passenger and freighter B747 and B767 aircraft supplied by its customers.

strengthen the already strong partnership of AAWW with the German integrator. Without the integration of Southern Air Holdings, AAWW is operating 23 of its 58 aircraft (40% of its fleet) for DHL. (Atlas Air, 2016a)

Southern Air, a subsidiary of AAWW, provides global ACMI, CMI, commercial and government charter services operating a fleet of B777Fs and B737-400Fs. It specialises in long-haul, heavy-lift operations. Since it was established in 1999 out of the assets of Southern Air Transport and started operations in 1999, data are only available from 2002. In 2007, Oak Hill Capital Partners acquired majority ownership of Southern Air and merged Cargo 360, another all-cargo carrier, into the airline. In 2011, Southern Air entered into a multiple year contract with DHL. This contract involves 5 B777Fs and 5 B737-400Fs. In September 2012, it voluntarily filed for US Chapter 11 bankruptcy protection. Daily operations were not affected. The carrier emerged from Chapter 11 in 2013 with a completed mandatory financial restructuring. Currently, DHL is Southern Air's only customer. (Blachly, 2013; Southern Air, 2014)

ABX Air, a subsidiary of Air Transport Services Group (ATSG), offers ACMI and ACMI-F[7] services using B767-200F and B767-300F aircraft. The carrier does not operate larger capacity, long-haul freighter aircraft. Between 1980 and 1988, ABX Air was known as Airborne Express, the third largest provider of air freight services in the US. In 2003, DHL acquired the sales and ground network of Airborne Express. As a result, ABX Air became an independent publicly traded company, entering into contracts with DHL to continue providing service. Data of ABX are only available since 2005. (ABX Air, 2015)

Evergreen International Airlines provided scheduled and ACMI services with a fleet of B747Fs. Due to a reduced number of contracts with the US Department of Defense, a key customer, and the global economic crisis, the carrier went bankrupt in 2014. (Bloomberg, 2014)

Finally, Kalitta Air is an all-cargo carrier that operates US domestic and international scheduled and charter services. It is mainly known for its long-haul, heavy payload flights operated by its fleet of 13 B747Fs. Five of its B747-400Fs are used for international DHL operations. However, since 2016, the carrier is diversifying its fleet with B767-300ERFs. Through this fleet diversification strategy, Kalitta aims at further developing its US domestic operations. (Kalitta Air, 2014; Ball, 2016)

[7] An ACMI-F service includes aircraft, crew, maintenance, insurance and fuel.

Table 1 shows the main characteristics of the sample airlines at the beginning (1990) and end (2014) of the dataset, as well as for 2005, the first year for which data of all sample carriers are available. Comparing the average stage length of FedEx and UPS on the one hand with that of the non-integrated carriers on the other hand indicates that the integrators have a larger share of US domestic operations in their activities.

= Table 1 about here =

4.2. Input and output variables

Since this research concerns all-cargo carriers, only one output variable is considered, namely freight service (measured in RTKs). Four input variables are considered: labour, fuel, capital and materials. The total cost is measured as the sum of labour, fuel, capital and materials costs. The labour unit cost (UC_Labour) is calculated as the total labour cost, involving salaries and related benefits, divided by the number of full-time equivalent employees[8] (FTEs). The unit cost of fuel (UC_Fuel) is measured as the total fuel cost divided by the total fuel consumption. The capital unit cost (UC_Capital) is measured as the sum of depreciation, amortisation and rentals expenses divided by the number of Available Tonne Kilometres (ATKs). The use of ATKs as a proxy for capital quantity involves that no distinction is made between flight equipment and ground property and equipment. While a fleet quantity index as in Oum, Fu and Yu (2005) would be a better approximation for the capital quantity, this was impossible in this research due to the lack of detailed fleet composition data over the time period considered. The materials cost is the cost of maintenance materials and other materials such as utilities, stationery, printing and office supplies. The materials unit cost (UC_Material) is proxied by the Producer Price Index (PPI), as was done in Zou and Hansen (2010), since no data are available for the materials quantity. This approximation involves that the materials unit cost only varies by quarter, not by carrier. All cost statistics are expressed in 2010 dollars.

The time trend variable (t) represents technical change over time. In order to be able to distinguish between economies of scale (EOS) and economies of density (EOD), two network variables are included in the models, namely the number of points served and the average stage length. The number of points served are measured as the number of unique origins and destinations. The average stage length is calculated as the total distance flown divided by the number of departures. Additionally, the load factor, measured by RTKs divided by ATKs, is incorporated in the

[8] In the case of FedEx, its transport related employees are not considered in order to make the data comparable with those of UPS. Considering FedEx versus UPS, FedEx includes its ground operations (trucking) in its reports and its trucking related employees are categorised as transport related employees. UPS considers its trucking operations as a separate company and the airline contracts out to that company for the services. UPS's transport related employees are zero over the considered period.

model, as it is another important environmental variable that influences the efficiency and the production frontier of an airline (Coelli et al., 1999). Finally, the quarterly dummy variables are included in the model to account for seasonality and a possible peak in operations during the last quarter, as is often seen with integrators.

5. Results

The estimation results of the translog cost function from Equation (10) with second-order time-dependent and firm-specific inefficiency terms, are partly given in Table 2. For the complete output, we refer to Appendix A. The final estimations exclude Southern, because it is considered an outlier with a very specific cost structure. Including it in the panel led to biased results. Plotting output (RTK) divided by total cost[9], as shown in Appendix E, confirms that Southern produces an extreme amount of output with its inputs, especially before 2007. Their capital cost is very low, which might be the result of mainly operating old aircraft under operating lease. More accurate fleet data would allow discussion of this observation in more detail. Moreover, the chosen translog specification proves to be a better specification than the more restricted Cobb-Douglas specification. A likelihood test results in a test statistic L of 240 (=2*(419.0-299.0)), which corresponds to p<0.0001 under a χ^2_{34}-distribution.

= Table 2 about here =

The output in Table 2 shows that all first-order coefficients are significant at the five percent level. They all have the same sign as the correlations of the independent variables with the dependent variable, which moreover are the expected signs according to economic theory. Total costs increase with increasing output, as well as with an increase in the unit cost of any of the production factors. It can be seen that according to these findings, the capital cost accounts for more than half (53%) of the total cost. A quarter of the cost (24%) can be attributed to labour and the rest of the costs is incurred by fuel (14%) and materials (9%). The large impact of capital on total costs implies that this input should be used at maximal efficiency. Capital-intensive and expensive airplanes should fly as much as possible with a load factor as high as possible in order to achieve high cost-efficiency. It can also be observed that total costs increase slightly with more points served. Higher average

[9] Total cost is used as a proxy for total input used.

stage length and load factor both result in a reduction of total costs, indicating the existence of scale economies at route level. Economies of density and economies of scale at airline level are respectively calculated as 1.287 and 1.222 at the sample mean.[10]

This confirms that both increasing the density of the existing network as well as increasing the scale of the operations by adding points served, lead to savings in average costs. It is important that policy makers take this into account when evaluating merger and acquisition requests by cargo carriers. The different u and η coefficients reported in Appendix A enable calculations of efficiencies of the all-cargo carriers and their evolutions over time, according to Equations (6) and (7) in Section 3. The outcomes are presented graphically in Fig. 1.

= Figure 1 about here=

A first observation for all carriers is the efficiency dip around or just before the financial crisis of 2008. From the graph, it is also apparent that the integrators, FedEx and UPS, exhibit low efficiency values based on this panel. This result is in contrast with the fact that integrators are currently considered among the best performers in the air cargo industry, dominating an increasing share of the business. Their low efficiency scores in this study show however that, when only considering their air cargo operations, they do not excel in terms of efficiency. Integrators have a relatively higher total cost than non-integrated airlines. This can be explained by the fact that integrators use relatively more inputs to produce their output, for example to guarantee sufficient spare capacity.

In August 2016, Atlas announced a cooperation agreement with FedEx including the leasing of five Boeing 747-400Fs in the December peak season between 2016 and 2021 to the integrator (Atlas Air, 2016b). This spare capacity is an additional cost, but serves to prevent waiting time in the most time-sensitive air express segment. In addition, integrators are operating transport networks with very high fixed costs, so they have to deal with a higher share of overhead costs compared to the smaller, non-integrated cargo carriers. This suggests that the above-average performance of integrators should be caused by other factors than the efficiency of their air cargo operations. Some explanations are possible. First of all, their vertically integrated structure involving a total control of the door-to-door chain and their important share in the fast-growing air

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[10] $EOD = \frac{1}{0.777} = 1.287$ and $EOS = \frac{1}{0.777+0.041} = 1.222$.

express market allows them to charge higher mark-ups and realise higher incomes. In addition, their significant scale and density economies led to decreasing average costs, explaining their external growth strategies over the past years. Moreover, being integrated leads to reduced transaction costs and increased transparency.

UPS performs better than FedEx until 2005, after which their efficiencies converge and FedEx slightly outperforms UPS. The efficiency improvement of FedEx since 2010 results from a number of measures the integrator took to cut costs and streamline its operations in response to the recession. FedEx reduced capacity by retiring some of its oldest and most inefficient aircraft such as the A310, B727 and the MD10-10s. In addition, it implemented a number of human resource related measures to reduce its labour cost. Examples are temporary salary reductions, abolishment of bonuses, work hour reductions and lay-offs. FedEx was hit harder by the crisis than UPS due to the higher revenue share of its air express operations. (FedEx, 2010)

The evolution of the non-integrators' efficiency is more or less similar to that of the integrators, with a decrease until around the economic crisis and a recovery or stabilisation afterwards. Evergreen[11] experiences a relatively steeper decline in efficiency. Polar and Atlas as sister companies exhibit very similar evolution in efficiency until 2007. Polar recovered better from the crisis than Atlas and was able to increase its efficiency since 2007, the year in which its partnership with DHL Express started. Finally, also ABX shows an extensive increase in efficiency since 2007, a proof of flexible reactions of a small and relatively new carrier to turmoil caused by the crisis. It reaches the highest efficiency of the panel at the end of 2013, which is equal to the efficiency of Evergreen in the early 1990s.

Although we use a larger sample and a different methodology that allows to differentiate between true efficiency and random effects, the results in this paper show some similarities with the findings of Balliauw et al. (2016, p. 64). The decrease of Atlas' efficiency over time and the emergence of Polar as one of the most efficient airlines in the sample after 2009 is confirmed here. Also the recovery of Evergreen and Kalitta after the 2008 crisis is apparent in both studies.

Not detected in the study of Balliauw et al. (2016) however was the efficiency decrease of the integrators FedEx and UPS running up to the financial crisis and the crossing of their efficiency curves. However, integrated and non-integrated cargo carriers have different business models. They differ a lot in size, the type of operations involved and the services offered. Integrators focus on the even more time-sensitive, smaller express parcels and carry out all ground operations themselves, which involves that there might be cost interactions between their air and ground

[11] Evergreen went bankrupt in 2013.

operations. Hence, combining the cost structure of integrated and non-integrated carriers in one cost function can be subject to some critique. To study the differences between the cost structures of both carrier types, the panel is split up in two separate panels and the analyses for both groups can be compared. Looking at the efficiencies and cost structures of both carrier types separately allows to account for different production process characteristics and to take them into account when calculating efficiencies.

= Figure 2 about here=

Fig. 2A for integrators and Fig. 2B for non-integrators confirm the observations from the joint analysis of integrators and non-integrators. UPS performs better than FedEx. Since the efficiency scores are calculated separately for both types of carriers, the efficiencies of the integrators exhibit a different shape than when a single panel is used. This is a consequence of the assumption that both production processes differ too much to be combined in one cost function. It can also be seen in Fig. 2A that the efficiencies of the integrators are first increasing during the growth years of air cargo, followed by a period of decreasing efficiency under the influence of the financial crisis. For the non-integrated carriers, relative efficiencies are stable and similar to the observations based on Fig. 1, with ABX again making a strong leap forward and Evergreen undergoing the highest descent.

= Table 3 about here=

Table 3 illustrates the differences in cost structures, based on the SFA estimations with separate panels for integrators and non-integrators, each with their own typical production process. For the integrators, it was decided to leave the proxied unit cost of materials out of the analysis, as it exhibits high correlations with the other variables in the model. This solves the problem of a singular Hessian matrix, which occurs in cases of high multicollinearity. The resulting outputs for both models have the expected signs of the significant variables. The density and scale economies for integrators (EOD = 1.66, EOS = 1.63) are larger than for non-integrators (EOD = 1.34, EOS = 1.21), which explains their objective to expand their operations by take-overs and mergers (see e.g. FedEx taking over TNT). The importance of the fourth quarter for integrators is visible in the output in Appendix B. Because of the end-of-the-year demand peak for express parcels, integrators might be able to use their inputs in a more efficient way in this fourth quarter.

The results show that the total costs of both integrators and non-integrators depend mostly on the capital input price. For non-integrated carriers the input share of capital is almost 50%, which indicates that capital is an important input for the provision of their ACMI-services. Labour has the second-largest impact on the total costs of non-integrators, with a share of 21%. Fuel and materials only account for respectively 10% and 13% of their total costs. This might be explained by the fact that these costs are borne by its customer, i.e. the lessee wet-leasing the aircraft under an ACMI-contract. This is often an integrator, using ACMI-services. For integrators, fuel is much more important (31%) and is followed by labour (29%). The lower capital input share of integrators (40%) compared to non-integrators (48%) can be explained by the fact that integrators have many cooperation agreements with other airlines, e.g. ACMI-providers, operating flights on behalf of them. In addition, they buy capacity on flights of combi carriers or other cargo operators. In these cases, the capital cost is borne by the ACMI-provider and not by the integrator. Based on the results in Table 3, non-integrators can benefit relatively more from increasing the load factor of their aircraft than integrators, whereas integrators can more easily increase their number of points served. The larger impact of the load factor on the total costs of non-integrators might be a consequence of the larger cost share of fuel, compared to integrators. Non-integrators can also benefit from reducing their average stage length, whereas this coefficient is not significantly different from zero in the case of integrators.

6. Conclusions and future research

Air cargo is an important contributor to the global economic development as well as to the profitability of most airlines and airports. Since the financial crisis in 2008, the air cargo industry, and particularly the all-cargo segment, is experiencing difficulties as a result of overcapacity, a shift towards belly freight and decreasing yields. Integrators seem to be among the best performing all-cargo carriers and even among the best performers in the overall air cargo industry.

A review of the literature shows that more research is required to gain additional insights into the efficiency of the all-cargo segment. As a result, in this paper, a stochastic frontier analysis based on a translog cost function is conducted in order to investigate efficiency differences between US all-cargo carriers over time and to get an idea about the cost structure of the sample carriers. The results show that capital has the largest impact on the carriers' total costs, followed by labour. Capital and labour together account for 77% of the total costs of all-cargo carriers. Also materials and fuel have an important impact on the total costs and require a well thought-out strategy. Moreover, the industry exhibits density and scale economies. The efficiency results reveal that the integrators UPS and FedEx perform worse in terms of efficiency than the non-integrated all-cargo carriers, which is in contrast with their above-average performance in terms of market share and profitability. It is also remarkable that smaller carriers like ABX seem to react in a more flexible way to crisis periods. The effects of the crisis are clearly visible in the efficiency scores for all sample carriers. Regarding the integrators, the results illustrate that FedEx has a lower efficiency than UPS.

Since integrated and non-integrated all-cargo carriers have different business models, a comparison is challenging. The cost structure of the integrators' air cargo operations is impacted by that of their ground operations and vice versa, whereas non-integrated all-cargo carriers only have flying operations. Therefore, an additional analysis is carried out to gain more insight into the differences between the cost structures of both groups of carriers. This showed that capital has the largest impact on the cost structure of all carriers, but that the impact for non-integrators is larger than for integrators as a result of their different business model. The integrated carriers exhibit larger scale and density economies than the non-integrators. We also saw that the efficiencies of integrators are not correctly estimated when they are analysed jointly with non-integrated carriers as a result of their different production process.

In order to improve the estimation results and interpretation, it would be worthwhile to have access to information on fleet characteristics such as aircraft size, age and fleet mix. In addition, more accurate fleet data could be used to enhance the capital unit cost estimations in future research.

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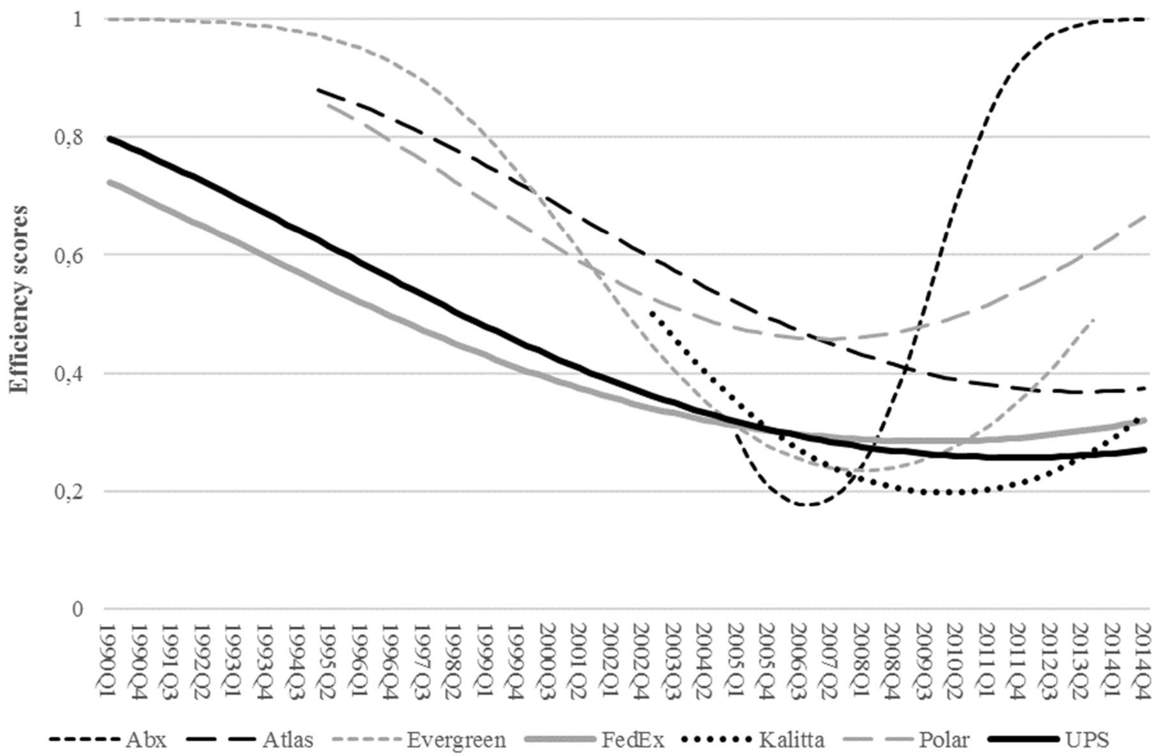
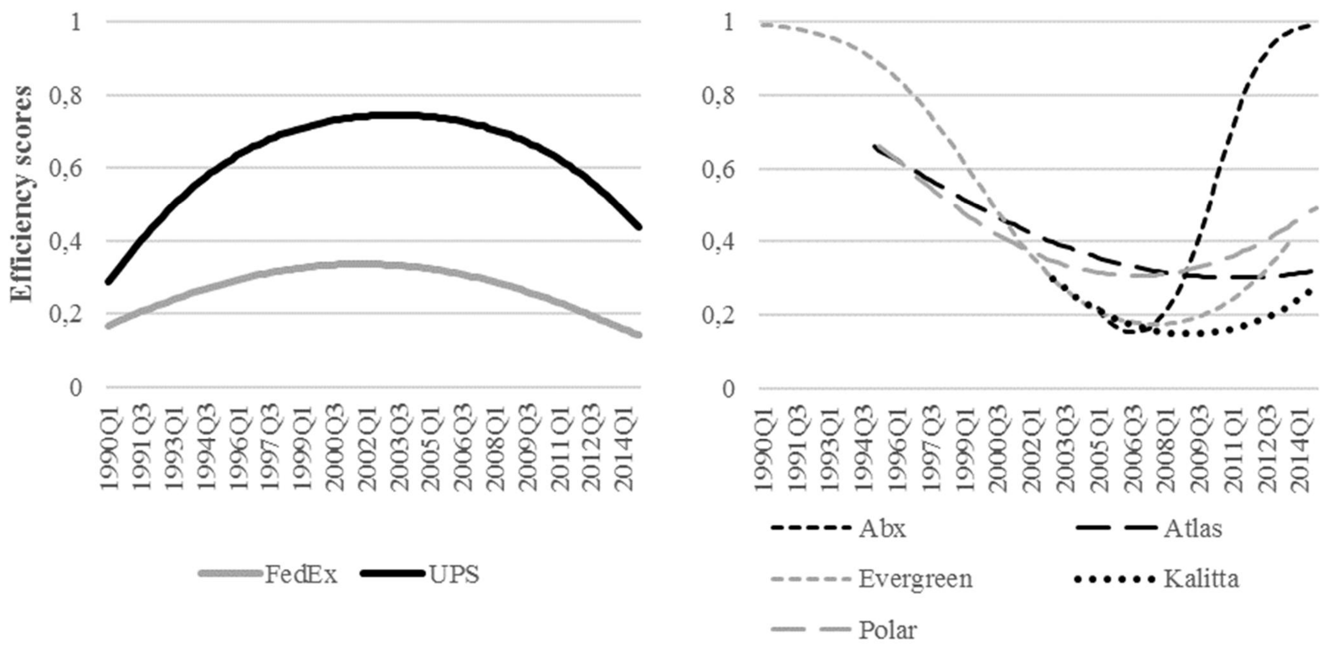


Fig. 1. Efficiency scores of all-cargo carriers over time, excluding Southern.



(a) Integrators (b) Non-integrators

Fig. 2. Efficiency scores of all-cargo carriers over time, based on SFA estimations with separate panels for integrators and non-integrators, excluding Southern.

Table 1

Main characteristics of sample airlines at the beginning, middle and end of the dataset.

Airline	Operating Revenues (US$ 000)	Number of FTEs	Number of gallons	ATKs	RTKs	Load factor (%)	Average stage length (km)	N° of points served
1990								
FedEx	7 612 985	17 346	612 277 579	10 001 652 922	6 187 072 734	62	863	43
UPS	861 524	2754	NA	4 308 145 189	2 362 061 664	55	1301	19
Polar	NA	NA	NA	NA	NA	NA	NA	NA
Atlas Air	NA	NA	NA	NA	NA	NA	NA	NA
Southern	NA	NA	NA	NA	NA	NA	NA	NA
ABX Air	NA	NA	NA	NA	NA	NA	NA	NA
Evergreen	217 608	578	80 052 809	217 334 699	153 229 589	71	3660	19
Kalitta	NA	NA	NA	NA	NA	NA	NA	NA
2005								
FedEx	20 533 392	33548	1 150 576 457	23 021 238 386	14 627 834 243	64	1135	341
UPS	4 105 212	5811	625 686 000	13 560 546 487	8 432 516 656	62	1728	137
Polar	720 933	737	176 418 791	3 897 591 825	2 598 620 191	67	4492	52
Atlas Air	953 554	4806	418 635 543	9 084 760 721	6 000 472 459	66	4748	80
Southern	81 115	180	299 972	1 516 657 997	1 013 652 684	67	5001	13
ABX Air	396 638	2885	128 964 196	2 103 906 043	903 215 361	43	1047	124
Evergreen	463 385	446	95 388 415	528 378 177	443 334 696	84	3816	17
Kalitta	494191	689	97 296 215	3 375 268 248	2 220 780 178	66	4792	41
2014								
FedEx	26 523 112	57 308	1 117 241 207	28 530 187 917	16 078 851 021	56	1251	325
UPS	5 814 195	5404	725 771 000	17 842 760 831	11 208 152 112	63	1941	134
Polar	1 084 579	156	133 302 413	3 790 983 151	2 849 987 243	75	4802	15
Atlas Air	1 634 220	1703	361 654 242	8 754 602 892	4 651 518 781	53	3826	92
Southern	152 093	364	5 622 488	1 927 369 874	1 512 797 748	78	5469	25
ABX Air	306 071	450	985 084	1 491 710 660	735 632 755	49	1484	59
Evergreen	NA	NA	NA	NA	NA	NA	NA	NA
Kalitta	659 284	1018	43 564 653	2 716 916 862	1 843 486 196	68	4628	43

Source: Compiled from BTS (2015).

Table 2

Excerpt of ML estimation, translog cost function model with firm-specific inefficiencies, excluding Southern.

Variable	Coefficient	Prob.
Output	0.777	0.0000
Labour	0.241	0.0000
Fuel	0.141	0.0000
Capital	0.526	0.0000
Materials	0.092	0.0397
Number of points served	0.041	0.0545
Average stage length	-0.228	0.0000
Load factor	-0.578	0.0000
Log likelihood	419.0	
Included observations	515	

Table 3
Excerpt of ML estimations for separate integrator and non-integrator panels.

	Integrators		Non-integrators	
Variable	Coefficient	Prob.	Coefficient	Prob.
Output	0.601296	0.0000	0.745	0.0000
Labour	0.293586	0.0000	0.211	0.0000
Fuel	0.309265	0.0000	0.098	0.0000
Capital	0.397154	0.0000	0.482	0.0000
Materials	N/A	N/A	0.129	0.0319
Number of points served	0.011480	0.4804	0.080	0.0161
Average stage length	0.543758	0.0983	-0.238	0.0000
Load factor	-0.319631	0.0016	-0.536	0.0000
Log likelihood	391.5		215.8	
Included observations	182		333	

APPENDIX A.

Table A.1

ML estimation translog SFA, excluding Southern.

Variable	Coefficient	Std. Error	z-Statistic	Prob.
Trend	-0.020104	0.003954	-5.084785	0.0000
Trend^2	0.000121	3.98E-05	3.037524	0.0024
Ln(RTK)	0.776677	0.040153	19.34281	0.0000
Ln(UC_Fuel)	0.140693	0.017260	8.151567	0.0000
Ln(UC_Capital)	0.526176	0.038993	13.49424	0.0000
Ln(UC_Material)	0.092384	0.044922	2.056543	0.0397
Ln(Points)	0.041442	0.021550	1.923049	0.0545
Ln(ASL)	-0.227924	0.031936	-7.136968	0.0000
Ln(Load)	-0.577974	0.086862	-6.653913	0.0000
Ln(RTK)*Ln(RTK)	0.042177	0.038171	1.104945	0.2692
Ln(UC_Labour)*Ln(UC_Fuel)	-0.015636	0.021194	-0.737790	0.4606
Ln(UC_Labour)*Ln(UC_Capital)	-0.047942	0.037351	-1.283550	0.1993
Ln(UC_Labour)*Ln(UC_Material)	-0.046570	0.050820	-0.916372	0.3595
Ln(UC_Fuel)*Ln(UC_Capital)	0.026921	0.018381	1.464607	0.1430
Ln(UC_Fuel)*Ln(UC_Material)	-0.025929	0.024178	-1.072443	0.2835
Ln(UC_Capital)*Ln(UC_Material)	-0.135951	0.046249	-2.939538	0.0033
Ln(RTK)*Ln(UC_Fuel)	0.063303	0.014882	4.253643	0.0000
Ln(RTK)*Ln(UC_Capital)	0.055525	0.025516	2.176036	0.0296
Ln(RTK)*Ln(UC_Material)	-0.038096	0.034458	-1.105569	0.2689
Q1	-0.229691	0.057705	-3.980418	0.0001
Q2	-0.226518	0.058483	-3.873202	0.0001
Q3	-0.219187	0.058487	-3.747629	0.0002
Q4	-0.220055	0.055511	-3.964182	0.0001
u_ABX	-7.352492	0.844979	-8.701390	0.0000
η1_ABX	0.490690	0.053341	9.199053	0.0000
η2_ABX	0.007615	0.000860	8.854270	0.0000
u_Atlas	-0.015613	0.102224	-0.152738	0.8786
η1_Atlas	0.004588	0.006129	0.748591	0.4541
η2_Atlas	0.000386	0.000113	3.425107	0.0006
u_Evergreen	-0.690253	0.109627	-6.296384	0.0000
η1_Evergreen	0.078309	0.005966	13.12602	0.0000
η2_Evergreen	0.001450	0.000116	12.50148	0.0000
u_FedEx	0.132943	0.237501	0.559756	0.5756
η1_FedEx	0.009196	0.005951	1.545133	0.1223
η2_FedEx	0.000222	7.92E-05	2.798546	0.0051
u_Kalitta	0.102016	0.083352	1.223928	0.2210
η1_Kalitta	0.040449	0.005986	6.756624	0.0000
η2_Kalitta	0.001074	0.000149	7.196615	0.0000
u_Polar	-0.897336	0.340429	-2.635895	0.0084
η1_Polar	0.042803	0.014747	2.902536	0.0037
η2_Polar	0.000704	0.000168	4.189688	0.0000
u_UPS	0.269497	0.138842	1.941027	0.0523
η1_UPS	0.005831	0.006958	0.838066	0.4020
η2_UPS	0.000238	8.57E-05	2.777877	0.0055
Log likelihood	418.9513	Schwarz criterion		-1.093513
Avg. log likelihood	0.813498	Hannan-Quinn criter.		-1.314015
Akaike info criterion	-1.456122			
Determinant residual covariance	0.011506			
R-squared	0.994542	Mean dependent var		0.271638
Adjusted R-squared	0.994043	S.D. dependent var		1.453304
S.E. of regression	0.112165	Sum squared resid		5.925674
Durbin-Watson stat	0.706438			

Notes: Estimation Method: Full Information Maximum Likelihood (BFGS / Marquardt steps)

Sample: 1990Q1 2014Q4 IF @CROSSID<>7; included observations: 515; convergence achieved after 121 iterations; coefficient covariance computed using outer product of gradients; coefficient substitutions according the restrictions guaranteeing linear homogeneity of the estimated translog function:

- Ln(UC_Labour) = 1 - Ln(UC_Fuel) - Ln(UC_Capital) - Ln(UC_Material)
- Ln(UC_Labour)*Ln(UC_Labour) = - Ln(UC_Labour)*Ln(UC_Fuel) - Ln(UC_Labour)*Ln(UC_Capital) - Ln(UC_Labour)*Ln(UC_Material)
- Ln(UC_Fuel)*Ln(UC_Fuel) = - Ln(UC_Labour)*Ln(UC_Fuel) - Ln(UC_Fuel)*Ln(UC_Capital) - Ln(UC_Fuel)*Ln(UC_Material)
- Ln(UC_Capital)*Ln(UC_Capital) = - Ln(UC_Capital)*Ln(UC_Fuel) - Ln(UC_Labour)*Ln(UC_Capital) - Ln(UC_Capital)*Ln(UC_Material)
- Ln(UC_Material)*Ln(UC_Material) = - Ln(UC_Material)*Ln(UC_Fuel) - Ln(UC_Material)*Ln(UC_Capital) - Ln(UC_Labour)*Ln(UC_Material)
- Ln(RTK)*Ln(UC_Labour) = - Ln(RTK)*Ln(UC_Fuel) - Ln(RTK)*Ln(UC_Capital) - Ln(RTK)*Ln(UC_Material)

APPENDIX B.

Table B.1
ML estimation translog SFA, integrators panel.

Variable	Coefficient	Std. Error	z-Statistic	Prob.
Trend	0.033082	0.016411	2.015893	0.0438
Trend^2	-0.000317	0.000150	-2.116306	0.0343
Ln(RTK)	0.601296	0.112994	5.321502	0.0000
Ln(UC_Fuel)	0.309265	0.021480	14.39803	0.0000
Ln(UC_Capital)	0.397154	0.039494	10.05595	0.0000
Ln(Points)	0.011480	0.016270	0.705602	0.4804
Ln(ASL)	0.543758	0.328891	1.653308	0.0983
Ln(Load)	-0.319631	0.101341	-3.154008	0.0016
Ln(RTK)*Ln(RTK)	0.085727	0.177949	0.481753	0.6300
Ln(UC_Labour)*Ln(UC_Fuel)	-0.055599	0.051669	-1.076059	0.2819
Ln(UC_Labour)*Ln(UC_Capital)	-0.155116	0.042338	-3.663764	0.0002
Ln(UC_Fuel)*Ln(UC_Capital)	-0.133774	0.028017	-4.774695	0.0000
Ln(RTK)*Ln(UC_Fuel)	-0.065329	0.056418	-1.157948	0.2469
Ln(RTK)*Ln(UC_Capital)	0.014007	0.066943	0.209244	0.8343
Q1	-1.581943	0.953310	-1.659422	0.0970
Q2	-1.593280	0.952015	-1.673586	0.0942
Q3	-1.593880	0.952491	-1.673381	0.0943
Q4	-1.604267	0.949280	-1.689982	0.0910
u_FedEx	0.673450	0.470491	1.431379	0.1523
η1_FedEx	-0.022651	0.003849	-5.885123	0.0000
η2_FedEx	-0.000219	3.84E-05	-5.699044	0.0000
u_UPS	-0.183753	0.950295	-0.193364	0.8467
η1_UPS	-0.045722	0.036753	-1.244046	0.2135
η2_UPS	-0.000503	0.000407	-1.238032	0.2157

Log likelihood	391.4595	Schwarz criterion	-3.615510
Avg. log likelihood	2.150877	Hannan-Quinn criter.	-3.866739
Akaike info criterion	-4.038017		
Determinant residual covariance	0.000793		

R-squared	0.998831	Mean dependent var	0.132600
Adjusted R-squared	0.998661	S.D. dependent var	0.825999
S.E. of regression	0.030224	Sum squared resid	0.144334
Durbin-Watson stat	1.597511		

Notes: Estimation Method: Full Information Maximum Likelihood (BFGS / Line Search steps); Sample: 1990Q1 2014Q4; included observations: 182; convergence achieved after 119 iterations; coefficient covariance computed using outer product of gradients; coefficient substitutions according the restrictions guaranteeing linear homogeneity of the estimated translog function:

- Ln(UC_Labour) = 1 - Ln(UC_Fuel) - Ln(UC_Capital)
- Ln(UC_Labour)*Ln(UC_Labour) = - Ln(UC_Labour)*Ln(UC_Fuel) - Ln(UC_Labour)*Ln(UC_Capital)
- Ln(UC_Fuel)*Ln(UC_Fuel) = - Ln(UC_Labour)*Ln(UC_Fuel) - Ln(UC_Fuel)*Ln(UC_Capital)
- Ln(UC_Capital)*Ln(UC_Capital) = - Ln(UC_Capital)*Ln(UC_Fuel) - Ln(UC_Labour)*Ln(UC_Capital)
- Ln(RTK)*Ln(UC_Labour) = - Ln(RTK)*Ln(UC_Fuel) - Ln(RTK)*Ln(UC_Capital)

APPENDIX C.

Table C.1

ML estimation translog SFA, non-integrators panel excluding Southern.

Variable	Coefficient	Std. Error	z-Statistic	Prob.
Trend	-0.025698	0.006809	-3.774375	0.0002
Trend^2	0.000168	6.63E-05	2.537296	0.0112
Ln(RTK)	0.744761	0.042936	17.34586	0.0000
Ln(UC_Fuel)	0.097853	0.020267	4.828111	0.0000
Ln(UC_Capital)	0.482306	0.045043	10.70764	0.0000
Ln(UC_Material)	0.128552	0.059923	2.145295	0.0319
Ln(Points)	0.080075	0.033286	2.405676	0.0161
Ln(ASL)	-0.238185	0.047104	-5.056578	0.0000
Ln(Load)	-0.536028	0.131110	-4.088392	0.0000
Ln(RTK)*Ln(RTK)	0.042363	0.056649	0.747819	0.4546
Ln(UC_Labour)*Ln(UC_Fuel)	-0.017264	0.031481	-0.548389	0.5834
Ln(UC_Labour)*Ln(UC_Capital)	-0.059714	0.053566	-1.114790	0.2649
Ln(UC_Labour)*Ln(UC_Material)	-0.031086	0.072492	-0.428822	0.6681
Ln(UC_Fuel)*Ln(UC_Capital)	0.033654	0.031463	1.069633	0.2848
Ln(UC_Fuel)*Ln(UC_Material)	-0.032548	0.039180	-0.830720	0.4061
Ln(UC_Capital)*Ln(UC_Material)	-0.145987	0.068633	-2.127071	0.0334
Ln(RTK)*Ln(UC_Fuel)	0.063875	0.028517	2.239889	0.0251
Ln(RTK)*Ln(UC_Capital)	0.062943	0.037543	1.676552	0.0936
Ln(RTK)*Ln(UC_Material)	-0.042984	0.053299	-0.806471	0.4200
Q1	-0.066339	0.080840	-0.820625	0.4119
Q2	-0.054774	0.082084	-0.667291	0.5046
Q3	-0.045101	0.081680	-0.552170	0.5808
Q4	-0.048200	0.078229	-0.616132	0.5378
u_ABX	-6.663504	1.165681	-5.716404	0.0000
η1_ABX	0.448630	0.073119	6.135626	0.0000
η2_ABX	0.006950	0.001181	5.886838	0.0000
u_Atlas	-0.001257	0.138036	-0.009106	0.9927
η1_Atlas	0.006320	0.008137	0.776650	0.4374
η2_Atlas	0.000371	0.000140	2.642989	0.0082
u_Evergreen	-0.593977	0.145474	-4.083050	0.0000
η1_Evergreen	0.075135	0.007493	10.02779	0.0000
η2_Evergreen	0.001372	0.000150	9.118839	0.0000
u_Kalitta	0.120881	0.117122	1.032091	0.3020
η1_Kalitta	0.041399	0.008281	4.999479	0.0000
η2_Kalitta	0.001060	0.000201	5.284967	0.0000
u_Polar	-0.793937	0.432573	-1.835384	0.0664
η1_Polar	0.042438	0.018633	2.277607	0.0228
η2_Polar	0.000681	0.000203	3.360833	0.0008

Log likelihood	215.8306	Schwarz criterion	-0.633489
Avg. log likelihood	0.648140	Hannan-Quinn criter.	-0.894767
Akaike info criterion	-1.068051		
Determinant residual covariance	0.016016		

R-squared	0.978905	Mean dependent var	0.136332
Adjusted R-squared	0.976259	S.D. dependent var	0.872650
S.E. of regression	0.134459	Sum squared resid	5.333383
Durbin-Watson stat	0.731040		

Notes: Estimation Method: Full Information Maximum Likelihood (BFGS / Marquardt steps); sample: 1990Q1 2014Q4 IF @CROSSID<>6; included observations: 333; convergence achieved after 130 iterations; coefficient covariance computed using outer product of gradients; coefficient substitutions according the restrictions guaranteeing linear homogeneity of the estimated translog function:

- Ln(UC_Labour) = 1 - Ln(UC_Fuel) - Ln(UC_Capital) - Ln(UC_Material)

- Ln(UC_Labour)*Ln(UC_Labour) = - Ln(UC_Labour)*Ln(UC_Fuel) - Ln(UC_Labour)*Ln(UC_Capital) - Ln(UC_Labour)*Ln(UC_Material)
- Ln(UC_Fuel)*Ln(UC_Fuel) = - Ln(UC_Labour)*Ln(UC_Fuel) - Ln(UC_Fuel)*Ln(UC_Capital) - Ln(UC_Fuel)*Ln(UC_Material)
- Ln(UC_Capital)*Ln(UC_Capital) = - Ln(UC_Capital)*Ln(UC_Fuel) - Ln(UC_Labour)*Ln(UC_Capital) - Ln(UC_Capital)*Ln(UC_Material)
- Ln(UC_Material)*Ln(UC_Material) = - Ln(UC_Material)*Ln(UC_Fuel) - Ln(UC_Material)*Ln(UC_Capital) - Ln(UC_Labour)*Ln(UC_Material)
- Ln(RTK)*Ln(UC_Labour) = - Ln(RTK)*Ln(UC_Fuel) - Ln(RTK)*Ln(UC_Capital) - Ln(RTK)*Ln(UC_Material)

APPENDIX D

Table D.1

Correlation matrix: Entire panel.[1]

	Ln(TC)	Ln(RTK)	LN(UC_Labour)	Ln(UC_Fuel)	Ln(UC_Capital)	Ln(UC_Material)	Ln(Points)	Ln(ASL)	Ln(Load)	Q1	Q2	Q3	Q4
Ln(TC)	1.000000	0.846464	0.351566	0.343406	0.032240	0.325868	0.742595	-0.470395	-0.403281	-0.031375	-0.014356	-0.000646	0.046260
Ln(RTK)	0.846464	1.000000	0.296320	0.162282	-0.367589	0.191896	0.745839	-0.344525	-0.344255	-0.054442	-0.017979	0.005249	0.066971
LN(UC_Labour)	0.351566	0.296320	1.000000	0.775039	-0.313766	0.546945	0.278896	0.065207	-0.343663	-0.020990	-0.034863	-0.008603	0.064333
Ln(UC_Fuel)	0.343406	0.162282	0.775039	1.000000	-0.105367	0.611026	0.182343	-0.015344	-0.259748	-0.026905	-0.030270	0.021331	0.035642
Ln(UC_Capital)	0.032240	-0.367589	-0.313766	-0.105367	1.000000	-0.071935	-0.254030	-0.136078	0.233850	0.043969	0.019252	0.000105	-0.063162
Ln(UC_Material)	0.325868	0.191896	0.546945	0.611026	-0.071935	1.000000	0.309857	0.341500	-0.213564	-0.018324	-7.76E-06	0.000969	0.017312
Ln(Points)	0.742595	0.745839	0.278896	0.182343	-0.254030	0.309857	1.000000	-0.409021	-0.476955	-0.005140	-0.028726	-0.035204	0.069073
Ln(ASL)	-0.470395	-0.344525	0.065207	-0.015344	-0.136078	0.341500	-0.409021	1.000000	0.402217	-0.013502	-0.002655	0.012363	0.003720
Ln(Load)	-0.403281	-0.344255	-0.343663	-0.259748	0.233850	-0.213564	-0.476955	0.402217	1.000000	-0.024736	0.009037	0.046057	-0.030517
Q1	-0.031375	-0.054442	-0.020990	-0.026905	0.043969	-0.018324	-0.005140	-0.013502	-0.024736	1.000000	-0.330749	-0.334188	-0.332469
Q2	-0.014356	-0.017979	-0.034863	-0.030270	0.019252	-7.76E-06	-0.028726	-0.002655	0.009037	-0.330749	1.000000	-0.334188	-0.332469
Q3	-0.000646	0.005249	-0.008603	0.021331	0.000105	0.000969	-0.035204	0.012363	0.046057	-0.334188	-0.334188	1.000000	-0.335925
Q4	0.046260	0.066971	0.064333	0.035642	-0.063162	0.017312	0.069073	0.003720	-0.030517	-0.332469	-0.332469	-0.335925	1.000000

[1] Excluding Southern.

Table D.2

Correlation matrix: Integrators panel.

	Ln(TC)	Ln(RTK)	LN(UC_Labour)	Ln(UC_Fuel)	Ln(UC_Capital)	Ln(UC_Material)	Ln(Points)	Ln(ASL)	Ln(Load)	Q1	Q2	Q3	Q4
Ln(TC)	1.000000	0.978663	0.231916	0.756484	0.683717	0.750113	0.889541	-0.028300	0.343096	-0.018819	0.000228	-0.002825	0.021280
Ln(RTK)	0.978663	1.000000	0.251257	0.714265	0.647498	0.740918	0.893567	-0.001359	0.362737	-0.076026	-0.008543	-0.005205	0.089157
LN(UC_Labour)	0.231916	0.251257	1.000000	0.723412	-0.513890	0.745682	0.379046	0.942018	-0.117564	-0.005343	-0.002239	-0.006204	0.013731
Ln(UC_Fuel)	0.756484	0.714265	0.723412	1.000000	0.091855	0.916969	0.752995	0.554680	0.116288	-0.035579	-0.011042	0.016165	0.030116
Ln(UC_Capital)	0.683717	0.647498	-0.513890	0.091855	1.000000	0.108193	0.490916	-0.713421	0.429382	0.035030	0.018788	0.006776	-0.060201
Ln(UC_Material)	0.750113	0.740918	0.745682	0.916969	0.108193	1.000000	0.746260	0.592783	-0.008948	-0.012483	-0.000163	-0.003595	0.016149
Ln(Points)	0.889541	0.893567	0.379046	0.752995	0.490916	0.746260	1.000000	0.151702	0.217436	-0.001580	-0.010381	-0.018924	0.030797
Ln(ASL)	-0.028300	-0.001359	0.942018	0.554680	-0.713421	0.592783	0.151702	1.000000	-0.301092	-0.030726	-0.013494	0.005256	0.038641
Ln(Load)	0.343096	0.362737	-0.117564	0.116288	0.429382	-0.008948	0.217436	-0.301092	1.000000	-0.122124	-0.003371	0.118268	0.006312
Q1	-0.018819	-0.076026	-0.005343	-0.035579	0.035030	-0.012483	-0.001580	-0.030726	-0.122124	1.000000	-0.328467	-0.333315	-0.333315
Q2	0.000228	-0.008543	-0.002239	-0.011042	0.018788	-0.000163	-0.010381	-0.013494	-0.003371	-0.328467	1.000000	-0.333315	-0.333315
Q3	-0.002825	-0.005205	-0.006204	0.016165	0.006776	-0.003595	-0.018924	0.005256	0.118268	-0.333315	-0.333315	1.000000	-0.338235
Q4	0.021280	0.089157	0.013731	0.030116	-0.060201	0.016149	0.030797	0.038641	0.006312	-0.333315	-0.333315	-0.338235	1.000000

Table D.3

Correlation matrix: Non-integrators panel.[1]

	Ln(TC)	Ln(RTK)	LN(UC_Labour)	Ln(UC_Fuel)	Ln(UC_Capital)	Ln(UC_Material)	Ln(Points)	Ln(ASL)	Ln(Load)	Q1	Q2	Q3	Q4
Ln(TC)	1.000000	0.640080	0.676151	0.513134	-0.197399	0.755415	0.435538	0.292598	-0.388686	-0.066482	-0.032482	-0.001340	0.100310
Ln(RTK)	0.640080	1.000000	0.423272	0.161030	-0.701918	0.418748	0.637709	0.354151	-0.205705	-0.084109	-0.028810	0.009962	0.102917
LN(UC_Labour)	0.676151	0.423272	1.000000	0.782893	-0.298128	0.528286	0.323903	-0.014122	-0.383349	-0.026459	-0.045959	-0.009709	0.082166
Ln(UC_Fuel)	0.513134	0.161030	0.782893	1.000000	-0.128590	0.574942	0.033658	-0.074741	-0.305227	-0.025792	-0.037050	0.023843	0.038904
Ln(UC_Capital)	-0.197399	-0.701918	-0.298128	-0.128590	1.000000	-0.105649	-0.616813	-0.051011	0.263844	0.050040	0.021356	-0.001265	-0.070126
Ln(UC_Material)	0.755415	0.418748	0.528286	0.574942	-0.105649	1.000000	0.264457	0.289186	-0.365444	-0.022626	-0.000411	0.003844	0.019177
Ln(Points)	0.435538	0.637709	0.323903	0.033658	-0.616813	0.264457	1.000000	-0.116232	-0.581303	-0.006809	-0.048171	-0.058536	0.113750
Ln(ASL)	0.292598	0.354151	-0.014122	-0.074741	-0.051011	0.289186	-0.116232	1.000000	0.322267	-0.019133	-0.003927	0.022160	0.000812
Ln(Load)	-0.388686	-0.205705	-0.383349	-0.305227	0.263844	-0.365444	-0.581303	0.322267	1.000000	-0.010260	0.011991	0.039280	-0.041168
Q1	-0.066482	-0.084109	-0.026459	-0.025792	0.050040	-0.022626	-0.006809	-0.019133	-0.010260	1.000000	-0.332000	-0.334664	-0.332000
Q2	-0.032482	-0.028810	-0.045959	-0.037050	0.021356	-0.000411	-0.048171	-0.003927	0.011991	-0.332000	1.000000	-0.334664	-0.332000
Q3	-0.001340	0.009962	-0.009709	0.023843	-0.001265	0.003844	-0.058536	0.022160	0.039280	-0.334664	-0.334664	1.000000	-0.334664
Q4	0.100310	0.102917	0.082166	0.038904	-0.070126	0.019177	0.113750	0.000812	-0.041168	-0.332000	-0.332000	-0.334664	1.000000

[1] Excluding Southern

APPENDIX E.

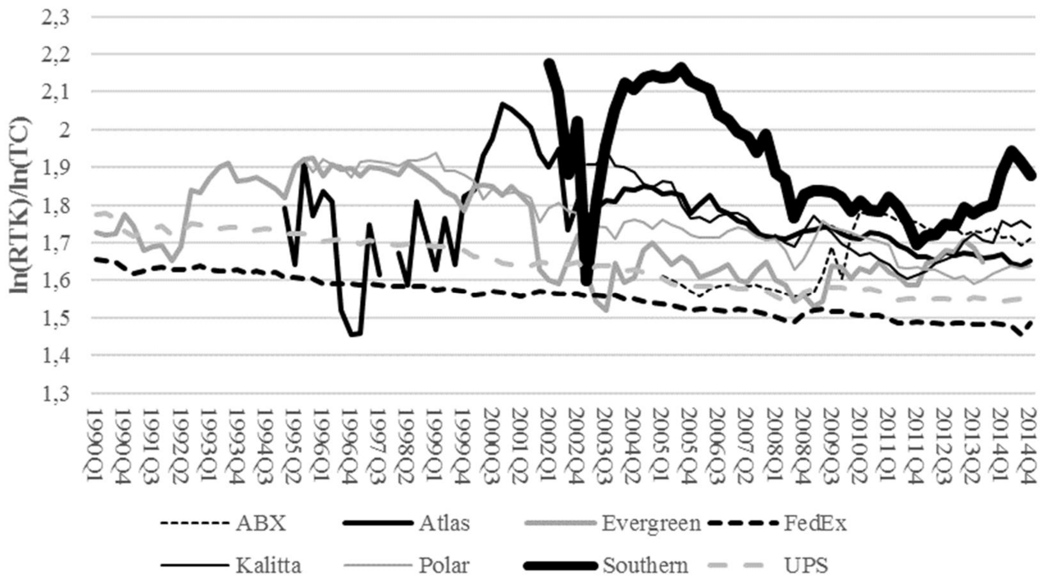


Fig. E.1. Plot of ln(RTK)/ln(TC), with TC as a proxy for the total input used.