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Does ANSP size and scope matter in the European ANS market? A multi-product Stochastic Frontier Approach

Sven Buyle[*], Wouter Dewulf, Franziska Kupfer, Evy Onghena, Hilde Meersman, and Eddy Van de Voorde

Department of Transport and Regional Economics, University of Antwerp
Prinsstraat 13, 2000 Antwerpen, Belgium

Abstract

This paper assesses the existence of economies of scale and cost complementarities in the European air navigation services (ANS) industry to provide policymakers and air navigation service providers (ANSPs) insight into the economic viability of possible industry-led consolidation and unbundling opportunities. While previous studies using parametric methods made abstraction of the multi-product nature of the ANS industry, this paper tries to fill that gap by estimating a stochastic multi-product translog cost frontier. The existence of economies of density and scale is evaluated from the estimated cost frontier at the sample means as well as for individual ANSPs in the panel. The results suggest that during the period from 2006 to 2016 the European ANS industry faced economies of density and produced at constant economies of scale in the sample means. However, cost complementarities do not seem to be present.

Keywords— stochastic frontier analysis, air navigation service providers, economies of density, economies of scale, cost complementarities

1 Introduction

The European air navigation services (ANS) industry is changing. Under the influence of the Single European Sky (SES) and Single European Sky ATM Research (SESAR) initiatives, national markets for terminal ANS are opening up, and new technologies are being developed. The question arises how European air navigation service providers (ANSPs) should react to the challenges caused by these market changes.

As part of the SES initiative, functional airspace blocks (FABs) were established in an attempt to optimise ANS provision over state boundaries by enhancing cooperation between ANSPs. The ultimate aim as mentioned in the SES framework regulation is to, where appropriate, eventually have one integrated ANSP for a FAB (European Commission, 2004). To date, the FABs seem to be somewhat rigid constructions (European Commission, 2018). However, the consolidation question remains very present in the European ANS industry. The SES II+ package, which is still in the process for approval, aims to further improve efficiency in the sector by partly unbundling terminal from en-route services and fostering industry-led consolidation (European Commission, 2018). An econometric analysis might help policymakers and ANSPs to understand whether such unbundling *(Are there economies of scope?)* and consolidation *(Are there economies of scale?)* could be economically viable.

To assess possible consolidation strategies, this paper presents the estimates of a multi-product translog cost frontier for the European ANS industry from which measures for economies of scale and scope are derived in the sample means. The paper contributes to the existing literature by using a para-

[*]Corresponding author. E-mail: sven.buyle@uantwerp.be

metric method to estimate economies of scale, taking into account the multi-product nature of the ANS industry. The use of a multi-product approach allows assessing the existence of cost complementarities between the considered services which are, to the best of our knowledge, not yet investigated thoroughly.

The remaining of the paper is structured as follows: first, a brief review of existing literature on ANS costs and efficiency is presented, where after the methodology used in this paper is explained. Section 4 gives an overview of the dataset and variables used in this study. The estimation results are presented and discussed in section 5, followed by the conclusions to be drawn from this analysis.

2 Literature review

There has already been done some research into efficiency and economies of scale in the European ANS industry. Table 1 provides an overview of the methodologies used as well as the variables taken into account by different authors. The table also mentions whether increasing returns to scale (IRS) or decreasing returns to scale (DRS) were observed. The primary focus of these papers is on efficiency, which can be analysed by two main methodologies: Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA).

The first study to apply DEA on the data of the EUROCONTROL Performance Review Unit (PRU) is one by Button and Neiva (2014). They made benchmarks for relative efficiency for the period from 2002 to 2009, but were not particularly interested in the existence of economies of scale. A later study by Bilotkach et al. (2015), which used a cost-DEA model did consider economies of scale. They conclude that the majority of ANSPs in their panel operated under economies of scale from 2002 to 2004. They find that, from 2005 to 2011, the number of ANSPs operating under economies of scale declined while the number of ANSPs operating under constant and decreasing returns of scale increased. Furthermore, they observe that the group of ANSPs operating under increasing returns to scale in 2011 is composed almost exclusively of Eastern European ANSPs. A later study by Standfuß et al. (2017) on 2014 data also finds similar results in one of their models estimated. They were particularly interested in the link between economies of scale and airspace size, concerning possible consolidation opportunities. Their study suggests the existence of a turning point between increasing and decreasing returns to scale. They find that all ANSPs with controlled airspace above 250,000 square kilometres operate under decreasing returns to scale, while those with an airspace of less than 105,000 square kilometres operate under increasing returns to scale.

From the studies using SFA, three make use of the Cobb-Douglas functional form (which implies a priori restrictions on its derivatives) and only one of the translog functional form. All SFA studies included in table 1 have in common that they estimate single product cost functions, while the ANS industry is a multi-product environment. This issue is in most papers solved by using a consolidated product index: composite flight hours, a weighted sum of instrumental flight rules (IFR) airport movements controlled and en-route flight hours controlled. However, as Grebensek and Magister (2013) and also Standfuß et al. (2018) suggest, the use of composite flight hours might bias efficiency benchmarking results. COMPAIR (2017) estimates a cost function for each output, which requires distinguishing costs connected to terminal services from costs related to en-route services. This paper tries to fill the gap in the literature by using a multi-product translog approach in which both services can be considered together.

All SFA studies considered here suggest that the average ANSP faces economies of scale (increasing output reduces long-term average costs, all else equal). However, they differ in the strength of the economies found. COMPAIR (2017) finds only small economies to exist, both for terminal as for en-route services (a 10% traffic increase would lead to a 9% increase in costs). Comparable results are found by Competition Economists Group (2011). NERA Economic Consulting (2006) and Dempsey-Brench and Volta (2018) however find economies of scale for the average ANSP to be rather large. Analysing ANSP cost structure from a multi-product perspective could bring more insight as it allows to look at how each product contributes to the existence of total

Table 1: Overview of ANSP cost related research found in academic literature

				Inputs												Outputs				Exog. variables				
Author(s)	**Methodology**	**Data**	**Scale econ.**	total gate-to-gate ATM/CNS cost	other gate-to-gate cost	total en-route cost	total terminal cost	gate-to-gate labour cost	terminal labour cost	ATCO labour cost	ATCO hours in operation	support staff labour cost	capital cost	composite infrastructure units	non-staff operating cost	total flight hours controlled	IFR airport movements controlled	composite flight hours	minutes of ATFM delay	traffic variability	complexity	airspace size	business environment quality	network concentration index
NERA Economic Consulting (2006)	SFA Cobb-Douglas	'01 - '04	IRS							x		x	x		x			x		x	x	x		
Competition Economists Group (2011)	SFA Cobb-Douglas	'02 - '09	IRS	x						x		x	x		x			x		x	x	x	x	x
Button and Neiva (2014)	DEA	'02 - '09	n.a.	x	x											x	x		x					
Bilotkach et al. (2015)	DEA	'02 - '11	IRS - DRS	x						x		x	x		x	x	x							
Standfuß et al. (2017)	DEA	'14	IRS - DRS								x	x		x	x	x	x	x						
COMPAIR (2017)	SFA Cobb-Douglas	'04 - '14	IRS			x		x					x			x				x	x	x		
COMPAIR (2017)	SFA Cobb-Douglas	'04 - '14	IRS				x		x				x				x			x	x	x		
Dempsey-Brench and Volta (2018)	SFA translog	'06 - '14	IRS	x						x		x	x		x			x		x	x	x		

Source: own composition

economies of scale as well as if cost complementarities are present.

3 Methodology

3.1 Multi-product cost theory

In multi-product cost theory, a firm uses a set of inputs $X = \begin{pmatrix} x_1 & \cdots & x_n \end{pmatrix}$ (e.g. labour, capital, raw materials) to produce a set of outputs $Q = \begin{pmatrix} q_1 & \cdots & q_m \end{pmatrix}$.

Each of the inputs x_i have a particular price w_i which forms a cost for the firm. Consider the vector $W = \begin{pmatrix} w_1 & \cdots & w_n \end{pmatrix}$ as the vector of input prices, then total costs TC are given by

$$TC = W^T X = \sum_{i=1}^{n} w_i x_i$$

Because of the relation between input and output vectors coming from the production process, total costs TC can also be written as the sum of a function of output vector Q, input quantity vector X and input price vector W with a function of exogenous variables Z:

$$TC = f(Q; X; W) + g(Z)$$

When estimating this total cost function, the functional form of f should be specified. As described by McFadden (1978) such a functional form should meet specific theoretical properties. In order to behave as described in traditional economic theory, the cost function should be: continuous, non-negative, strictly positive for non-zero output bundles, non-decreasing in input prices, positively linear homogeneous in input prices, and concave.

One commonly used functional form, which will also be used in this paper, is the translog functional form. The multi-product translog is a flexible functional form; it does not imply any a priori restrictions on first and second order derivatives in contrast to the also widely used Cobb-Douglas function. This flexibility allows calculating measures for economies of scale for individual firms as opposed to looking only at the industry level. However, restrictions are needed to make sure the resulting cost function is linear homogeneous in input prices. Another advantage of the multi-product translog compared with more complex functional forms is its relatively small number of parameters to be estimated. (Caves et al., 1980)

The multi-product translog functional form as first introduced by Burgess (1974) can be written as

$$\begin{aligned}\ln TC =& \alpha_0 + \sum_{i}^{m} \alpha_i \ln q_i + \sum_{i}^{n} \beta_i \ln w_i \\ & + \frac{1}{2} \sum_{i}^{m} \sum_{j}^{m} \delta_{ij} \ln q_i \ln q_j \\ & + \frac{1}{2} \sum_{i}^{n} \sum_{j}^{n} \gamma_{ij} \ln w_i \ln w_j \\ & + \sum_{i}^{m} \sum_{j}^{n} \rho_{ij} \ln q_i \ln w_j \\ & + g(\zeta; Z)\end{aligned}$$

in which the q_i's are the products produced, the w_i's the input prices and the α_i's, β_i's, δ_{ij}'s, γ_{ij}'s, ρ_{ij}'s and ζ_i's the parameters to be estimated.

3.2 Stochastic frontier analysis

The cost function is estimated as a stochastic frontier, taking into account inefficiency as deviations from the optimal cost function that can be reached with the current production technology.

Different stochastic frontier model specification alternatives have been tested for this study. Two observations are considered regarding the model specification: (1) as indicated by e.g. Standfuß et al. (2018) there is a high degree of heterogeneity between the European ANSPs; (2) from the authors' research prior to this study it is learned that the composed error term often is heteroskedastic. The latter causes a potentially severe problem in a stochastic frontier context (Kumbhakar and Lovell, 2000).

Simar et al. (1994) and Caudill et al. (1995) independently proposed a model specification that incorporates both heterogeneity as well as heteroskedasticity in the inefficiency term. From all model specification alternatives that have been tested for this study, the Caudill et al. (1995) model seems to provide the most promising results.

This model can be specified as

$$\ln TC_{it} = f(\ln Q_{it}; \ln W_{it}; Z_{it}; \beta) + v_{it} + u_{it}$$

$$u_{it} = \exp(A_{it}\xi) \cdot \eta_{it}$$

in which Z_{it} and A_{it} are vectors of exogenous variables, β and ξ vectors of parameters to be estimated. The v_{it} are the independent and identically distributed (i.i.d.) random errors which follow a $N(0, \sigma_v^2)$ distribution and the u_{it} are the non-negative inefficiency terms which are, as opposed to commonly used SFA models, not i.i.d. since the standard deviation of u_{it} is given by

$$\sigma_{uit} = \exp(A_{it}\xi) \cdot \sigma_\eta$$

The model hence accounts for multiplicative heteroskedasticity. When A_{it} includes an intercept, this simplifies to

$$\sigma_{uit} = \exp(A_{it}\xi)$$

Caudill et al. (1995) assume the η_{it} to be exponentially distributed such that a maximum likelihood estimation method can be used.

The vector Z is composed out of five contextual variables which are assumed to affect the production technology used and hence determine the shape of the frontier. In this study these variables are the logarithm of the number of en-route sectors open at the ANSP's maximum configuration as a measure for its geographical span; an index reflecting the complexity of the airspace; a traffic variability index; a time index to reflect technological progress; and a dummy to distinguish the ANSPs operating under the European common performance scheme. The maximum sector configuration will be used to calculate economies of scale measures (see Section 3.3).

As noted by Caudill et al. (1995) there is a common advice shared between econometricians that heteroskedasticity can be expected when observations of different size are used, which is the case for European ANSPs. Therefore they include size related variables into vector A. In this paper A only contains the logarithm of the number of en-route sectors open at maximum configuration to reflect ANSP size. Including other size related variables does not produce satisfactory results.

The model used in this study differs from that of the earlier studies mentioned in Section 2. While NERA Economic Consulting (2006) and Competition Economists Group (2011) rely mainly on the traditional Pitt and Lee (1981) model with time-invariant inefficiency, COMPAIR (2017) and Dempsey-Brench and Volta (2018) take into consideration exogenous influences in the inefficiency component respectively via the Battese and Coelli (1995) model and an adapted version of the Battese and Coelli (1992) model with time-varying inefficiency. The model specification used here is most closely aligned with the one used by Dempsey-Brench and Volta (2018) with the difference that they put the exponential distribution assumption on u_i and bridge to u_{it} via Battese and Coelli (1992).

The translog cost frontier must satisfy the following additional restrictions

- symmetry
  $\delta_{ij} = \delta_{ji}$ and $\gamma_{ij} = \gamma_{ji}$
- linear homogeneity in factor prices
  This is implemented by dividing all monetary variables by one of the input prices (Schmidt and Lovell, 1979, eq. 5).
- monotonicity in outputs and factor prices
  All output and price elasticities of total cost should be positive for all observations. This is implemented by using a restricted maximum likelihood estimation method.

3.3 Economies of scale

When services are considered to have a spatial aspect (e.g. transportation) firm size has two dimensions: the size of the service network and the magnitude of services provided. In this case, Caves et al. (1984) make a distinction between economies of *scale* and economies of *density*. Economies of density are said to exist if long-term average costs decline as output increases while network size remains fixed. In a multi-product setting, this can be measured as

$$S_D = \frac{1}{\epsilon_{TC,Q}} = \frac{1}{\sum_{i=1}^{m} \epsilon_{TC,q_i}}$$

with ϵ_{TC,q_i} the elasticity of total cost with respect to output q_i. A metric with a value higher than one indicates economies, lower than one diseconomies and equal to one constant economies of density.

For the multi-product translog functional form, the output elasticities of total cost are given by

$$\epsilon_{TC,q_i} = \alpha_i + \sum_{j=1}^{m} \delta_{ij} \ln q_j + \sum_{j=1}^{n} \rho_{ij} \ln w_j$$

If long-term unit costs decline when output *and* network size increases, Caves et al. (1984) define economies of scale measured by

$$S_S = \frac{1}{\epsilon_{TC,Q} + \epsilon_{TC,N}}$$

with $\epsilon_{TC,N}$ the elasticity of total cost with respect to network size.

3.4 Cost complementarities

As demonstrated by Baumol et al. (1988) weak inter-product cost complementarities are a sufficient, but not necessary, condition for economies of scope. If inter-product cost complementarities exist, the marginal cost of producing one output decreases with increasing quantities of the other outputs. Mathematically this condition can be written as

$$\frac{\partial^2 TC(Q)}{\partial q_i \partial q_j} \leq 0; i \neq j; \forall q_i \in Q$$

For the multi-product translog cost function, this comes down to

$$\alpha_i \alpha_j + \delta_{ij} \leq 0; i \neq 1; \forall i, j \in \{1, ..., m\}$$

4 Data

The estimations presented here are based on panel data gained from the EUROCONTROL ACE Benchmarking reports. The panel contains ten years of data for 36 European ANSPs from 2006 until 2016. The panel is slightly unbalanced with eight missing observations. Data for ARMATS (Armenia) and HCAA (Greece) is incomplete for the years before 2009. Data for ANS Finland (Finland) is removed for the years 2006 and 2007 because of an inconsistency in how costs are attributed between the ANS and airport operations.

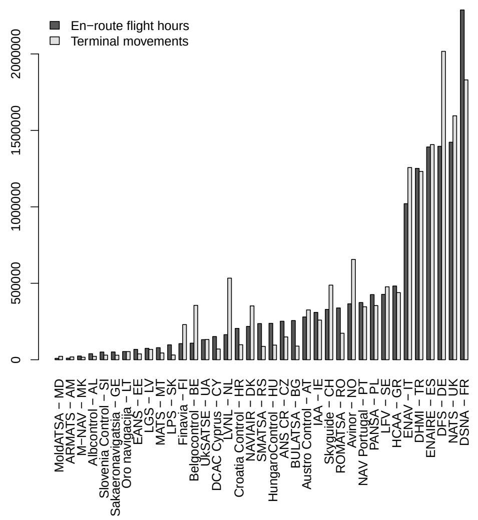
As discussed in Standfuß et al. (2018) there is a high degree of heterogeneity in the kind of services offered and the conditions in which these are provided. The variables incorporated in the model should reflect this heterogeneity as much as possible.

Since the ANS industry is a multi-product environment, at least two outputs have to be considered: the annual number of IFR en-route flight hours controlled by the ANSP (EN-ROUTE) and the yearly number of IFR terminal movements controlled by the ANSP (TERMINAL). These two outputs reflect the regulated part of the ANSP's operations. Despite that a wide set of non-regulated, commercial services are gaining importance (Tomová, 2016), there is still insufficient publicly available and reliable data to measure their output.

Figure 1 illustrates the high diversity between the ANSPs in the panel. The figure also shows that both outputs are correlated. ANSPs that have a higher number of en-route movements also tend to have a higher number of terminal movements. As discussed by Balliauw et al. (2018) this high correlation between the two outputs might result in multicollinearity problems. To overcome this issue the correlation between the output variables is reduced by dividing the IFR en-route flight hours by the number of en-route sectors open at maximum configuration.

As discussed in Section 3.1, five contextual variables are taken into account in the frontier part of the model (vector Z): the logarithm of the maximum number of en-route sectors, airspace complexity, traffic variability, a time index and a European performance scheme dummy. All are assumed to have an

Figure 1: En-route and Terminal movements (2016)



Source: own composition

impact on the shape of the cost frontier. The EUROCONTROL complexity index is supposed to capture external complexity of the airspace, while the variability index reflects the the percentage of traffic in the peak week of the year compared with an average week. Adding the logarithm of a variable to the translog cost frontier makes that its coefficient can be interpreted as an elasticity. The coefficient of the maximum en-route sectors will be used to calculate the network size elasticity included in the economies of scale measure.

The number of en-route airspace sectors at maximum operation is also included in vector A which influences the distribution of the inefficiency component u_{it}.

Three factor prices are included in the model: the capital user cost (CAPITAL), the average wage (WAGE) and the unit price of non-staff operational costs (GDPDEF). The total ATM/CNS gate-to-gate costs (TC) are used as the dependent total cost variable.

The capital user cost is the price paid (as an internal cost) by the firm for the use of capital services delivered by one unit of its capital goods. This price is calculated by dividing the total user costs by a measure of the total capital stock. According to the literature the total user cost of capital is composed out of three main components: the cost of financing the capital investment (which is an opportunity cost), the value loss of the asset due to ageing (i.e. depreciation) and the expected price changes of the assets (i.e. revaluation) (OECD, 2009).

For the purpose of this paper, the assumption is made that there are no expected price changes other than changes in the general price level taken into account in the opportunity costs. Depreciation is excluded as different accounting rules across countries may bias the estimation results. Hence, the total user cost of capital is calculated as the sum of the cost of equity and interest costs through the weighted average cost of capital (this is what is called the capital cost in the ACE Benchmarking reports). The total net book value of assets in operation adjusted by the national capital goods price index from Eurostat is used as the measure of total capital stock (as in previous studies). Missing values in the capital goods price index are imputed via a predictive mean matching method. It should be noted that the exact timing of capital investments by the different firms in the panel is unknown and possibly differs across firms, which might lead to possible bias.

The average wage is the price paid by the firm for one full-time equivalent (FTE) of labour. It is calculated as the total ATM/CNS gate-to-gate staff costs divided by the total staff FTEs. Previous studies have used a separate wage for operational air traffic controller (ATCO) staff and non-ATCO staff. However, both tend to be highly correlated, leading to multicollinearity problems in the model. For this reason, only one average wage is used in this study.

Since almost all European ANSPs are former government bodies the question arises if seconded staff are included in the staff costs disclosed to the PRU. As mentioned in the Specification for Economic Information Disclosure (SEID), the decision to include the cost of external staff in the reported staff costs is left to the ANSP. This might cause bias in the labour price measure.

Table 2: Descriptive statistics of data after PPP adjustment (2016)

Variable	**Mean**	**SD**	**Minimum**	**Maximum**
TC	329,168	404,541	22,297	1,542,389
EN-ROUTE	398,042	516,743	9,442	2,287,512
DENSITY	22,449	10,889	4,378	50,060
TERMINAL	416,986	548,460	16,511	2,017,084
CAPITAL	0.16	0.14	0.01	0.76
WAGE	143	69	30	410
GDPDEF	115	25	94	242

Total costs and wages expressed in thousands.

Source: own composition

Non-staff operational costs are the costs not included in one of the previous cost categories. Its unit price is approximated by the country GDP deflator sourced from the World Bank.

All monetary variables are adjusted by purchase power parities (PPP) and divided by the country GDP deflator to implement homogeneity in factor prices. To be able to interpret the estimated parameters as cost elasticities evaluated at the sample means, all explanatory variables are normalised by dividing the observations by the sample means (Gillen et al., 1990). Normalisation should also reduce the severity of possible multicollinearity problems in the model.

An overview of the descriptive statistics of the dataset used for 2016 is provided in table 2. As is visible in the table, most variables vary strongly between the ANSPs.

5 Results and discussion

The maximum likelihood estimations for the efficiency effects model are presented in table 3. Since the coefficient of the maximum number of sectors in vector A is significant, there is some justification for the use of a heteroskedastic frontier model. The estimated coefficients also suggest that airspace complexity and traffic variability significantly increase total costs, while technological progress and the common performance scheme have a negative impact.

5.1 Factor price elasticities

The coefficients of the outputs and factor prices can be interpreted as elasticities of total cost evaluated in the sample means. All are significant. For the efficient firm, the labour force contributes 55% to the total cost, while the capital input contributes 41%. This suggests that the ANS industry is labour intensive, which is in line with the results of previous research. Even though ANS require continuous investment in technology infrastructure as well as in its maintenance, the actual control of air traffic relies heavily on a human interaction between ATCOs and pilots. The remaining 4% of total costs can be attributed to the non-staff operational costs. This small share includes, amongst others, infrastructure maintenance cost and electricity costs.

Table 3: Maximum likelihood estimates translog cost frontier

	Estimate	**Std. Error**	**t value**	**Pr(> |t|)**	
(Intercept)	6.20	0.20	30.75	< 0.01	***
EN-ROUTE	0.54	0.07	7.76	< 0.01	***
TERMINAL	0.24	0.05	4.65	< 0.01	***
WAGE	0.55	0.05	11.23	< 0.01	***
CAPITAL	0.41	0.04	10.06	< 0.01	***
(EN-ROUTE)^2	0.03	0.08	0.33	0.74	
(TERMINAL)^2	-0.05	0.01	-3.32	< 0.01	***
(WAGE)^2	0.21	0.06	3.55	< 0.01	***
(CAPITAL)^2	0.08	0.02	3.93	< 0.01	***
EN-ROUTE*TERMINAL	0.14	0.03	4.17	< 0.01	***
WAGE*CAPITAL	-0.07	0.05	1.26	0.21	
EN-ROUTE*WAGE	-0.13	0.08	-1.59	0.11	
EN-ROUTE*CAPITAL	-0.05	0.05	-0.95	0.34	
TERMINAL*WAGE	-0.03	0.03	-0.85	0.40	
TERMINAL*CAPITAL	0.01	0.02	0.21	0.84	
Z_MAX SECTOR	0.74	0.05	15.15	< 0.01	***
Z_COMPLEXITY	0.05	0.01	8.91	< 0.01	***
Z_VARIABILITY	1.53	0.16	9.33	< 0.01	***
Z_TIME	-0.01	0.01	-2.01	0.04	*
Z_CPR	-0.09	0.04	-2.15	0.03	*
A_(Intercept)	-2.69	0.64	-5.78	< 0.01	***
A_MAX SECTOR	-0.89	0.21	-4.29	< 0.01	***
$\log(\sigma_v)$	-1.53	0.06	-24.75	< 0.01	***

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘°’ 0.1 ‘ ’ 1

Source: own composition

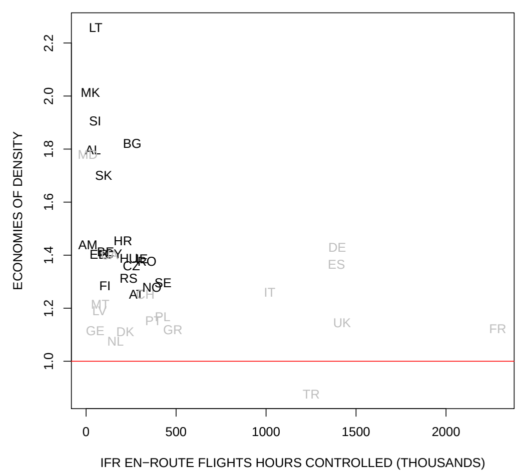
5.2 Output elasticities

If evaluated in the sample means, the output elasticities suggest that a 10% increase in annual en-route flight hours per sector would lead to a 5.4% increase in total costs, compared with an increase of only 2.4% in total cost for a 10% increase in annual terminal movements. Hence, the en-route services seem to have a more substantial impact on total costs as can also be observed in COMPAIR (2017). This might be due to the difference in how the workload of the two services is managed. En-route services are sector based, while the terminal services are function based. Arblaster (2018) describes that increasing en-route traffic requires more airspace sectors and the number of ATCOs employed increases proportionally with the number of sectors. Arblaster (2018) also argues that an increase in airspace sectors leads to the need for more coordination and a higher airspace complexity. Both lead to an increase in costs.

From the model, an estimate can be calculated for the economies of density measure in the sample means. This measure equals 1.28 and is significantly different from one (p-value 0.0174). This indicates that the European ANS industry operates at economies of density in the sample means. A combination of various factors can explain this finding. When the output is increased, part of the infrastructure investment will be borne by an increasing number of movements. Investment in surveillance radar systems and navigation aids, for example, depends on geographical scope rather than the number of movements or flight hours. However, a larger scale will result in a higher demand for IT capacity to manage the increase in flight operational data. An increase in movements also leads to a higher density in airspace sectors. ATCOs can only keep track of a given number of aircraft in their sector simultaneously. Hence sectors will have to be split up as complexity and density increase, leading to higher coordination and additional staff costs which have a substantial contribution to total costs (Arblaster, 2018). These effects might or might not compensate, depending on the current scale at which the ANSP is operating.

It might be useful to this extent to look at the output elasticities for the individual ANSPs and the economies of density measures derived from them as no ANSP is producing exactly at the sample means. It is reasonable that, as shown in Standfuß et al. (2017), some ANSPs in the panel face economies of density while others face diseconomies of density due to their larger operational size.

Figure 2: Economies of density vs. en-route output (2016)

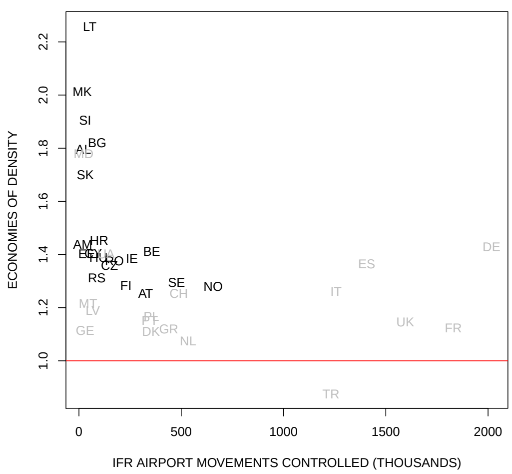


Source: own composition

Figure 2 plots the economies of density measures for each ANSP in 2016 against the annual en-route flights hours controlled. Figure 3 shows a similar picture for the terminal movements. The ANSPs for which the measure is not significantly different from one (p-value above 0.1) are printed in grey.

Larger ANSP such as DSNA (France - FR), DFS (Germany - DE), NATS (United Kingdom - UK), ENAIRE (ES) and ENAV (IT) are producing at constant economies of density. Smaller ANSPs such as for example LGS (Latvia - LV), M-NAV (Macedonia - MK), Slovenia Control (Slovenia - SI), Albcontrol (Albania - AL), produced at economies of density in 2016.

Figure 3: Economies of density vs. terminal output (2016)



Source: own composition

5.3 Economies of scale

The maximum number of en-route sectors has a significant impact on the cost volumes of the ANSP. An ANSP that handles more en-route sectors tends to have a higher total cost as higher infrastructure investments are needed to cover a larger geographical area. Increasing its airspace with 10% would lead to a cost increase for the ANSP of 2.0%, considering that this increase in geographical scope does not add additional output or influences factor prices.

Assuming that the number of en-route sectors is an indicator of the geographical span of the ANSP, economies of scale in the sample means are estimated at 1.01 which is not significantly different from one (p-value 0.569). The model, therefore, provides some evidence that the European ANS industry has produced at constant economies of scale in the sample means for the years 2006 to 2016.

Looking at the economies of scale measures for individual ANSPs, there are only five observations with significant economies of scale around 1.1.

5.4 Cost complementarities

Concerning economies of scope, the estimations suggest that inter-product cost complementarities do not exist, as the metric equals to 0.27 which is significantly larger than zero (p-value < 0.001). As described earlier, having cost complementarities is a sufficient but not a necessary condition for economies of scope. It is not entirely clear from the data which costs are shared between both services. More research is required to make definite conclusions on whether economies of scope are present in the ANS sector.

6 Conclusions

In this paper, a multi-product translog cost frontier was estimated for the European ANS industry by use of panel data from the yearly EUROCONTROL ACE Benchmarking reports. Afterwards, the existence of economies of density and scale were evaluated from the estimated cost frontier at the sample means. Inter-product cost complementarities were assessed to get insight into the presence of economies of scope. The paper differs from previous research because it takes into account the multi-product nature of the ANS industry. It tries to overcome possible bias from using composite flight hours in a single product cost function or from estimating separate cost functions for each product.

The results of the analysis suggest that over the period 2006 - 2016, the European ANS industry produced at economies of density in the sample means and at constant economies of scale (taken into account the number of en-route sectors). When looking at the individual ANSPs, there are only five observations in the panel at which the ANSP produced at significant economies of scale, while the majority of observations (two third) show diseconomies of scale. The results presented in this paper do not support a strong economic rationale for more consolidation between European ANSPs.

This study suggests that no cost complementarity between en-route and terminal services exists. More research into economies of scope in the ANS industry needs to be done to make definite conclusions on whether there is an economic rationale for supporting the current EU policy of fostering service unbundling.

The study presented in this paper has several limitations which are left for future research. The paper identified the existence or non-existence of economies of scale but did not look into the particular nature of those economies. The estimated cost function is unable to identify product-specific economies of scale, nor economies of scope. The calculation of economies of scope and product-specific economies of scale requires that the functional form can handle zero values for the output variables; which is not possible in the translog functional form due to the use of logarithms.

The current study does not look at cost efficiencies in particular. These will be calculated from the SFA and analysed in future research.

This study, as most of the previous studies conducted, focuses on scale economies at the ANSP level. It might be interesting to study cost economies and efficiency at the individual area control centre or control tower level. However, data availability might be an issue. The scope of the research is also limited to the regulated part of the ANS sector. It might be interesting to take into account non-regulated services as they gain importance in the ANSP revenue structure if such data might become available.

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