Economies of Scale and Cost Complementarities in the European ANS Industry: a Multiproduct Translog Cost Function Approach

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Abstract

This paper assesses the existence of economies of scale and cost complementarities in the European air navigation services (ANS) industry to provide policy makers and air navigation service providers (ANSPs) insight into the economic viability of possible industry-led consolidation opportunities. While previous studies using parametric methods made abstraction of the multiproduct nature of the ANS industry, this paper tries to fill that gap by estimating a multiproduct translog cost function. The existence of economies of scale is evaluated from the estimated cost function at the sample means as well as for individual ANSPs in the panel. The results suggest that most European ANSPs produced, on average, at constant economies of scale or small diseconomies of scale over the period 2011 - 2015, while cost complementarities do not seem to exist.

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 bounderies 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 rather inflexible 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 industry by partly unbundling terminal from en-route services and to foster industry-led consolidation (European Commission, 2018). Econometric analysis might help policy makers 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 multiproduct translog cost function for the European ANS industry from which measures for economies of scale are derived for each ANSP. The results presented provides ANSPs and policy makers insight in which cases consolidation might be economically beneficial. The paper contributes to the existing literature by using a

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parametric method to estimate economies of scale, taking into account the multiproduct nature of the ANS industry. This allows to assess the existence of cost complementarities between the considered services which is, to the best of our knowledge, not yet thoroughly investigated.

The remaining of the paper is structured as follows: first, a brief review of existing literature on ANS costs and efficiency is presented, whereafter 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 where 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, with regard to 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 multiproduct 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) 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 multiproduct 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. Analyzing ANSP cost structure from a multiproduct perspective could bring more insight as it allows to look at how each product contributes to the existence of

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

global economies of scale as well as if economies of scope are present.

3 Methodology

3.1 Multiproduct cost theory

In multiproduct 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 a function of output vector Q, input quantity vector X and input price vector W:

$$TC = f(Q; X; W)$$

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 certain 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, nondecreasing 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 multiproduct 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 allows to calculate 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 homogenous in input prices. Another advantage of the multiproduct translog compared with more complex functional forms is its relatively small number of parameters to be estimated. (Caves et al., 1980)

The multiproduct translog functional form as first introduced by Burgess (1974) can be written as

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

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 and ρ_{ij}'s the parameters to be estimated. However, by applying Shepherd's Lemma, there is also information available on the cost shares which gives a set of $n + 1$ equations to be estimated. (Brown et al., 1979)

$$\frac{\partial \ln TC}{\partial \ln w_i} = \frac{w_i}{TC} \frac{\partial TC}{\partial w_i} = \frac{w_i x_i}{TC} = s_i$$

With s_i the share of input i in total cost. Note that by definition should hold

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

For the multiproduct translog function, the cost shares are given by

$$s_i = \beta_i + \sum_{j=1}^{m} \rho_{ji} \ln q_j + \sum_{j=1}^{n} \gamma_{ij} \ln w_j$$

The translog cost function must satisfy the following additional restrictions

- symmetry
  $\delta_{ij} = \delta_{ji}$ and $\gamma_{ij} = \gamma_{ji}$

- linear homogeneity in factor prices $\sum_{i=1}^{n} \beta_i = 1$; $\forall j = 1, ..., n : \sum_{i=1}^{n} \gamma_{ij} = 0$; and $\forall i = 1, ..., m : \sum_{j=1}^{n} \rho_{ij} = 0$

3.2 Economies of scale

Economies of scale are said to exist if long-term average costs decline as output increases (all else equal) (Caves et al., 1984). In a multiproduct setting, this can be measured as

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

with ϵ_{TC,q_i} being 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 returns.

For the multiproduct translog functional form, the output elasticities of total cost are given by

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

3.3 Economies of scope

Economies of scope are said to exist if the cost of producing all outputs jointly is less than the total cost of producing them separately (Willig, 1979).

$$TC(Q) < \sum_{i=1}^{n} TC(0, ..., q_i, ...0)$$

This is usually measured as

$$S_c = \frac{\sum_{i=1}^{n} TC(0, ..., q_i, ..., 0) - TC(Q)}{TC(Q)}$$

This measure however requires to set q_i values to zero which leads to calculation problems in the translog functional form. In this paper economies of scope will therefore be assessed indirectly by looking into cost complementarities.

3.4 Cost complementarities

As demonstrated by Baumol et al. (1988) weak interproduct cost complementarities are a sufficient, but not necessary, condition for economies of scope. If interproduct 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 multiproduct 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

In this paper, a multiproduct translog cost frontier is estimated for European ANSPs by use of panel data gained from the EUROCONTROL ACE Benchmarking reports. The panel contains nine years of data for 36 European ANSPs from 2007 until 2015. The panel is slightly unbalanced as not all ANSPs are included in the reports starting from 2007, while for others some of the variables used in the model contain missing values.

The total IFR flights controlled by the ANSP (Q1) and the total IFR airport movements controlled by the ANSP (Q2) are used as output variables for respectively en-route and terminal services.

Three input prices are being considered:

1. Capital unit cost (CAPITAL)
The sum of ATM/CNS gate-to-gate capital costs and ATM/CNS gate-to-gate depreciation costs divided by the net book value of fixed assets in operation.

2. Wages Total ATM/CNS gate-to-gate staff costs divided by total Full Time Equivalents (FTEs) in operations.

3. Unit price of non-staff operational costs (CPI)
Non-staff operational costs are the costs not included in one of the previous cost categories.

Its unit price is approximated by the country consumer price index (CPI) sourced from the World Bank as suggested by Dempsey-Brench and Volta (2018).

As the dependent total cost variable, the total ATM/CNS gate-to-gate costs are used. Because the cost values mentioned in the ACE Benchmarking reports are rounded, total costs are recalculated as the sum of the reported ATM/CNS gate-to-gate staff costs, non-staff operational costs, depreciation costs, capital costs and exceptional costs. As shown in figure 1, the exceptional costs only represent a tiny share of total costs for some ANSPs while for most they are absent. This is why the exceptional costs are not taken into consideration in this study.

All monetary variables are adjusted for inflation to 2015 prices by taking into account the inflation percentages mentioned in the ACE Benchmarking reports.

To be able to interpret the estimated parameters as cost elasticities evaluated at the sample means, all explanatory variables are normalized by dividing the observations by the sample means (Gillen et al., 1990).

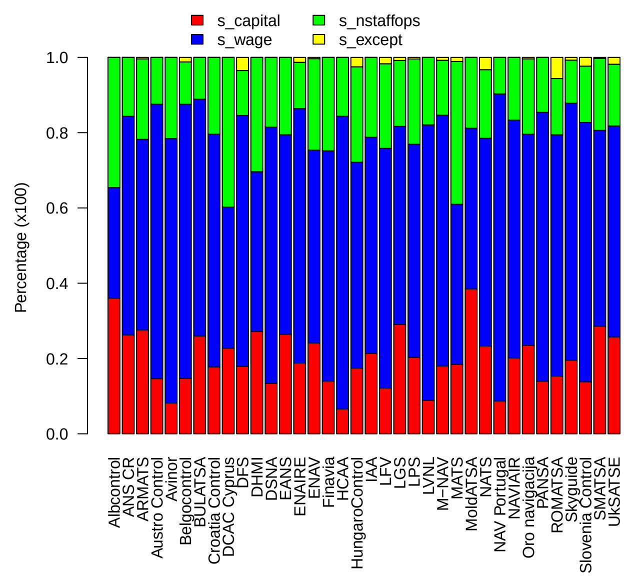
An overview of the descriptive statistics of the dataset used is provided in table 2. As is visible in the table and also in figure 1, most variables vary strongly between the ANSPs.

5 Results and discussion

The translog model and its cost shares are estimated by use of the iterated Seemingly Unrelated Regression (SUR) method developed by Zellner (1962) and implemented in the systemfit package in R by Henningsen and Hamann (2007). The SUR method allows estimating the cost equation and two share equations as one system of equations. The third share equation, belonging to the non-staff operational costs, is not evaluated as it is linearly dependent on the two others.

The estimation results for the cost equation are presented in table 3, and the share equation estimates are shown in tables 4 and 5.

Figure 1: Average cost shares of total Gate-to-Gate ATM/CNS costs (2007 - 2015)



Source: own composition

Table 2: Descriptive statistics of data after inflation adjustment (2007 - 2015)

Variable	**Mean**	**SD**	**Minimum**	**Maximum**
ACC_GTG_TOT	193,003	278,081	3,659	1,213,782
Q1	715,481	698,402	34,770	2,935,173
Q2	425,811	574,708	11,008	2,163,665
CAPITAL	0.21	0.09	0.01	0.88
WAGE	71	43	4	218
CPI	92	12	40	161
SHARE_CAPITAL	0.20	0.08	0.05	0.45
SHARE_WAGE	0.60	0.12	0.19	0.86
SHARE_NSTAFFOPS	0.19	0.08	0.07	0.48

Total costs and wages expressed in thousands, WACC and CPI are indices.

Source: own composition

The coefficients of the outputs and input prices are all significant and have a positive sign. This result satisfies the general requirement of the cost function to be non-decreasing in input prices. The coefficients of the input prices also correspond to the average cost shares in table 2. The labour costs represent the most significant share (60%) in the total cost structure, followed by non-staff operational costs with a share of 21%. Capital costs have a share of 19% in the total cost structure. This suggests that ANS are still quite labour intensive.

The coefficients of both outputs suggest that a 10% increase in en-route flights handled would lead to a 7.9% increase of total costs compared to an increase of only 3.0% in total cost for a 10% increase in airport movements controlled. Hence, the en-route services seem to have a larger impact on total costs as can also be observed in COMPAIR (2017).

The measure of economies of scale at the sample means can be calculated directly from the estimation results. A wald test is performed to test whether the measure is significantly different from one. The results are shown in table 6.

Despite that both output elasticities are smaller than one (0.79 and 0.30), the wald test suggests that small diseconomies of scale are present at the sample means. If output increases by 1%, this leads to an average cost increase of 1.09%. These results differ from Dempsey-Brench and Volta (2018) which might be due to the possible bias in the use of the composite flight hour measure in that study. However, it is more useful to look at the output elasticities for the individual ANSPs and the economies of scale measures derived from them. It is reasonable that, as shown in Standfuss et al. (2017), some ANSPs in the panel face scale economies while others face scale diseconomies due to their larger operational size. 13 out of 36 ANSPs in the panel have an average measure larger than one (suggesting economies of scale) compared to 23 ANSPs with an average measure lower than one (suggesting diseconomies). However, 53% of all observations in the panel have a measure not significantly different from one (suggesting constant returns of scale). Most of the ANSPs facing economies of

Table 3: Multiproduct translog cost function estimates

	Estimate	Std. Error	t value	Pr(> |t|)	
(Intercept)	11.94	0.03	365.16	< 0.001	***
log(Q1)	0.79	0.08	9.46	< 0.001	***
log(Q2)	0.30	0.07	4.55	< 0.001	***
log(CAPITAL)	0.19	0.00	49.26	< 0.001	***
log(WAGE)	0.60	0.01	96.26	< 0.001	***
log(CPI)	0.21	0.01	40.55	< 0.001	***
log(Q1)^2	0.12	0.10	1.27	0.204	
log(Q2)^2	0.02	0.05	0.36	0.719	
log(CAPITAL)^2	0.03	0.00	8.71	< 0.001	***
log(WAGE)^2	0.05	0.00	12.38	< 0.001	***
log(CPI)^2	-0.01	0.01	-2.37	0.018	*
log(Q1):log(Q2)	-0.04	0.12	-0.33	0.738	
log(CAPITAL):log(WAGE)	-0.09	0.00	-18.92	< 0.001	***
log(CAPITAL):log(CPI)	0.04	0.01	5.85	< 0.001	***
log(WAGE):log(CPI)	-0.02	0.01	-2.00	0.046	*
log(Q1):log(CAPITAL)	0.04	0.01	5.37	< 0.001	***
log(Q1):log(WAGE)	-0.02	0.01	-1.48	0.140	
log(Q1):log(CPI)	-0.02	0.01	-2.25	0.025	*
log(Q2):log(CAPITAL)	-0.01	0.00	-2.07	0.039	*
log(Q2):log(WAGE)	0.00	0.01	0.15	0.878	
log(Q2):log(CPI)	0.01	0.01	1.38	0.167	

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

Residual standard error: 0.408 on 299 degrees of freedom
Number of observations: 320 Degrees of Freedom: 299
SSR: 50.729 MSE: 0.166 Root MSE: 0.408
Multiple R-Squared: 0.915 Adjusted R-Squared: 0.911

Source: own composition

Table 4: Estimates for capital cost share equation

	Estimate	**Std. Error**	**t value**	**Pr(> |t|)**	
(Intercept)	0.19	0.00	49.26	< 0.001	***
log(Q1)	0.04	0.01	5.37	< 0.001	***
log(Q2)	-0.01	0.00	-2.07	0.039	*
log(CAPITAL)	0.05	0.01	8.71	< 0.001	***
log(WAGE)	-0.09	0.00	-18.92	< 0.001	***
log(CPI)	0.04	0.01	5.85	< 0.001	***

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

Residual standard error: 0.057 on 314 degrees of freedom
Number of observations: 320 Degrees of Freedom: 314
SSR: 1.001 MSE: 0.003 Root MSE: 0.057
Multiple R-Squared: 0.506 Adjusted R-Squared: 0.498

Source: own composition

Table 5: Estimates for air traffic controller (ATCO) labour cost share equation

	Estimate	**Std. Error**	**t value**	**Pr(> |t|)**	
(Intercept)	0.60	0.01	96.26	< 0.001	***
log(Q1)	-0.02	0.01	-1.48	0.140	
log(Q2)	0.00	0.01	0.15	0.878	
log(capital)	-0.09	0.00	-18.92	< 0.001	***
log(wage)	0.11	0.01	12.38	< 0.001	***
log(CPI)	-0.02	0.01	-2.00	0.046	*

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

Residual standard error: 0.092 on 314 degrees of freedom
Number of observations: 320 Degrees of Freedom: 314
SSR: 2.681 MSE: 0.009 Root MSE: 0.092
Multiple R-Squared: 0.417 Adjusted R-Squared: 0.408

Source: own composition

Table 6: Wald test for constant economies of scale

Estimate	Chisq	Pr(>Chisq)	2.5%	97.5%
0.92	6.74	0.009	0.86	0.98

Source: own composition

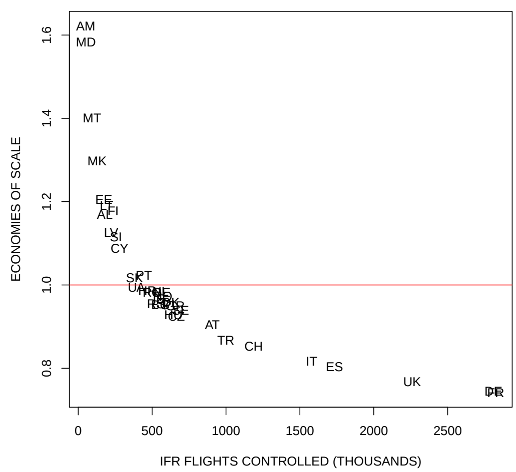
scale are located in Eastern-Europe, which confirms the findings of Bilotkach et al. (2015).

Figure 2 plots the average economies of scale measure against the average en-route flights controlled for each ANSP in the panel. The graph shows that, as expected, the economies of scale measure decreases with output level. Smaller ANSPs such as ARMATS (Armenia - AM), MoldATSA (Moldova - MD), MATS (Malta - MT) and M-NAV (Macedonia - MK) show relatively high values for the economies of scale measure. The larger ANSPs such as DSNA (France - FR), DFS (Germany - DE), NATS (United Kingdom - UK), ENAIRE (Spain - ES) and ENAV (Italy - IT) seem to face diseconomies of scale, suggesting that they produce above their minimum efficient scale. There is also a cluster around the line of constant returns of scale, consisting of: NAV Portugal (Portugal - PT), UkSATSE (Ukraine - UA), LPS (Slovakia - SK), LVNL (Netherlands - NL), IAA (Ireland - IE), Belgocontrol (Belgium - BE), Avinor (Norway - NO), ROMATSA (Romania - RO) and Croatia Control (Croatia - HR). These ANSPs control around 400 thousand and 500 thousand en-route movements per year.

Figure 3 shows a similar picture for terminal movements. Both graphs are more or less identical for both ends of the spectrum. The cluster around the line of equal returns, however, is more spread out for the terminal movements. This makes it more difficult to determine the turning point between economies and diseconomies of scale.

With regard to economies of scope, table 7 suggests that interproduct cost complementarities do not exist as the value of the estimate is positive. However, the estimate is not significantly different from zero at the 95% level. The absence of cost complementarities makes it unlikely that economies of scope between

Figure 2: Economies of Scale vs. en-route output level (2007-2015)



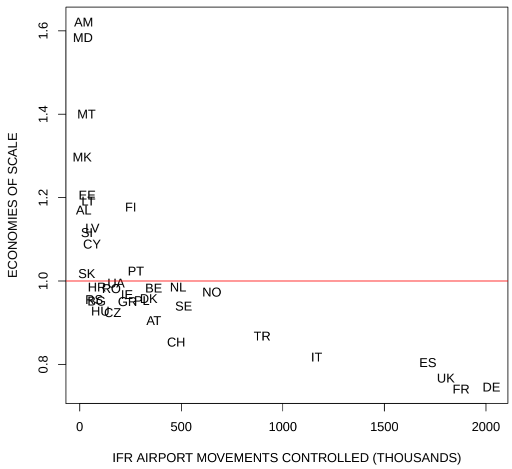
Source: own composition

Table 7: Wald test for cost complementarities

Estimate	Chisq	Pr(>Chisq)	2.5%	97.5%
0.19	2.93	0.087	-0.03	0.41

Source: own composition

Figure 3: Economies of Scale vs. terminal output level (2007-2015)



Source: own composition

en-route and terminal services exist.

6 Conclusions

In this paper a multiproduct translog cost function 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 scale was evaluated from the estimated cost function, both at the sample means as for individual ANSPs. Interproduct cost complementarities where assessed to get insight into the existance of economies of scope. The paper differs from previous research in that it takes into account the multiproduct nature of the ANS industry and uses a flexible functional form without restrictions on first and second order derivatives, as opposed to a Cobb-Douglas functional form. 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 many European ANSPs produced, on average, at constant economies of scale or small diseconomies of scale over the period 2007 - 2015. Only the four smallest and five largest ANSPs show outspoken, respectively, economies and diseconomies of scale. An optimal output level for en-route services seems to exist around 400 thousand and 500 thousand annual movements. The location of the optimal output level for terminal services, however, is much more unclear.

With regard to implications for policy and industry, one might argue that consolidation is only beneficial from the economic perspective for part of the European ANSP market. The results suggest that larger diseconomies of scale start to appear from 600 thousand en-route flights controlled onwards, under the assumption that terminal and en-route services are offered within the same firm. This study was unable to identify a cost complementarity between en-route and terminal services, which might suggest that there are no significant cost savings from offering both services within the same ANSP.

The research presented in this paper has several limitations which are left for future research. Firstly, the estimated multiproduct translog cost function could be extended to include exogenous variables such as airspace size, traffic complexity and traffic variability as well as a time trend. Secondly, 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 or density. The calculation of economies of scope and product-specific economies of scale require that the functional form is able to handle zero values for the output variables; which is not possible in the translog functional form due to the use of logaritms.

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