Ownership Form & Air Navigation Service Provider Performance

Nicole Adler, Adit Kivel
Hebrew University of Jerusalem, Israel
Jerusalem, Israel

Eef Delhaye, Stef Proost
Transport & Mobility Leuven & KU Leuven
Leuven, Belgium

***Abstract*—The ownership form of Air Navigation Service Providers varies across countries ranging from state agencies, to semi-private firms with for-profit or not-for-profit mandates. This research focusses on the link between the performance of ANSPs and their ownership form. A theoretical economic model suggests that effort to achieve efficiency will be higher in the case of public companies with a board of stakeholders composed of airspace users and in the case of private companies in which stakeholders are also shareholders. A stochastic frontier analysis estimation of the production and cost functions of 37 European air navigation service providers over nine years suggests that the public-private ownership form achieves statistically significantly higher efficiency levels compared to a governmental corporation which in turn is an improvement over a state agency.**

ANSP performance, ownership, SFA

I. Introduction

Air traffic control provision is one of the last elements of the aviation supply chain to be considered for liberalization. In the United States, where the Federal Aviation Administration serves the entire market as a single government agency, there has been a long discussion as to whether there is a need to commercialize or privatize the service ([24][25]). In Europe, the fragmentation of service provision, the home bias of each member state for the national provider, the monopolistic nature of some of the air traffic control services, the network component of most services and the split incentives which require the service providers to invest in new technology without enjoying the direct benefits neither encourage cost nor productive efficiency in Europe ([1] and [6]).

With respect to other industries, [2] analyze the combined impact of ownership form, economic regulation and competition on airport performance using data envelopment analysis. The empirical results suggest that in the absence of competition, public airports operated less cost efficiently than fully private airports. In a competitive setting, public and fully private airports operate equally efficiently, however private airports set higher aeronautical charges. In an industry in which there is no competition given the current geographical monopoly status of the ANSPs, it is unclear whether a public or private ownership form would stimulate innovation and create a more productive sector [3]. On the one hand, private firms with access to financial markets may have greater interest in cost efficiency. On the other hand public firms may reduce the level of information uncertainty; information which is required in regulating such firms. [23] focus on the choice of public versus private provision of goods and services as a function of transaction costs. One of their conclusions is that neither public nor private provision can fully resolve incentive problems that arise from imperfect information. [15] develop a model in which a provider chooses to invest in improving the quality or reducing the costs of a specific service. The results of the model suggest that the case for privatization is stronger when quality-reducing cost reductions can be controlled through contract or competition, when quality improvements are important, and when patronage and powerful unions are a problem. Hence, there would seem to be a basis for arguing that there is a relationship between performance and ownership form.

In this research, we develop in section II an economic model in order to analyze the ANSP market and the potential impact of moving from a government agency to a more commercialized setting. Next, in section III, this model is tested empirically for the European air navigation providers by estimating econometrically both production and cost functions and their relationship with ownership form. Section IV draws conclusions.

II. Economic Model

In this section we develop an economic model to understand the possible links between performance, regulation and ownership form. For this analysis we extend the theoretical model presented in [10] explaining the efficiency efforts of a regulated monopoly as a function of the objective of the monopolist and the regulatory framework in place. We assume that the objective of an ANSP is likely to draw from three underlying interests, namely maximization of consumer surplus (CS) of the airlines (and indirectly passengers) with weight parameter $\gamma_1^{\mathrm{ANSP_i}}$, maximization of profits (π^{ANSP}) with weight parameter $\gamma_2^{\mathrm{ANSP_i}}$ and national interest (NI) with weight parameter $\gamma_3^{\mathrm{ANSP_i}}$. The national interest represents two factors: first the benefits of the union of ANSP personnel under the form of higher wages and more relaxed working conditions and second the national manufacturers of air traffic control equipment. This leads to the ANSP mixed goal function of firm *i* presented in (1).

$$Goal^{ANSP_i} = \gamma_1^{ANSP_i} CS + \gamma_2^{ANSP_i} \pi^{ANSP_i} + \gamma_3^{ANSP_i} NI \quad (1)$$

In contrast to Blondiau et al. (2016), the weights now also depend on the ownership form of the ANSP. Multiple assumptions are possible including (1) a public company $\text{ANSP}_{\text{public}}$ could strive for socially optimal decisions such that the sum of consumer and producer surplus are maximized, $\gamma_1^{\text{ANSP}} = \gamma_2^{\text{ANSP}}$; $\gamma_3^{\text{ANSP}} = 0$; (2) a public company may attach a higher value to NI as a result of lobbying or fraud $\gamma_3^{\text{ANSP}} > 0$; or (3) a private company $\text{ANSP}_{\text{private}}$could be influenced by the type of shareholders. Depending on the shareholder composition, a higher weight may be placed on consumer surplus $\gamma_1^{\text{ANSP}} > \gamma_2^{\text{ANSP}}$ (e.g. when airlines are represented on the board) or on profit $\gamma_1^{\text{ANSP}} < \gamma_2^{\text{ANSP}}$ (e.g. when pension funds are shareholders). The same argument may also hold true for public companies in which the consumers are represented on the board.

We assume that the production costs to provide air navigation services can be broken down into three components; a fixed ANSP cost per flight-km controlled a, an imperfectly observable cost component θ that varies as a function of the complexity of the airspace managed and differences in operational practices and an imperfectly observable cost reduction potential e or efficiency expressed in average costs per flight-km. This leads to the ANSP cost per flight-km c controlled expressed in (2).

$$c(e) = a + \theta - e \quad (2)$$

The ANSP operating costs are expressed in (3) in which D represents the total number of standardized flights.

$$OC_{ANSP} = D \cdot c(e) = D \cdot (a + \theta - e) \quad (3)$$

For the management and personnel of the ANSP, effort e is costly in terms of stress and longer hours but such costs are not represented in the accounting system. We represent this subjective cost as a quadratic function, SC_e defined in (4), which means that exerting more effort becomes increasingly costly. We further assume that the costs of effort are higher for relatively larger ANSPs, hence we include the demand parameter D to represent the scale of operations.

$$SC(e) = D \cdot \frac{\emptyset \cdot e^2}{2} \quad (4)$$

The ANSP also receives an income, which depends on the regulated charge permitted. Current SES II regulation is influenced by both price-cap (p_{cap}) and cost-plus (p_{cost}+) regulatory approaches. Under cost-plus regulation, the ANSP charges are equal to the total accounting cost divided by traffic served plus a cost mark-up on capital which allows ANSPs to make a small profit. Under a price-cap, charges are determined by expected costs and demand. Cost efficiency incentives are very different in the two systems. In a pure cost-plus system, all costs are covered so incentives to make large efforts to reduce costs are low. In a price-cap system, any average cost realization below the price cap becomes a profit. Hence we use the general form for price-cap and cost-plus regulation as shown in (5). The charge depends on the weights given to the two types of regulation. The level of effort also plays a role. We use a static formulation here where the realization of cost for an individual ANSP does not affect the price-cap of that ANSP in the future years. Otherwise there will be strategic behavior by each ANSP and the price-cap will be less efficient because too much effort by one ANSP will have a negative ratchet effect on the price-cap of that ANSP. The price-cap is changed over time but it is a function of the aggregate performance of the ANSP's in Europe and the change is not individualized per ANSP.

$$p_{charge}(e) = (1 - B)p_{cap} + Bp_{cost+} = (1 - B)\frac{E(tot\ cost)}{E(D)} + B\frac{tot\ cost}{D} = A + Bc(e) \quad (5)$$

In the second line of (5), A stands for the first term that is constant and exogenous because it is the cost and demand expected by the regulator that is used for the price cap, while only the second term (*Bc(e)*) is influenced by the ANSP.

For this analysis, we use two additional assumptions. First, we assume that A and B are given, this means that the price cap and the mix of price cap and cost plus regulation is given. Second, we assume that the national interest groups prefer the status quo as they were well served in the period before the change in European regulation. Assuming national interest was historically the main ANSP incentive, we have set the importance of national interest proportional to the costs of efficiency effort. This reflects the idea that adding consumer surplus incentives and profit incentives on top of the national interest will require additional efficiency efforts. $\emptyset$ is introduced to interpret $\gamma_3^{ANSP_i}$ as a share of the actual costs in (6).

$$\gamma_3^{ANPS_i} NI = -\gamma_3^{ANPS_i} SC(e) = -\gamma_3^{ANPS_i} D\frac{\emptyset e^2}{2} \quad (6)$$

Applying the two assumptions, we derive the efficiency effort e that is optimal from the point of view of the ANSPs, assuming fixed demand $\overline{D}$, by differentiating the objective function 7 derived from equation 1 with respect to efficiency efforts e and applying equations 5 and 6:

$$Goal^{ANSP_i} = \gamma_1^{ANSP_i} \overline{D}\left(p_{max} - p_{charge}\right) + \gamma_2^{ANSP_i}\left(\overline{D}\left(p_{charge} - c(e)\right) - SC_e\right) - \gamma_3^{ANSP_i} SC_e \quad (7)$$

where the change in consumer surplus equals the difference between the maximum price (the price cap (p_{cap})) and the price actually set (p_{charge}).

Consequently, (8) estimates optimal ANSP efficiency effort as follows.

$$e^* = \frac{\gamma_2^{\text{ANSP}_i} + B(\gamma_1^{\text{ANSP}_i} - \gamma_2^{\text{ANSP}_i})}{(\gamma_2^{\text{ANSP}_i} + \gamma_3^{\text{ANSP}_i})\emptyset} \quad (8)$$

Based on equation 8, we find that effort is increasing in the weight attached to consumer surplus ($\gamma_1^{ANSP_i}$). Airlines, the consumers of ANSPs, have a strong interest in lower costs.

Hence if the ANSP places a higher weight on its' consumers, it will have a stronger interest in reducing costs and exerting efficiency efforts. Effort is decreasing in the weight attached to national interest ($\gamma_3^{ANSP_i}$). If there is a strong home bias, for example towards local intermediate good suppliers, or if there is a strong labor union lobby, the ANSP is less interested in reducing its cost. This is to the benefit of the home suppliers and labor lobby. The influence of the weight attached to profit on effort depends on how close the price regulation resembles a price cap. The effort is highest in the case of a pure price cap, but decreases when cost plus is applied too (representing a higher B value in (5)). We now return to the role of ownership. If state agencies care more about national interest (high ($\gamma_3^{ANSP_i}$) coefficient) then the effort level in 8 will be lower than when a government corporation has consumers on the board: a high $\gamma_1^{ANSP_i}$ weight will increase the cost reduction effort.. If the private firm is controlled by private shareholders, its main interests are profits (high $\gamma_2^{ANSP_i}$) and if the price-cap is weak, the firm will invest effort in achieving efficiency but not necessarily low prices: a monopolist prefers a high price when demand is not elastic. A government corporation with airlines on its board may be as productive and cost efficient as a private firm but this will be translated into lower prices and higher consumer surplus rather than high profits. This means that reality may be more complex than the simple public/private classification of ANSP's: the type of price regulation as well as the ownership structure matter for the efficiency incentives. As price regulation is the same for all ANSPs, it is of interest to check if performance is indeed a function of ownership form. We focus on this question in the next section.

III. Econometric Estimation of the Cost and Production Functions of ANSPs

In this section, we conduct an econometric study in which we analyze ANSP data mainly drawn from the Performance Review Unit's air traffic management cost-effectiveness (ACE) reports. The inputs consist of labor, capital and non-staff operating inputs, the outputs consist of total flight hours controlled en-route and IFR airport movements.

We build on earlier literature in the econometric cost-efficiency benchmarking of ATM in Europe including [26] with earlier contributions by [17] and [18]. We extend the previous studies in a number of ways. First, we have collated the newest performance data that has become available since the previous studies but removed the oldest data because of changes in the data collection procedures, thus the dataset spans the years 2006 to 2014 inclusively. Second, we estimate two cost and two production functions, per en-route and per terminal control. Previous studies estimated a joint cost function for en-route and terminal provision, known as gate-to-gate provision, utilizing an aggregate output measure referred to as 'composite flight hours'. However, the aggregation of en-route flight hours and terminal movements is somewhat artificial and relatively crude. The goal is to reduce potential bias due to variation in boundaries between en-route and terminal activities among ANSPs. However, the composite flight hour measure may also suffer from bias as it rests on the accuracy of aggregate costs at the European level. Previous studies (e.g. [22]) have documented that significant bias may also exist in the composite flight hour measure due to the existence of cross-subsidization between en-route and terminal control activities. Consequently, unlike previous econometric benchmarking studies, we estimate the activities separately. This does come at the cost of a less reliable cost break down with respect to the two activities. Furthermore, we estimate both productivity and cost functions whereas only the latter has been published to date. The economic theory underlying the estimation of a cost function relies on the assumption that firms minimize costs subject to the available technologies. However, this may be less relevant for ANSPs because, despite a large majority being corporatized public entities, they are also statutory monopolies and up until 2009 were operating under a full cost recovery regime. The price cap incentive regulation in place since 2010 is set at the European level and appears to have political issues in setting strong price caps, suggesting that the impact has been weak [6]. Therefore, it could be argued that most ANSPs face relatively weak incentives to ensure an efficient use of inputs during the period considered in this analysis.

This section is structured as follows. In section A, we present the methodological modelling approach relevant to analyze the air traffic control market. In section B, we discuss the dataset and the approach taken to construct the variables for the cost and production functions. Finally, in section C, we present the results of the estimations.

A. *Stochastic frontier analysis*

The model published in [4] analyzes panel-data, which accounts for potential heteroscedasticity and includes explanatory variables in the inefficiency distribution. The production model in [4] defines inefficiency as in equation (9) and output as in (10). In these equations y_{it}, x_{nit} represent the output and the exogenous explanatory variables n for ANSP i in year t. The inefficiency term u_{it} is half normal distributed and positive with mean $z_{it}'\delta$. The error term is v_{it}:

$$u_{it} \sim N^+(z_{it}'\delta, \sigma_u^2) \tag{9}$$

$$E(\ln y_{it}) = \beta_0 + \sum_n \beta_n \ln x_{nit} + E(v_{it}) - E(u_{it}) \tag{10}$$

$$= \beta_0 + \sum_n \beta_n \ln x_{nit} - \left\{ z'_{it}\delta + \frac{\phi(\frac{z'_{it}\delta}{\sigma_u})}{\Phi(\frac{z'_{it}\delta}{\sigma_u})} \right\}$$

where $\emptyset(\cdot)$ and $\Phi(\cdot)$ are the density and cumulative distribution functions of the standard normal variable respectively. We apply the same model to estimate a Cobb-Douglas cost function, which represents a log-linear relationship between cost, input prices, output level and exogenous drivers[1]. The relationship can be written as specified in (11).

$$\ln(\frac{E_{it}}{w_{kit}}) = \beta_0 + \beta_y \, ln\, y_{it} + \textstyle\sum_{n \neq k} \beta_n \, ln(\frac{w_{nit}}{w_{kit}}) + v_{it} + u_i \quad (11)$$

where costs E_{it} are logarithmically transformed. The explanatory variables W_{kit} are normalized and logarithmically transformed factor prices k per unit i per year t and the output level is y_{it}. The explanatory variables should be uncorrelated with the error term as they are determined exogenously to the production and cost relationships. The error term is decomposed into a noise term v_{it} and an inefficiency term u_i. The noise term is usually assumed to be random with zero mean, whereas the inefficiency is strictly non-negative and assumed to follow a half-normal, truncated-normal or exponential distribution.

In order to estimate the en-route air traffic control production function we solve (12) and (13) simultaneously.

$$\ln(IFR\ flight\ hours_{it}) = \beta_0 + \beta_1 \ln(ATCO_{it}) + \beta_2 ln(sectors_{it}) + \beta_3 \ln(seasonality_{it}) + \beta_4 \ln(complexity_{it}) + V_{it} - U_{it} \quad (12)$$

$$U_{it} = \delta_1 \ln(complexity)_{it} + \delta_2 ownership[corp]_{it} + \delta_3 ownership[agency]_{it} + \tau_{it} \quad (13)$$

where i refers to the i^{th} ATC provider; t represents the year of the observation; ln represents a natural logarithm; V_{it} represents identical and independent error terms with a normal distribution $N(0,\sigma^2)$; U_{it} represents the inefficiency term in the form of a truncated normal distribution with mean ($z_{it\delta}$) as in (9) and is a function of environmental variables (complexity and ownership form); τ_{it} is a random variable defined by the truncation of the normal distribution (with a mean of zero and constant variance). U_{it} is expressed without an intercept which means that there is no constant element of inefficiency that is identical for all units at all times given the level of heterogeneity. The estimates for the terminal data will be similar but with the appropriate variables as displayed in table 2.

B. European ANSP dataset

We derive most of the data from the air traffic management cost-effectiveness benchmarking reports, which contain information on ANSP costs and revenues each year, reported separately for en-route and terminal control. They also report the output measures including instrumental flight rules (IFR) controlled in kilometers and in hours en-route and movements around airports. Detailed input components include annual employment costs for air traffic controllers (ATCO) and support staff, the hours worked in air control centers, towers and approach centers and the net book value of fixed assets on the balance sheet. Airspace characteristics reported per ANSP include the maximum number of en-route sectors, traffic density, seasonality (equal to traffic levels in the peak month divided by average monthly traffic), size of airspace in square kilometers and traffic complexity. The complexity index represents an aggregate of structural complexity (derived from vertical, horizontal and speed interactions) and adjusted density. Indicators related to institutional settings include the form of ownership[2] with a distinction between a state agency [AGENCY], a government-owned corporation [CORP], or a public-private joint venture which is the default in equation 13. Relevant economic indicators include the purchasing power parity index, intermediate goods and energy price index, exchange rates and inflation rates.

Data quality is an important element of the statistical analysis. Many of the numbers were collected manually from annual reports which increases the probability of errors. In addition, there may be inconsistencies in the numbers reported for one ANSP over time. In a few instances, this is caused by a change in the construction of the indicator. We conducted checks on the evolution of all relevant indicators per ANSP and applied corrections where necessary based on the imputation technique, with linear interpolation of values for one variable based on the evolution over time for another variable[3]. We found errors in the reports and have corrected them accordingly. We note that from 2006 to 2008 and in 2010, the number of flight kilometers published in the reports is defined as 'distance' whereas other years utilize flight km. The 'distance' variable was incorrect for MUAC, Germany, Belgium and the Netherlands due to double counting. We note that the IFR airport movements reported for Greece in 2014 is three times higher than in 2013 which could represent an error. Finally, new variables were added to the reports from 2010, including seasonality. We assume

[1] The advantage of the Cobb-Douglas specification is its duality property and simplicity. Furthermore, since all the models proved to be statistically significant, there was no need to move to the more flexible translog function. The functions are also useful for defining the air traffic control function in ongoing work modeling air navigation service provision within a game theoretic framework.

[2] In general, most European ANSPs fall under government-owned corporation.

3 For example, evolution of "staff cost in en-route control" for Finavia is imputed using interpolation based on the evolution of "total cost in en-route control" for Finavia.

that the 2010 values remained consistent in the earlier years. In addition, we assume that the maximum number of sectors remains constant. We also dealt with missing data through imputation based on linear interpolation of values for the same variable in neighbouring ANSPs (or countries)[4]. After performing these checks, we obtain a representative panel dataset of 37 ANSPs covering nine years (2006-2014), with no drastic jumps or structural breaks over the years. The panel is close to being balanced although ARMATS (Armenia) is missing for the years 2006 to 2008. The dataset is available from the authors for purposes of replicability.

From the dataset, we construct a number of indicators that are applied in the SFA as listed in Tables 1 and 2.

Table 1: Variables in stochastic frontier cost function

Dependent Variable	
	total cost/cost of operation index
Independent Inputs	
Output	total IFR flight hours controlled (en-route) and total IFR airport movements (terminal)
Labor	(total staff cost/ATCO hours)/ cost of operation index
Capital	((depreciation cost + cost of capital)/(NBV/capital goods price index))/cost of operation index
Environmental variables	
Airspace characteristics	seasonality, complexity
Ownership form	governmental agency, corporation, public-private firm

where the cost of operation index $= \frac{\text{intermediate goods and energy price index}}{\text{ppp}}$,

PPP= $\frac{\text{purchasing power parity}}{\text{exchange rate}}$ and NBV=net book value.

In order to ensure comparability, monetary indicators are standardized using purchasing power parity and a cost of operation index. Standardization ensures that the econometric cost function is homogeneous and in alignment with the underlying economic theory on production and cost functions [13].

Table 2: Variables in stochastic frontier production function

Dependent Variable		
	En-route	*Terminal*
	total IFR flight hours controlled	total IFR airport movements
Independent Inputs		
Labor	ATCO hours in air control centers	ATCO hours in approach centers and towers
Capital	maximum number of en-route sectors	(NBV/ capital goods price index)*PPP
Environmental Variables		
Airspace characteristics	seasonality, complexity	
Ownership form	government agency, corporation, public-private firm	

4 For example, we impute missing values on "cost of capital" for Croatia, based on observations in Serbia and in Slovenia.

Finally, we apply a logarithmic transformation to all continuous variables because of the log-linear characteristic of the Cobb-Douglas models.

C. *Estimation of stochastic frontier cost and production functions*

We implement the estimation in STATA, using the tailor-made SFPANEL package [7]. We tested a number of alternative specifications including SFA with time decay in the inefficiency term [5], SFA with exogenous drivers affecting the distribution of the inefficiency term [4] and the true fixed effects model with time-variation in the inefficiency term and unit-specific intercepts [14]. We only present the results of [4] specification as this model provided the most promising estimations, although none were materially different. We estimate all models with robust standard errors to account for possible heterogeneity in the noise error term despite the increase in estimated standard errors and reduction in the statistical significance of the results obtained.

In Table 3 we present the results of the stochastic production and cost functions for en-route operations and in Table 4 we present the equivalent for terminal operations. Each of the SFA production and cost estimates in Tables 3 and 4 include two models. The first model does not limit the average distribution of the inefficiency. When such a model was not able to explain the inefficiency (σ_u was not significant), we include explanatory variables to describe the mean of the distribution of the inefficiency. The σ_u and λ in Models 1 are usually insignificant hence the complexity and ownership variables are clearly an important element in explaining ANSP inefficiency levels (except for the analysis of the terminal production function in which σ_u of model 1 is significant).

All variables in the Cobb-Douglas functions proved highly significant across all models. With respect to output, it is clear that there are small economies of scale ranging from 10 to 15%. In the cost analyses, labor is significantly more important than capital which represents their proportions in the total cost functions. The environmental variables are also highly significant and with the expected signs. Seasonality and complexity both increase costs as expected. However, complexity both increases costs but also reduces inefficiency. We assume that additional complexity would appear to require a consistent and professional management that is better able to utilize labor resources. Furthermore, it would appear that the public private partnership model creates substantial incentives, since the government ownership form variables decrease efficiency levels. This seems to suggest that under government ownership a relatively high weight is placed on national interest, such as local suppliers and labor unions. This is confirmed by analysis focusing specifically on the role and preferences of unions (see [9]). The agency variable represents ANSPs that in general belong to the

Department of Transport or Civil Aviation Authority and are the most directly connected to the government.

Based on the results of Models 2 of the en-route analyses, Fig. 1a and 1b present average production and cost efficiencies for the 37 countries over the nine years of analysis, and Fig. 2a and 2b present the average production and cost efficiencies per ANSP.

Table 3: En-route frontier cost and production functions estimates

Enroute, cost

Para.	Label	Model 1 Estimate		Model 1 SE	Model 2 Estimate		Model 2 SE
Elasticities							
β_1	x_1 (Total IFR flight hours controlled)	0.919	**	0.016	0.905	**	0.018
β_2	x_2 (Labor cost)	0.385	**	0.035	0.417	**	0.041
β_3	x_3 (Capital cost)	0.216	**	0.021	0.218	**	0.022
Environmental variables							
β_{Z1}	Z_1 (Seasonality)	1.379	**	0.192	1.686	**	0.214
β_{Z2}	Z_2 (Complexity)				0.700	**	0.153
Exogenous inefficiency determinants[a]							
δ_1	Z_{u1} (Complexity)				-0.846	**	0.133
δ_2	Z_{u2} (Ownership gov/corp)				1.596	**	0.337
δ_3	Z_{u3} (Ownership agency)				1.563	**	0.344
	sigma_u	**0.080**		**2.463**	**0.296**	**	**0.025**
	sigma_v	**0.327**	**	**0.013**	**0.181**	**	**0.022**
	lambda	**0.246**		**2.466**	**1.633**	**	**0.041**
	Log Likelihood	**-97.510**			**-57.280**		

Enroute, production

Para.	Label	Model 1 Estimate		Model 1 SE	Model 2 Estimate		Model 2 SE
β_1	x_1 (Labor)	0.451	**	0.074	0.423	**	0.060
β_2	x_2 (Enroute sectors)	0.582	**	0.084	0.520	**	0.064
β_{Z1}	Z_1 (Seasonality)	-1.017	**	0.232	-2.492	**	0.200
β_{Z2}	Z_2 (Complexity)				-0.989	**	0.102
δ_1	Z_{u1} (Complexity)				-1.553	**	0.102
δ_2	Z_{u2} (Ownership gov/corp)				2.935	**	0.225
δ_3	Z_{u3} (Ownership agency)				2.623	**	0.232
	sigma_u	**3.723**		**25.244**	**0.340**	**	**0.023**
	sigma_v	**0.271**	**	**0.029**	**0.142**	**	**0.019**
	lambda	**13.745**		**25.237**	**2.395**	**	**0.037**
	Log Likelihood	**-150.271**			**-59.249**		

A */** next to coefficient indicates significance at the 5%/1% level.

[a] A positive efficiency score parameter estimate shows that the variable has a negative effect on efficiency

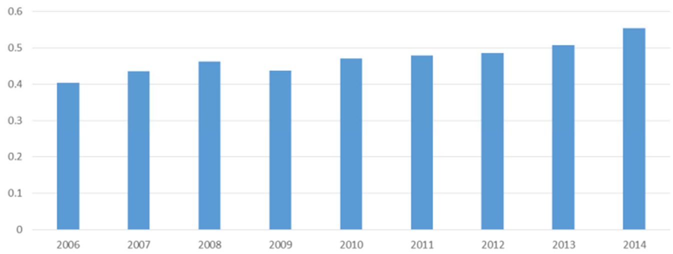

Figure 1a: Average production efficiency for en-route ANSPs from 2006 to 2014

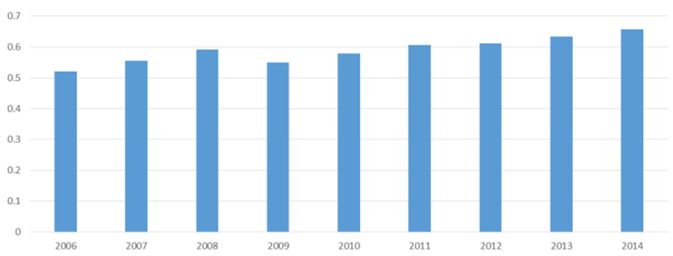

Figure 1b: Average cost efficiency estimates for en-route ANSPs from 2006-2014

Figure 1a suggests that the efficiency estimates gradually improve from 0.4 to 0.55 with a dip in 2009 due to the financial crisis which reduced air traffic movements substantially. Efficiency scores in the cost analysis of Figure 1b are also slightly higher, ranging from 0.52 to 0.65. Figures 1a and 1b therefore indicate that cost efficiency trends over time are positive although still lie at around 40% inefficiency on average by 2014. This means that the average ANSP is 60% less production efficient than the best performing ANSP and 45 to 40% less cost-efficient than the best performing ANSP. On the other hand, the averages mask large, statistically different estimates across the ANSPs, as presented in Fig. 2a and 2b.

When comparing efficiency levels across ANSPs, as presented in Figures 2a and 2b, we see that the efficiency levels of ten of the ANSPs lie above 0.7 with MUAC, NATS and SkyGuide at the top. Eighteen of the smallest ANSPs scores lead the bottom of the rank with efficiency estimates below 0.4. As noted above, the cost analysis scores are slightly higher so that only seven countries are below 0.4.

In Table 4, we present the SFA cost and production estimates for the terminal activities of the ANSPs. We note that terminal activities are reported at the country level hence aggregate air traffic control procedures at large hub airports and small, regional spokes may lead to less reliable comparisons.

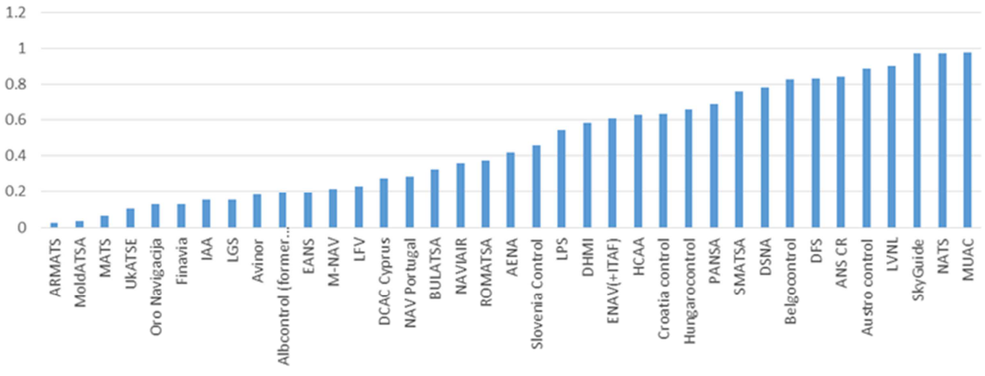

Figure 2a: Average production efficiency estimates per en-route ANSP

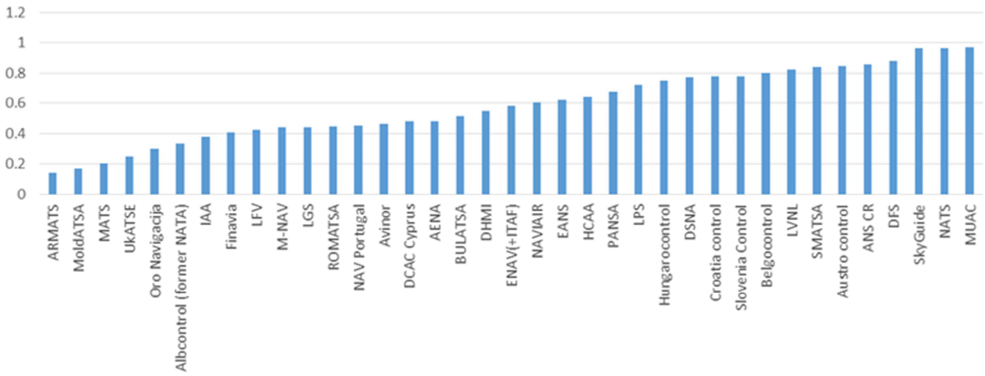

Figure 2b: Average cost efficiency estimates per en-route ANSP

Table 4: Terminal frontier cost and production functions estimates

Terminal, cost

Para.	Label	Model 1 Estimate		SE	Model 2 Estimate		SE
Elasticities							
β_1	x_1 (IFR airport movements)	0.841	**	0.020	0.874	**	0.019
β_2	x_2 (Labor cost)	0.454	**	0.037	0.492	**	0.043
β_3	x_3 (Capital cost)	0.072	**	0.022	0.053	**	0.013
Environmental variables							
β_4	Z_1 (Seasonality)	2.337	**	0.210	2.310	**	0.229
β_5	Z_2 (Complexity)				0.194	*	0.080
Exogenous inefficiency determinants[a]							
δ_1	Z_{u1} (Complexity)				-0.548	**	0.077
δ_2	Z_{u2}(Ownership gov/corp)				1.280	**	0.164
δ_3	Z_{u3}(Ownership agency)				1.372	**	0.171
	sigma_u	**1.180**		**1.521**	**0.418**	**	**0.026**
	sigma_v	**0.246**	**	**0.035**	**0.082**	**	**0.024**
	lambda	**4.401**	**	**1.498**	**5.068**	**	**0.037**
	Log Likelihood			**-135.581**			**-101.612**

Terminal, production

Para.	Label	Model 1 Estimate		SE	Model 2 Estimate		SE
β_1	x_1 (Labor)	0.537	**	0.029	0.594	**	0.031
β_2	x_2 (*NBV*)	0.472	**	0.020	0.399	**	0.270
β_3	Z_1 (Seasonality)	-2.884	**	0.155	-3.147	**	0.037
β_4	Z_2(Complexity)				0.072	*	0.172
δ_1	Z_{u1} (Complexity)				-0.640		0.935
δ_2	Z_{u2}(Ownership gov/corp)				-0.369		1.025
δ_3	Z_{u3}(Ownership agency)				-0.441		1.222
	sigma_u	**1.022**	**	**0.235**	**0.565**	*	**0.282**
	sigma_v	**0.184**	**	**0.012**	**0.230**	**	**0.017**
	lambda	**5.543**	**	**0.236**	**2.453**	**	**0.279**
	Log Likelihood	**-71.139**			**-52.122**		

A */** next to coefficient indicates significance at the 5%/1% level.

[a] A positive efficiency score parameter estimate shows that the variable has a negative effect on efficiency

The terminal cost function shows that all variables are statistically significant with the expected signs. The second model proved the most relevant with both complexity and ownership form explaining the levels of inefficiency. Again, small economies of scale are estimated at 12 to 15%. Increased complexity improves efficiency levels, which may indicate supplementary economies of scale caused by the additional workload required to handle the complexity. Ownership form also impacts terminal ANSP activities with the agency approach causing slightly higher levels of cost inefficiency compared to the government corporation which in turn adds substantial cost inefficiency above and beyond the public-private form. However, terminal production would not appear to be impacted by the ownership form and model 1 is sufficient.

Figures 3a and 3b present changes in terminal efficiencies over time. Terminal control providers suffered substantially in 2009 as a result of the financial crisis and subsequent reduction in air traffic movements. The largest impacts are clearly shown with respect to the production function which suggests that the ANSPs had difficulty recovering until 2014. Average cost efficiency levels were also impacted in 2009 but gradually improved. However, we also note that average cost efficiency estimates peak at around 0.59 by 2014 and although the trend is positive, the levels of inefficiency are rather substantial.

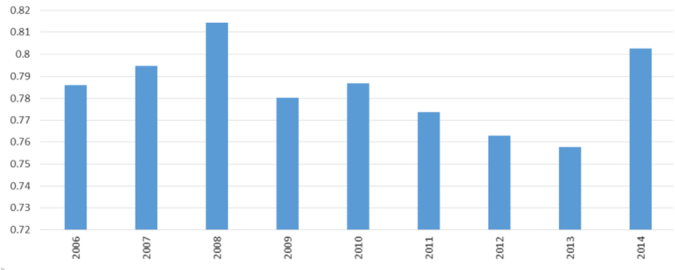

Figure 3a: Average terminal production efficiency estimates from 2006 to 2014

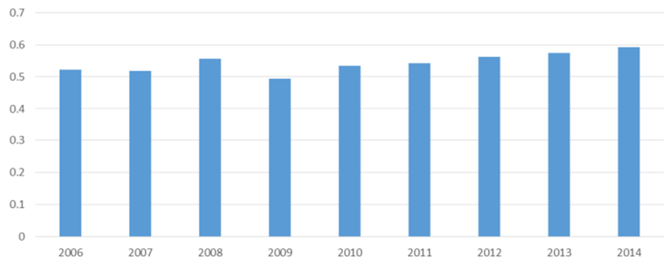

Figure 3b: Average terminal cost efficiency estimates from 2006 to 2014

Whilst the average production efficiency estimates lie around 0.8 in 2014, this masks large heterogeneity between the providers (not shown for the sake of brevity). Cost efficiency estimates range from 0.12 for the Armenian ANSP to 0.92 in Switzerland and Germany. The efficiency estimates show a mix across the continent with Slovenia and Croatia performing relatively better than some of the Western European countries, including Sweden and France.

IV. Conclusions and Future Directions

In this research we focus on the effect of ownership form and airspace characteristics on ANSP performance in Europe. Based on a simple economic model, we learn that effort and efficiency will likely be higher in the case of public companies with a board of stakeholders and in the case of a private company where stakeholders are also shareholders, as is the case with MUAC, NATS and Skyguide. Strong national interest encouraging technology purchases from local suppliers or powerful labor unions, on the other hand, decrease efficiency.

We also estimate econometrically the cost and production functions of 37 European ANSPs over a nine year timeframe. The coefficients are significant and present the expected signs. We note that input prices for labor costs (wages) seems to carry a greater importance in comparison to capital costs. This observation may be explained by the higher share of labor costs at the ANSP total cost level. With respect to the cost function and economies of scale, we find that a 10% increase in traffic given airspace size corresponds, on average, to a cost decrease of around 12%. Structural differences in air traffic characteristics between ANSPs are important in explaining productivity and efficiency performance differences. Seasonality and traffic complexity seem to be particularly relevant. The results of the models also show that complexity explains inefficiency levels but perhaps in an unexpected direction. Given the significant and negative value of the parameter, this suggests that the managers of ANSPs handling higher levels of complexity are more efficient.

We find, consistently, a negative time trend in levels of inefficiency suggesting that, on average, the Single European Skies initiative has been encouraging improvements in cost and productive efficiency over time although much work remains. The significance of the ownership variables in most of the results clearly shows that the choice is fundamental and impacts the production process directly and the level of inefficiencies too. We find that private-public partnerships achieve significantly higher productivity and cost efficiency. This suggests that governmental agencies and corporations attach a much higher weight to national interests than to the airspace users.

Future directions include expanding the dataset to cover the United States (at the level of the air route traffic control centers), Canada, Australia and New Zealand in order to further develop the analysis and better understand the impact of fine-grained differences in ownership form and the potential for economies of scale.

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