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Analysis of the evolution of cost-effectiveness in the provision of air navigation services at Functional Air Blocks

Alberto Ansuategi[a,b], Ibon Galarraga[b,c], Luis Orea[d], Thomas Standfuss[e]

[a]*Instituto de Economía Pública, UPV/EHU, Lehendakari Agirre 83, 48015 Bilbao, Spain*
[b]*Basque Centre for Climate Change (BC3), Edificio Sede 1, UPV/EHU Scientific Park, 48940 Leioa, Spain*
[c]*Metroeconomica SL, Colon de Larreategui 26, 48009 Bilbao, Spain*
[d]*Universidad de Oviedo, Avda. del Cristo, s/n, 33006 Oviedo, Spain*
[e]*German Aerospace Center (DLR), Köln, Germany*

Abstract

The so–called Single European Sky (SES) legislation is intended to have a major impact on the fragmentation in the European Air Traffic Management and Communications, Navigation and Surveillance (ATM/CNS) system. One of the fundamental aspects of the SES initiative are the Functional Airspace Blocks (FABs), which have the goal of reducing the inefficiencies – in terms of safety, capacity, and cost – that result from the fragmentation of European airspace. FABs are seen as an explicit bottom–up first step to the ultimate integration of European airspace.

In this paper we focus on the analysis of the evolution of the cost effectiveness in the provision of ATM/CNS services at FABs. In doing so, we proceed in two steps. First, we develop a theoretical framework that allows us to decompose the change in cost-effectiveness of FABs into its basic sources. Second, we use Stochastic Frontier Analysis (SFA) techniques to estimate the cost equations and decompose the change in the cost effectiveness of the nine European FABs into several components.

The analysis contributes to shed some light on (1) the drivers of changes in the ANSPs and FABs cost-effectiveness over 2006-2016, (2) the role played by FABs in enhancing cooperation between ANSPs to obtain operational efficiency gains and (3) the existence of economies of scale in the European ATM/CNS service provision.

Keywords: cost-effectiveness, air traffic management, decomposition analysis, stochastic frontier analysis

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1. Introduction

The “Roadmap to a single European Transport Area” [8] recognizes the need to develop a competitive and efficient system that will bring down barriers and increase mobility. In this regard, for a key transport mode such as aviation, the main challenge is to address the capacity, efficiency and connectivity constraints imposed by a fragmented European airspace. In order to achieve this, a High Level Group report was launched in November 2000 [5] and, as a result, the EU responded with an ambitious regulatory initiative: the so–called Single European Sky (SES) Legislation.

The SES legislation is intended to have a major impact on the fragmentation in the European Air Traffic Management and Communications, Navigation and Surveillance (ATM/CNS) system. It was adopted by the EU Council and European Parliament and entered into force in April 2004. One of the fundamental aspects of the SES initiative are the Functional Airspace Blocks (FABs), which have the goal of reducing the inefficiencies[1] –in terms of safety, capacity, and cost - that result from the fragmentation of European airspace. FABs are seen as an explicit bottom–up response to the ultimate integration of European airspace.

The regulatory framework on which FABs were developed was settled in the first legislative package of the SES (SES I) [6]. Nowadays FABs are the main mean for reducing the European airspace fragmentation. The SES II tackles the creation of FABs in terms of service provision, in addition to the airspace organization issues [7]. There are nine FABs planned for Europe (see Figure 1 and Table A.1) and their implementations are long term plans that have been suffering important delays. Whilst the FABs should have been completed by December 2012, implementation is still far too slow for almost all FABs [20].

A number of publications and studies have tried to assess the cost effectiveness of Air Navigation Service Providers (ANSPs) as one of the main indicators for measuring the performance of ATM system. Thus, Eurocontrol, an intergovernmental organisation with 41 Member and 2 Comprehensive Agreement States, has been producing benchmarking reports of European ANSP’s cost efficiency for the last 16 years. Three econometric studies using stochastic frontier analysis (SFA) have also been conducted. In 2006 NERA Economic Consulting [23] applied SFA techniques to compare the efficiency of European ANSPs between 2001–2004. However, due to the lack of data the study did not allow to draw major conclusions. Five years later a Competition Economists Group (CEG) implemented a more ambitious estimation of European ANSPs cost efficiency using a stochastic frontier approach [2]. With a Cobb-Douglas specification for the cost function and the inclusion of several explanatory variables, these authors found the presence of economies of scale in the provision of air navigation services. More recently, Dempsey and Volta [3] have used an SFA

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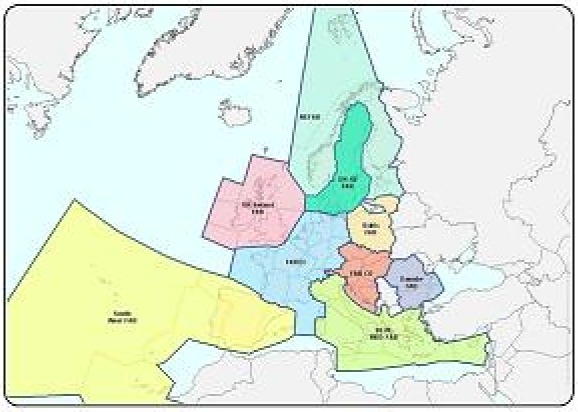
[1] An economic study of the European FABs [1] concludes that the fragmented air traffic management in Europe impacts on safety, limits airspace capacity, and above all, adds costs to the system.

approach to test whether the institutional structures of ANSPs have an impact on their cost-efficiencies, reaching the conclusion that ownership is not directly impacting neither the ANSPs cost structures nor their cost efficiencies and that the European ANSPs are operating on the increasing return to scale part of the technology. However, no research has been undertaken in order to analyse the evolution of cost effectiveness in the provision of air navigation services at FAB level. The aim of our research is to fill this gap in the literature.

The paper is structured in five sections. After this brief introduction, section 2 develops the theoretical framework that will allow us to decompose the change in cost-effectiveness of FABs into several components. Sections 3 and 4 present the data and the results of the analysis. Finally, section 5 draws conclusions and suggest future research directions.

Figure 1: Functional Airspace Blocks



Source: European Commission

2. The methodology

2.1. Decomposing the change in cost-effectiveness

This sub–section develops a theoretical framework that allows us to decompose the change in cost-effectiveness of FABs into its basic sources. Let us first assume that for the i–th ANSP ATM/CNS provision costs can be modelled entirely by using the following cost equation:

$$C_i = C\left(Y_i, W_i, Z_i, K_i, t\right)/E_i \tag{1}$$

where C_i is a measure of ATM/CNS provision costs, Y_i stands for the number of flight–hours controlled, W_i is a vector of input prices, Z_i is a vector of observable environmental variables, t is a time trend capturing technical change and other exogenous temporal effects, and K_i is a measure of capital. The latter variable is included either to control for the quasi-fixed nature of this input or as an additional output variable. $E_i \leq 1$ measures the ANSPs' cost efficiency. Finally, $C\left(Y_i, W_i, Z_i, K_i, t\right)$ represents the minimum cost of providing a given amount of outputs and, assuming the necessary derivative properties –including continuity and differentiability–, it yields the input demand functions by applying Shephard's lemma. Note that if the technology satisfies the customary axioms, the above cost function is homogeneous of degree one in input prices, and non–decreasing in outputs and in input prices. The efficiency term E_i leaves room for both technical and allocative inefficiencies. However, Kumbhakar et al. [22] point out that outputs and input prices are endogenous if firms are allocatively inefficient because in this case the traditional E_i term depends on Y_i and W_i.

In what follows we will show that an estimated cost function can constitute a useful tool for the measurement of changes in the cost–effectiveness of FABs and the decomposition of these changes into their basic sources. We will define cost–effectiveness here in terms of average costs. Thus, the cost effectiveness indicator of a FAB comprising N ANSPs (AC) would be obtained dividing total ATM/CNS provision costs by the number of flight–hours controlled:

$$AC = \frac{C}{Y} = \frac{\sum_{i=1}^{N} C_i}{\sum_{i=1}^{N} Y_i} \tag{2}$$

Therefore, the aggregate (or mean) rate of growth of the cost–effectiveness of the FAB can be decomposed as follows[2]:

$$\dot{AC} = \dot{C} - \dot{Y} = \sum_{i=1}^{N} p_i \dot{C}_i - \sum_{i=1}^{N} s_i \dot{Y}_i \tag{3}$$

where $p_i = \frac{C_i}{C}$ and $s_i = \frac{Y_i}{Y}$ represent the shares of the i–th ANSP in total provision costs and controlled traffic hours, respectively. Using an estimated cost function and a similar procedure, $\dot{C}_i$ can be further decomposed as:

$$\dot{C}_i = \left(\varepsilon_{CYi} - 1\right) \dot{Y}_i + \varepsilon_{CKi} \dot{K}_i + \varepsilon_{CWi} \dot{W}_i + \varepsilon_{CZi} \dot{Z}_i + \varepsilon_{Cti} - \dot{E}_i + \dot{Y}_i \tag{4}$$

where ε_{CYi}, ε_{CKi}, ε_{CZi} and ε_{Cti} are all cost elasticities with respect to their respective cost drivers. Equation (4) provides a meaningful decomposition of changes of the total cost of the i–th ANSP into cost changes attributed to increases in output, capital, input prices, environmental deterioration, technical change and efficiency improvements. Using this decomposition, and substracting the output increase $\dot{Y}_i$ in both sides of equation (4), we get the decomposition of the average cost of the ANSP instead of its total cost.

If we substitute (4) into (3) we obtain:

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[2] Dotted variables represent time derivatives.

$$\dot{AC} = \sum_{i=1}^{N} p_i \left(\varepsilon_{CYi} - 1\right) \dot{Y}_i + \sum_{i=1}^{N} p_i \varepsilon_{CKi} \dot{K}_i + \sum_{i=1}^{N} p_i \varepsilon_{CWi} \dot{W}_i + \sum_{i=1}^{N} p_i \varepsilon_{CZi} \dot{Z}_i + \sum_{i=1}^{N} p_i \varepsilon_{Cti} - \sum_{i=1}^{N} p_i \dot{E}_i + \sum_{i=1}^{N} \left(p_i - s_i\right) \dot{Y}_i \quad (5)$$

Equation (5) can in turn be expressed in the following way:

$$\dot{AC} = SE + KE + IPE + ZE + TCE + ECE + RE \quad (6)$$

where $SE = \sum_{i=1}^{N} p_i \left(\varepsilon_{CYi} - 1\right) \dot{Y}_i$ measures the scale effects associated to output expansions, $KE = \sum_{i=1}^{N} p_i \varepsilon_{CKi} \dot{K}_i$ adjusts the previous effect when the output expansion requires enlarging the capital of ANSPs, $IPE = \sum_{i=1}^{N} p_i \varepsilon_{CWi} \dot{W}_i$ measures increases in average costs caused by increases in input prices, $ZE = \sum_{i=1}^{N} p_i \varepsilon_{CZi} \dot{Z}_i$ represents the increases in average costs caused by deterioration of environmental conditions, $TCE = \sum_{i=1}^{N} p_i \varepsilon_{Cti}$ stands for technical change where a negative (positive) value represents technical progress (regress), $ECE = -\sum_{i=1}^{N} p_i \dot{E}_i$ measures the effect of efficiency improvements on FAB's cost–effectiveness, and $RE = \sum_{i=1}^{N} \left(p_i - s_i\right) \dot{Y}_i$ can be interpreted as an air traffic redistribution effect under constant returns to scale (CRS). Under increasing or decreasing returns to scale, the (variable) redistribution effect (VRE) is captured by the summation of the scale effect (SE) and the CRS-based redistribution effect (RE), i.e.: $VRE = SE + RE = \sum_{i=1}^{N} \left(p_i \varepsilon_{CYi} - s_i\right) \dot{Y}_i$. Table 1 summarizes the decomposition methodology and the effects described above.

Table 1: Decomposition analysis: effects and formulae

Effect	**Formula**
Scale effect (SE)	$\sum_{i=1}^{N} p_i \left(\varepsilon_{CYi} - 1\right) \dot{Y}_i$
Capital effect (KE)	$\sum_{i=1}^{N} p_i \varepsilon_{CKi} \dot{K}_i$
Input price effect (IPE)	$\sum_{i=1}^{N} p_i \varepsilon_{CWi} \dot{W}_i$
Environmental factor effect (ZE)	$\sum_{i=1}^{N} p_i \varepsilon_{CZi} \dot{Z}_i$
Technical change effect (TCE)	$\sum_{i=1}^{N} p_i \varepsilon_{Cti}$
Efficiency change effect (ECE)	$-\sum_{i=1}^{N} p_i \dot{E}_i$
Redistribution effect (RE)	$\sum_{i=1}^{N} \left(p_i - s_i\right) \dot{Y}_i$

2.2. Estimation method

In this sub–section we introduce the parametric frontier technique used to estimate the cost equation (3). After adding a time subscript, the econometric specification of (3) can be written as[3]:

$$lnC_{it} = \alpha_{FAB} + \alpha_t + TL\left(Y_{it}, W_{it}, K_{it}, \beta\right) + \gamma Z_{it} + v_{it} + u_{it} \tag{7}$$

where β is now a vector of technological parameters of the cost function, γ measures the effect of observable environmental variables, v_{it} is the traditional two-sided noise term that captures random shocks, $u_{it} = -lnE_i \geq 0$ is a one–sided random term capturing the inefficiency of ANSPs, α_{FAB} measures time-invariant unobserved cost drivers that are common to all ANSPs belonging to the same FAB and α_t captures the effect of time-varying exogenous cost factors common to all ANSPs that are not observed by the researcher.

Equation (7) is estimated via maximum likelihood (ML) once particular distributional assumptions on both random terms are made. As it is common in the SFA literature, we will assume that $v_{it} \sim \mathcal{N}(0, \sigma_v)$ and that the inefficiency term is independently distributed across firms and over time, and follows a half-normal distribution, i.e. $u_{it} \sim \mathcal{N}^+(0, \sigma_u)$. This model can accommodate heteroskedastic noise and inefficiency terms simply by making σ_v and σ_u functions of some exogenous variables. Both technological parameters of the cost function and the structure of the two error components (i.e., the variance of v_{it} and u_{it}) are estimated simultaneously in a single stage using ML. Regardless of whether the model is homoscedastic or not, efficiency scores are estimated for each firm using the conditional distribution of u_{it} given $v_{it} + u_{it}$ introduced by Jondrow et al.[21].

3. The data

Most data used in our analysis are extracted from the ATM Cost–Effectiveness (ACE) Benchmarking reports published on an annual basis by EUROCONTROL [9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19]. The data set includes information for 37 European ANSPs for 2006 to 2016. The output measures for ANS provision are two: for en–route services, the en–route flight–hours controlled, and for terminal services, the number of IFR airport movements controlled. However, as suggested in the EUROCONTROL's ACE Benchmarking reports, it is better to consider a "gate–to–gate" perspective to avoid heterogeneity between ANSPs in the allocation of costs between these two types of services.

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[3] The initial and most commonly employed Cobb-Douglas (CD) cost function places significant restrictions on technological and economic behaviour relations. For example, in production analysis they restrict all output and input elasticities to be common to all firms and returns to scale do not vary with firms size; while for cost minimization, the linear or log-linear specifications imply that inputs demand, or the share of each input in costs, are independent of the output level. While these characteristics are quite restrictive, these functions are "well-behaved" and satisfy all desirable neoclassical properties. The Translog (TL) functional form can be seen as a second-order approximation of the underlying technology [4]. However, it is not globally well-behaved. As imposing regularity conditions globally often comes at the cost of limiting the flexibility of the functional form, the common practice is to evaluate the estimated functions at the sample mean, rather than at each individual observation.

Thus, we follow the approach in the aforementioned reports and consider a composite indicator of gate to gate flight hours determined by weighting the output measures by their respective average cost of the service for the whole Pan-European system[4]. As capital (K) we use the net book value for fixed assests in operation. The price of Air Traffic Controllers (ATCOs) (w_1) and the price of other labour (w_2) correspond to ATCOs in OPS employment costs divided by ATCOs in OPS hours on duty and the total employment costs for support staff divided by the total number of support staff, respectively. Following the technical note produced by a group of competition economists for EUROCONTROL's Performance Review Unit (PRU) [2], a producer price index for all goods provided by Eurostat (turned into real terms using a general price index as deflator) is used for the price of non-staff operating inputs (w_3). We also follow the same report when calculating the capital related input price (w_4) as the sum of depreciation costs and the cost of capital divided by the net book value in operation adjusted by the annual produced price index provided by Eurostat. The size of the airspace controlled by each ANSP (z_1) is measured in square kilometres. The structural traffic complexity (z_2) is composed of the sum of three metrics: ascending and descending routes, crossing routes, and variable speeds (a proxy for traffic mix). The traffic variability measure (z_3) is computed as traffic at the peak week divided by the traffic in the average week. Three additional variables that will be used as potential regressors of the inefficiency term are the number of ANSPs integrating the FAB (FAB number), the size of the airspace controlled by the FAB (FAB size) and the inverse of the productivity of ATCOs (atcop) that is obtained dividing the total number of ATCOs in OPS by the number of flight–hours controlled. With regard to the ownership structure, we follow ACE Benchmarking Reports and Dempsey and Volta [3] considering 4 ANSPs under public ownership (DCAC, DSNA, MCCA and DHMI), 3 ANSPs (MUAC, NATS and Skyguide) under private ownership and all the remaining as commercialised companies. Table 2 provides summary statistics of the dataset.

4. Results

In Table 3 we show the parameter estimates. The first order coefficientes of controlled composite flight–hours, capital and input prices are positive and statistically different from zero. In general all the first order coefficientes have the expected sign and their magnitudes are in line with those of previous studies. Shares in total costs are not substantially different from those obtained by CEG [2] and Dempsey and Volta [3]: 32% for ATCOs, 22% for non-ATCO staff, 12 % for non-staff operating inputs and 34 % for capital. The main difference with these studies is the share of capital in total costs, which is higher in our study. However, note that the CEG study [2] covers the period 2003-2010, and therefore

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[4] Composite gate–to–gate flight–hours = En–route flight–hours + 0.27 × IFR airport movements.

Table 2: Summary statistics

Variable	N	Mean	St. Dev.	Min	Max
C	399	219472	307985	4720	1300000
Y	399	497847	628878	10097	2800000
K	399	189041.6	255579	3593.04	977021
w1	399	85.563	50.005	6.704	238.418
w2	399	73.294	45.989	5.859	201.920
w3	399	102.53	12.24	55.84	205.61
w4	399	0.242	0.104	0.011	1.147
z1	399	353964	430217	17800	2200000
z2	399	4.76	3.33	0.46	13.72
z3	399	1.27	0.14	1.09	1.76
atcop=ATCOh/Y	399	1.69341	1.234088	.4936508	8.603349
FAB members	399	4.6	1.9	2	7
FAB size	399	1359694	704887	399000	2871000
Dpubl	399	0.098	0.297	0	1
Dpriv	399	0.083	0.276	0	1
Dcomm	399	0.820	0.385	0	1

the difference with our estimate for the cost share of capital may be reflecting the postponement or cancellation of investment projects that took place during the economic recession starting in 2008. With regard to the study by Dempsey and Volta [3], it assumes that capital is a variable input, an assumption that we can reject in our specification as we do reject that ε_{CKi} is equal to zero.

In addition to the frontier parameters, Table 3 also displays the coefficients of the variables that are related to the inefficiency term. We use a quadratic time trend, the (inverse of) the productivity of ATCOs, the size of the airspace controlled by the FAB and the number of ANSPs integrating the FAB to explain the heterogeneity in the inefficiency term. We find a significant improvement in cost–effectiveness at a decreasing rate over time that is common across all ANSPs. We also get that ANSPs' inefficiencies decrease with productivity of ATCOs. Another result is that ANSPs' inefficiency tends to increase with the number of FAB members and this inefficiency tends to decrease with the total size of the airspace cotrolled by the FAB. With regard to the structure of the noise term, we model it as a function of the log of composite traffic–hours and the three environmental variables: namely, the size (in logs) of the airspace controlled, the structural traffic complexity and the traffic variability. We find that, in the case of the size of the controlled airspace, cost–effectiveness is not only lower the larger the airspace, but that it is also more difficult to predict. In the case of structural traffic complexity, cost effectiveness is lower the higher the traffic complexity, but it is also more difficult to predict. In the case of increased traffic variability, we find no significant effect on cost–effectiveness but a significant positive effect on the noise term.

Figure 2 presents the time–series evolution of the decomposition of changes in cost–effectiveness at FAB level into the eight components described in section 2.1. Table 4 presents the estimated average annual percent change of cost–

effectiveness at FAB level attributed to each effect. Figure 3 contains the dendrogram for a cluster analysis (using single–linkage clustering with the default Euclidean distance) of the nine FABs based on the estimated average annual contributions of the different driving forces included in Table 4. In what follows we can enumerate few features related to each of these estimated effects:

- Average ATM/CNS provision costs decrease for five out of the nine FABs. The improvement in cost–effectiveness is specially high for Danube, BLUE MED and SW FAB, with estimated average annual percent reductions accounting for 3.76, 2.34 and 1.87, respectively. The improvement in cost-effectiveness in UK-Ireland and NEFAB is more modest (at an annual rate of 0.35 in both cases). Average provision costs increase over time for the rest of the FABs, with average annual percent rates of increase ranging from 0.22 (FAB CE) to 1.32 (DK-SE).

- The capital effect drives a substantial increase in average ATM/CNS provision costs for the Baltic FAB (at an average annual percent rate of 1.47) and a moderate increase for UK-Ireland and FAB CE (at average annual percent rates of 0.30 and 0.21, respectively). In the rest of the FABs, the capital effect contributes to improve the cost-effectiveness of FABs, with estimated average annual percent reductions ranging from 1.96 (Danube) to 0.31 (BLUE MED). These effects respond to the fact that in some FABs there are important inverstments in capital whereas in others the capital stock decreases.

- Input price effects have exerted an strong pressure to rise average ATM/CNS provision costs in all FABs. The price of ATCO hours have risen for most FABs, with the only exceptions of BLUE MED, where they decresead at an average annual percent rate of 0.02, and SW FAB, where they decreased at an average percent rate of 1.56. For the rest of FABs, percent rates of increase in the price of ATCO hours ranges from 6.22 (Danube) to 0.87 (NEFAB). With regard to the price of non-ATCO staff, there have been increases in every FAB, with average annual percent rates of increase ranging from 6.54 (NEFAB) to 1.03 (SW FAB). The price of capital shows relatively high average annual percent rates of increase for all FABs, ranging from 9.38 (NEFAB) to 0.49 (UK-Ireland). The price of non–staff operating costs decreases at an average annual percent rate of approximately 1.5 for UK-Ireland and 0.5 for FABEC and DK-SE and increases at an average annual percent rate of approximately 0.5 for FAB CE and BLUE MED and 1 for SW FAB, Danube, NEFAB and Baltic.

- Changes in environmental factors contribute to moderately reduce average ATM/CNS provision costs in all FABs but DK-SE, where changes in environmental factors jointly drive average provision costs to grow at an average annual percent rate of 0.04. This is so despite the fact that in many FABs, specially in Danube and FAB CE, there are important increases in traffic complexity. Notice that traffic complexity does not have a significant effect on ANSPs' costs, but it does have a significant positive effect on ANSPs' cost uncertainty. However, this effect is not captured by our cost decomposition.

- Technical change contributes to reduce average ATM/CNS provision costs in all FABs at an annual average percent rate of 0.85, although the time series decompositions shows that this contribution seems to be stronger from year 2011 on. Indeed, while the rate at which average costs decrease from 2006 to 2011 is zero, thge average rate from 2011 0n is about 1.5 percent.

- Efficiency changes are important drivers of reductions in average ATM/CNS provision costs in all FABs but FABEC and FAB CE, where efficiency changes drive estimated average provision costs to increase at an average annual percent rate of 0.43 and 0.42, respectively.

- Variable redistribution effects contribute to reduce significantly average ATM/CNS provision costs for Danube, Baltic, FAB CE and NEFAB, with annual average percent rates of 1.83, 1.55, 0.84 and 0.75, respectively. For the rest of FABs variable redistribution effects contribute moderately to reduce average ATM/CNS provision costs. In the other FABs the efficiency level increases at 1.29 percent on average. Thus, most FABs' cost–effectiveness improved abut 2 percent annually due to improvements in ANSPs' technology and efficiency.

- The dendrogram represented in Figure 3 suggests the existence of four groups of FABs based on the nature of the driving forces behind their cost-effectiveness performance: (i) NEFAB, FABEC, FAB CE and DK-SE, (ii) SW FAB, UK-Ireland and BLUE MED, (iii) Baltic and (iv) Danube. The first group shows a poor performance in cost–effectiveness over time with technical, efficiency and capital changes unable to compensate the increase in average provision costs induced by increases in input prices. The second group shows a better performance in cost–effectiveness over time with technical change, efficiency changes and capital changes outweighting the effect of increases of input prices. In the Baltic and the Danube FABs all the driving forces with the exception of capital and input prices contribute to reducing average provision costs. However, in the former the important capital stock investments produced in the 2006-2016 period drive average provision costs upward and in the latter the reduction in the capital stock leads to important annual reduction rates in average provision costs.

Table 3: SFA Results

	Coef.		**s.e.**	**t-ratio**
Frontier parameters				
lnY	0.539	***	0.029	18.800
lnK	0.344	***	0.016	21.730
$ln(w2/w1)$	0.217	***	0.015	14.930
$ln(w3/w1)$	0.117	***	0.015	7.830
$ln(w4/w1)$	0.342	***	0.012	28.760
$0.5lnY^2$	0.095	*	0.057	1.660
$0.5lnK^2$	-0.094	**	0.038	-2.480
$0.5ln(w2/w1)^2$	0.025		0.048	0.530
$0.5ln(w3/w1)^2$	0.470	***	0.107	4.400
$0.5ln(w4/w1)^2$	0.278	***	0.044	6.280
$lnY * lnK$	0.065	*	0.040	1.650
$lnY * ln(w2/w1)$	0.049		0.040	1.240
$lnY * ln(w3/w1)$	0.043		0.068	0.640
$lnY * ln(w4/w1)$	-0.116	***	0.030	-3.820
$lnK * ln(w2/w1)$	-0.038		0.038	-1.010
$lnK * ln(w3/w1)$	-0.028		0.059	-0.470
$lnK * ln(w4/w1)$	0.127	***	0.030	4.220
$ln(w2/w1) * ln(w3/w1)$	-0.015		0.050	-0.300
$ln(w2/w1) * ln(w4/w1)$	0.033		0.039	0.830
$ln(w3/w1) * ln(w4/w1)$	-0.305	***	0.064	-4.790
$lnz1$	0.073	***	0.022	3.330
$z2$	-0.021	***	0.007	-2.830
$z3$	0.007		0.062	0.110
Intercept	11.299	***	0.021	532.140
Noise term				
lnY	-5.881	***	0.682	-8.620
$lnz1$	7.622	***	0.711	10.720
$z2$	0.813	***	0.160	5.080
$z3$	15.713	***	2.114	7.430
Intercept	-10.831	***	0.722	-15.000
Inefficiency term				
t	-0.390	***	0.124	-3.140
$0.5t^2$	0.060	***	0.021	2.930
$ln(ATCOh/Y)$	2.161	***	0.264	8.180
FAB members	0.142	**	0.059	2.410
FAB size	-0.312	**	0.153	-2.040
Intercept	-3.182	***	0.325	-9.800
Obs.	399			
Log likelihood	464.5			
FAB dummies		Yes		
ANSP dummies(a)		Yes		
Time dummies		Yes		
LR tests (df)				
CD	345.8(15)			
Long-run k	428.7(4)			
v=hom	427.2(5)			
u=hom	388.1(9)			

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Figure 2: Time series decomposition of changes in cost–effectiveness at FAB level (2006-2016)

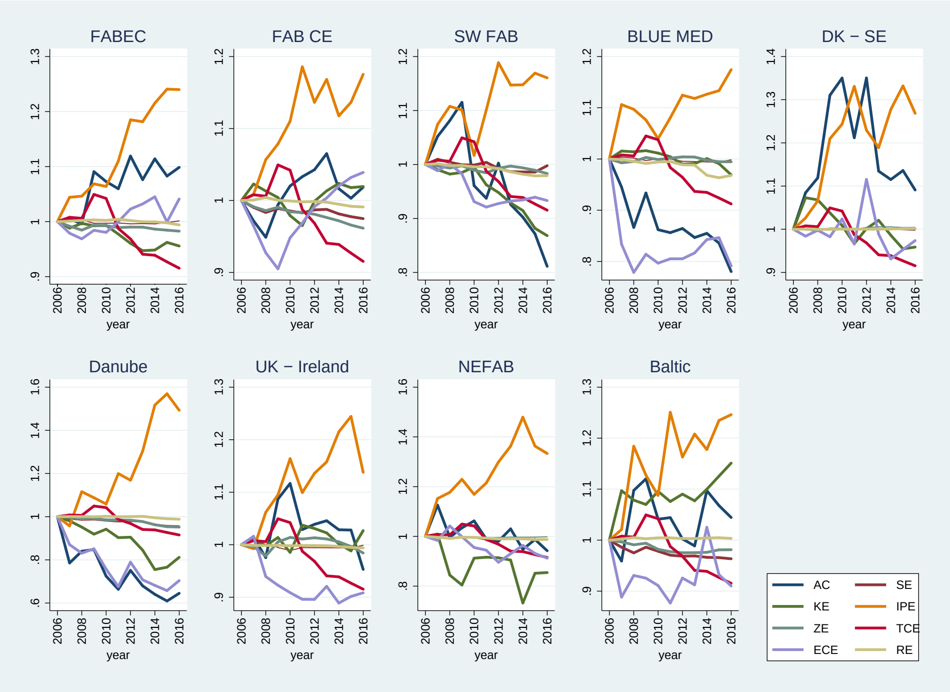
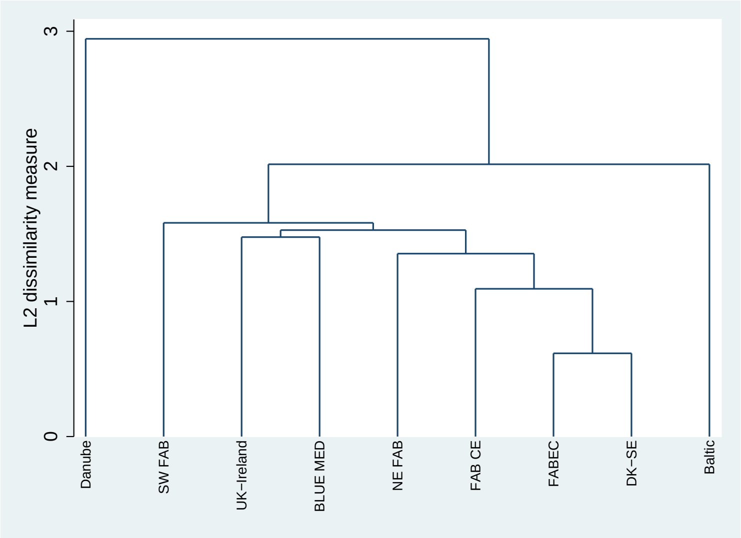


Table 4: Estimated average annual percent change of cost–effectiveness at FAB level attributed to each effect (2006-2016)

FAB	$\dot{AC}$	**SE**	**KE**	**IPE**	**ZE**	**TCE**	**ECE**	**RE**	**VRE**
FABEC	1.02	-0.08	-0.45	2.20	-0.17	-0.85	0.43	-0.06	-0.14
FAB CE	0.22	-0.75	0.21	1.68	-0.39	-0.85	0.42	-0.09	-0.84
SW FAB	-1.87	-0.20	-1.39	1.62	-0.17	-0.85	-0.67	-0.21	-0.41
UK-Ireland	-0.35	-0.08	0.30	1.42	-0.15	-0.85	-0.91	-0.06	-0.14
BLUE MED	-2.34	-0.34	-0.31	1.69	-0.05	-0.89	-2.12	-0.32	-0.66
Danube	-3.76	-1.72	-1.96	4.43	-0.49	-0.85	-3.05	-0.12	-1.83
NEFAB	-0.35	-0.63	-1.00	3.12	-0.02	-0.85	-0.85	-0.12	-0.75
DK-SE	1.32	-0.08	-0.36	2.58	0.04	-0.85	-0.04	0.02	-0.06
Baltic	0.64	-1.59	1.47	2.49	-0.19	-0.85	-0.72	0.03	-1.55

Figure 3: Dendrogram for FAB cluster analysis



5. Conclusions

One of the main objectives of the SES initiative is to reduce cost inefficiencies that result from the fragmentation of European airspace. Thus, FABs are key factors in pursuing such an objective, as long as they are able to optimise and/or integrate the provision of air navigation services. In 1997 the Member States of EUROCONTROL jointly took the decision to establish an independent performance review system that would address all aspects of air traffic management. They also decided to study and promote measures for improving cost–effectiveness and efficiency in the field of air navigation. Since 2003, the EUROCONTROL's PRU produces annual reports that provide a detailed benchmarking of cost–effectiveness performance at ANSP level including a trend analysis of three main drivers (productivity, employment costs and support costs). These reports examine both individual ANSPs and the Pan-European ATM/CNS system as a whole. In our work we have used the same database used for these benchmarking reports, but instead of focusing on individual ANSPs and just three drivers, we have proposed a way to analyse cost–effectiveness that allows us to deal with air navigation service provision at a FAB level with a richer decomposition of the changes into not just three but eight driving forces.

Based on this decomposition analysis we find that the nine FABs can be clustered into four groups. The first group, comprising NEFAB, FABEC, FAB CE and DK-SE, is characterized by its inability to compensate the input price effect, that drives average costs upward, with improvements in efficiency. The second group, comprising SW FAB, UK-Ireland and BLUE MED, is in turn able to bring average costs down thanks to the combination of efficiency and capital effects. The other two FABs, Baltic and Danube, are far from the other

FABs and among themselves. Thus, the Baltic FAB, having been able to reduce average costs through efficiency improvements and traffic redistribution effects, shows an overall increase in average provision costs due to the combined effect of capital and input prices that outweight the other effects. In the Danube FAB, despite the fact of having the strongest input price effect in all FABs, the rest of the effects re-inforce each other in reducing average costs and, consequently, it shows the best performance of all the FABs, reducing average provision costs at an average annual percent rate of 3.76.

Another interesting result of our analysis is that the contribution of the technical effect to drive down average provision costs seems to be stronger from year 2011 on. This may be interpreted as the effect of the deadline of the SES legislation for the FABs to be fully operational before December 2012. However, it could also be a sign of the end of the full cost recovery regime that was applied to most ANSPs until December 2011.

A third result that is worth taking into account is the traffic redistribution effect, which contributes significantly to reduce average provision costs in Danube, Baltic, FAB CE and NEFAB and is less significant for the rest of the FABs. It should be noted that if the FABs were to be effective tools in reducing inefficiencies, they should involve traffic redistribution actions between ANSPs facilitated by the implementation of cross border sectorisation and service provision. The estimated traffic redistribution effect for some FABs may be signaling, therefore, the implementation of such measures.

Future directions include expanding the definition of cost–effectiveness from financial cost–effectiveness to economic cost–effectiveness, which means taking into account not only the direct costs linked with ATM/CNS provision but also the indirect costs (delays, additional flight time and fuel burn) borne by airspace users. This extension of the analysis could help shedding some light on the concern that some financial cost–efficiency savings are accompanied by delay (and other indirect) costs.

Annex

Table A.1: Composition of Functional Airspace Blocks

ANSP	**FAB**	**Country**
Belgocontrol	FABEC	Belgium
DFS		Germany
DSNA		France
LVNL		Netherlands
MUAC		Maastricht *
Skyguide		Switzerland
ANS CR	FAB CE	Czech Republic
Austro Control		Austria
Croatia Control		Croatia
Hungaro Control		Hungary
LPS		Slovakia
Slovenia Control		Slovenia
ENAIRE	SW FAB	Spain
NAV Portugal		Portugal
IAA	UK-Ireland	Ireland
NATS		UK
DCAC Cyprus	BLUE MED	Cyprus
ENAV		Italy
HCAA		Greece
MATS		Malta
BULATSA	Danube	Bulgaria
ROMATSA		Romania
Avinor	NEFAB	Norway
EANS		Estonia
Finavia		Finland
LGS		Latvia
LFV	SE-DK	Sweden
NAVIAIR		Denmark
Oro navigacija	Baltic	Lithuania
PANSA		Poland

* The Maastricht Upper Area Control Centre (MUAC) is an international non-profit air navigation service provider, operated by EUROCONTROL on behalf of four States - Belgium, Germany, Luxembourg and the Netherlands.

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