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Cost-efficiency benchmarking of European air navigation service providers

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ABSTRACT

This study uses EUROCONTROL data on operating performance of the national air navigation service providers over the 2002–2011 time period to document in detail the efficiency changes across providers and time using data envelopment analysis. Our results suggest that overall providers' productivity improved over the time period covered by the data, driven by improvements in technical rather than allocative efficiency. However, some trend reversals in the post-2008 crisis period are also observed.

1. Introduction

This study examines the cost efficiency and productivity of individual national providers of air navigation services (ANS) within the European airspace. The Performance Review Unit (PRU) of EUROCONTROL – the European organisation for the safety of air navigation – regularly performs and commissions studies with the aim of monitoring performance of national service providers. Those studies use the Tornqvist index to measure the productivity of ANS units over time, and stochastic frontier analysis to obtain a cost function and inefficiency measures. We use the data envelopment analysis (DEA)-Malmquist index which is more general than the Tornqvist index. Following Simar and Wilson (1998, 1999), we make use of bootstrap in order to obtain bias-corrected confidence intervals for the Malmquist index, its components, and efficiency scores.

We apply DEA to the EUROCONTROL PRU 2002–2011 dataset (EUROCONTROL, 2004–2012, 2013a) to evaluate the relative efficiency of individual Air Navigation Service Providers (ANSPs). Our data analysis demonstrates that overall productivity of national ANSPs has increased over the time period covered by the data. In particular, three out of four providers have increased their productivity; and about two out of three have become more cost efficient. At the same time, we also observe a disturbing trend of declining cost and allocative efficiency scores after 2007. In case of allocative efficiency, the average of scores for 2010 is nearly back to its 2002 level.

Unfortunately, published PRU reports do not include efficiency scores for individual navigation service providers. Such information would be of obvious importance, given the discussion about possible consolidation of air navigation services

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in Europe – an important and politically sensitive issue. EUROCONTROL (2006) studied the cost of fragmentation in the European en-route ATM/CNS[1] system, estimating that, on aggregate, a half of the total cost stems from unexploited economies of scale, as many European Area Control Centres happen to be below an optimum economic size. Our study adds to this debate by exploring the efficiency parameters of the current system, including the scale and the governance structure used in providing ANS services.

The rest of the paper is organised as follows. The next section describes air navigation services in Europe, the underlying institutional background, and previous studies on the subject. This is followed by a discussion of DEA method used to estimate efficiency and productivity. Section 4 describes the data, and Section 5 presents and discusses the results of our data analysis exercise. Section 6 concludes.

2. Air navigation services in Europe

Air navigation services in Europe are harmonised and integrated by EUROCONTROL. Headquartered in Brussels, this international organisation supports its member states in reaching the goal of safe, efficient and environmentally-friendly air traffic operations. In addition to all the EU members, ANSPs of Switzerland, Norway, Albania, Armenia, former Yugoslav republics, Georgia, Turkey, Moldova and Ukraine are members of EUROCONTROL.

National air navigation service providers in Europe are responsible for organising and managing the flow of traffic in the air and on the ground in a dedicated airspace. According to EUROCONTROL, in most countries these providers operate as public enterprises, subject to national laws and regulations. As of 2011, among 37 European ANSPs there were 15 state enterprises, 13 joint stock companies (11 of which were fully state owned), five "state bodies" with autonomous budget, two limited liability companies (also state owned), one independent administrative body, and one international organisation (EUROCONTROL, 2013a). This decentralised structure is in stark contrast to that of the United States, where a single government agency (Federal Aviation Administration or FAA) manages the airspace of about the same size. On the surface, FAA appears to do this job more effectively. EUROCONTROL (2013b) states that the US FAA employs nearly 40 per cent fewer staff as compared to EUROCONTROL organisations. Further, FAA has to control 70 per cent more flight hours in an airspace that is nearly twice as dense.

One of EUROCONTROL's declared missions is to facilitate creation of the Single European Sky (SES) – an EU initiative aimed at designing a more efficient air navigation system around "functional airspace blocks" rather than national boundaries.[2] Establishment of such a system may yield redundancies in some of the national ANS providers' workforce and infrastructure. This understandably creates opposition from the corresponding interest groups, with periodic strikes by air traffic controllers working for national ANSPs.

As the European ANS industry function was based on the full cost recovery principle until 2012, the incentives for cost efficiency were minimal.[3] We can therefore expect that costs due to inefficiencies were passed on to the system's users: airlines, and – to the extent competitive pressures allowed the airlines to do so – passengers.

As we noted above, the Performance Review Unit (PRU) of EUROCONTROL is responsible for periodic evaluation of the system's performance, including performing or commissioning studies of providers' efficiency and productivity. Table 1 below summarises some key features of several most relevant previous efforts in the field.

The most important findings of those studies are as follows. Mouchart and Simar (2003) find that the returns to scale in the production process of the ACC are increasing or near constant for small units, and decreasing for larger units. Most of the scale inefficiency can be explained by congestion, an appropriate measure of which is being the number of flight hours controlled per cubic root of the volume of the controlled area. EUROCONTROL (2005) finds that Total Factor Productivity (TFP) increased by about 2 per cent between 2001 and 2003. The NERA (2006) estimated Cobb-Douglas cost function, using a random effects time-invariant model as the preferred specification, regressing total cost on output, input prices, and network size. In general, this produced coefficients that are significant, have the right sign and appear to be robust. However, the model is likely to overestimate inefficiency, due to the lack of variation within the four year sample period in the exogenous control factors (network size, traffic complexity and seasonal variability).

EUROCONTROL (2011) estimates indicated that a 10% increase in output increases costs by 5.7%. A 10% increase in either the ATCO or support staff wages translates in 2.8% increase in costs; very similar elasticities are obtained by the True Random Effects model. The results of both the Pitt and Lee and the True Random Effects models suggest the existence of economies of scale. PRB (2013) suggests significant economies of density in the provision of air traffic management/communication, navigation and surveillance (ATM/CNS) services (a 10% increase in output contributing to a 4.6% increase in costs, according to Pit and Lee model), but also the presence of economies of scale. Cost-inefficiency estimates range between 10% (Greene model) and 70% (Pit and Lee model) in 2011, indicating the strong effect of modelling choice on the efficiency estimates.

[1] Air Traffic Management/Communication Navigation Surveillance.

[2] A functional airspace block (FAB) is a SES notion, defined as "an airspace block based on operational requirements and established regardless of State boundaries, where the provision of air navigation services and related functions are performance-driven and optimised with a view to introducing, in each FAB, enhanced cooperation among ANSPs or, where appropriate, an integrated provider." (European Commission, 2009).

[3] As from 1 January 2012, the *determined cost* method is used to calculate ANS charges in EU member states. It incorporates the risk sharing mechanism, if traffic volume or/and costs deviate from forecasts (European Commission, 2010). It means that revenue shortages will no longer be necessarily covered by increased charges in the following period, and also allows for a certain proportion of revenue excess over determined costs to be kept by ANSPs. The new method thus arguably incentivises the cost-efficiency of EU ANSPs.

Table 1
Previous ANS efficiency studies.

Study/report reference	Subject	Sample	Method	Output measure(s)
Mouchart and Simar (2003)	Productive efficiency of European Area Control Centres	Cross section (2001), 57 observations	DEA	1. Total flight-hours controlled, 2. Number of IFR movements controlled, 3. Number of sectors, and 4. Sum of sector hours
EUROCONTROL (2005)	Total factor productivity of European ANSPs	29 ANSPs (2001–2003), 87 observations	Tornquist TFP index	1. Number of flight-hours controlled and 2. Number of IFR airport movements
NERA (2006)	ATM/CNS cost benchmarking of European ANSPs	33 ANSPs (2001–2004), 125 observations	Stochastic Frontier Analysis	1. Composite flight hours controlled
EUROCONTROL (2011)	Cost-efficiency benchmarking of European ANSPs	2002–2009, 250 observations	Stochastic Frontier Analysis	1. Composite flight hours controlled
PRB (2013)	Cost-efficiency benchmarking of European ANSPs	2002–2011	Stochastic Frontier Analysis	1. Composite flight hours controlled
Button and Neiva (2014)	Economic efficiency of European ATC systems	36 ANSPs (2002–2009), 279 observations	DEA	1. IFR flight-hours controlled, 2. IFR airport movements controlled, 3. Delay minutes reciprocal

Sublimating the findings of six separate streams of technical analysis, including the aforementioned cost function estimate, the same report estimates, at SES level, a 10–40% overall "unit cost performance gap between the current position and an efficient ANS system", based on data available as of early 2013.

Button and Neiva (2014) in their study of EUROCONTROL ANSPs also find that some providers managed to increase their efficiency over time, while for others the trend has been the opposite. Another interesting result of this work is that lower level of government control appears to decrease the relevant provider's efficiency level, contrary to a priori expectations. Our study differs from Button and Neiva's work in that we offer a more diverse set of efficiency indicators for more years.

3. Methodology

The methodological apparatus used in estimating cost functions and evaluating relative efficiency of firms is quite well developed. Over the years, Cobb-Douglas and translog cost function estimations have become workhorses of cost data analysis and DEA has become a workhorse of efficiency analysis. The main goals of the relevant data analysis exercises are (a) the estimation of cost efficiency and/or productivity of ANSPs; (b) the decomposition of cost efficiency and productivity into allocative and technical inefficiency; and (c) evaluation of returns to scale.

The determination of the cost efficiency of an ANSP can be achieved by determining a (in case of DEA a piece-wise linear) cost or production frontier. An ANSP is efficient only if it operates on the frontier. The distance from a point in the interior of the production set to the frontier represents a measure of relative efficiency. When information on prices of factors of production is obtained, it is possible to decompose the cost efficiency (the cost efficiency in case of a cost frontier) into allocative efficiency and technical efficiency. Allocative efficiency involves the optimal input mix that produces a given quantity of output at a minimum cost, whereas technical efficiency measures the performance using only information on input and output quantities.

3.1. Data envelopment analysis

The methodologies based on nonparametric techniques require no specification of the functional form. In particular, DEA is based on a mathematical programming technique (Charnes et al., 1978) where the frontier is the benchmark, against which the relative performance of the decision making units such as ANSPs is measured. Most empirical applications of DEA to air transport have investigated the efficiency of airports (Pels et al., 2001, 2003; Gitto and Mancuso, 2012a) or airlines (Merkert and Hensher, 2011). Button and Neiva (2014) were the first to use DEA to study ANSPs. Instead, a cost-DEA model was never applied to the study of ANSPs.

The assumed production set allows for variable returns to scale (VRS). The use of VRS specification permits separating the technical efficiency from the scale efficiency and to determinate if a unit exhibits constant (CRS), increasing (IRS) or decreasing (DRS) returns to scale.

Fare et al. (1994) extended the DEA models to compute cost efficiency. A cost measure of efficiency indicates the extent to which a production unit minimises the cost of producing a fixed level of outputs, given input prices. Allocative efficiency is then computed as the ratio between cost efficiency and technical efficiency. If a unit shows allocative inefficiency, then it could change its inputs mix better with the prevailing input prices.

However, as argued in the literature (Simar and Wilson, 1998), efficiency scores provided by the DEA estimator are biased. This is related to the uncertainty connected to the sampling variation and, *inter alia*, to the number of inputs and outputs used in the estimation (Simar and Wilson, 2008). However, it is possible to use bootstrap methods in order to make inference, allowing for proper correction of the bias in DEA estimator and obtaining confidence intervals of the efficiency scores.

In sum, our model is tailored to ANS benchmarking in order to assess the relative efficiency of ANS units. The model encourages the inclusion of industry knowledge in the form of constraints and encapsulates them in the dynamic clustering approach.

3.2. Total factor productivity

Index numbers are a common technique to measure changes in total factor productivity (TFP) (Coelli et al., 2005). With those indices we want to measure the firm's ability to convert inputs (capital and labour) into outputs. Measuring productivity changes necessarily involves measuring changes in the levels of output and the associated changes in the input usage. Such changes are easy to measure in the case of a single input and a single output, but are more difficult when multiple inputs and outputs are considered.

Our approach is based on Malmquist index, as discussed below. The Malmquist TFP index measures the TFP changes between two periods by calculating the ratio of the distances relative to a common technology. It is possible to incorporate inefficiency in the model in order to measure the changes in technical efficiency. In fact, Fare et al. (1994) showed how to compute Malmquist productivity index from DEA efficiency scores and to decompose productivity into efficiency change (technological catch-up) and technological change (movement of the frontier).

Maniadakis and Thanassoulis (2004) extend the Fare et al. framework, developing a cost Malmquist productivity index (*CM*). This approach is based on cost distance function and takes into account also allocative inefficiency in productivity measurement. In order to investigate the sources of productivity change, such index is decomposed into various terms. Cost productivity change is decomposed into cost efficiency change (*CEC*) and cost technical change (*CTC*). Cost efficiency change component measures the "catch up" of the ANSPs with respect to the cost frontier, while cost technical change captures the combined effect of input price and technology over time. Both these components are decomposed into input quantities and input price. In fact, cost efficiency change is decomposed into technical efficiency change (*TEC*) and allocative efficiency change (*AEC*): so that, we can capture the "catch up" effect due to technical and allocative efficiency. Similarly, cost technical change is decomposed into technical change (*TC*) and price change (*PE*). While technical change is the change in the technical frontier and it reflects the change in technology (innovation), the price change term captures the contribution of relative input price changes on the shift of the cost frontier. In other terms, by the price change components, we identify a rearrangement of the input case mix at industry level.

Note also that productivity change (PROD) as defined by Fare et al. (1994), is determined by technical efficiency change (*TEC*) and technical change (*TC*). The estimation of the cost Malmquist productivity index and its components is done using DEA method. This requires solving several linear programming models for each ANSP (see Maniadakis and Thanassoulis, 2004, for details). Thus, to summarise, we apply the following decompositions:

$$\begin{aligned} CM &= CEC \times CTC \\ CEC &= TEC \times AEC \\ CTC &= TC \times PE \\ PROD &= TEC \times TC \end{aligned} \tag{1}$$

Moreover, following Simar and Wilson (1999), we make inference on the above indices in order to determine if the estimated changes are significant at a 1%, 5% or 10% level. Note also that the bias is not a relevant problem here since DEA estimates are biased in the same direction. Gitto and Mancuso (2012b) applied successfully such procedure to determine productivity change of Italian airports.

4. Data

Our data come from regular annual EUROCONTROL's Air Traffic Management Cost-Effectiveness (ACE) Benchmarking Reports for the 2002–2011 time period (EUROCONTROL, 2004–2012, 2013a). For each individual air navigation service provider (ANSP) we have annual information on the following variables:

– Total flight hours controlled by individual ANSP (Y_1). This variable represents, broadly speaking, the key output of en-route air traffic control.
– Instrument flight rules (IFR) airport movements controlled by individual ANSP (Y_2). This variable is a proxy for the output of terminal air traffic control – covering initial and final phases of flight.
– Gate-to-gate Air Traffic Management/Communication Navigation Surveillance (ATM/CNS) cost (expressed in constant year 2005 Euros). At the basic level, this represents total cost of core ANSP operation (but does not include cost of meteorological services, EUROCONTROL costs, etc.). On average, ATM/CNS cost represents about 85% of total Air Navigation Services (ANS) cost in Europe.
– Input prices, computed separately for air traffic controllers ($w1$), other staff members ($w2$), capital ($w4$), and other non-staff related inputs ($w3$). Input prices are computed following EUROCONTROL (2013a).

The choice of the variables was largely driven by the performance measures and indicators, which were employed in the previous studies using largely the same data source, albeit we use a different methodology.

Table 2 presents the descriptive statistics for all our variables.

Table 2
Descriptive statistics.

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	All
Total flight-hours controlled by the ANSP (Y1)	323,166(457,050)	329,330(452,390)	347,505(464,965)	359,161(470,119)	370,457(486,045)	393,358(512,565)	402,645(513,216)	366,326(468,739)	375,970(470,479)	391,057(484,397)	366,811(473,389)
IFR Airport movement controlled by the ANSP (Y2)	437,933(651,323)	402,081(575,851)	416,498(585,270)	422,639(595,132)	429,090(611,095)	448,162(632,147)	442,552(622,411)	399,441(567,133)	400,432(562,692)	415,336(580,932)	421,225(590,971)
Total Cost (EUR 000s)	172,833(257,435)	173,872(257,872)	180,966(266,645)	184,845(271,450)	190,270(274,983)	203,708(298,230)	211,003(302,863)	204,852(303,049)	202,042(280,206)	211,856(286,832)	194,175(277,762)
Labour Price, ATC, (EUR/Hour) ($w1$)	49.87(31.54)	52.73(33.74)	56.67(36.14)	59.82(36.92)	63.36(38.64)	68.97(40.87)	73.91(42.73)	73.00(45.48)	77.13(44.14)	83.86(46.08)	66.36(40.99)
Labour Price, Other Staff (EUR/Hour) ($w2$)	46.79(32.79)	49.60(37.88)	50.57(35.85)	52.23(35.75)	54.09(35.56)	59.47(39.19)	60.34(37.15)	59.68(36.52)	61.31(37.23)	63.28(36.89)	55.96(36.50)
Capital Price ($w4$)	19.15(9.92)	21.34(12.11)	2.97(13.21)	19.37(8.35)	21.22(9.86)	21.95(10.11)	22.40(7.89)	24.22(9.18)	25.55(12.23)	26.79(15.18)	22.58(11.15)
Other non-staff related operating inputs ($w3$)	88.49(8.88)	90.51(6.41)	94.80(3.66)	100.00(0.00)	105.46(3.17)	109.20(5.87)	117.29(11.06)	113.43(10.04)	118.62(13.44)	126.36(17.95)	106.90(15.36)

Note: reported values are annual averages across the ANSPs, with standard deviations in parentheses.

Table 3
Efficiency scores with estimated 95-percent confidence intervals, 2011.

ANSP	Cost efficiency				Technical efficiency				Allocative efficiency				Scale efficiency	
	Eff. score	Bias corr. eff. score	Lower bound	Upper bound	Eff. Score	Bias corr. eff. score	Lower bound	Upper bound	Eff. score	Bias corr. eff. score	Lower bound	Upper bound	Bias corr.	
AENA	0.741	0.654	0.597	0.723	1.000	0.854	0.697	0.993	0.741	0.799	0.625	1.692	0.978	drs
ANS-CR	0.467	0.407	0.370	0.452	0.706	0.649	0.601	0.700	0.662	0.622	0.549	0.715	0.894	irs
ARMATS	0.354	0.313	0.276	0.348	1.000	0.862	0.729	0.992	0.354	0.374	0.290	0.618	0.645	irs
Austro	0.743	0.657	0.605	0.724	0.871	0.797	0.736	0.864	0.853	0.820	0.744	0.927	1.000	–
Avinor	1.000	0.880	0.776	0.992	1.000	0.852	0.688	0.991	1.000	1.064	1.000	1.794	1.000	–
Belgo	0.736	0.660	0.584	0.729	1.000	0.866	0.743	0.992	0.736	0.783	0.623	1.064	1.000	–
BULATSA	0.367	0.319	0.288	0.355	0.908	0.839	0.771	0.902	0.404	0.377	0.333	0.428	0.949	drs
Croatia	0.459	0.399	0.357	0.444	0.556	0.503	0.449	0.552	0.825	0.787	0.702	0.873	0.977	irs
Cyprus	0.652	0.567	0.512	0.630	1.000	0.858	0.728	0.992	0.652	0.678	0.536	1.044	1.000	–
DFS	0.714	0.630	0.573	0.698	1.000	0.851	0.686	0.991	0.714	0.776	0.603	1.902	0.933	drs
DHMI	0.450	0.397	0.359	0.437	0.726	0.656	0.578	0.720	0.619	0.605	0.515	0.786	0.875	drs
DSNA	0.555	0.485	0.441	0.538	1.000	0.852	0.685	0.992	0.555	0.593	0.463	1.386	0.682	drs
EANS	0.860	0.755	0.689	0.831	1.000	0.851	0.688	0.992	0.860	0.926	0.754	2.120	1.000	–
ENAV	0.539	0.473	0.432	0.525	0.961	0.866	0.734	0.953	0.562	0.547	0.469	0.750	0.899	drs
Finland	0.917	0.812	0.709	0.909	1.000	0.861	0.731	0.992	0.917	0.965	0.847	1.325	1.000	–
HCAA	0.454	0.393	0.349	0.439	0.573	0.518	0.456	0.568	0.792	0.752	0.656	0.824	0.983	drs
Hungaro	0.479	0.418	0.380	0.463	0.666	0.607	0.554	0.661	0.719	0.685	0.600	0.773	0.945	irs
IAA	0.738	0.644	0.585	0.714	1.000	0.901	0.817	0.993	0.738	0.711	0.616	0.814	1.000	–
LFV	0.779	0.684	0.622	0.759	1.000	0.877	0.758	0.992	0.779	0.786	0.652	0.962	1.000	–
LGS	0.618	0.547	0.492	0.601	0.933	0.846	0.757	0.925	0.663	0.645	0.555	0.798	0.886	irs
LPS	0.297	0.258	0.229	0.287	0.675	0.618	0.561	0.671	0.440	0.413	0.354	0.495	0.629	irs
LVNL	0.901	0.808	0.715	0.894	1.000	0.855	0.710	0.992	0.901	0.989	0.820	1.849	1.000	–
MATS	0.543	0.475	0.434	0.524	1.000	0.860	0.734	0.992	0.543	0.566	0.456	0.870	1.000	–
M-NAV	0.274	0.242	0.221	0.265	1.000	0.874	0.747	0.993	0.274	0.281	0.233	0.408	0.659	irs
MoldATSA	0.372	0.338	0.302	0.369	1.000	0.869	0.747	0.992	0.372	0.402	0.321	0.620	0.706	irs
MUAC	1.000	0.851	0.688	0.992	1.000	0.851	0.688	0.992	1.000	1.000	1.000	1.000	1.000	–
NATA-Alb	0.248	0.218	0.199	0.240	1.000	0.911	0.831	0.992	0.248	0.239	0.209	0.286	0.372	irs
NATS	0.713	0.625	0.567	0.695	1.000	0.864	0.742	0.993	0.713	0.739	0.598	1.123	0.953	drs
NAV-Portugal	0.867	0.762	0.701	0.842	1.000	0.887	0.768	0.992	0.867	0.862	0.766	1.051	1.000	–
NAVIAIR	0.799	0.702	0.628	0.784	1.000	0.893	0.818	0.993	0.799	0.786	0.666	0.947	1.000	–
Oro-Navigacija	0.386	0.338	0.307	0.373	0.744	0.676	0.593	0.738	0.519	0.498	0.434	0.637	0.791	irs
PANSA	0.615	0.539	0.494	0.596	0.875	0.799	0.726	0.867	0.704	0.670	0.592	0.730	1.000	–
ROMATSA	0.397	0.344	0.311	0.383	0.649	0.602	0.555	0.644	0.611	0.566	0.502	0.633	0.962	drs
Skyguide	0.637	0.562	0.511	0.623	0.952	0.866	0.792	0.945	0.669	0.647	0.563	0.790	0.950	drs
Slovenia	0.471	0.411	0.373	0.455	0.892	0.803	0.707	0.884	0.527	0.510	0.438	0.660	0.890	irs
SMATSA	0.355	0.307	0.269	0.344	0.544	0.498	0.447	0.539	0.654	0.610	0.522	0.681	0.836	irs
UkSATSE	0.345	0.315	0.283	0.342	0.518	0.470	0.415	0.514	0.666	0.675	0.582	0.866	0.980	drs

An interesting (although expected) feature of our data is the significant variability across the national service providers. While variability in total operations and total cost is not surprising, given the substantial differences in sizes across countries and the fact that ANSPs are linked to the countries' borders; the differences in per unit costs are quite substantial as well.

5. Results and discussion

We will proceed by employing the Data Envelopment Analysis (DEA) – our non-parametric technique of choice. DEA allows benchmarking of operating performance of various firms that employ fundamentally the same technology by comparing the amount of inputs used to generate the outputs. For the purposes of our analysis, the inputs include average employment costs of ATCOs in OPS, cost for support staff, non-staff operating costs, capital related input. The outputs are total flight-hours controlled by the ANSP and IFR airport movement controlled by the ANSP. PRU studies (NERA, 2006; EUROCONTROL, 2011; PRB, 2013) used composite flight-hours as (single) output. Here instead, we prefer to use separately

Table 4
Mean bias-corrected efficiency, 2002–2011.

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Cost efficiency	0.467	0.474	0.489	0.564	0.546	0.555	0.538	0.541	0.54	0.519
Technical efficiency	0.724	0.721	0.724	0.729	0.722	0.709	0.772	0.798	0.793	0.783
Allocative efficiency	0.669	0.684	0.686	0.796	0.776	0.81	0.706	0.694	0.689	0.669
Number of ANSPs – IRS	18	21	16	12	15	10	9	10	12	12
Number of ANSPs – CRS	11	7	9	11	12	16	18	19	14	14
Number of ANSPs - DRS	3	6	9	12	9	10	9	8	11	11
Number of ANSPs (total)	32	34	34	35	36	36	36	37	37	37

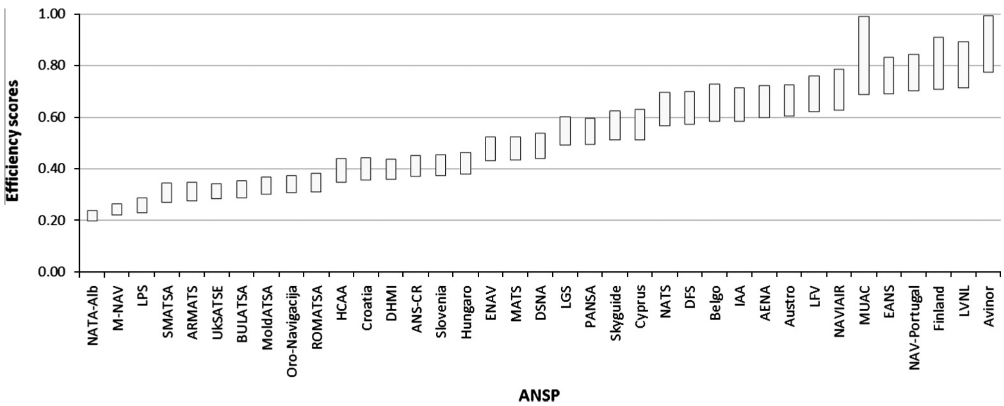

Fig. 1. Cost-efficiency scores with estimated 95-percent confidence intervals, 2011.

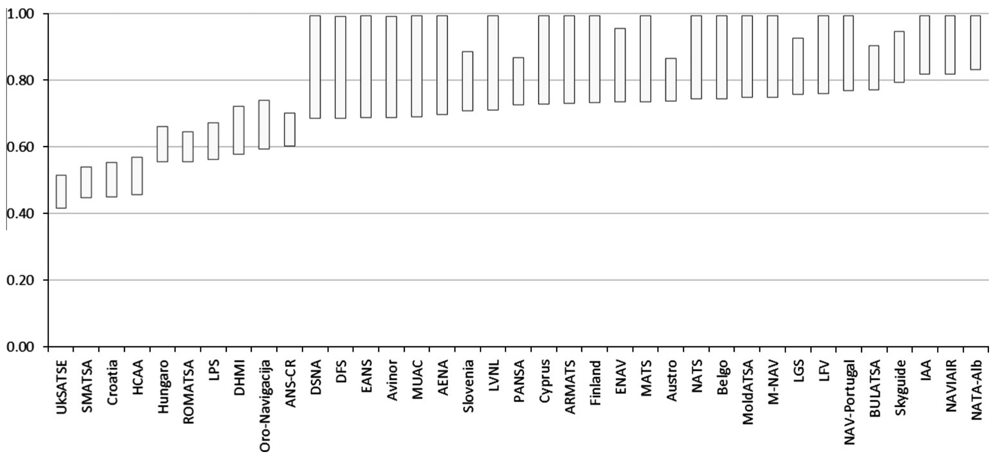

Fig. 2. Technical efficiency scores with estimated 95-percent confidence intervals, 2011.

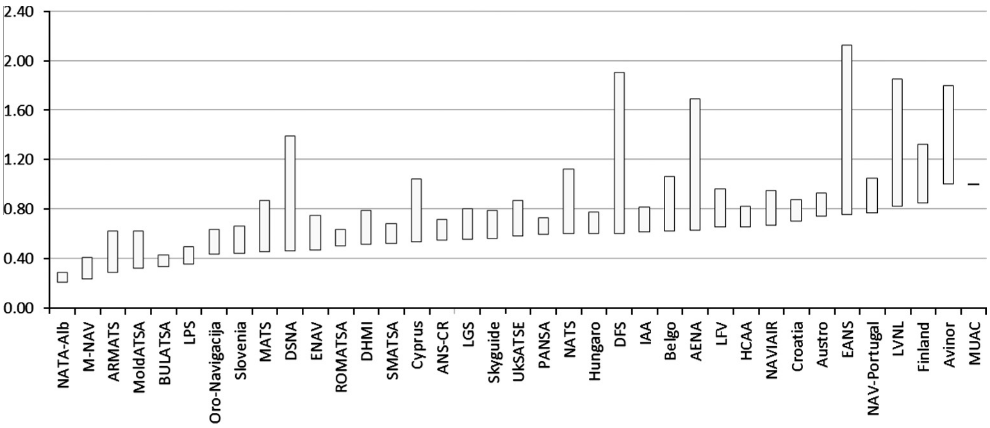

Fig. 3. Allocative efficiency scores with estimated 95-percent confidence intervals, 2011.

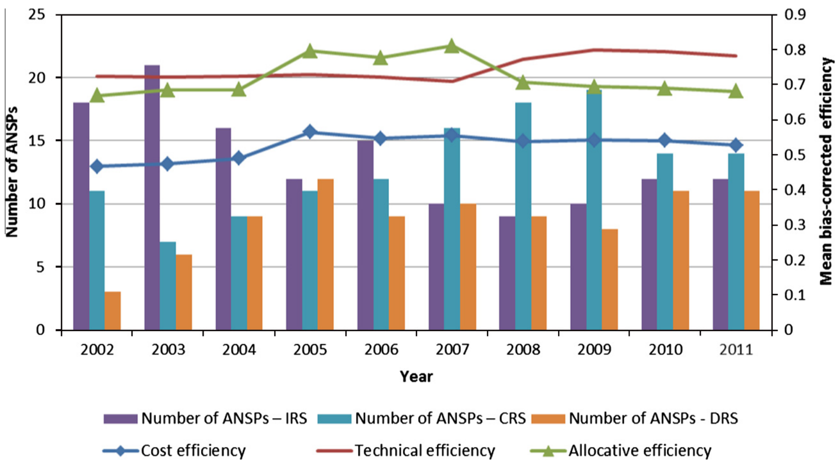

Fig. 4. Mean bias-corrected efficiency, 2002–2011.

both variables which compose composite flight-hours. In this way, we increase the flexibility of our model, since we do not impose a fixed factor of substitution between the outputs, but we leave to the non-parametric model to calibrate the efficiency frontier. On a related matter, Grebenšek and Magister (2013) suggest that the use of composite flight hours, as calculated by EUROCONTROL, is a possible source of bias in ANSP benchmarking exercises.

Table 3 presents the individual ANSP efficiency scores for 2010. The lower and upper bounds of the reported 95% confidence intervals are obtained using the method proposed by Simar and Wilson (1998). Table 4 reports on the evolution of averaged efficiency indices over time. Some of the numbers from these tables are further visualised in Figs. 1–4.

From these tables it is clear that cost efficiency varies greatly across ANSPs and that on average efficiency is not particularly high: the mean bias corrected efficiency does not exceed 0.57, only few individual ANSPs have a relative cost efficiency exceeding 0.75. This can be contributed for a large part to inefficient allocations of inputs since ANSPs exhibit high technical (residual) efficiency scores which are moderately dispersed across the providers.[4] One explanation for the inefficient allocation may be differences in wages, while capital inputs and the technologies they employ are perhaps more similar. EUROCONTROL (2013a) reports a wide range of ATCO-hour employment costs across ANSPs from below €30 per hour (e.g. NATA Albania) to €164 (AENA), with an average of €101.

The efficiency frontier is defined by Avinor (Norwegian ANSP) and MUAC (a EUROCONTROL-operated provider of high-altitude navigation services over Benelux and Northern Germany). These two providers exhibit perfect efficiency scores in all three dimensions, as reported in Table 3. Overall, allocative and cost efficiency of the Western European providers appears to be higher than the same figures for their counterparts from the Eastern Europe. Technical efficiency scores, however, are

[4] The corresponding coefficient of variation from Table 3 for the bias-corrected technical efficiency scores is 17%. The coefficient of variation for the bias-corrected scores for the cost efficiency from Table 3 is 36%, or double that for technical efficiency scores.

Table 5
Cost Malmquist productivity results for ANSP, 2002–2011.

ANSP	CM	CEC	CTC	TEC	AEC	TC	PE	PROD
AENA	0.845***	0.985	0.858	0.926**	1.063*	0.898	0.956	0.831***
ANS-CR	0.911***	1.123	0.812	1.011	1.110	0.912	0.890**	0.922
LFV	1.119***	1.284	0.872	1.002	1.281***	1.174**	0.743***	1.177
BULATSA	0.364***	0.518***	0.702***	0.321***	1.613***	0.746**	0.940	0.240***
Austro	0.847***	0.898*	0.942	1.014	0.886	0.893	1.055	0.905***
Avinor	0.489***	0.608***	0.803*	0.837	0.727***	0.773**	1.040	0.646***
Belgo	0.890***	1.077	0.826	0.888	1.213	0.806*	1.024	0.716***
Croatia	0.630***	0.860**	0.733**	1.167	0.737***	0.643***	1.140	0.750***
Cyprus	0.365***	0.701***	0.520***	0.732***	0.958	0.888	0.585***	0.650***
DFS	0.883***	0.857	1.031	1.036	0.827	0.901	1.144	0.933
DHMI	0.659***	0.778***	0.848	0.789***	0.985	0.957	0.885	0.755***
DSNA	0.944***	1.118	0.844	1.214	0.921	0.873	0.967	1.060***
EANS	0.589***	0.821***	0.717***	1.000	0.821	0.703***	1.020	0.703***
ENAV	1.015	1.188	0.854	0.959**	1.238**	0.962	0.888***	0.922*
Finland	0.516***	0.856	0.603***	1.000	0.856	0.761***	0.792***	0.761***
M-NAV	0.368***	0.554***	0.664***	0.381***	1.454***	0.725***	0.916	0.276***
Hungaro	0.815***	1.089	0.749**	1.034	1.053	0.920	0.814***	0.952
IAA	1.131***	1.236	0.915	1.000	1.236***	1.549***	0.591***	1.549
LGS	0.407***	0.520***	0.783	0.665***	0.782*	0.810	0.968	0.538***
LPS	0.699***	1.018	0.687***	0.893**	1.140**	0.779	0.882***	0.696***
LVNL	0.867***	0.899*	0.964	1.000	0.899	0.970	0.994	0.970
MATS	0.678***	0.880*	0.770**	0.746***	1.179	0.946	0.814***	0.706***
MoldATSA	0.432***	0.638***	0.677***	0.536***	1.190	0.738***	0.917	0.396***
MUAC	0.730***	1.000	0.730	1.000	1.001**	0.600***	1.216***	0.600***
NATA-Alb	0.979***	1.408	0.695***	1.084	1.298***	0.951	0.731***	1.031
NATS	0.804***	0.813**	0.989	1.107	0.735**	0.944	1.047	1.045
NAV-Portugal	0.682***	0.752***	0.906	0.901*	0.836*	0.721***	1.257*	0.649***
NAVIAIR	1.011	1.070	0.945	1.000	1.070	0.966	0.978	0.966
Oro-Navigacija	0.510***	0.699***	0.729***	0.600***	1.165**	0.729***	0.999	0.438***
ROMATSA	0.356***	0.499***	0.713***	0.353***	1.414***	0.683***	1.044	0.241***
Skyguide	1.233***	1.300	0.949	1.094	1.188	1.014	0.935	1.110
Slovenia	0.492***	0.684***	0.720***	0.698***	0.980	0.913	0.788***	0.637***
g. mean	0.682	0.864	0.789	0.834	1.036	0.855	0.923	0.714
g. mean (%)	31.80	13.62	21.05	16.59	−3.56	14.46	7.71	28.65

Notes: CM: Cost Malmquist, CEC: cost efficiency change, CTC: cost technical change, TEC: technical efficiency change, AEC: allocative efficiency change, TC: technical change, PE: price change, PROD: productivity change.
* Statistically significant at 10% level according to the bootstrap confidence intervals. 5000 bootstrap replications.
** Statistically significant at 5% level according to the bootstrap confidence intervals. 5000 bootstrap replications.
*** Statistically significant at 1% level according to the bootstrap confidence intervals. 5000 bootstrap replications.

more evenly distributed across the regions. We would further claim that one of the key takeaway messages of our study is that ANSPs exhibit on average higher and more uniform technical efficiency levels, whereas their cost and allocative efficiency scores are more dispersed. This finding has a clear policy implication for EUROCONTROL – fragmentation of European air space appears to have created more disparities in how the various providers are run than in the technology they employ. This factor will likely play a crucial role in the process of establishment of the Singe European Sky.

Even though ANSPs are very heterogeneous in terms of size and output, scale efficiency is on average very high. Only few ANSPs have scale efficiency score below 0.8. The exploitation of the scale efficiency (due to increasing economies of scale) varies across ANSPs. From Table 4 we can conclude that in the years 2002–2004 the majority of ANSPs were operating under the economies of scale. For the remaining years of the number of providers operating under the economies of scale has been declining. This result is not entirely consistent with PRB (2013), which reports unexploited scale economies. However, PRB (2013) uses a different methodology (Cobb-Douglas cost function estimation) and effectively reports averaged estimates. One factor which could explain the fact that fewer ANSPs operate under economies of scale at the end of our observation period as compared to the beginning is a simple increase in the amount of work they have to do. ANSPs average number of flight hours controlled increased by 17% over 2002–2011 time period.

Another interesting observation with regard to economies of scale comes from Table 3. Looking at the identity of providers that are not exploiting economies of scale, i.e. operating under increasing returns to scale, we note that all of them are located in Eastern Europe. While not all Eastern European ANSPs operate under increasing returns to scale, none of the providers from the Western Europe does.

Over time, ANSPs have become more cost efficient, as reported in Table 4. There have also been some gains in technical efficiency, with a considerable jump from 2007 to 2008. The trend for allocative efficiency is a bit less encouraging: most of the gains observed in 2002–2007 have been wiped out in the trend reversal that followed. One explanation for this could relate to the inertia in the industry, especially with respect to labour: when traffic goes down, the commensurate adjustment in employment is generally slow. In fact, the total traffic controlled by the system did decrease substantially post-2008.

Table 6
Cost Malmquist index summary of annual means, 2002–2011 (%).

Index	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11
CM	5.31%	10.15%	3.56%	3.06%	6.63%	2.28%	−4.59%	4.37%	4.07%
CEC	−1.52%	5.05%	11.76%	−2.70%	3.35%	−2.16%	−0.15%	2.42%	−3.53%
CTC	6.73%	5.37%	−9.29%	5.60%	3.40%	4.35%	−4.43%	2.00%	7.34%
TEC	−2.24%	6.09%	6.79%	−1.50%	1.00%	6.93%	0.03%	1.63%	−3.21%
AEC	0.71%	−1.10%	5.34%	−1.18%	2.37%	−9.77%	−0.18%	0.80%	−0.31%
TC	5.58%	0.10%	−7.16%	5.57%	7.02%	−4.98%	−5.61%	2.24%	6.94%
PE	1.21%	5.27%	−1.99%	0.03%	−3.89%	8.89%	1.12%	−0.25%	0.43%
PROD	3.46%	6.18%	0.11%	4.16%	7.94%	2.29%	−5.59%	3.83%	3.96%

Notes: CM: Cost Malmquist, CEC: cost efficiency change, CTC: cost technical change, TEC: technical efficiency change, AEC: allocative efficiency change, TC: technical change, PE: price change, PROD: productivity change.

The analysis of cost-DEA Malmquist index follows Maniadakis and Thanassoulis (2004). The corresponding results are reported in Table 5. A value of the index less than one implies productivity progress, a value greater than one implies regress. The significance of productivity change has been obtained following the procedure described by Simar and Wilson (1999). Looking at Table 5 we can say, for each individual ANSP, whether its efficiency has increased or decreased over the time period covered by our data. Table 6 presents similar information, averaged across the air navigation service providers.

Overall, the results paint the following picture. First, we see cost productivity improvements for most of the providers. Second, technical efficiency change rather than allocative efficiency change appears to be the major source of improvement reported. Yet, the magnitude of technical efficiency improvements is not striking for most providers. So, the components related to the production functions (measured in physical terms) are the major sources of cost productivity improvement.[5] Innovation is measured by shift in the cost boundary (*CTC*), which in this case is caused by shift of the production boundary and not by changes in relative input prices. In other word, ANSPs did not improve their input mix but instead improved their technical productivity. Again, this may be the consequence of some inertia in the industry, caused by strict regulations in terms of national laws and standards of quality.

6. Conclusions

This study provides a comprehensive examination of the efficiency of European air navigation service providers. We use non-parametric data analysis and find that overall productivity of service providers has increased over the time period covered by our data. Furthermore, the productivity improvements are related to technical rather than allocative efficiency. Finally, most of the allocative efficiency gains achieved prior to the 2007–2008 economic crisis have been wiped out, with the corresponding scores returning to their pre-crisis level. This finding appears to underscore the labour-related disputes that are periodically erupting in this industry.

Our study is the first one in the literature to employ EUROCONTROL data to publicly report efficiency scores for individual navigation service providers, and to also document the evolution of these scores over an extended time period. We are also able to delve deeper into the question of the sources of efficiency changes. Our results suggest that providers did improve their technical productivity over time. At the same time, we find more disparities in how the various providers are run. This evidence implies an inefficient mix of inputs used by ANSPs. However, our analysis only looks at efficiency differences given the current organisational arrangements and ignores potential efficiency gains that could be achieved by moving to a system of the Single European Sky (SES). We believe that understanding of this issue is important for European Commission's effort at creating the Single European Sky.

The findings of our study can feed into the general debate on ways to reform the European air navigation system with the view at increasing its efficiency. We are able to identify a number of national providers that are better exploiting returns to scale, whilesome of the ANSPs operate in the decreasing returns to scale area. Whether this suggests they are inefficient, or simply suffer from technical or allocative efficiency issues, remains an open question to be tackled in future studies.

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[5] This is more evident if we consider that, from Eq. (1), we can rearrange the terms as $CM = PROD \times AEC \times PE$, that is a term (*PROD*) based on the changes in production functions and the remaining terms based on changes in price and cost function.

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