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Total Factor Productivity of European Air Navigation Services Providers: Basic Concepts and Empirical Application

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Total Factor Productivity of European Air Navigation Services Providers:
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ABSTRACT

This note presents the methodology used to measure the Total Factor Productivity (TFP) of European Air Navigation Service Providers (ANSPs). Several inputs and outputs are defined and selected for the purposes of computing multilateral output and input indexes associated with the provision of ATM/CNS. TFP scores and TFP growth rates are computed for the European system and for each ANSP using a panel of 29 ANSPs and three years (2001-2002-2003) derived from the ATM Cost-Effectiveness (ACE) data set. A sensitivity analysis of TFP scores suggests that TFP levels are fairly stable and not too sensitives to the various hypotheses considered. Finally, a regression analysis is performed to identify the impact of selected exogenous factors (e.g. airspace density, traffic variability) on TFP scores.

Keywords

EUROCONTROL Performance Review Unit – TFP methodology – input and output indexes – European Air Navigation Service Providers – ATM/CNS provision – ACE data set – TFP scores and TFP growth rates – Gross versus Residual TFP- OLS estimation – Exogenous factors.

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TABLE OF CONTENTS

INDEX OF TABLES AND FIGURES

EXECUTIVE SUMMARY

This technical note applies standard economic and statistical tools for the measurement of Total Factor Productivity of 29 European Air Navigation Service Providers (ANSPs). Productivity is a key element of cost-effectiveness, hence the importance of accurately measuring and analysing productivity and its trend over time. Its measurement allows the identification and promotion of best practice among ANSPs and contributes to informed decisions making among stakeholders. This is particularly relevent in the context of likely technological (e.g. datalink) and organisational/institutional changes (e.g. Single European Sky) of the European ATM/CNS system.

Essentially, the TFP is a ratio that measures how effectively an ANSP converts all its input resources (labour, materials, energy, machines, etc.) into outputs/services. When several inputs are used and/or several outputs produced an aggregated measure of input and an aggregated measure of output have to be computed in order to obtain a TFP score. The aggregation procedure developed by Caves *et al.* (1982) is based on the Tornqvist index.

In this note, using the data available from the ATM-Cost-effectiveness (ACE) data base, two output metrics are used to characterise the services provided for en-route and terminal ANS: the number of flight-hours controlled and the number of IFR airport movements, respectively. Similarly, three input categories are identified: labour, capital, and other (operating) inputs. The labour input is broken down into two different categories: Air Traffic Controllers (ATCOs in OPS) and all the other (support) staff.

Between 2001 and 2003, the TFP index increased by some 2% at European system level. At ANSP level the TFP growth rates range from +37% to -21%. However, the period under analysis is, to some extent, atypical for the industry and more years will be needed to infer a solid trend analysis.

At ANSP level, TFP scores show a wide dispersion: there is a factor of 2.2 between the first and third quartiles of the TFP distribution. This result is comparable with the dispersion of the (partial) ATCO-hour productivity indicator presented in the ACE 2003 Benchmarking Report. In fact the correlation between the TFP score and the ATCO-hour productivity indicator is relatively high (a R^2 of 0.74).

The results of a sensitivity analysis suggest that the TFP scores are fairly stable and not too sensitive to the different hypotheses considered.

When interpreting the differences among TFP scores, it is important to account for exogenous factors that are beyond ANSP's managerial control (e.g. "traffic complexity"). A regression analysis of the TFP scores on selected exogenous variables shows how these influence the observed TFP scores. However, proper econometric analysis would require accounting for specific effects relating to each ANSP. Unfortunately, for the time being the size of the sample (i.e. 29 ANSPs over three years) does not allow for such an empirical estimation. Further research area is outlined in this context.

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1 INTRODUCTION

To support cost-effectiveness and productivity analysis a Specification for Information Disclosure was developed so that Air Navigation Service Providers (ANSPs) could provide the PRC with a range of economic and operational information. As of 2002, ANSPs are required to submit annual data according to the Specification for Economic Information Disclosure[1] (EID) document. In parallel to the development of the Specification for Information Disclosure, Key Performance Indicators (KPIs) for cost-effectiveness and productivity were developed in 2001 by an ad-hoc KPIs Working Group led by the PRU[2]. As of 2003, a comprehensive analysis of data provided by ANSPs is produced by the PRU in a document entitled "ATM Cost-Effectiveness (ACE) Benchmarking Report"[3]. In these reports, a performance framework is proposed to analyse cost-effectiveness and productivity and measures of partial productivity indicators are compared. Cost-effectiveness is analysed and broken down into productivity, employment costs and support costs. All else being equal, an improvement of productivity contributes to better cost-effectiveness, hence the importance of accurately measuring and analysing productivity and its trend over time. Indeed, the accurate measurement of productivity growth in ATM/CNS should play an important role in providing effective information to identify and promote best practice among ANSPs and in contributing to informed decisions making among stakeholders (e.g., airspace users, regulators, policy makers). This is even more crucial given the envisaged technological (e.g. datalink) and organisational/institutional changes (e.g. Single European Sky) in Europe.

As identified by the KPIs Working Group, several benchmarking tools, including **Total Factor Productivity** (TFP), can be developed for the purposes of comparing performance and identifying best practice. In fact the ACE data set allows for such tools to be empirically applied and open new opportunities to study the economics of ANS. The main objective of this paper is to briefly introduce standard economic and statistical tools used in applied economics for TFP measurement. This paper also presents a framework that can be applied to make TFP comparisons among ANSPs (i.e., cross-section data) and across time (i.e. time series data). As the use of such techniques is relatively new in the field of ANS, it is important to pay particular attention to the definition of ANSP inputs (resources) and outputs (products).

TFP measurement has been applied to various economic sectors, including public utilities and services. There is a rich literature on productivity measures applied to air transportation, but so far the focus has been exclusively on airlines and airports (see e.g., Oum *et al*. (1992), Oum *et al*. (1999)). A recent study has shown that the TFP in the US air transport industry increased at an average annual rate of 2% over the 1972-2001 period, almost triple the 0.7% rate for the private business sector as a whole (see Duke and Torres, 2005).

Finally, recent economic theory suggests that TFP indexes can be used for setting the X factor under price-cap regulation schemes (e.g, Bernstein and Sappington, 1999).

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[1] Decision No. 88 of the EUROCONTROL Commission, November 2001. For more details see Performance Review Commission web site at www.eurocontrol.int/prc.

[2] For more details see Performance Review Unit Working Paper on "Cost-effectiveness and Productivity KPIs", October 2001, www.eurocontrol.int/prc.

[3] ACE Benchmarking Reports can be found on the PRC web site at www.eurocontrol.int/prc.

Recently, Lawrence and Diewert (2004) used the TFP methodology to compute X factors for New Zealand's electricity distributors, where the X factor is established taking into account both the (historic) difference in TFP growth rates and difference in input prices growth rates between the regulated industry and the rest of the economy.

The structure of the paper is the following: Section 2 introduces the basic concepts of productivity measurement and explains how to construct an aggregated output index from disaggregated output metrics. Section 3 presents the input and output data required to construct productivity indexes in the specific case of ATM/CNS provision, multilateral inputs and outputs indexes are then computed. Section 4 displays TFP multilateral indexes for the European system and at ANSP level. Section 5 provides a sensitivity analysis of the TFP scores, while Section 6 provides a preliminary econometric analysis of the TFP scores. Finally, Section 7 concludes. A complete set of references is provided in the bibliography. The appendix provides an example to illustrate how the multilateral TFP index is calculated.

2 BASIC PRODUCTIVITY MEASUREMENT CONCEPTS

The definition and measurement of productivity have been extensively studied in both theoretic and empirical economic analysis. Essentially, **Total Factor Productivity** (TFP) is a ratio that measures how effective a firm/organization (or industry, country) converts all its input resources (labour, materials, energy, machines, etc.) into outputs (goods and services). This definition is quite straightforward where a firm produces one output with one input, however difficulties arise when several inputs are used and/or several outputs produced: an aggregated measure of input and an aggregated measure of output have to be computed in order to obtain a TFP index.

Not surprisingly, **Partial** Factor Productivity indexes (PFP), rather than a TFP index, are often used to make comparisons between firms. A PFP index is the ratio of some quantity of output by some quantity of input. An example of PFP can be found in the ACE 2003 Benchmarking Report (section 5.3.2) which displays the hourly productivity of Air Traffic Controllers (ATCOs) as the ratio of the flight-hours controlled (output) to the ATCOs-hours worked (input).

PFP indexes are usually easy to compute, understand, and interpret. They are therefore often used in economic studies. However, a PFP does not give a global view of productivity. For example, an increase in labour productivity can be outweighed by a decrease in capital productivity so that the TFP actually decreases. TFP takes into account all the inputs and outputs metrics and summarizes the comparison in an overall productivity index. Hence, this gives a more comprehensive picture of productivity. The main challenge is to calculate aggregated outputs and inputs indexes given data availability. Clearly, the outputs and inputs metrics selected impact the results of any productivity analyses. For this reason, care must be taken to select input and output measures that are sufficiently broad and applicable to the analytical questions to be addressed.

In the case of ANSPs productivity comparisons, several issues make the construction of the TFP index difficult: First, how can the different ANSPs' input/output metrics be aggregated? Second, how can quality of service and exogenous factors be taken into account in TFP results? Each of these issues is briefly addressed in the following sections.

2.1 Index numbers theory

An index number is defined as a real number that measures changes in a set of related variables (Coelli *et al*. (1998)). TFP is an index number given that it enables the change in productivity to be measured over time for a given firm, and/or it enables productivity to be compared across different firms for a fixed time period.

2.1.1 Properties of index numbers

As there exist several index number formulae, Fisher (1922) proposed a number of criteria to assess the global performance of those indexes: *positivity* (the index is positive), *continuity*, *proportionality* (if all the quantities produced by a firm increase by the same proportion, then its output index increases by that proportion), *commensurability* (independence of the units of measurement of quantities), *time-reversal test* (if one exchanges the firm and the "reference" firm, the new index is equal to the inverse of the previous one), *mean-value test* (the index is ranked between the extreme values of the partial quantity ratios), *factor-reversal test* (a link between quantity index, price index and value index) and *transitivity* (invariance of the results with respect to the “reference” firm).

The Fisher Index satisfies all criteria except the last one. Similarly, the Tornqvist Index satisfies all criteria except the last two. For the other usual indexes, at least three criteria are not satisfied. This explains the extensive use of the Fisher and the Tornqvist indexes in empirical studies, even though it can be shown that all the indexes are highly correlated and, from a practical point of view, provide very similar results[4].

2.1.2 Multilateral aggregation method

In the case of time-series comparisons (same ANSP observed over different time periods), the results in terms of TFP can be ranked by (natural) time order, i.e. start from a notional value (generally 100 or 1) and compute for each period *t* the TFP index for the ANSP at date *t*, the “reference” ANSP being the same ANSP at the previous time *t-1*. The whole series of TFP indexes can be computed with this rule (the indexes are said to be chained).

In the cross-section case (several ANSPs observed at a fixed time period), there is no natural order and the choice of the sequence order can affect the results. Given that the ACE data set comprises cross-section information for 29 ANSPs over a three year period (2001, 2002 and 2003), it is important that a proper framework be developed to analyse TFP in the context of panel data. In other words, the TFP indexes should provide consistent productivity comparisons across ANSPs and across time. This can be achieved with transitive indexes. Unfortunately, no index number (even Fisher or Tornqvist) satisfy the transitivity property (see Section 2.1.1 above).

Caves *et al.* (1982) developed an aggregation procedure based on the Tornqvist index that enables comparisons to be made among panel data observations (time series of cross-section) by generating transitive indexes. This procedure is known as the CCD[5] aggregation method[6] and the indexes arising from this procedure are “multilateral”:

$$\ln Q_{st} = \frac{1}{2}\sum_{i=1}^{N}\left(\omega_{it} + \overline{\omega_i}\right)\times\ln\left(\frac{q_{it}}{\tilde{q}_i}\right) - \frac{1}{2}\sum_{i=1}^{N}\left(\omega_{is} + \overline{\omega_i}\right)\times\ln\left(\frac{q_{is}}{\tilde{q}_i}\right),$$

where:

- N is the number of outputs (respectively inputs);
- Q_{st} is the multilateral output (respectively input) index for the ANSP t with ANSP s as base;
- ω_{it} represents the revenue share (respectively cost share) relating to output i (respectively input i) for ANSP t;
- q_{it} is the quantity of output i (respectively input i) relating to ANSP t;
- $\overline{\omega_i}$ represents the arithmetic mean across all ANSPs of the revenue shares (respectively cost shares) relating to output i (respectively input i), and;

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[4] See Diewert (1992) for a theoretical analysis.

[5] Caves, Christensen, Diewert.

[6] The formula is explained in further detail with a numerical example in the Appendix.

- $\tilde{q}_i$ represents the geometric mean across all ANSPs of the quantities associated to output i (respectively input i).

In this formula, the comparison of two ANSPs is made by comparing each ANSP with the average ANSP. Note that revenue shares are used as weights for the aggregation of outputs, while cost shares are used for the aggregation of inputs. A drawback of this methodology is that it cannot define an index for an ANSP which displays a zero quantity in one input or output.

This paper follows the CCD methodology to compute estimates of the relative levels of TFP for the 29 ANSPs during the three year period 2001-2003.

2.2 Gross (observed) TFP index versus "residual" TFP index

There exist a number of characteristics that influence the performance measures based on observed TFP index. These include, inter alia, output and operating characteristics such as average transit time per aircraft, traffic variability, and a number of "complexity" variables such as the structure of the traffic mix and the density of the airspace. Many of these factors are largely beyond ANSPs' managerial control, i.e. they are exogenous, and as such, the differences in these factors will need to be controlled before making any meaningful comparison of performance across different ANSPs or over time within an ANSP. Similarly, the level of quality of service associated with a given output can also affect the gross (observed) TFP index.

To overcome this problem, some researchers have suggested a "two-step" approach to adjust the gross TFP results by regressing the results over a number of variables deemed relevant to capture the effects of the "uncontrollable" factors and to adjust for the quality of service (see e.g., Caves *et al*. (1981), Oum and Yu (1995)). However, there is discussion among researchers on the way such ad-hoc adjustments could and should be performed. This work will be left for future research where TFP can be explicitly derived from a structural model which can be empirically estimated. As a first attempt, this paper proposes to regress the observed TFP index on a set of relevant variables in order to estimate which variable seems to empirically affect the TFP level.

3 EMPIRICAL APPLICATION TO ANS

3.1 Scope of the analysis

The data used were collected in the context of Economic Information Disclosure (EID) to the EUROCONTROL Performance Review Commission (PRC) for the years 2001, 2002 and 2003. The data were collected and validated in cooperation with the European ANSPs and comprise economic, financial and operational information. An economic analysis of the data can be found in the ACE Benchmarking Reports (see PRC web site at www.eurocontrol.int/prc). There are large variations in geographical scope, output size, and other market and operating characteristics among the sample ANSPs. Note that for time comparison purposes only those 29 ANSPs[7] that have consistently provided information since the ACE 2001 are taken into account (see Figure 1).

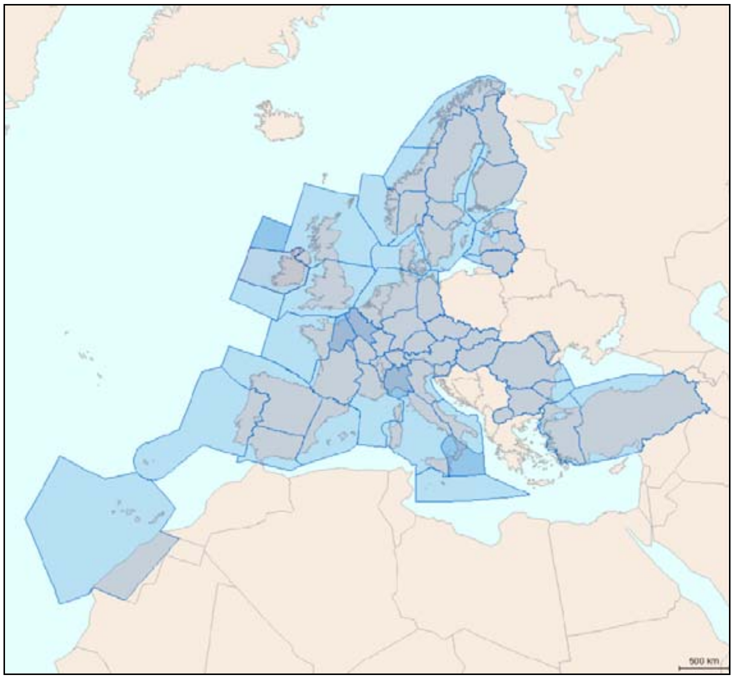

Figure 1: ANSPs providing information since ACE 2001

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[7] Aena (Spain), ANS CR (Czech republic), ANS SE (Sweden), ATSA Bulgaria, Austro Control, Belgocontrol (Belgium), DFS (Germany), DHMI (Turkey), DNA (France), EANS (Estonia), ENAV (Italy), Finland CAA, FYROM CAA (Macedonia), HungaroControl, IAA (Ireland), LGS (Latvia), Oro Navigacija (Lithuania), LPS (Slovak Republic), LVNL (The Netherlands), MIA/MATS (Malta), MoldATSA (Moldova), MUAC (Maastricht), NATAM/Avinor (Norway), NATS (UK), NAV Portugal (FIR Lisboa) (Portugal), NAVAIR (Denmark), ROMATSA (Romania), Skyguide (Switzerland), Slovenia CAA.

3.2 Definition of ANS and its breakdown

According to ICAO, ANS comprise Air Traffic Management, Communication, Navigation, and Surveillance (ATM/CNS), and other services such as Aeronautical Information Services (AIS), Aeronautical Meteorological Services (MET), and Search and Rescue Services (SAR) (see PRU Working Paper "Cost effectiveness and Productivity KPI's" (2001)). Costs for the provision of ATM/CNS comprise the bulk of ANS costs (some 90%). Moreover, MET services are often provided by organisations other than ATM/CNS providers[8]. Besides, it would be very difficult to obtain output metrics for the other services such as MET, AIS and SAR. Therefore, for the purposes of this paper, the analysis will only focus on ATM/CNS provision.

3.3 Definition of outputs for ATM/CNS provision

ANS cover three phases of the flight: en-route control, approach control and terminal control. There is no precise (operational) definition on where the boundaries are set for the approach control phase. In practice, the approach control phase depends on the organisation of the operational units within the different ANSPs so that it can be part of the en-route control or the terminal control.

Most European ANSPs apply two types of charges associated with ANS provision: en-route charges and terminal navigation charges (TNC). Because some discretion is used to allocate costs for the approach control phase either to en-route or to terminal, any productivity/cost-effectiveness analysis which focuses on one phase of flight (e.g. en-route) is likely to be affected by differences in allocation of costs (i.e. inputs). It is therefore useful to have a "gate-to-gate" TFP measure and to compute a global output measure that combines the service provided for the three phases of flight.

Several potential measures can be used to characterise the services provided. The fact that controlling a flight in an en-route environment is different from controlling a flight in a terminal environment requires particular attention for the selection of relevant output metrics.

3.3.1 En-route

In the en-route control environment, air traffic controllers (ATCOs) can be viewed as producing capacity to provide a "safe, efficient and orderly flow" of air traffic: from a "demand side" aircraft pass into specific en-route sectors and ATCOs ensure that aircraft are separated according to well defined criteria. From a "supply side" the ATM system provides a volume of (en-route) sector-hours which will determine the amount of capacity provided. Capacity cannot be stored and this available capacity can be used more or less extensively by aircraft depending on the traffic volume fluctuations (hour, day, week, season). Clearly, there are no obvious ways to measure capacity as it has both spatial and temporal dimensions. Having a metric which is straightforward to compute and comparable across ANSPs inevitably requires the use of proxies to estimate en-route production.

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[8] See Performance Review Unit "Report on Aeronautical MET Costs", May 2004, www.eurocontrol.int/prc.

The number of flights or movements controlled is clearly not entirely satisfactory as an en-route output measure given that, first, it depends on the volume of airspace controlled by a given ANSP (a movement over 100 km is not the same as a movement over 1000 km), second, it does not reflect the work involved for providing the service (a movement in a highly dense part of airspace is not the same as a movement in a sparse area). Moreover, this metric depends on the organisation of the operational units (e.g. if one ANSP decides to combine two adjacent ACCs, its output measured in terms of movements will be divided by a factor of (nearly) two.

In empirical work on airline productivity micro-economists use (amongst other) the number of passenger-miles transported as a production metric. A natural translation of this measure to ATM/CNS provision is the number of kilometres controlled or flight-hours controlled. These measures are readily available and, contrary to movements, they reflect the size of the area involved (see KPI Working Paper).

The number of kilometres controlled is one of the metrics proposed for measuring the production associated with en-route ANS. Clearly, there are several ways to define the number of kilometres for a given flight: it can be the great circle distance, the distance along the flight plan or the real distance flown. However, these measures are very close to each other.

The number of flight-hours controlled is highly correlated with kilometres and easier to obtain from an empirical point of view (it is measured for each ATC operational unit described in the EUROCONTROL Central Flow Management Unit (CFMU) environment, and can be summed up without problem). This proxy will be used to characterise en-route production: it has the attractive properties of being easy to compute, transparent, measured consistently across ANSPs and additive.

3.3.2 Terminal

Controlling a flight in a terminal area consists in arranging take-off and landing sequencing. Using kilometres or flights-hours controlled would not be appropriate in the context of terminal control. The number of airport movements handled would seem a better metric to capture the terminal output. Logically, all IFR and VFR airport movements should be counted because both consume non-negligible resources. However, within EUROCONTROL Member States there is no comprehensive data set on the number of controlled VFR airport movements (see KPI Working Paper). Preliminary indications are that the number of controlled VFR airport movements is relatively marginal with respect to IFR airport movements. As a consequence, only IFR movements are considered for the terminal output metric.

3.4 Definition of input metrics for ATM/CNS provision

Inputs can be aggregated or disaggregated depending on data availability. For the purposes of this study the following three main categories of inputs are considered: labour, capital, and other (operating) inputs which comprise items such as materials, energy, purchased goods and services, etc. The economic analysis of ACE data suggests that

ATM/CNS provision is both labour and capital intensive. We detail below these three input categories.

3.4.1 Labour

Labour is one of the two usual inputs (with capital) used in basic models of firm production. In fact ATM/CNS provision is found to be a relatively labour intensive activity. On average, the cost share of labour is equal to some 56% of the total ATM/CNS provision costs. It is generally the largest cost items for ANSPs.

There are several different categories of staff associated with ATM/CNS provision[9]. Among the various categories, Air Traffic Controllers (ATCOs) are the work force directly involved in the "production" process. As ATCOs are the most highly specialised and scarce resource in this process[10], their average employment costs are significantly higher than for the other staff categories.

For the purpose of this analysis, two types of labour input are considered: ATCOs in Operations on the one hand (some 30% of total staff), and all the other remaining staff, on the other hand (some 70% of total staff). The latter type can be viewed as support staff for the ATM/CNS process (assistants, engineering, administration staff, etc.).

For each labour input a quantity and a price series are required to compute a TFP index. In the ACE data, we observe both the number of full-time equivalent (FTE) ATCOs in Operations and the associated number of working hours on duty in Operations. Due to international differences in the number of hours worked per year (because of differences in local legislation, etc.), it is preferable to use the number of ATCOs working hours rather than the number of FTE ATCOs.

On the other hand, for all the other remaining staff FTEs had to be used since no data on the number of working hours is available.

3.4.2 Capital

ANSPs use capital services in the ATM/CNS production process. The costs share associated with these capital services amount to some 20% of the annual ATM/CNS provision costs. These comprise two parts: (1) depreciation and (2) an element reflecting the opportunity cost of capital.

Several types of capital services are used including: buildings, controller working positions, various ATM equipment with sophisticated Flight Data Processing (FDP) and Radar Data Processing (RDP) systems, CNS infrastructure (such as NAVAIDS, surveillance radars) etc.

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[9] See the Specification for Information Disclosure, Table C, which can be found on the web site at www.eurocontrol.int/prc.

[10] In fact, in the Specification for Information Disclosure different sub categories of ATCOs are defined, including ATCOs in Operations, ATCOs on other duties, and ATCO trainees. ATCOs in Operations hold the required licence to provide ATC services. The PRU computes its (partial) productivity indicators on the basis of FTE ATCOs in Operations.

Ideally, one would observe the inventory list of all the key assets which comprise the **flow**[11] of capital services used in the production process: the number of ATC operational units/buildings, such as ACCs[12], APPs[13], TWRs[14], and their operating hours; the number of controller working positions hours that have been used, operating hours of NAVAIDs (such as ILSs, VORs, DMEs) and surveillance radars, etc. Then, for each of these capital quantities an economic cost would be determined and used to aggregate the various quantities.

In empirical analysis, however, the capital input is often the most problematic to measure and assess. First, an inventory list of the key physical capital is generally not available for research purposes. What is usually available is the aggregated accounting value of the **stock** of physical capital, as reported in the year-end Balance Sheet statement, which sometimes includes the disclosure of a subset of key assets (typically land, building, machines, equipment, etc). Second, as opposed to labour services which are hired by an ANSP, capital services are generally bought by the ANSP and owned throughout the asset life. As a consequence, the computation of an economic cost for the capital services rendered is not straightforward given that it has to take into account the purchase price and its economic depreciation throughout the asset life. In fact, if all the assets were rented or leased, the price (annual costs) of each capital service would correspond to its rental/leasing fee. Finally, there are different ways to report accounting values of purchased assets: the Gross Book Value (GBV) at historical costs, the GBV at replacement costs, and the Net Book Value (NBV) which is the GBV value less the cumulative (accounting) depreciation. From an economic point of view it would be preferable to use the GBV at replacement (i.e. market value) costs since this measure would be less influenced by different depreciation rules[15] and different positions in the investment cycle. However, only NBV values are currently available from the ACE data.

Given these limitations, empirical TFP analysis typically uses proxies to measure the amount of capital services and their associated prices. Examples include, inter alia, the accounting value of the rolling stock and the rail length for rail studies (Australian Industry Commission, 1992), the number of buses in a urban transport study (Oben *et al*. (1992), the number of gates and runways for airport studies (Gillen and Lall (1999)), and a fleet quantity index for airline studies (Oum and Yu (1996)). Clearly, the choice of proxies is often determined by the availability of data.

As a consequence, for the purposes of this study it is assumed that the flow of capital services can be proxied by, on the one hand, the number of hours en-route sectors are open and, on the other hand, by the number of APPs and TWRs operational units.

The number of hours en-route sectors are open is directly related to the productive capability performed by Area Control Centres (ACCs) in the en-route environment. Each sector requires a number of controller working positions equipped with sophisticated ATM tools and software, etc. Moreover, the size of the ACC building is usually related to the number of controller working positions. By and large, the number of sector-hours is a fair

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[11] In most empirical work, it is assumed that the stock of capital at the end of the period, which is more readily available, is proportional to the flow of capital used during the period.

[12] Area control centers.

[13] Approach control units.

[14] Tower control units.

[15] This is a recurrent problem in international comparisons of capital productivity.

reflection of the direct physical assets used by ACCs, although it is likely that some capital assets might not necessarily be proportional to the number of sector-hours.

Similarly, the number of APP and TWR operational units managed[16] by an ANSP is more relevant in the context of the terminal output metric. The number of APPs and TWRs should correlate fairly well with the number of terminal NAVAIDS (ILS, DME, etc.) and other communication and surveillance equipment[17]. A limitation with the use of the TWR operational units as proxy for the terminal capital input is that a small TWR unit opened 8 hours a day represents the same input quantity than a large TWR unit opened 20 hours a day.

Clearly, future research and further data would be required for the measurement of physical capital and its monetary value, especially in the context of terminal control. At this stage, it is important to note that since the cost share associated with capital for terminal ANS is only some 4%, the assumptions used to derive the capital input will not highly impact on the final TFP index results.

3.4.3 Other operating inputs

For pragmatic reasons, the third input considered includes a variety of heterogeneous items which comprise (non-staff) operating costs and exceptional cost items[18]. The costs share associated with these other operating inputs amount to some 20% of the total ATM/CNS provision costs. Operating costs for ATM/CNS provision include purchase of goods (raw materials, energy, and non-capitalised maintenance parts, furniture, etc.), purchase of (outsourced) services[19], and cost items such as, rentals, insurance, etc.

Clearly, no readable quantities are available for this “catch-all” input. The information from the ACE data set does not allow us to have a very detailed understanding of the various sub-items (e.g., telecommunications, outsourcing services, rents and insurance, parts, etc.) comprising operating costs. In fact, only a lump sum (monetary) figure is observed corresponding to the total (non-staff) operating costs.

In several empirical studies (e.g. Oum and Yu, 1996), the operating expenses are deflated by an appropriate price index to obtain a series of quantity for “other operating inputs”. The underlying assumption from this computation is that all the operating expenses are made at local prices. Therefore, similar amounts of operating costs would represent the same “quantity” if the ANSPs/countries face the same cost of living. On the contrary, for a country

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[16] The degree of flexibility to adapt the level of inputs may vary since some inputs tend to be fixed in the short run. There is arguably little managerial discretion to decide which APPs and TWRs to be operated, although some discretion on the number of operating hours could be envisaged.

[17] It should also be noted that some ANSPs do not own all the teminal CNS infrastructure that might be located near an airport. This underestimates the true cost of capital related to terminal ANS.

[18] Only few ANSPs report exceptional cost items. For more details see the ACE Benchmarking Reports.

[19] Some ANSPs prefer to use internal staff for the whole ATM/CNS “production” process, including technical maintenance and R&D functions, while other ANSPs prefer to outsource some elements of the process. In the latter case, the costs associated with outsourced staff/services are included as operating costs. Clearly any PFP indicator that is measured on the internal staff only is likely to be affected by differences in outsourcing policies. On the other hand, the TFP framework has the advantage of being a global measure and, hence its results less likely to be influenced by the organisation of the production process.

whose cost of living is half the level of another country, this assumption means that it would use twice the quantity of "other operating inputs". This assumption is appropriate when the share of "local" expenditure (such as rent, purchase of local services and goods, etc) is large and the share of expenditures in international market prices (such as specialised consulting services, insurance, energy, etc) is small. The current data availability unfortunately offers no clue on the nature of these expenditures, and it is likely to vary from one ANSP to another. Therefore for the purposes of this study, it is assumed[20] that 50% of the expenditures are made in international market prices and 50% in local prices. Note that Section 5 provides a sensitivity analysis of TFP scores and the hypothesis that 100% of the expenditures are made in local prices is considered. In future research it would be interesting to further refine this assumption and perhaps identify two types of "other operating inputs": those that are bought at local market prices and those procured at world market prices.

3.5 Multilateral output and input indexes

In Section 3.3 we distinguish two categories of outputs for the ATM/CNS provision: the number of flight-hours controlled and the number of IFR airport movements. Table 1 displays the outputs and the revenues derived from the EID for the years 2001-2003. For ease of comparison between ANSPs the two following adjustments have been made on revenues data:

1. En-route revenues have been reduced by an amount corresponding to EUROCONTROL costs. This will enhance the comparability since four ANSPs in the sample are not under the full-cost recovery mechanism and do not recover EUROCONTROL costs.

2. Contrary to en-route, whereby costs equal revenues by virtue of the full cost recovery regime [21], terminal ANS revenues do not necessarily match terminal ANS costs. For example, a "loss" in terminal ANS is often recovered from a surplus arising in other activities (e.g. consultancy, etc) or from state subsidies. As a consequence, for those ANSPs[22], cost rather than revenue shares are used to compute the multilateral output indexes.

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[20] Using the Price Level Index for GDP from EUROSTAT (the ratio of Purchasing Power Parities (PPP) to the exchange rate for each country).

[21] Except for NATS which operates under economic regulation with a price-cap incentive scheme.

[22] The share of en-route and terminal ATM/CNS provision costs have been used to compute the multilateral output indexes for Aena (2001-2002-2003), ATSA Bulgaria (2001), DHMI (2001-2002-2003), EANS (2001-2002-2003), ENAV (2001), Finland CAA (2001-2002-2003), FYROM CAA (2003), IAA (2002), LGS (2002), LPS (2001, 2002), MATS (2003), NAV Portugal (FIR Lisboa) (2001-2002), Oro Navigacija (2003) and ROMATSA (2002, 2003).

ANSPs	Year 2001				Year 2002				Year 2003			
	Total en-route revenues excluding EUROCONTROL receipts (in '000 Euro 2003)	Total flight hours controlled by ANSP ('000)	Terminal revenues (in '000 Euro 2003)	IFR Airport movements controlled by the ANSP	Total en-route revenues excluding EUROCONTROL receipts (in '000 Euro 2003)	Total flight hours controlled by ANSP ('000)	Terminal revenues (in '000 Euro 2003)	IFR Airport movements controlled by the ANSP	Total en-route revenues excluding EUROCONTROL receipts (in '000 Euro 2003)	Total flight hours controlled by ANSP ('000)	Terminal revenues (in '000 Euro 2003)	IFR Airport movements controlled by the ANSP
Aena	398 407	1 087	121 637	1 599	468 517	1 073	128 284	1 580	576 976	1 131	140 148	1 669
ANS CR	35 268	120	14 974	102	42 868	132	17 328	109	42 210	152	20 118	121
ANS Sweden	119 794	407	22 844	630	129 404	383	23 513	584	131 906	383	24 583	556
ATSA Bulgaria	77 742	117	7 830	46	74 762	119	7 723	52	64 033	114	5 366	59
Austro Control	118 834	219	34 429	303	120 958	213	32 460	306	123 900	220	34 100	321
Avinor	58 892	246	58 534	556	60 697	242	101 711	509	69 004	271	70 693	544
Belgocontrol	109 673	124	32 039	389	141 310	112	27 011	361	160 250	108	29 467	367
DFS	608 197	1 231	205 687	1 911	635 251	1 190	202 547	1 883	793 291	1 181	225 955	1 919
DHMI	186 489	356	75 397	330	130 998	386	72 514	328	123 372	389	65 468	328
DNA	748 243	1 915	193 312	1 972	808 476	1 972	205 787	1 964	884 624	1 999	196 358	1 879
EANS	8 162	28	567	26	8 305	29	697	27	8 303	32	694	28
ENAV	393 773	1 005	69 474	1 208	390 353	983	148 526	1 198	495 640	1 033	150 933	1 256
Finland CAA	20 689	117	9 555	262	23 202	109	12 655	244	23 000	109	8 356	246
FYROM CAA	7 557	18	3 155	18	6 827	17	3 728	15	8 061	18	1 138	14
HungaroControl	38 623	141	6 816	77	49 975	139	8 819	74	50 810	149	8 966	85
IAA	50 092	196	7 874	236	52 012	188	7 339	229	73 654	197	10 017	237
LGS	12 334	31	2 544	18	12 350	31	1 594	17	12 294	35	2 271	18
LPS	22 224	44	1 183	18	25 587	46	1 086	23	28 980	54	1 478	28
LVNL	104 140	166	67 323	494	107 497	154	82 101	477	125 205	146	69 900	456
MATS	7 875	25	1 514	27	9 068	26	1 481	26	11 481	32	32	27
MoldATSA	1 391	5	925	11	1 559	5	912	11	1 743	5	807	10
MUAC	100 836	438	n/appl	n/appl	104 683	428	n/appl	n/appl	110 181	440	n/appl	n/appl
NATS	666 511	1 289	147 574	1 725	628 498	1 245	142 933	1 699	623 495	1 225	142 219	1 741
NAV Portugal (FIR Lisboa)	85 321	216	15 830	214	109 497	218	16 442	217	107 297	222	18 211	218
NAVIAIR	63 076	212	22 846	371	59 335	200	21 735	355	71 471	193	20 269	352
Oro Navigacija	9 886	21	1 378	22	9 952	23	1 362	21	11 379	23	1 281	25
ROMATSA	95 176	182	14 254	65	107 182	187	7 297	68	115 423	206	8 668	81
Skyguide	116 126	319	57 325	476	128 019	303	53 140	450	135 276	303	58 153	432
Slovenia CAA	11 541	25	1 439	23	10 123	24	1 222	24	11 072	24	1 241	26
European system level	4 276 870	10 299	1 198 259	13 130	4 457 266	10 177	1 331 946	12 850	4 994 329	10 396	1 316 889	13 041

Table 1: Outputs and revenues for 2001-2003

ANSPs	Year 2001									
	ATCOs in OPS		Other staff		Other operating input		Capital for en-route ANS		Capital for terminal ANS	
	Staff costs for ATCOs in OPS (in '000 Euro 2003)	ATCO-hours on duty ('000)	Staff costs for other staff (in '000 Euro 2003)	Other staff	Direct operating costs (in '000 Euro 2003)	"Other operating input" ('000)	En-route capital-related costs (in '000 Euro 2003)	Number of en-route sector-hours ('000)	Terminal capital-related costs (in '000 Euro 2003)	Number of TWRs operational units
Aena	239 285	2 336	108 777	1 983	126 949	1 373	63 656	279	34 698	34
ANS CR	7 946	234	13 623	597	10 632	161	15 923	27	3 236	4
ANS Sweden	27 100	542	50 291	591	37 975	354	12 029	138	3 032	35
ATSA Bulgaria	12 458	341	25 303	1 185	23 979	483	16 951	38	1 839	5
Austro Control	31 822	350	57 799	654	17 215	168	23 370	45	6 990	6
Avinor	36 796	679	26 937	649	33 199	294	15 463	126	17 036	12
Belgocontrol	31 786	395	45 403	767	17 681	174	12 959	40	2 572	5
DFS	157 690	2 126	311 854	3 311	112 626	1 067	115 816	630	49 546	17
DHMI	7 211	753	41 486	4 304	35 256	576	60 397	88	14 609	34
DNA	189 355	3 199	370 459	6 264	144 119	1 420	186 848	468	32 084	77
EANS	893	58	1 395	66	1 501	21	1 344	9	383	1
ENAV	146 552	1 894	120 341	1 940	174 400	1 802	64 996	307	14 039	26
Finland CAA	16 289	318	16 120	328	10 777	102	4 269	25	7 129	19
FYROM CAA	1 217	137	2 884	155	3 235	57	2 977	35	1 098	2
HungaroControl	6 793	263	11 690	517	16 980	257	8 658	26	115	1
IAA	15 162	377	21 271	304	15 740	148	4 825	88	1 226	3
LGS	956	67	2 479	83	6 731	99	3 816	20	1 101	1
LPS	3 914	182	7 304	388	6 761	112	7 449	26	349	6
LVNL	19 077	274	63 788	840	31 460	307	18 392	30	17 444	4
MATS	2 580	79	2 971	155	1 045	27	1 928	12	360	1
MoldATSA	220	97	582	224	754	13	498	18	256	1
MUAC	27 050	276	50 891	366	12 003	117	10 891	68	n/appl	n/appl
NATS	138 949	1 649	283 578	4 026	322 734	3 017	172 593	436	3 532	14
NAV Portugal (FIR Lisboa)	27 349	314	64 340	592	12 664	147	11 086	38	3 039	6
NAVIAIR	17 562	343	33 131	556	22 926	204	8 959	61	1 559	8
Oro Navigacija	1 378	113	3 737	256	3 286	52	3 093	15	154	4
ROMATSA	19 475	808	21 337	1 323	21 177	394	21 434	96	2 432	17
Skyguide	43 892	364	74 971	745	34 883	296	14 793	75	6 958	4
Slovenia CAA	3 663	102	1 486	66	3 484	42	2 962	14	409	3
European system level	1 234 421	18 671	1 836 228	33 235	1 262 172	13 284	888 376	3 277	227 226	350

ANSPs	Year 2002									
	ATCOs in OPS		Other staff		Other operating input		Capital for en-route ANS		Capital for terminal ANS	
	Staff costs for ATCOs in OPS (in '000 Euro 2003)	ATCO-hours on duty ('000)	Staff costs for other staff (in '000 Euro 2003)	Other staff	Direct operating costs (in '000 Euro 2003)	"Other operating input" ('000)	En-route capital-related costs (in '000 Euro 2003)	Number of en-route sector-hours ('000)	Terminal capital-related costs (in '000 Euro 2003)	Number of TWRs operational units
Aena	279 274	2 667	124 006	2 033	121 424	1 313	61 165	300	31 885	34
ANS CR	9 285	233	15 469	603	12 932	185	16 346	26	3 616	4
ANS Sweden	45 445	768	33 485	444	44 148	407	16 865	132	816	35
ATSA Bulgaria	12 129	344	23 283	1 164	22 938	446	17 013	38	2 062	5
Austro Control	32 327	359	53 824	618	15 209	148	20 619	46	6 329	6
Avinor	50 016	665	30 746	648	36 450	312	16 568	117	24 748	12
Belgocontrol	38 596	343	48 879	769	17 308	171	11 798	39	2 226	5
DFS	157 593	2 152	337 418	3 343	89 918	855	130 574	606	47 925	17
DHMI	8 177	824	47 046	4 437	38 931	590	55 864	114	11 977	34
DNA	193 690	3 269	391 300	6 466	147 178	1 441	168 996	487	31 933	77
EANS	1 091	46	1 316	73	1 304	18	1 796	9	1 196	1
ENAV	151 453	2 007	151 796	2 041	167 531	1 715	70 062	306	15 868	26
Finland CAA	15 572	318	16 188	350	13 918	132	3 942	25	6 118	19
FYROM CAA	1 459	88	2 101	191	2 821	49	3 573	9	1 852	2
HungaroControl	8 933	269	14 563	542	17 168	243	8 428	26	1 887	1
IAA	16 459	363	22 620	319	19 539	182	3 917	95	968	3
LGS	1 318	96	2 040	56	6 307	94	3 619	18	494	1
LPS	4 080	171	7 580	382	6 078	99	7 721	22	418	6
LVNL	20 214	283	77 135	904	28 841	279	16 936	30	18 582	4
MATS	1 544	101	4 399	164	2 239	27	1 905	12	360	1
MoldATSA	219	66	444	242	787	14	565	18	352	1
MUAC	28 151	276	51 843	388	14 771	143	9 918	68	n/appl	n/appl
NATS	131 616	1 815	255 523	3 555	190 870	1 803	228 394	416	3 635	14
NAV Portugal (FIR Lisboa)	28 862	352	56 297	593	12 790	148	15 226	41	3 480	6
NAVIAIR	20 490	337	30 208	535	15 694	138	9 048	61	2 154	8
Oro Navigacija	1 444	108	3 503	252	3 399	52	2 598	15	124	4
ROMATSA	20 951	839	24 694	1 305	23 724	443	22 358	96	2 680	17
Skyguide	42 878	385	77 010	842	17 888	152	19 321	81	8 400	4
Slovenia CAA	4 874	106	1 435	64	3 189	38	2 266	14	221	3
European system level	1 328 139	19 647	1 906 151	33 324	1 095 294	11 638	947 401	3 267	232 306	350

ANSPs	Year 2003									
	ATCOs in OPS		Other staff		Other operating input		Capital for en-route ANS		Capital for terminal ANS	
	Staff costs for ATCOs in OPS (in '000 Euro 2003)	ATCO-hours on duty ('000)	Staff costs for other staff (in '000 Euro 2003)	Other staff	Direct operating costs (in '000 Euro 2003)	"Other operating input" ('000)	En-route capital-related costs (in '000 Euro 2003)	Number of en-route sector-hours ('000)	Terminal capital-related costs (in '000 Euro 2003)	Number of TWRs operational units
Aena	373 302	2 768	131 433	2 021	126 697	1 359	66 973	303	33 651	34
ANS CR	9 918	236	17 747	599	11 310	162	14 794	28	4 920	4
ANS Sweden	44 332	739	34 509	452	36 298	331	15 590	132	754	35
ATSA Bulgaria	10 709	342	19 943	1 096	12 336	235	18 889	38	1 146	5
Austro Control	35 282	378	57 618	586	13 500	131	19 500	48	6 100	6
Avinor	46 047	663	20 794	737	23 913	208	16 073	117	22 744	20
Belgocontrol	33 071	385	59 151	795	17 248	170	11 532	39	2 310	5
DFS	191 451	2 000	314 224	3 375	88 140	836	148 490	698	40 568	17
DHMI	8 710	858	48 518	4 391	41 568	618	53 422	114	11 460	29
DNA	198 957	3 306	391 138	6 686	151 484	1 467	181 412	502	30 522	77
EANS	1 321	50	1 529	73	1 499	21	1 785	10	1 200	1
ENAV	143 585	1 885	163 761	1 905	190 317	1 914	85 037	327	24 487	26
Finland CAA	17 713	283	10 750	325	13 576	128	3 057	25	4 151	19
FYROM CAA	1 437	87	2 291	196	3 834	67	3 599	10	1 191	2
HungaroControl	10 437	271	16 305	492	13 889	194	7 808	28	1 768	1
IAA	16 533	359	33 914	255	19 930	183	3 800	60	986	3
LGS	1 633	108	1 435	55	5 612	86	4 372	18	971	1
LPS	4 432	147	8 049	386	6 542	101	8 692	26	483	6
LVNL	20 559	257	72 817	921	25 957	250	13 850	30	16 743	4
MATS	1 615	103	3 405	150	7 069	87	1 429	12	231	1
MoldATSA	211	63	779	268	862	15	391	18	209	3
MUAC	28 613	277	53 386	392	13 935	134	14 245	68	n/appl	n/appl
NATS	138 563	1 822	218 199	3 499	184 512	1 800	206 285	457	2 941	14
NAV Portugal (FIR Lisboa)	33 907	380	54 866	530	12 123	138	13 677	42	3 174	6
NAVIAIR	20 899	336	29 567	487	12 778	112	12 451	61	3 314	8
Oro Navigacija	1 543	109	4 206	252	2 753	42	3 736	15	162	4
ROMATSA	27 549	747	30 537	1 402	33 453	623	18 095	96	2 451	17
Skyguide	44 013	386	89 894	869	6 965	60	23 691	78	9 313	4
Slovenia CAA	4 321	100	2 327	65	2 270	26	2 738	14	225	3
European system level	1 470 664	19 447	1 893 091	33 260	1 080 371	11 498	975 411	3 411	228 175	355

Table 2: Inputs and costs for 2001-2003

Similarly the three input categories discussed in Section 3.4 and their associated costs are presented in Table 2. The labour input comprises the number of ATCOs in Operations (measured in terms of working hours) and the remaining support staff (measured in terms of FTE). The number of sector-hours and the sum APP and TWR operational units characterise the capital input (respectively for en-route and terminal ANS). Finally, the price level indexes of GDP[23] are used to compute a quantity series of “other operating inputs”.

To obtain a single measure that characterises ANSPs’ outputs or inputs, the different metrics reported in Table 1 and Table 2 are aggregated using the CCD methodology (see Section 2.1.2) to obtain multilateral output and input indexes, respectively.

The multilateral output indexes and their growth rates between 2001 and 2003 are displayed in Table 3 below.

ANSPs	Multilateral output index (2001)	Multilateral output index (2002)	Multilateral output index (2003)	Change 2001-2003 in %	Change 2001-2002 in %	Change 2002-2003 in %
Aena	1.000	0.987	1.043	4%	-1%	6%
ANS CR	0.095	0.104	0.118	24%	9%	13%
ANS Sweden	0.371	0.348	0.345	-7%	-6%	-1%
ATSA Bulgaria	0.085	0.087	0.086	2%	3%	-1%
Austro Control	0.197	0.192	0.200	1%	-2%	4%
Avinor	0.272	0.271	0.287	6%	0%	6%
Belgocontrol	0.135	0.118	0.115	-15%	-12%	-3%
DFS	1.141	1.106	1.100	-4%	-3%	0%
DHMI	0.291	0.309	0.311	7%	6%	1%
DNA	1.606	1.643	1.647	3%	2%	0%
EANS	0.023	0.024	0.025	12%	4%	8%
ENAV	0.874	0.858	0.900	3%	-2%	5%
Finland CAA	0.133	0.124	0.123	-7%	-7%	0%
FYROM CAA	0.015	0.013	0.014	-5%	-10%	6%
HungaroControl	0.104	0.099	0.108	3%	-5%	9%
IAA	0.170	0.163	0.171	1%	-4%	5%
LGS	0.023	0.023	0.026	11%	-2%	12%
LPS	0.032	0.035	0.041	28%	8%	18%
LVNL	0.193	0.185	0.170	-12%	-4%	-8%
MATS	0.021	0.022	0.025	19%	4%	15%
MoldATSA	0.005	0.005	0.005	6%	2%	4%
MUAC*	0.332	0.324	0.333	0%	-2%	3%
NATS	1.144	1.110	1.102	-4%	-3%	-1%
NAV Portugal (FIR Lisboa)	0.180	0.181	0.185	3%	1%	2%
NAVIAIR	0.203	0.192	0.184	-9%	-5%	-4%
Oro Navigacija	0.018	0.019	0.020	13%	7%	5%
ROMATSA	0.126	0.130	0.144	15%	3%	11%
Skyguide	0.296	0.279	0.276	-7%	-6%	-1%
Slovenia CAA	0.021	0.020	0.020	-1%	-3%	2%

Table 3: Multilateral output indexes (2001-2003)

Table 3 shows that that there is a wide range of output levels but also of output growth rates among ANSPs. In order to make the interpretation of the results easier, the values

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[23] See footnote 20

displayed in Table 3 are relative to Aena 2001 (the "reference" observation with a value of 1.000). A value lower (higher) than 1.000 indicates an output lower (higher) than Aena's 2001 output. The multilateral CCD aggregation method allows transitive comparisons across all observations (time series of cross-section). For example, Table 3 indicates that DNA's 2003 output is some 65% greater than Aena's 2001 output. Notice the significant differences in the output growth rate among ANSPs during the 2001-2003 period (-15% for Belgocontrol to +28% for LPS). Because of the terrorist attacks in September 2001, the Iraq war and the SARS epidemic in Spring 2003, all three years were, to some extent, atypical for the ATM industry. This also shows that, to a large extent, the level of output is exogenous for any given ANSP and that the challenge is to flexibly adjust the inputs to current and expected output levels.

As displayed in Table 1, MUAC only generates an output in the en-route environment. It is not possible to define a multilateral CCD index when one input or one output is zero. Therefore for MUAC (asterisked in Table 3) Fisher output indexes were computed since these are not affected when one output is equal to zero. It should be noted that the multilateral CCD and Fisher indexes are highly correlated (i.e. R^2 at 0.99 for the sample of ANSPs) and the two indexes produce very similar figures. Therefore, for the purpose of this paper these indexes can be considered as comparable.

Figure 2 shows that the multilateral output index is highly correlated (R^2 close to 1.000) with the output index (i.e. "composite flight-hours") used in the ACE reports, even though the formulae differ[24].

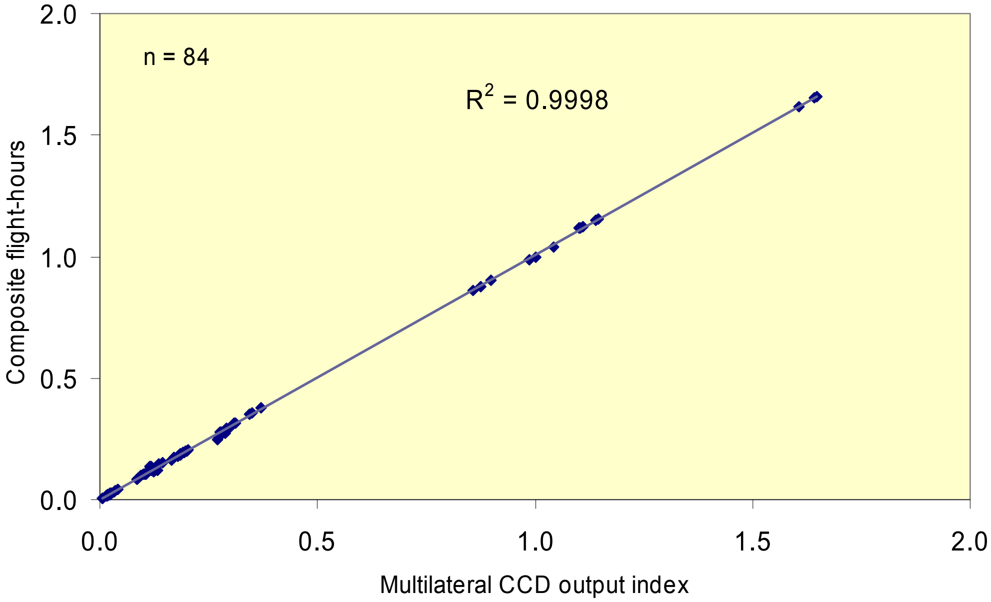

Figure 2: Multilateral CCD output index and composite flight-hours

Table 4 displays the multilateral input indexes for the whole sample observations. As for the sample of output indexes, there is a wide range both in terms of input levels and input

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[24] The "composite flight-hours" used in the ACE data analysis are computed using a Laspeyres index procedure.

growth rates during the 2001-2003 period. However, it is likely that some changes in data reporting between 2001 and 2003 have occurred and this could potentially explain some of the largest variations observed in Table 4. It is important to underline that data accuracy is improving each year and that trends observed in the multilateral input index will reflect more and more genuine performance changes.

ANSPs	Multilateral input index (2001)	Multilateral input index (2002)	Multilateral input index (2003)	Change 2001-2003 in %	Change 2001-2002 in %	Change 2002-2003 in %
Aena	1.000	1.050	1.083	8%	5%	3%
ANS CR	0.138	0.142	0.142	3%	3%	-1%
ANS Sweden	0.286	0.309	0.288	1%	8%	-7%
ATSA Bulgaria	0.270	0.262	0.212	-21%	-3%	-19%
Austro Control	0.182	0.177	0.173	-5%	-3%	-2%
Avinor	0.292	0.291	0.298	2%	0%	2%
Belgocontrol	0.194	0.186	0.196	1%	-4%	5%
DFS	1.106	1.071	1.097	-1%	-3%	2%
DHMI	0.598	0.671	0.676	13%	12%	1%
DNA	1.684	1.732	1.772	5%	3%	2%
EANS	0.025	0.024	0.026	5%	-2%	6%
ENAV	1.017	1.012	1.018	0%	-1%	1%
Finland CAA	0.129	0.137	0.128	0%	6%	-6%
FYROM CAA	0.066	0.046	0.051	-23%	-30%	10%
HungaroControl	0.154	0.150	0.137	-11%	-3%	-8%
IAA	0.147	0.157	0.132	-10%	7%	-16%
LGS	0.054	0.050	0.050	-7%	-7%	0%
LPS	0.107	0.098	0.100	-7%	-8%	2%
LVNL	0.198	0.202	0.197	-1%	2%	-3%
MATS	0.038	0.042	0.058	50%	8%	39%
MoldATSA	0.038	0.036	0.041	7%	-5%	12%
MUAC*	0.133	0.141	0.141	6%	6%	0%
NATS	1.507	1.239	1.260	-16%	-18%	2%
NAV Portugal (FIR Lisboa)	0.164	0.169	0.164	0%	3%	-3%
NAVIAIR	0.186	0.168	0.157	-16%	-10%	-6%
Oro Navigacija	0.062	0.061	0.058	-5%	-1%	-4%
ROMATSA	0.384	0.397	0.437	14%	3%	10%
Skyguide	0.227	0.215	0.194	-14%	-5%	-10%
Slovenia CAA	0.041	0.040	0.036	-12%	-2%	-10%

Table 4: Multilateral input indexes (2001-2003)

Table 4 shows that in 2003 several ANSPs used fewer inputs than in 2001. For ATSA Bulgaria, NATS, NAVIAIR, HungaroControl, Skyguide and Slovenia CAA, the decrease of the multilateral input index is mainly driven by a significant decrease of the "other operating inputs" (associated with operating costs) between 2001 and 2003. Given the somewhat exogenous nature of the output, it is particularly important for an ANSP to flexibly adjust its level of inputs.

It should be noted that the high input index increase (+50%) for MATS is the result of changes in data reporting between 2001 and 2003.

4 TFP RESULTS

4.1 TFP results at European system

The methodology presented in Section 2.1.2 and the CCD multilateral inputs and outputs presented in Section 3.5 are used to compute the productivity of the European ANS system as a whole. The multilateral TFP index is obtained by dividing the multilateral output index by the multilateral input index. Figure 3 displays the multilateral input, output and TFP indexes for the European system.

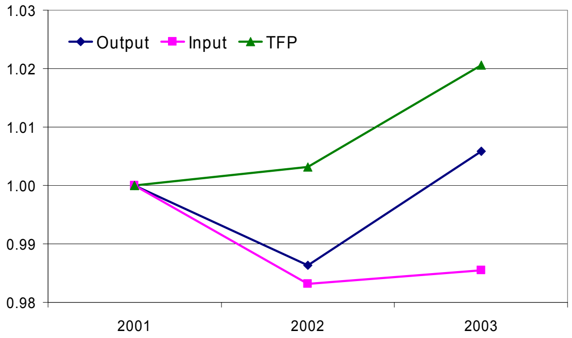

Figure 3: Multilateral input, output and TFP indexes for the European system

Figure 3 shows that between 2001 and 2003, the TFP index increased by some 2% at European system level. It is also worth noting that although the growth of output was negative between 2001 and 2002[25], the TFP of the European system slightly increased since the level of inputs has been reduced at a greater rate. Between 2002 and 2003 gains in TFP were achieved since the output index increased at a greater rate than the input index.

Figure 4 above displays on the one hand the TFP and, on the other hand, the five partial productivities computed as the output index divided by the relevant input quantity.

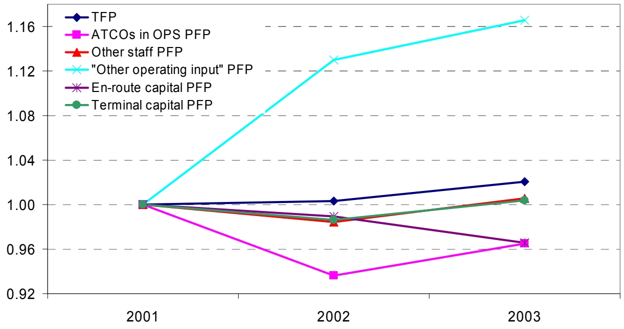

Figure 4: Partial productivity indexes for European system

Figure 4 shows that the impact of each input on TFP varies in time. This is a key feature of TFP which allows for the relative importance of inputs to change over time. Indeed, Figure

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[25] 2002 was a very special year for air transport due to the impact of the terrorist events of September 2001.

4 indicates that the partial productivity of the “other operating inputs” increased by some 16% between 2001 and 2003 while the partial productivity of “other staff” and terminal capital increased by less than 1%. On the other hand, the partial productivity of ATCOs in OPS and en-route capital both decreased by some 3.5%. In other words, the positive TFP growth achieved at European system level is mainly driven by a strong increase of the “other operating inputs” productivity which offsets the decrease of productivity of ATCOs in OPS and en-route capital.

4.2 TFP results at ANSP level

Table 5 below displays the multilateral TFP indexes for the 29 ANSPs which are computed using the multilateral CCD inputs and outputs presented in Section 3.5. The TFP indexes are normalised so that the level of Aena in 2001 is 1.000. The results show significant differences with values ranging in 2003 from 0.129 for MoldATSA to 2.364 for MUAC[26]. The highest TFP figure without MUAC is Skyguide with 1.422, i.e. some 47% higher TFP than the reference value (Aena 2001).

ANSPs	Multilateral TFP index (2001)	Multilateral TFP index (2002)	Multilateral TFP index (2003)	Change 2001-2003 in %
Aena	1.000	0.941	0.964	-4%
ANS CR	0.689	0.731	0.834	21%
ANS Sweden	1.297	1.127	1.197	-8%
ATSA Bulgaria	0.314	0.333	0.406	29%
Austro Control	1.080	1.088	1.152	7%
Avinor	0.932	0.931	0.964	3%
Belgocontrol	0.696	0.635	0.587	-16%
DFS	1.031	1.032	1.003	-3%
DHMI	0.486	0.460	0.460	-5%
DNA	0.954	0.948	0.930	-3%
EANS	0.914	0.964	0.979	7%
ENAV	0.860	0.848	0.885	3%
Finland CAA	1.032	0.903	0.959	-7%
FYROM CAA	0.225	0.289	0.278	23%
HungaroControl	0.679	0.660	0.785	16%
IAA	1.157	1.041	1.291	12%
LGS	0.435	0.460	0.518	19%
LPS	0.301	0.356	0.412	37%
LVNL	0.977	0.917	0.864	-12%
MATS	0.554	0.530	0.440	-21%
MoldATSA	0.131	0.140	0.129	-1%
MUAC*	2.490	2.302	2.364	-5%
NATS	0.759	0.896	0.875	15%
NAV Portugal (FIR Lisboa)	1.096	1.074	1.129	3%
NAVIAIR	1.087	1.145	1.172	8%
Oro Navigacija	0.286	0.309	0.339	19%
ROMATSA	0.328	0.328	0.330	1%
Skyguide	1.302	1.296	1.422	9%
Slovenia CAA	0.509	0.505	0.573	13%
1st quartile	0.486	0.460	0.460	
2nd quartile	1.032	1.032	1.003	

Table 5: Multilateral TFP indexes (2001-2003)

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[26] MUAC is a highly atypical ANSP as a whole, providing services in Upper Airspace only.

Table 5 also reports the first and third quartiles of the TFP scores distribution. These two quartiles provide further insights on the dispersion of the TFP results. In 2003, there is a factor of 2.2 between the two quartiles. This result is in line with the dispersion of the (partial) ATCO-hour productivity indicator[27] presented in the ACE 2003 Benchmarking Report (see also Section 4.5 for further details).

It should be noted that those significant differences among TFP levels may be driven by exogenous factors that are beyond ANSPs' managerial control (e.g. "traffic complexity"). An analysis of the impact of external factors on TFP scores is provided in Section 6. Therefore, although it is informative to look at relative TFP scores among ANSPs, it is more valuable to consider the TFP growth rate for a given ANSP since this is more readily comparable.

Table 5 indicates that TFP growth rates range from -21% for MATS to +37% for LPS. Table 5 also suggests that TFP increased in a majority of ANSPs between 2001 and 2003. Changes in TFP can be broken into an "output effect" (i.e. the input level remaining constant) and an "input effect" (i.e. the output remaining constant). Figure 5 shows both the input and output effects between 2001 and 2003 for the 29 ANSPs. As argued earlier, the level of output is, to a large extent, not within an ANSP's control, while the level of inputs is a managerial choice.

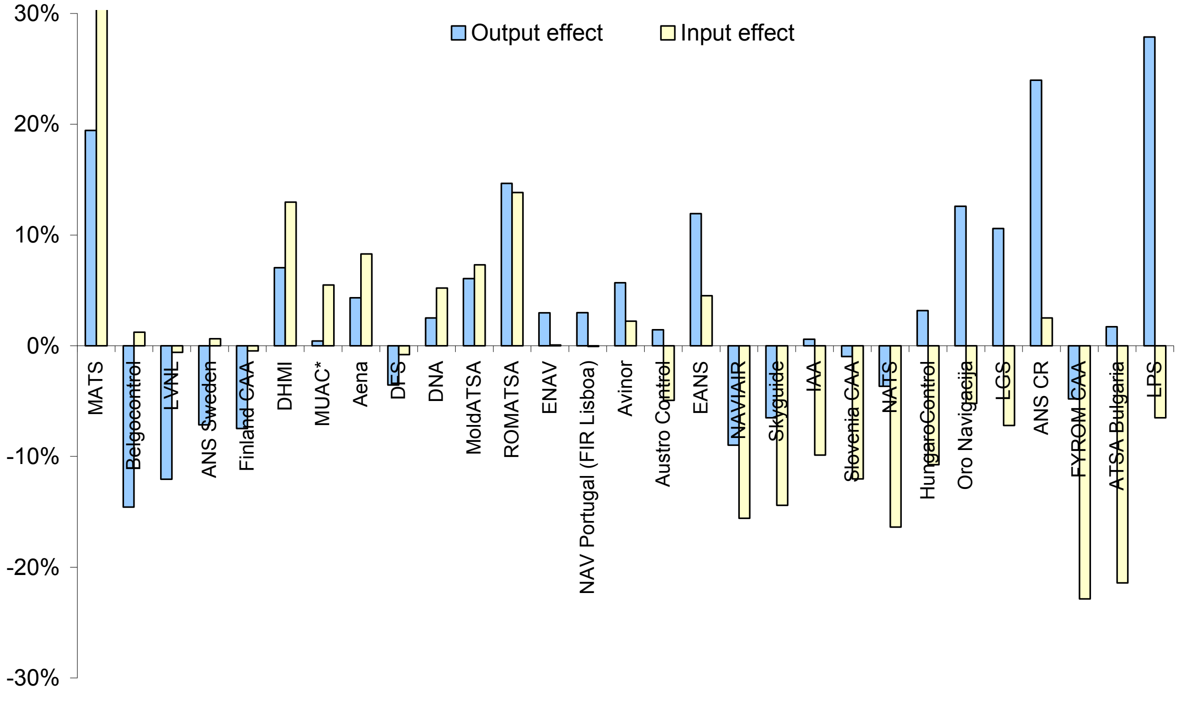

Figure 5: Breakdown of TFP into output and input effects

Between 2001 and 2003, four ANSPs achieved TFP growth rates greater than 20%: LPS (+37%), ATSA Bulgaria (+29%), FYROM CAA (+23%) and ANS CR (+21%). Figure 5 indicates that for ANS CR and LPS, the TFP increase is driven by an increase in the volume

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[27] In the ACE data analysis, the ATCO-hour productivity indicator is the ratio of the "composite flight-hours" with the number of ATCO-hours on duty.

of output. On the other hand, ATSA Bulgaria and FYROM CAA achieved significant TFP improvement by reducing the quantity of inputs.

Notice that eleven ANSPs experienced a negative TFP growth between 2001 and 2003. For Aena (-4%) and DHMI (-5%), the TFP decrease is mainly driven by a significant increase of inputs. Similarly, the traffic downturn is the main driver of the TFP decrease for ANS Sweden, Finland CAA, LVNL and Belgocontrol.

The high TFP decrease (-21%) for MATS is driven by a large increase of input quantities (+50%, capped in Figure 5). This increase is the result of changes in data reporting between 2001 and 2003. Data accuracy has improved each year since the implementation of Information Disclosure in 2001, and is further expected to improve as greater experience is gained. Clearly, as accuracy improves, trends observed in TFP will become more and more related to genuine performance changes.

4.3 Relationship between TFP scores and output index

As shown in Section 3.5, there is a wide range among output levels controlled by ANSPs. In 2003, NATS, the second largest ANSP (in terms of output), had an output level that was more than 75 times greater than the second smaller ANSP, FYROM CAA. In such a context, it is important to investigate whether, and to what extent, differences in output levels are related to differences in TFP scores. Table 6 displays the 2003 output index and TFP scores for each ANSP.

ANSPs	2003 Output		2003 TFP
	Rank	Level	
MUAC*	7	0.333	2.364
Skyguide	10	0.276	1.422
IAA	14	0.171	1.291
ANS Sweden	6	0.345	1.197
NAVIAIR	13	0.184	1.172
Austro Control	11	0.200	1.152
NAV Portugal (FIR Lisboa)	12	0.185	1.129
DFS	3	1.100	1.003
EANS	25	0.025	0.979
Avinor	9	0.287	0.964
Aena	4	1.043	0.964
Finland CAA	17	0.123	0.959
DNA	1	1.647	0.930
ENAV	5	0.900	0.885
NATS	2	1.102	0.875
LVNL	15	0.170	0.864
ANS CR	18	0.118	0.834
HungaroControl	20	0.108	0.785
Belgocontrol	19	0.115	0.587
Slovenia CAA	26	0.020	0.573
LGS	23	0.026	0.518
DHMI	8	0.311	0.460
MATS	24	0.025	0.440
LPS	22	0.041	0.412
ATSA Bulgaria	21	0.086	0.406
Oro Navigacija	27	0.020	0.339
ROMATSA	16	0.144	0.330
FYROM CAA	28	0.014	0.278
MoldATSA	29	0.005	0.129

Table 6: Relationship between TFP scores and output index

Figure 6 indicates that the largest ANSPs in terms of output do not have the highest TFP. Furthermore as shown in Figure 6 below, for the five largest ANSPs (DNA, NATS, DFS, Aena and ENAV), the output level does not seem to impact the TFP scores.

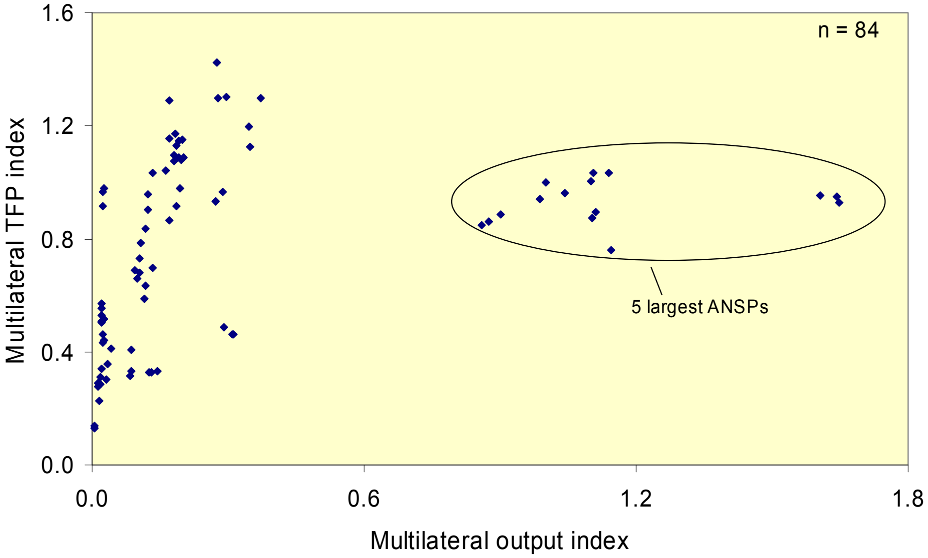

Figure 6: TFP scores versus output index

However, for the other smaller ANSPs, the TFP level seems to be influenced by the level of output which could indicate that some scale effects are at play (there is also some dispersion of TFP scores for a given level of output). Clearly, further work would be needed to better characterise the relationship between output levels and TFP scores. This could be achieved by explicitly deriving a structural (e.g. production or cost) model which can be empirically estimated.

4.4 Relationship between TFP scores and financial cost-effectiveness

In the ACE reports, the PRU uses the financial cost-effectiveness KPI to assess and compare the performance of the European ANSPs. This is computed as the ratio of the (gate-to-gate)[28] ATM/CNS provision costs to the composite flight-hours. This unit cost can be further broken down into three key economic ratios: (1) ATCO-hour productivity, (2) employment costs per ATCO-hour and (3) support cost ratio. All else being equal, higher productivity and lower support cost ratios will increase cost-effectiveness, while higher employment costs per ATCO-hour contribute to lower cost-effectiveness. In other words, productivity is only one, albeit important, driver for the level of ATM/CNS provision unit costs. Nevertheless, it is interesting to see to which extent TFP scores and unit costs correlate. This is done in Figure 7.

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[28] This is the aggregation of en-route and terminal ANS.

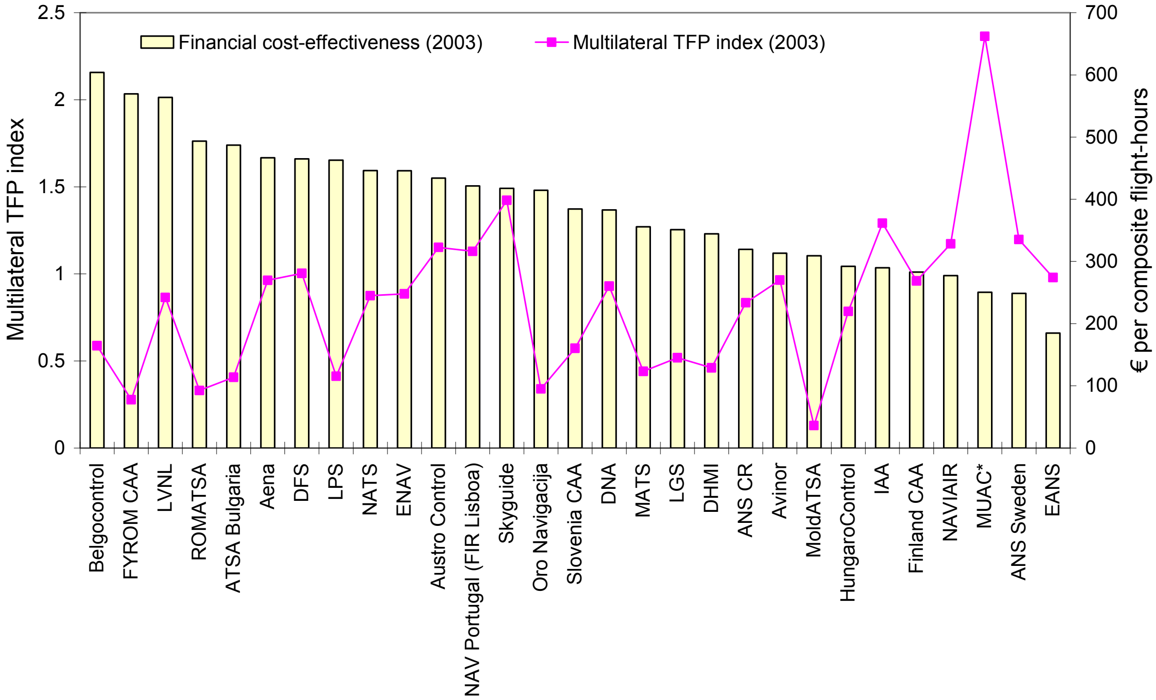

Figure 7: TFP scores and financial cost-effectiveness

As suggested by Figure 7 there is no clear relationship between TFP scores and ATM/CNS provision unit costs. Low TFP scores are associated with both high ATM/CNS unit costs (i.e. Belgocontrol, FYROM CAA, ROMATSA and ATSA Bulgaria) and low ATM/CNS unit costs (i.e. MoldATSA, MATS, LGS, DHMI, Oro Navigacija). The latter result suggests that factors other than productivity, (i.e. economic and environmental factors), are at play to explain the difference in unit costs (e.g. employment costs, cost of living).

4.5 Comparison between TFP scores and ATCO-hour productivity

As indicated in Section 4.2 above, the results of Table 5 display significant differences in TFP scores across ANSPs. In 2003, there is a factor of 2.2 between the first and third quartiles of the TFP distribution. This range is comparable to the dispersion obtained with the (partial) ATCO-hour productivity indicator presented in the ACE 2003 Benchmarking Report (see Figure 8 below). In fact, there is a factor of 2 between the first and second quartiles of the ATCO-hour productivity distribution. Clearly, as illustrated in Figure 8 below, TFP scores and the (partial) ATCO-hour productivity are fairly correlated (a R^2 of 0.74). Figure 8 also indicates that for a given level of ATCO-hour productivity, ANSPs achieve different TFP levels. For example, Avinor and HungaroControl report similar levels of ATCO-hour productivity, while Avinor reports a markedly higher TFP score. This result is not so surprising since the TFP index encompasses information on several other inputs.

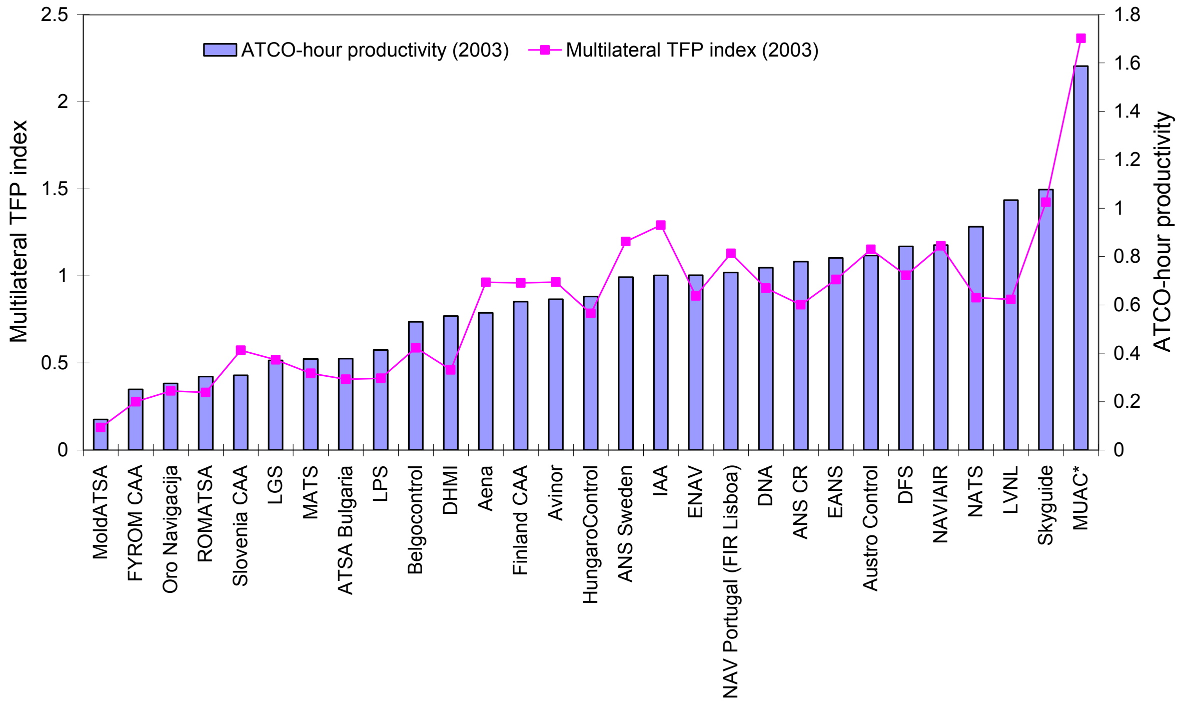

Figure 8: TFP and (partial) ATCO-hour productivity, 2003

5 SENSITIVITY ANALYSIS OF TFP SCORES

This section provides a sensitivity analysis of the TFP scores obtained in Section 4.

For the purposes of this paper four different assumptions are separately considered:

- Hypothesis 1: rather than using the number of FTE “other remaining staff” (see Section 3.4.1), an attempt is made to take into account possible differences in working hours among ANSPs. However, as mentioned in 3.4.1, we do not measure the average number of working hours for “other remaining staff”. It is however proposed to use the information available for ATCOs in OPS. By doing so we do not assume that the “other remaining staff” are working the same number of annual hours than ATCOs in OPS. It is only assumed that the ratio is the same between those two categories for any given pair of ANSPs;
- Hypothesis 2: rather than assuming that the operating expenses are made 50% in international markets and 50% in local prices (see also Section 3.4.3), it is assumed that all operating expenses are made at local prices.
- Hypothesis 3: rather than the number of sector-hours, the number of sectors is used to characterise the quantity of capital used for en-route (see also Section 3.4.2);
- Hypothesis 4: rather than the sum of TWRs and APPs operational units, only the number of TWRs is used to characterise the quantity of terminal capital (see also Section 3.4.2).

The results are displayed in Figure 9 below where the x-axis corresponds to the base line TFP scores as measured and reported in Table 5 (for year 2003).

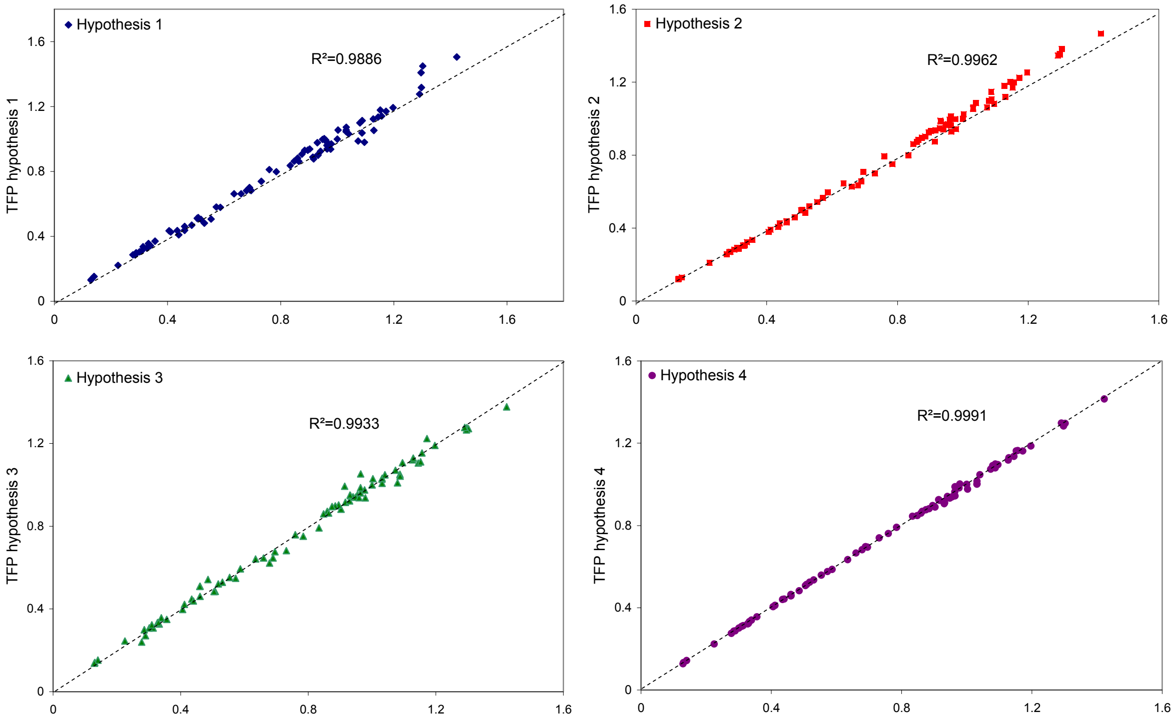

Figure 9: Sensitivity of the base line TFP scores to changes in assumptions

For each of the four different hypotheses, new TFP scores are computed and plotted on the y-axis of Figure 9. The closer the points to the 45° line (i.e. the bisecting line) the lesser the difference between the base line TFP scores and the new TFP scores.

Figure 9 shows that for the four hypotheses, all the points are close to the bisecting line, although some marginal dispersion exists on a few occasions (e.g. three observations on the right corner of Hypothesis 1 with higher TFP scores than the base line). Overall, the results suggest that the TFP scores are fairly stable and not too sensitive to the four hypotheses considered. Clearly, this is an encouraging result.

6 ANALYSIS OF DRIVERS FOR DIFFERENCES IN TFP SCORES

As argued in Section 4 numerous factors impact on TFP scores and TFP growth rates, some of which are beyond ANSPs' control. For this reason, it is important to recognise, and when possible account for, operating characteristics which are largely beyond ANSPs' managerial control. In fact, the "gross" TFP scores as presented in Table 5 above can be driven by external factors that do not relate to the managerial efficiency to adjust the amount of inputs used (relative to outputs produced) given input prices. Therefore, differences in these operating characteristics will need to be controlled before making any normative assessment of the TFP performance across ANSPs. As mentioned in Section 2.2, it is not straightforward to compute a "residual" TFP index from an empirical point of view. Therefore, as a first step we will focus on potential correlations between the TFP scores and exogenous factors related to "traffic complexity".

For the purpose of this study, the following six (exogenous) variables have been considered as "uncontrollable" operating characteristics:

- The amount of flight level changes (ΔFL): ATCOs workload increases as the amount of flight level changes increases. Higher amount of ΔFL (per 100km controlled) are therefore expected to lead to lower TFP;

- The average transit time (ATT): This depends on the geographical area of responsibility of an ANSP. All else being equal, higher ATT contributes positively to the output metric and therefore is expected to lead to higher TFP;

- The traffic variability (VAR): Some ANSPs tend to experience relatively high levels of seasonal traffic variability. All else being equal, higher VAR has an (negative) impact on the level of inputs and therefore is expected to lead to lower TFP;

- The number of proximate pairs (PP): This indicator measures the likelihood of close approaches of flight paths: occasions on which two aircrafts approach within 10 nautical miles horizontal distance and 1000 ft vertically. All else equal, higher PP lead to an increase in workload and in inputs, leading to lower TFP;

- The percentage of overflights (%OV): Flights in vertical evolution generate more workload than cruising overflight traffic. All else being equal, a higher %OV is expected to lead to higher TFP;

- The density of the airspace (DEN): This metric measures how concentrated the traffic is within a particular volume of airspace. It is to a large extent outside the control of an ANSP. On the one hand, higher DEN contributes to higher utilisation of input resources and therefore to higher TFP. On the other hand, there is a threshold above which higher DEN leads to a disproportionate increase in workload and in inputs, leading to lower TFP. The extent to which higher DEN leads to lower or higher TFP is therefore a key empirical question.

Given that the quality of service associated with ATM/CNS provision is an important characteristic from an airspace users' perspective, and that trade-offs exist between the amount of inputs and the level of quality, "gross" TFP scores should arguably also be adjusted to reflect significant differences in the quality of service. To this end, an additional variable is included in the regression analysis to capture the penalty incurred to airspace users by a lesser quality of service[29]:

- Average en-route ATFM delay per flight controlled (AVGDEL): Given trade-offs between the amount of inputs and delay, high AVGDEL tend to over-estimate the "gross" TFP due to under provision of inputs. Therefore, ANSPs with significant AVGDEL are expected, all else being equal, to have higher gross TFP. In practice, few ANSPs tend to experience significant AVGDEL and several ANSPs do not display any ATFM delays at all. Therefore a dummy variable is included where the AVGDEL is greater than 1 minute.

Figure 10 below displays the correlation matrix of the exogenous variables described above.

	DEN	VAR	ATT	ΔFL	%OV	PP	Dummy_delays
DEN	1	-0.33	-0.01	0.61	-0.28	0.94	0.43
VAR		1	-0.26	-0.54	0.69	-0.41	-0.21
ATT			1	-0.06	-0.58	-0.07	0.11
ΔFL				1	-0.64	0.72	0.09
%OV					1	-0.34	-0.17
PP						1	0.38
Dummy_delays							1

Figure 10: Correlation matrix of exogenous factors

We note that some of these exogenous variables are correlated. This is particularly the case for DEN and PP ($r = 0.94$). This suggests that those two variables cannot be used in the same statistical regression. This is also the case, but to a lesser extent, between %OV and VAR ($r = 0.69$), and between DEN and ΔFL ($r = 0.61$). Therefore, to avoid any bias in the sign and value of the estimated parameters, the following statistical relationship is estimated:

$$\text{Ln}(\text{"gross" TFP}) = a + b*\text{Ln}(\text{DEN}) + c*\text{Ln}(\text{VAR}) + d*\text{Ln}(\text{ATT}) + e*\text{Dummy\_AVGDEL} + f*\text{Dummy\_2002} + \text{Error};$$

This relationship is estimated using Ordinary Least Squares (OLS) regression for the whole sample[30] of ANSPs, i.e, 84 observations. In this regression both the dependent variable ("gross" TFP) and the explanatory variables are transformed into logarithms.

Table 7 reports the qualitative results of the TFP regression. It is worth noting that given the above specification, the dummy variables AVGDEL and Year 2002 have no statistical impact on the level of observed TFP.

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[29] This is measured in terms of ATFM delays given that this is the only metric which is consistently measured and available across the sample of ANSPs.

[30] MUAC is not included in the regression analysis.

	Estimated sign	Statistical significance
(Intercept)	-	Significant
DEN	+	Significant
VAR	-	Significant
ATT	+	Significant
Dummy_AVGDEL	-	Not Significant
Dummy_2002	+	Not significant

Table 7: Results of TFP regression

DEN has a strong positive influence on the observed “gross” TFP levels, while ATT has also a positive impact, although less significant. This means that an ANSP with longer ATT or greater DEN would be expected to have, all else being equal, higher TFP than other ANSPs.

On the opposite VAR has, as expected, a negative effect on “gross” TFP. Furthermore, with this specification, VAR displays the highest explanatory power.

The 29 ANSPs comprising the ACE data set show a wide range of environmental, cultural, and managerial policy settings which are often specific to each ANSP. Ideally, when regressing the levels of observed TFP on a set of exogenous variables, it would be important to account for **specific effects** relating to each time period and to each ANSP. Typically, these effects capture differences in TFP that are not accounted for by the differences in the exogenous variables selected in the regression model. Usually these effects are not observed and/or not easily quantified. Furthermore ANSPs’ specific effects can be correlated with the exogenous variables selected in the model. For example, it could be that DEN is correlated with the GDP per capita where the ANSP is operating. Econometric theory (e.g., Greene, 2000) suggests that it would be more appropriate to specify fixed or random effects models to determine more accurately the influence of the selected exogenous variables on observed TFP scores. Unfortunately, for the time being the size of the sample (i.e. 84 obs.) does not allow for an empirical estimation of such models.

Clearly, future work will be necessary towards the determination of TFP scores which are net of influences of the exogenous factors that affect ANSPs differently. To this end, a structural econometric model based on sound theoretical foundation, such as a flexible cost function specification, will be a necessary step to identify “residual” TFP scores.

7 CONCLUSIONS

The measurement of productivity and its trend is important to identify and promote best practice among ANSPs and to contribute to informed decision-making among stakeholders (e.g. airspace users, regulators, policy makers) especially in the context of likely technological (e.g. datalink) and organisational/institutional changes (e.g. Single European Sky) of the European ATM/CNS system.

This paper presents a methodology to measure TFP of the European ATM/CNS using ACE data for 29 European ANSPs over the 2001-2003 period.

Several inputs and outputs have been identified and aggregated into multilateral inputs and outputs indexes. TFP scores and growth rates are computed for the European system and for each ANSP. Between 2001 and 2003 the TFP increased by some 2% at European system level. The TFP growth rates range from +37% for LPS to -21% for MATS. TFP growth rates are broken down into an “output effect” and an “input effect”. Given the somewhat exogenous nature of the output, it is particularly important for an ANSP to flexibly adjust its level of inputs, since the latter is a managerial choice. The paper identifies ANSPs which achieved significant TFP improvement by reducing the quantity of inputs (often in the wake of a reduction of output in 2002).

At ANSP level, TFP scores show significant differences. The results are consistent with the findings from the ACE reports which displayed a wide range for the (partial) ATCO-hour productivity. Sensitivity analysis conducted on the TFP scores suggests that these are fairly stable and not too sensitive to the assumptions. This is an encouraging result, although we are aware of some of the current limitations with the measurement of operating inputs and capital data.

Finally, numerous factors impact on differences in TFP scores and TFP growth rates. For the purpose of this study, observed TFP scores are regressed against selected exogenous factors related to traffic complexity. Overall, the qualitative results of the TFP regression are intuitive, although some caution is required with their interpretation given the small data sample. The paper identifies the need for further work to refine the statistical specification and/or to take into account other factors that could generate differences in TFP scores. A structural econometric model based on sound theoretical foundation, such as a flexible cost function specification, will be a necessary step to identify “residual” TFP scores.

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9 APPENDIX MULTILATERAL TFP INDEXES: AN EXAMPLE

In this section we introduce a simple numerical example to illustrate the computation of the multilateral TFP index.
According to the method developed by Caves, Christensen and Diewert, multilateral output/input indexes are obtained using the following formula:

$$\ln Q_{st} = \frac{1}{2}\sum_{i=1}^{N}\underbrace{\left(\omega_{it}+\overline{\omega_i}\right)\times\ln\left(\frac{q_{it}}{\tilde{q}_i}\right)}_{A} - \frac{1}{2}\sum_{i=1}^{N}\underbrace{\left(\omega_{is}+\overline{\omega_i}\right)\times\ln\left(\frac{q_{is}}{\tilde{q}_i}\right)}_{B}$$

where:
- N is the number of outputs (respectively inputs);
- Q_{st} is the multilateral output (respectively input) index for the Firm t with Firm s as base;
- ω_{it} represents the revenue share (respectively cost share) relating to output i (respectively input i) for Firm t;
- q_{it} is the quantity of output i (respectively input i) relating to Firm t;
- $\overline{\omega_i}$ represents the arithmetic mean across all firms of revenue shares (respectively cost shares) relating to output i (respectively input i), and;
- $\tilde{q}_i$ represents the geometric mean across all firms of the quantities associated to output i (respectively input i).

The construction of the multilateral output/input indexes comprises two phases. First, ouputs (respectively inputs) of Firm t are aggregated using the revenue shares (respectively cost shares) (see (A) in the formula). Second, the aggregated output (respectively input) index is normalised with respect to the output (respectively input) index relating to Firm s (see (B) in the formula).

Let us consider the following numerical example which comprises three hypothetical firms that use two inputs to produce two outputs. Table 8 displays the output and revenue data that are required to compute the multilateral output index.

	Output1	Revenues output1	Share revenues output1 in total revenues	Output2	Revenues output2	Share revenues output2 in total revenues
Firm 1	1 000	400 000	67%	1 500	200 000	33%
Firm 2	120	70 000	93%	50	5 000	7%
Firm 3	2 000	700 000	78%	2 000	200 000	22%
Arithmetic mean			79%			21%
Geometric mean	621			531		

Table 8: Output data

The indexes will be normalised so that the level of output for Firm 1 is equal to 1.00. As a consequence, the multilateral output indexes for Firm 2 and Firm 3 will be expressed with

Firm 1 as base. According to the figures shown in Table 8, the multilateral output index for Firm 2 with respect to Firm 1 (i.e. O_{12}) is computed as follows:

$$\ln O_{12} = \frac{1}{2} \times \left((0.93 + 0.79) \times \ln\left(\frac{120}{621}\right) + (0.07 + 0.21) \times \ln\left(\frac{50}{531}\right) \right) - \frac{1}{2} \times \left((0.67 + 0.79) \times \ln\left(\frac{1000}{621}\right) + (0.33 + 0.21) \times \ln\left(\frac{1500}{531}\right) \right)$$

$\ln O_{12} = -2.37$ or $O_{12} = Exp(-2.37) = 0.09$.

	Input1	Cost input1	Share cost input1 in total costs	Input2	Cost input2	Share cost input2 in total costs
Firm 1	10	100 000	50%	500	100 000	50%
Firm 2	30	70 000	47%	100	80 000	53%
Firm 3	7	80 000	29%	1 000	200 000	71%
Arithmetic average			42%			58%
Geometric average	13			368		

Table 9: Input data

The same methodology is used to derive the multilateral input index for Firm 2 with respect to Firm 1 (i.e. I_{12}) according to the data reported in Table 9.

$$\ln I_{12} = \frac{1}{2} \times \left((0.47 + 0.42) \times \ln\left(\frac{30}{13}\right) + (0.53 + 0.58) \times \ln\left(\frac{100}{368}\right) \right) - \frac{1}{2} \times \left((0.50 + 0.42) \times \ln\left(\frac{10}{13}\right) + (0.50 + 0.58) \times \ln\left(\frac{500}{368}\right) \right)$$

$\ln I_{12} = -0.40$ or $I_{12} = Exp(-0.40) = 0.67$.

The multilateral TFP index is defined as the ratio of the multilateral output index to the multilateral input index.

As a consequence, according to our example, the multilateral TFP index of Firm 2 with respect to Firm 1 is equal to:

$$TFP_{12} = \frac{0.09}{0.67} = 0.13.$$