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BENCHMARKING OF AIR NAVIGATION
SERVICE PROVIDERS

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SUMMARY

This technical note sets out the results of an econometric analysis of the cost-effectiveness of air service navigation provision. This report has been commissioned to CEG experts by the Performance Review Unit (PRU) of EUROCONTROL.

The objectives of this analysis are to specify and estimate a cost function for the provision of gate-to-gate ATM/CNS services, to develop a framework which would allow to assess the cost-inefficiency of ATM/CNS provision, and to provide preliminary estimates of the European system cost-inefficiency.

KEYWORDS

ACE data, ANSPs, ATM/CNS services, benchmarking, exogenous factors, traffic complexity, cost of living, econometric modelling, cost function, OLS, stochastic frontier analysis, cost-inefficiencies, random effects, fixed effects.

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ECONOMETRIC COST-EFFICIENCY BENCHMARKING OF AIR NAVIGATION SERVICE PROVIDERS

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Final report

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May 2011

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1 INTRODUCTION

This report sets out the results of an econometric analysis of the cost-effectiveness of air service navigation provision. This report has been commissioned to CEG experts by the Performance Review Unit (PRU) of EUROCONTROL.

In the context of SES Performance Scheme aiming at improving ANS performance, it is key to be able to factually quantify the scope for improvement in ANS provision. The main objectives of this report are (1) to specify and estimate a cost function for the provision of gate-to-gate ATM/CNS services, (2) to develop a framework which would allow to assess the cost-inefficiency of ATM/CNS provision, and (3) to provide preliminary estimates of the European system cost-inefficiency considering models which allows to distinguish between inefficiency and the impact of exogenous factors.

There is a high level of heterogeneity in the Air Navigation Services (ANS) industry. European Air Navigation Service Providers (ANSPs) operate in operational and economic conditions that vary significantly from country to country. Differences in performance across ANSPs may not only be due to inefficiency but also to factors specific to the ANSPs (both exogenous and endogenous). Exogenous factors are those outside the control of an ANSP; endogenous factors are those entirely under the ANSP's control. A quantitative analysis of ANSPs cost-inefficiencies will need to account for exogenous factors to the maximum extent possible, while encouraging the optimisation of endogenous factors through the recognition and movement towards best practice. It should be noted that the quality of service provided by the ANSPs is not accounted for in the econometric model presented in this report. Similarly, environmental constraints, which in some cases may have an impact on ANSP performance, are not taken into account in this analysis.

Where exogenous effects can be measured (or at least a classification determined), their impact can be analysed using objective and appropriate statistical techniques. In particular, a quantitative approach based on the use of recognized econometrics techniques provides a tool to separate out and quantify the likely impact of measurable cost drivers, and to some extent to interpret what is not measurable and still contributes to overall cost differences. These techniques are extensively discussed in the economic literature and are used by economic regulators, alongside other methods, in other regulated monopoly industries (such as water, electricity, gas supply, and surface transport) to support comparisons, and cost efficiency targets.

The PRU has been developing an econometric approach for the cost benchmarking of air navigation service providers since 2005. The main data has been provided by ANSPs for the purposes of the ACE Benchmarking and now covers the period from 2002 to 2009 for a total of 250 observations.

Chapter 2 of this report presents background and contextual information. The econometric model is described in more detail in Chapter 3. Chapter 4 presents the data used in the econometric analysis. Finally, Chapter 5 presents the main results and their interpretation.

2 SETTING UP THE BACKGROUND

For a number of years, the PRU has been actively involved in assessing the efficiency of ANSPs in Europe. Since 1999, it has published an annual Performance Review Report (PRR), which presents a range of information in relation to three main key performance areas: safety, quality of service and cost-effectiveness. The PRR 2010 report presents high level cost indicators, such as the cost per km flown, and contains some qualitative discussion on exogenous factors (such as traffic complexity) that may affect these indicators. But it does not include any statistical analysis to adjust for such factors or otherwise to estimate ANSP efficiency. Since 2003, this high level analysis has been supplemented by an annual ATM Cost-Effectiveness (ACE) Benchmarking Report. The ACE 2009 Benchmarking Report, the latest in the series, is based on data supplied by 37 ANSPs in compliance with a mandatory specification for economic information disclosure¹. These data are subject to extensive validation and analysis by the PRU.

The economic theory underlying the estimation of a cost function relies on the assumption that firms minimise costs subject to the best available technology. Although a large majority of the European ANSPs are corporatized public entities, in the context of air navigation service provision this assumption may not entirely hold as ANSPs' overriding objective is to maintain safety standards. Furthermore the European ANSPs are statutory monopolies which over the 2002-2009 period operated under a full cost recovery regime². This means that these organisations are allowed to recover all their costs (though subject to some time delay) from their customers (airspace users). Therefore, it can be argued that most ANSPs faced relative weak incentives to ensure an efficient use of inputs and to minimise costs during the period considered in this analysis.

2.1 The ATM/CNS production process

A high level representation of the relationship of inputs and outputs in relation with the provision of ATM/CNS services is displayed in Figure 2.1 below.

¹ PRC Specification for Information Disclosure - Version 2.6, December 2008, can be found on the PRC web site.

² The single exception to this rule is NATS, which operates under an independent economic regulation regime (i.e. price cap).

An ANSP provides a specific level of ATC capacity which is determined by the number of airspace sectors that can be opened in its airspace for a given duration. This ATC capacity is used to cope with a specific and exogenous traffic demand (number of aircraft/flights that are planned to cross the ANSP's airspace).

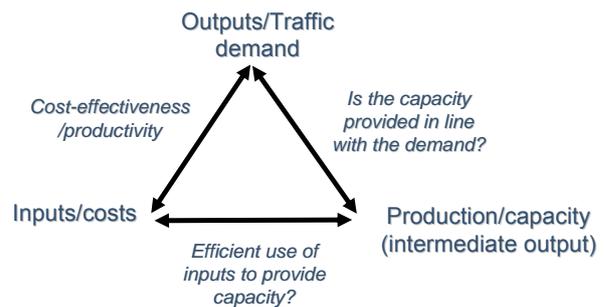


Figure 2.1: High level relationship between inputs and outputs

One could consider that the capacity provided by the ANSP corresponds to an “intermediate” output while the “final” output would be measured in terms of traffic volumes controlled in the ANSP's airspace (see Figure 2.1). The relationship between inputs/costs and final output/traffic demand depends (1) on the ANSP's ability to efficiently use its resources to provide a certain level of ATC capacity and (2) on the extent to which the capacity provided is in line with the traffic demand. The overall “outcome” of this process is the extent to which the flight (final output) has been safely controlled in a swift and timely manner.

The provision of ATC capacity requires a combination of inputs which includes:

- **Labour inputs:** there are two distinct categories of labour employed by ANSPs: Air Traffic Control Officers in Operations (ATCOs in OPS), which accounts for 50% of employment costs on average; and support staff (e.g. trainees, technical support staff, administrative staff, etc.).
- **Capital inputs:** capital inputs used in the provision of ATM/CNS³ services are varied. They include buildings, controller workstations, various ATM equipments (with sophisticated flight and radar data processing systems) and CNS infrastructure (such as surveillance radar).
- **Non-staff operating inputs:** the third category which captures all the remaining inputs not included in either labour or capital. This category includes, among other things, energy, communications, and the provision of any contracted services.

A key constraint, which drives much of the relationships described in Figure 2.1, is the volume of traffic that can be safely controlled by a single ATCO crew with a single workstation. Once a particular sector cannot safely handle any more traffic, an ANSP may open a new sector by reconfiguring its existing airspace so that it is divided up into more sectors. Opening more sectors requires more ATCOs to handle the additional traffic volumes. This can potentially imply an increase in the unit costs of ATM/CNS provision and a decrease of productivity.

³ ATM/CNS stands for Air Traffic Management, Communication, Navigation and Surveillance.

On the other hand, an ANSP with plenty of spare capacity may accommodate additional traffic without any significant impact on costs (i.e. the additional traffic volumes are absorbed using the same resources). This represents potential economies of **density**, as it relates to an increase in output while the network size remains unchanged. The potential for economies of density will weaken, however, at the point where additional traffic requires new sectors to be opened and therefore more ATCOs (and associated workstations) to be on duty.

The volume of traffic or size of operations is also expected to affect ANSPs unit costs and productivity. Given the nature of the industry, there are inevitably fixed costs (typically capital-related costs for the ATM systems and CNS infrastructure) which in the short term do not increase proportionally with the traffic. It is therefore likely that larger ANSPs should potentially benefit from these **scale** effects and, all else equal, have higher productivity and lower unit costs than smaller organisations.

2.2 Factors affecting ANSPs performance

There are exogenous and endogenous influences on ANSP performance. Exogenous factors are those outside the control of an ANSP; endogenous factors are those entirely under the ANSP’s control. Fair benchmarking needs to recognise the impact of exogenous factors. A quantitative analysis of ANSPs cost-inefficiencies will need to account for exogenous factors to the maximum extent possible, while encouraging the optimisation of endogenous factors through the recognition and movement towards best practice.

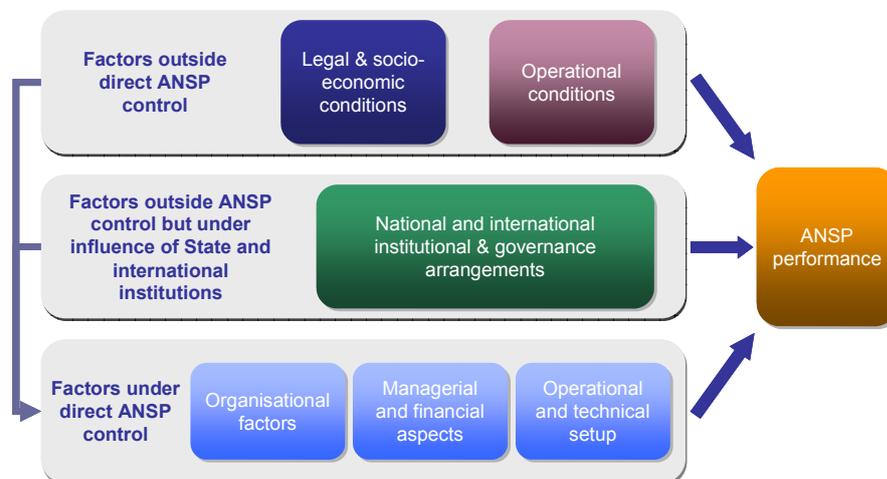


Figure 2.2: Factors affecting cost-effectiveness performance

Exogenous factors

Exogenous factors arise from the basic conditions in which an ANSP operates, which can differ from one country to another. Exogenous factors are likely to influence the way ANSPs organise and conduct their business. In some cases they may also affect the way an ANSP manages costs and determines the level of charges.

Exogenous factors cover a spectrum of observability and measurability. There are factors for which it is possible to derive metrics (examples are traffic complexity, market wage rates, and exchange rate volatility), but it is difficult to specify exactly how such factors might affect performance. Even more difficult to take into account are factors such as political influence on ANS provision. Finally, there will inevitably be exogenous factors that are simply impossible to identify/measure, although they are no less real than the other factors discussed.

In Figure 2.2, exogenous factors that could have an impact on performance have been classified into two main areas (top and central set of factors in Figure 2.2), according to which set of decision-makers have an influence over them:

- The top set concerns the **legal and socio-economic** conditions prevailing in individual countries. These are determined either by national policy-makers at a more general level (for example taxation policy), or by national and international macroeconomic conditions (for example, prevailing national wage rates). It also concerns the **operational conditions** under which the ANSP operates – what traffic patterns it has to deal with. In this case the relevant decisions may be made by airports, airlines, and especially, flying travellers.
- The central set concerns **institutional and governance** arrangements for ANS in a particular country. These arrangements are set in place by the policies and specific aviation laws of each country. These factors are exogenous to the ANSP but decision-making concerning some of them is largely driven by national aviation policy-makers. Some of these factors relate to international requirements such as those imposed by ICAO, EUROCONTROL and the Single European Sky. These policies at State and European level are subject to changes given strategic objectives for the sector.

There are a number of exogenous factors that are currently measured by PRU, these include:

- **The size of the ANSP:** through the number of flight-hours and airport movements handled by the ANSPs, or the size of the airspace controlled.
- **The cost of living in the country where the ANSP is operating.**
- **The adjusted density of traffic:** which is a measure of the concentration of traffic in a given volume of airspace (ANSP/ACC level), and defined in terms of minutes of interaction among aircraft per flight-hour.
- **The structural complexity of traffic:** which captures the fact that the traffic in some areas is structurally more complex. The structural complexity is itself the sum of three metrics reflecting that more ascending and descending routes, more crossing routes, and variable speeds – a proxy for traffic mix - are additive elements of traffic complexity. Clearly, ATC provision in lower airspace will, all other things being equal, face a relatively higher proportion of ascending and descending routes.
- **Traffic variability:** through the seasonal variability which is the ratio between the amount of

traffic handled by the ANSP in the peak week and the traffic handled on average during the year.

Endogenous factors

In principle, once the impact of all exogenous factors has been allowed for, the performance differences that remain should comprise residual inefficiency which lowers performance below that obtained by best practice. Such residual inefficiency arises from a number of endogenous factors, under the direct control of ANSPs.

The way that an ANSP manages its business to optimise performance is influenced by exogenous factors. “Best practice” in any given area will depend on the exogenous circumstances. ANSPs can therefore take action to fully exploit the benefit of their environment or to minimize the impact of relative disadvantages.

2.3 Quality of service provided by ANSPs

A number of factors affect aircraft operations and contribute to the quality of service that is provided to airspace users by an ANSP. These include:

- ATFM ground delays;
- Airborne holding (although these are mostly a consequence of airport constraints);
- Horizontal flight-efficiency and the resulting route length extension;
- Vertical flight-efficiency and the resulting deviation from optimal vertical flight profile.

The last three factors have also an environmental impact in terms of additional emissions (CO₂, NO_x, etc) and local air quality, hence external costs to society at large.

Data and methodology are currently being developed by the PRU to compute flight-inefficiencies at ANSP level. This would contribute to better reflect the quality of service associated with ATM/CNS provision, although it is important to bear in mind that local flight-efficiency improvements within a given ANSP can be limited as they might depend on European wide improvements in route and airspace designs.

As a consequence of these limitations, the quality of service associated with ATM/CNS provision by ANSPs is, for the time being, assessed only in terms of ATFM ground delays, which can be measured consistently and expressed in monetary terms. ATFM delays generally arise from the under-provision of capacity but may also be driven by one-off systems failures, problems caused by industrial action (including in other countries), or the impact of new investment (such as opening of a new control centre or the introduction of new systems, which may operate at reduced capacity for a short period of time).

It should be noted that if ATFM delays can capture insufficient capacity; they cannot be used to proxy for the existence of spare capacity (i.e. there are no “negative” delays).

3 THE MODEL

We adopt a statistical modelling approach based on the estimation of a “text book” cost function. The function describes the relationship between the costs and output(s), input prices, exogenous factors describing the ANSP operating environment and an error term. The error term mainly reflects the fact that it is impossible to capture every influence on an economic variable in a theoretical model and account for measurement errors (i.e. it is very difficult to obtain accurate measures of all the variables included in an econometric model).

The parameters of the cost function can be recovered empirically from the data using a suitable econometric technique. The choice of econometric technique is largely governed by assumptions imposed on the statistical error and how the statistical error relates to variables of the model. In the next sections, we describe our distinct approaches and discuss some advantages and disadvantages of the modelling approach.

3.1 Functional form used in the econometric analysis

The assumed functional form is a Cobb-Douglas cost function. The main advantage of the Cobb-Douglas functional form is that it assumes a simple parametric relationship between total costs and explanatory variables. As this relationship is estimated in logs, the coefficient of the cost function can be interpreted as long-term elasticity (e.g. impact of a 1% change in output on costs).

Alternative specifications typically used in econometric cost-benchmarking include quadratic functional forms and particularly the *translog*. These specifications may provide more flexibility and better reflect the characteristics of the industry but they require the estimation of a larger number of parameters and this may be difficult if the data set is not sufficiently large. The relatively “small” ACE data set (i.e. 8 years from 2002 to 2009 and 250 observations) is not sufficient to use a translog cost function in our analysis.

3.2 Models

The framework we consider consist of a Cobb-Douglas cost function which postulates a log-linear relationship between total costs, output, input prices and environmental variables. The empirical model is the following:

$$C_{it} = \alpha + \mathbf{x}_{it} \beta + u_{it} \quad (1)$$

where C_{it} denotes the logarithm of the total costs of gate to gate service provision in ANSP i in year t , \mathbf{x}_{it} denotes a set of explanatory variables (output, input prices, environmental variables), and u_{it} denotes the residual or statistical error. The environmental variables are used in addition to the output and input prices which feature in cost functions to decompose part of the other differences in costs according to measurable differences between ANSPs.

The interpretation of the error term (u_{it}) is important as well and can be attributed to distinct elements.

- a. First, there may be measurement error in variables. Measurement error in total costs could explain why we do not find an exact relationship.
- b. Second, the error may arise as we do not measure certain explanatory variables correctly. Some of our variables may be proxies of the underlying variable only and not measure them accurately.
- c. Third, there may be persistent differences across ANSPs in the cost relationship. The persistent differences may be attributable to distinct efficiency levels or alternatively differences in environmental variables. For example, an unobserved environmental factor may be persistently higher in one ANSP than in another. We might have omitted factors that are not readily measurable, such as governance and internal management arrangements, and that could impact costs.

We do not know the coefficients of interest which are (α, β) . We shall use econometric techniques to infer the coefficients of interest from the observed data. Distinct econometric techniques can be used. The distinct methods differ in the assumptions imposed on the statistical error u_{it} and how the statistical error relates to variables of the model. We first set out the assumptions in great detail and then comment on the implications of different assumptions.

In this analysis, we considered the four following estimation models:

- OLS (with Fixed Effects)
- Pitt and Lee Random Effects
- True Random Effects model
- Random coefficients model

1. OLS makes two key assumptions on the statistical error, the residuals u , when estimating relationship (1): First, a zero conditional mean assumption,

$$E[u|x]=0. \tag{A1}$$

Second, a full rank condition which requires that the set of covariates included in x is not linearly dependent,

$$\text{rank } E[x'x]=K \tag{A2}$$

where K denotes the number of explanatory variables contained in the vector x .

OLS with Fixed Effects. The statistical error is decomposed into two separate components:

$$u_{it} = \text{ANSPs-Dummies } a_i + \varepsilon_{it}$$

where ANSPs-Dummies are variables that equal one when ANSP i is considered and zero otherwise. It is assumed that the statistical error satisfies a zero conditional mean assumption, and the ANSPs-Dummies together with the \mathbf{x} variables satisfy a full rank condition.

The OLS Fixed Effects model can be recast as an OLS model by adding the ANSPs-Dummies as an additional explanatory variable in \mathbf{x} . The coefficient estimates for α and β can be obtained by using the “within” approach in which a transformation of all variables is taken by subtracting the average values of the same variable. An important feature of the OLS Fixed Effects model is that it imposes no distributional assumption on the a_i coefficients and allows the ANSPs-Dummies to be correlated with the explanatory variables in \mathbf{x} . Unlike the models below, the OLS Fixed Effects is therefore robust to correlation in the cost drivers with the disturbances. For example, the models’ estimates remain consistent when an efficient ANSP pays also a high wage which would result in a positive correlation between the wage and this ANSP dummy.

2. Pitt and Lee Random Effects. Pitt and Lee (1981) decompose the statistical error into two separate components:

$$u_{it} = \mu_i + \varepsilon_{it}$$

where the first component μ_i is time invariant and the second component ε_{it} may vary over time. The statistical errors, μ_i and ε_{it} , are now assumed to satisfy certain distributional assumptions.

They are independent and identical random draws from a half-normal and normal distribution respectively, with:

$$\mu_i \sim N^+(0, \sigma_u^2) \quad (\text{A3})$$

$$\varepsilon_{it} \sim N(0, \sigma_\varepsilon^2) \quad (\text{A4})$$

where σ_u^2 and σ_ε^2 denote the variance of the two inefficiency components and $N(\cdot, \cdot)$ denotes the normal distribution function and N^+ the half normal distribution function (i.e. a normal distribution function defined over positive realizations of the error). In other words, the half-normal distribution is the probability distribution of the absolute value of a random variable that is normally distributed with mean 0 and variance σ^2 . I.e. if X is normally, then $Y = |X|$ is half-normally distributed. The two error terms are assumed to be distributed independently from each other.

The distributional assumptions allow us to write out a likelihood function and define the likelihood estimator by maximizing the log-likelihood with numerical methods.

Due to the simulation of the likelihood function, the s estimator does not yield consistent estimates. However, in the limit, as the number of simulation draws gets large, the consistent and efficient estimates are approached. Note that here it is assumed that the two components of the error are not a function of the right hand side variables. The statistical error is assumed uncorrelated with the regressors \mathbf{x} .

An interpretation of the Pitt and Lee error structure is that technical inefficiency is fixed through time, and half-normally distributed. Here the error is made of a random term u_i (distributed as a half normal) which denotes the ANSP inefficiency and an idiosyncratic term (normally distributed and varying over time) which reflects other factors (measurement errors in costs, bad weather, etc.). The estimation of the Random Effects Pitt and Lee model rests on the assumption that the individual effect is uncorrelated with the regressors; unlike in the Fixed Effects model, where the individual effect can be freely correlated with the regressors.

3. True Random Effects model. Here the statistical error is decomposed into three separate components:

$$u_{it} = \delta_i + \mu_{it} + \varepsilon_{it}$$

$$\delta_i \sim N(0, \sigma_\delta^2) \tag{A5}$$

$$\mu_{it} \sim N^+(0, \sigma_u^2) \tag{A6}$$

$$\varepsilon_{it} \sim N(0, \sigma_\varepsilon^2) \tag{A7}$$

where the first components, δ_i is fixed through time and the other two components (u_{it} and ε_{it}) may vary over time. The statistical errors, $\delta_i, \mu_{it}, \varepsilon_{it}$, are again assumed to satisfy distributional assumptions. The error term δ_i reflects unobserved time invariant heterogeneity associated to each producer, while ε_{it} is an idiosyncratic term and μ_{it} is (time-varying) and positive, and assumed to be the term in the error related to inefficiency. The parameters σ_δ^2 , σ_u^2 and σ_ε^2 reflect the variances of the individual effects, idiosyncratic effect and inefficiency, respectively.

This model is similar to the following one as regards the interpretation of the error term, but the coefficients of the regressors are estimated differently in what follows.

4. Random coefficients model. This model additionally allows ANSP heterogeneity in the coefficients associated with the cost relationship. It decomposes the statistical error into four separate components:

$$u_{it} = \delta_i + \mu_{it} + \varepsilon_{it} + \mathbf{x}_{it} \Gamma h_i$$

where the first and fourth components, δ_i and h_i , are fixed through time and the second and third component, μ_{it} and ε_{it} , may vary over time. The first three statistical errors, $\delta_i, \mu_{it}, \varepsilon_{it}$, are assumed to satisfy distributional assumptions as in model 3. They are independent and identical random draws from a normal, half-normal and normal distribution respectively:

$$\delta_i \sim N(0, \sigma_\delta^2) \quad (\text{A8})$$

$$\mu_{it} \sim N^+(0, \sigma_u^2) \quad (\text{A9})$$

$$\varepsilon_{it} \sim N(0, \sigma_\varepsilon^2) \quad (\text{A10})$$

The fourth element in the error term allows for heterogeneous effects of the cost drivers entering in \mathbf{x} . The fourth element accounts for deviation from the mean effect, measured by β . Note that h_i is a multivariate random variable with mean zero and variance equal to the identity matrix. It is assumed that h_i are independent and identical random draws from a multivariate normal distribution,

$$h_i \sim N(\mathbf{0}, \mathbf{I}) \quad (\text{A11})$$

and the matrix Γ measures the covariance matrix associated with the heterogeneity of the ANSPs in regards to the scale and correlation of the variables entering the observable cost factors in \mathbf{x} . The true random coefficients model is a generalization of the true Random Effects model because not only does it allow the constant to be randomly distributed, but also the (slope) coefficients associated with the observable variables in \mathbf{x} . As in the true Random Effects model, the true random coefficients model requires that all random terms, including h_i , are uncorrelated with the regressors.

The coefficient $\beta_i = \mathbf{x}_{it} \Gamma h_i$ is random. It measures deviations in ANSP i relative to the mean effect β .

The distributional assumptions allow us to write out a likelihood function and define the likelihood estimator. The likelihood estimator is obtained by numerically maximizing the simulated likelihood. This estimator is not consistent but approaches a consistent and efficient estimator as the number of simulation draws get large. Note that here again it is assumed that the individual components of the statistical error are not a function of the right hand side variables. Thus, the statistical error is assumed to be uncorrelated with the regressors \mathbf{x} .

Remarks on the different models and assumptions

OLS Fixed Effects. This approach takes advantage of the time dimension of the panel data set by controlling for ANSP heterogeneity. It avoids making strong distributional assumption about the inefficiency component. As the Fixed Effects are used in the literature to estimate differences in efficiency between ANSPs, this approach will label as inefficiency all unobserved elements that vary across ANSPs but are constant over time. The inefficiencies attributed will thus be very large. We do not advise disseminating the findings with this method of estimation unless a different interpretation of the error is possible in the future. Additional variables correlated with efficiency may allow disentangling the residuals further into a component related to efficiency and one that is not. Unfortunately we have not been able to identify such additional variables yet.

The OLS Fixed Effects model is a natural first cut. We have used this specification to test for endogeneity of specific variables. The endogeneity tests are reported in section 5.4.

Stochastic frontier models

The other three models, which belong to the family of the stochastic frontier function models, make a-priory assumptions on the structure and distribution of the statistical error term. All of them include a term that is assumed to be positive and related to inefficiencies. Instead of identifying what is related to inefficiency in the unexplained residual, the econometrician makes assumptions on how to disentangle noise from inefficiency “decomposing” the statistical error. We have noted in some technical detail the different assumptions and their implication above. In sum, two crucial aspects emerge comparing these different models:

First, the econometric estimation approach yields consistent estimates when the distributional assumptions are satisfied. The OLS Fixed Effects model imposes weak assumptions and, in this sense, the resulting estimates can be viewed as “robust”. Care must be taken in interpreting the findings from the other models as not all assumptions may be met in practice. To the extent that one or more assumptions are violated, the impact of the cost drivers and the coefficient estimates will be erroneously measured.

Second, the time invariant component of the error, which is specific to one ANSP, may be alternatively interpreted as “inefficiency” or as relating to other exogenous unexplained differences between ANSPs. We understand from discussions with Eurocontrol that in practice inefficiency may be due in part to persistent effects over time that differ between ANSPs, but also to the ability to manage more efficiently resources which is likely to be captured to some extent by the time variant component of the error. As these models imply that either all or nothing of the time invariant component is labelled as inefficiency, the results that are produced may at most be interpreted as the lower or upper bounds of the real underlying inefficiency levels.

3.3 Main issues relating to the estimation of a cost function for the provision of ATM/CNS services

Assumption of cost minimisation: The economic theory underlying the estimation of a cost function relies on the assumption that firms minimise costs subject to the best available technology. The estimation of the cost function indicates the cheapest combination of inputs at the current factor prices to achieve a given level of output (assumed exogenous). An attractive feature of this interpretation is that the coefficient estimates under these behavioural assumptions can be interpreted as measures of returns to scale and measures of the input requirements in the production process. The coefficient estimates relate to how cost minimising firms adjust their production costs by adjusting the way they provide services in response to changes in input prices which they cannot control. However as mentioned in Chapter 2 above, European ANSPs are statutory monopolies which under the full cost recovery regime⁴ faced weak incentives to minimise costs.

Issue of endogeneity for explanatory variables: Endogeneity is a technical problem that arises when key variables are determined within the system being modelled rather than being determined exogenously by the external environment. Endogeneity can be a serious statistical issue as it biases the assessment of the effect of a particular factor on costs. Issues of endogeneity may arise for both output measures and input prices:

- a. In the ANSP industry endogeneity of output can be ruled out as flight-hours are beyond the control of the ANSP. The output is not determined in the ANSP market in itself. If output were a function of unobserved shocks in the statistical error which in turn affect costs, then this would result in biased and erroneous estimates. However, output does not respond to ANSP specific shocks.
- b. Unionization combined with a lack of competitive markets for key workers may imply that the wage levels are determined endogenously in some ANSPs rather than being exogenously set in broader labour markets⁵.

The endogeneity concern can be alleviated by including predicted variables instead of the explanatory variables that are suspected to be endogenous. The predicted variables are obtained by using suitable instruments that are correlated with the right hand side endogenous variable but are uncorrelated with the productivity shock. For example lagged wages, or wages in adjacent regions, may be used as 'instruments' for current wages in case endogeneity is a concern⁶.

⁴ The single exception to this rule is NATS, which operates under an independent economic regulation regime (i.e. price cap).

⁵ For example, labour input prices would be endogenous if the labour cost was higher when the ANSP is also less efficient in managing operations. In short, inefficiency may exist through excessive wages being paid, but the model will have difficulty determining this.

⁶ A suitable test is the Hausmann endogeneity test which allows the econometrician to formally test for the assumption that the error is not correlated with ATCOs wages. Unfortunately, to conduct the Hausmann test an additional variable needs to be included that is correlated with ATCOs wages and not contained in x , the set of explanatory variables in the Cobb Douglas specification. This variable

Comments on quality of service

The key measure of quality of service for ANSPs is the prevalence of delays. As discussed in Section 2.3, one might expect delays to be correlated with the under-provision of capacity. If some ANSPs operate at a lower spare capacity level on average we should observe that they are more severely affected by delays than other ANSPs. Operating closer to full capacity should be associated with lower costs than providing the same output with significant spare capacity still available. Thus, a priori we might expect a negative relationship between costs and delays.

The above argument suggests that controlling for ATFM delays in the cost function would be needed to ensure fair comparisons across ANSPs in respect of quality of service. However, there are reasons to believe that a negative correlation between delays and costs may now be less likely to emerge empirically. In recent times, (ground) ATFM delays have fallen and in many cases they are now very low indeed. Compared with several years ago, one-off or random events are more likely to account for a greater (and possibly quite large) proportion of observed ATFM delays than a general under-provision of capacity. Such events might include one-off systems failures, problems caused by industrial action (including in other countries), or the impact of new investment (such as opening of a new control centre or the introduction of new systems, which may operate at reduced capacity for a short period of time). Furthermore, delays can only capture insufficient capacity; they cannot be used to proxy for the existence of spare capacity (i.e. there are no “negative” delays) and this truncation of delays at zero is bound to weaken the negative correlation between costs and delays described above. Our approach is therefore to make no adjustment for quality of service in the cost function.⁷ However, it would be important in the context of future work to include the quality of service in the econometric cost-benchmarking analysis. It should also be noted that environmental constraints, which in some cases may have an impact on ANSP performance, are not taken into account in this analysis.

4 THE DATA

This section describes the data and reports summary statistics.

The ACE database has been building up since 2001 and is now providing an adequate basis for moving towards an econometric approach. Indeed the output of econometric analysis, among other evidence, has been taken into account in the 2010 PRB proposals to the EC on a range for an EU-wide cost-efficiency target for 2012-2014, although it is fair to say that a lower weight was given to this econometric evidence.

For the purpose of the work in progress the main cost drivers considered included:

should be a driver of wages, but have no direct impact on total costs other than through its role in setting wages on. Lagged wages or a combination of neighbouring country wages may come to mind, but it is not clear whether such variables are indeed very good instruments.

⁷ This approach is backed up by preliminary estimation results that found no evidence of an impact of observed delays on costs.

- Measures of traffic complexity, traffic variability, concentration of traffic by airport movement (in a given country) and of the size of airspace controlled;
- Direct measures or proxy measures of the price of key inputs for ATM/CNS provision (labour, capital, other inputs);
- The quality of the economy wide business environment;
- The effect of time (which may be a proxy for the impact, common to all ANSPs, of different global economic shocks, changes of regulation affecting all ANSPs and other common trends that may shape ANSPs operations).

In detail, key variables are defined and measured as follows

ATM/CNS provision costs [C]:

Total costs are defined as the sum of labour costs (for ATCOs in OPS and support staff), capital related costs and non- staff related operating costs from the ACE data. Please note that these costs are expressed in Euros and in real terms at 2009 prices.

Output measure [Y]:

Output is measured by composite flight hours from the ACE data set (variable 'Output (Y)' in the tables of results in the following section). The ACE data set includes this variable which summarises movements and hours controlled. Hence this is a measure that accounts for instances when hours and movements are not well correlated, without the need of using multiple outputs and specifying a multiple output (quadratic) cost function.⁸

Labour input prices [W1 and W2]:

The data set used for the econometric tests includes two input prices, a measure of the hourly average employment costs of ATCOs in OPS and a measure of average employment costs of support staff. The hourly average employment costs for ATCOs in OPS (variable 'W1 ATCOs in OPS' in the tables with results in the following section) correspond to the ATCOs in OPS employment costs divided by ATCOs in OPS hours on duty. The average employment costs of support staff (variable 'W2 Support staff' in the tables) correspond to the total employment costs for support staff divided by the total number of support staff.

Non-staff operating costs [W3]:

Non-staff operating costs⁹ are priced accordingly to a producer price index for all goods. This index is provided by Eurostat but unfortunately it excludes services.¹⁰ As Eurostat figures are provided at

⁸ Multiple outputs require a quadratic functional form and this does not perform well with the current data.

⁹ This cost category includes exceptional items

current prices, the producer price index has been turned into real terms using a general price index as deflator. The resulting non-staff related operating input prices are captured by the variable 'W3'.¹¹

Capital related input price [W4]:

The measurement of capital input prices is one of the most daunting tasks in cost function estimation due to data issues. As agreed with the PRU, the capital input price is defined as the ratio of capital-related costs (i.e. sum of depreciation costs and cost of capital) to a measure of capital physical inputs. The measure of capital physical inputs is computed for each ANSP as the NBV of fixed assets divided by the annual producer capital index from Eurostat. Missing values of the annual data of the producer price index for capital goods (from Eurostat) have been estimated on the basis of neighbouring countries. The capital input prices are captured by the variable 'W4' in the following section.

Traffic variability [VAR]:

Traffic variability measures are based on the ratio of the maximum traffic volumes to the average traffic volumes over a specific time period (e.g. week, month, etc.). The two traffic variability measures that were considered in the econometric analysis are (1) the traffic variability measured over three month periods and (2) the traffic variability measured on a weekly basis, that is, the peak week over the average week.

Business environment quality [BUS]:

The proxy variable for the quality of the economy-wide business environment is an index extracted for the relevant countries/ANSPs from the Transparency International database. This variable reflects the risk to invest in a given country taking into account the local business and institutional environments, lower is the index higher is the risk. Missing values in earlier years (e.g. Malta for 2002 and 2003) were approximated based on the index of the following year (e.g. Malta's index of 2004).

¹⁰ Eurostat provides annual figures for the industry producer index for all industries, though next to the services industry this excludes construction, sewerage, waste management and remediation activities as well as food, beverages and tobacco.

¹¹ A variant of W3 has also been created to meet the alternative hypothesis that half of inputs have the same price across countries. Our robustness tests have indicated that it is preferable to assume that all costs vary by country instead of this alternative hypothesis.

Structural traffic complexity [COMP]:

The structural traffic complexity score captures the fact that the traffic in some areas is structurally more complex. The structural complexity is composed of the sum of three metrics: ascending and descending routes, crossing routes, and variable speeds (a proxy for traffic mix). The structural traffic complexity figures are not available for 2002, so these figures were estimated based on the trend derived from the complexity figure for 2003 and 2004. We have explored as alternative measures the average flight level used or the share of overflights but these variables lack statistical power and appear uncorrelated with differences in ATM/CNS provision costs.

Time trend [T]:

Year dummies are designed to capture common macroeconomic effects: although they show a trend they are often not statistically significant. We have therefore chosen to add a time trend which is generally strongly significant. In our robustness checks we have included time dummies instead of the trend and our results; the results show that the residuals are strongly correlated in the two specifications, therefore the choice of including a time trend vs a set of time dummies has only a small impact on the findings.

Network concentration index [NET]:

The network concentration index is based on the number of airport movements controlled by the TWR operational units where the ANSP is responsible to provide ATC services. This index is calculated by (1) computing the share of each TWR operational unit in the total number of airport movement controlled by the ANSP and (2) summing the squared values of these shares.¹² This implies that the network concentration index will be highest, if all the airport movements of an ANSP are controlled by one TWR operational unit. In this case, the value of the network concentration index will be 1, i.e. the square of the TWR's share (100%) in the total number of airport movements controlled by the ANSP. On the contrary, if an ANSP is responsible to provide ATC services in 15 TWRs and assuming that 15% of the total airport movements is controlled by 5 TWRs (an individual share of 3% each) and that the remaining 85% are handled by 10 TWRs (an individual share of 8.5% each), then the network concentration index would amount to some 0.08 (i.e. $5 \times 0.03^2 + 10 \times 0.085^2$).

Size of airspace controlled [SIZE]:

The size of the airspace controlled by each ANSP is measured in square kilometres. The size of controlled airspace is almost invariant in time. This lack of variability over time may create problems in models with Fixed Effects. The rationale to include it is to allow a proper assessment of economies of scale (not just density) from the coefficients of output and airspace controlled.

¹² The concentration rate of each ANSP's airspace is calculated using the Herfindahl-Hirschmann Index (HHI) principle for measuring market concentration. The HHI is calculated by summing the squared market share figures of all companies in an industry. Hence, if an industry is monopolised, the HHI will be 1 (100% x 100%).

4.1 Some descriptive statistics

Our core specification includes variability, transparency and structural complexity. All variables are in logs (but for ANSP or time Fixed Effects).

- C: total ATM/CNS provision costs
- Y: output measure i.e. number of composite flight-hours
- W1: average employment costs per hour for ATCOs in OPS
- W2: average employment costs for support staff
- W3: price of non-staff operating inputs (index for producer goods)
- W4: capital input price
- VAR: Traffic variability
- NET: Network Concentration
- SIZE: Size of airspace controlled
- COMP: Structural traffic complexity
- BUS: Business environment quality
- T: time trend

In the estimation in practice we impose the homogeneity condition¹³ of cost functions, whereby all monetary variables (costs and the labour and capital input prices) are divided by the input price W3 (this explains why there is no standard error for W3 in the tables of results and also why the statistics reported below do not include W3).

Table 1: Summary table of the main variables

Variables (in logs)	Mean	Standard deviation	Observations
C	13.50	1.41	268
Y	12.28	1.33	268
W1	-0.80	0.86	268
W2	5.94	0.88	268
W4	-1.77	0.39	268
BUS	1.71	0.42	268
COMP	-0.31	0.34	268
VAR	0.21	0.10	268
NET	8.35	0.73	261 (7 missing MUAC)
SIZE	12.10	1.23	268

Source: CEG analysis.

¹³ Whereby all coefficient of input prices add up to one

5 MAIN RESULTS AND INTERPRETATION

In what follows we show the findings from two of the models described in Section 3, that is

- The Pitt and Lee model
- The True Random Effects model.

The FE OLS approach, although preferable in terms of flexibility and robustness to the correlation of the Fixed Effects with regressors, unfortunately does not appear promising as it provides very large inefficiency estimates, larger than expected. We present the results of the tests on endogeneity of ATCO labour costs in section 5.4 below.

At this stage the random coefficient model does not perform well as there are problems in convergence of the estimation. The model may be delivering more promising results in the future with an improved database. In the exploratory regressions we undertook, it looks like the heterogeneity affects mostly complexity or the input prices, W4 in particular. This suggests that the effect of capital input prices may be very heterogeneous across ANSPs.

5.1 Pitt and Lee Model

Table 2 presents the main results with the Pitt and Lee assumptions, while Table 3 presents the robustness tests.

We note that the coefficients of output, input prices, transparency, variability, airspace size, concentration are always strongly statistically significant.

Increasing output goes hand in hand with greater costs. The Pitt Lee model indicates that a 10% increase in output increases cost by 5.7%.

The coefficients on the labour input prices W1 and W2 show that a ten per cent increase in either the ATCO or support staff wages translates in about 3% increase in costs. The magnitude of the capital input price appears lower than expected (ie not in line with the share of costs related to capital costs) and as a consequence the implied scale of W3 is too large compared to expectations (and the share of non-staff operating costs in total costs).

Traffic variability goes hand in hand with greater costs given the level of composite hours. Variability is an important factor differentiating ANSPs and explaining the cost differences which are not due to input prices or the composite hours controlled.

The coefficient of the variable that measures the concentration of traffic across different airports in the network is negative suggesting that greater concentration goes hand in hand with lower (unit) costs. Just as variability this variable accounts for a significant part of differences between ANSPs which would otherwise be conflated in the error term.

The size of the airspace controlled is associated with greater costs. The coefficient of output and size of the airspace jointly suggest economies of scale.

The time trend coefficient is precisely and consistently estimated at -0.02, all else equal. This suggests that for all ANSPs there is a general tendency to decreasing unit costs in the period considered.

The quality of the business environment also goes hand in hand with lower (unit) costs.

Structural traffic complexity is expected to go hand in hand with greater costs; however there is no such evidence empirically given that the complexity variable coefficient is insignificant using the traffic structural complexity score. Using the overall complexity index provided similar results. Because the result was not expected, in addition, we performed the estimation using an alternative measure of complexity, that is the average flight level; but the coefficient was again insignificant. Lastly, we also attempted to proxy complexity with the share of over flights in total traffic (instead of the complexity score). Again, the coefficient was insignificant.

Table 2 below reports our main findings, in the Annex Table A we show a selection of a number of specifications which we estimated to perform robustness tests on these findings.

As regards the inefficiencies, which are estimated using the Battese and Coelli (1988)'s generalization to panel data of the Jondrow-Lovell-Materov-Schmidt (1982) estimator of technical efficiency¹⁴, the interpretation of the findings is that costs are 60% higher than the efficient benchmark. Network concentration, variability and airspace controlled contribute to explaining what would be otherwise also labelled as inefficiency (in a model without these variables inefficiencies would be deemed higher as the time invariant component of the error would be larger).

¹⁴ See Jondrow J., Lovell C.A.K, Materov S and Schmidt P. (1982) "On the Estimation of technical Inefficiency in the Stochastic Frontier Production Function Model", *Journal of Econometrics*, 19; and Battese G. and Coelli T. (1988) "Prediction of Firm Level Technical Efficiencies with a Generalized Frontier Production Function and Panel Data", *Journal of Econometrics*, 38. See also the Limdep manuals.

Table 2: Econometric results based Pitt and Lee Random Effects model

Variables	Coefficients [Standard errors]
Y	0.57*** [0.06]
W1	0.28*** [0.02]
W2	0.28*** [0.02]
W3	0.37
W4	0.07*** [0.02]
T	-0.02*** [0.00]
COMP	-0.04 [0.09]
BUS	-0.22*** [0.04]
VAR	1.27*** [0.20]
SIZE	0.28*** [0.11]
NET	-0.34*** [0.09]
Constant	4.27*** [1.45]
Observations	261
Inefficiencies	60%

Standard errors in brackets. * significant at 10%; ** significant at 5%; *** significant at 1%
Source: CEG analysis of client data.

Table 3 shows that the results are robust to including time dummies instead of a monotonic trend. The coefficients estimates are similar to those of the basic specification shown in Table 4 and therefore the elasticity of costs with respect to various regressors is generally of similar magnitude. The order of magnitude of estimated inefficiencies is the same (57% as opposed to 60%).

The inspection of the time effects shows that there is a change of direction in 2009. Over time and all else equal, progressively costs are lower, up to 2008; the 2009 dummy is however smaller than the one for 2008, thus inverting the “trend” and bringing (unit) costs back to the 2006/07 level, all else equal.

We also performed a range of additional robustness checks and tests on different specifications, which are not shown. For instance excluding MUAC from the sample (in models that did not include the network concentration variable), did not have a significant impact on the findings. Similarly, focusing on more recent years and ignoring 2002 and 2003 data produces similar results.

Table 3: Pitt and Lee Random Effects model with year effects

Main variables coefficients only	Coefficients [Standard errors]
Y	0.65*** [0.08]
W1	0.27*** [0.03]
W2	0.27*** [0.04]
W3	0.40
W4	0.06*** [0.02]
COMP	-0.02 [0.10]
BUS	-0.24*** [0.05]
VAR	1.31*** [0.25]
SIZE	0.25* [0.14]
NET	-0.26** [0.12]
Models includes constant and yearly time dummies	261 Observations
Observations	261
Inefficiency	57%

Standard errors in brackets. * significant at 10%; ** significant at 5%; *** significant at 1%
Source: CEG analysis of client data.

5.2 True Random Effects model

In the following table we show our main results. In the annex Table B more results are shown illustrating different specifications we estimated for robustness tests.

Looking at the main results, compared to the Pitt and Lee model this model shows a larger coefficient for output. However, the coefficients on output and controlled airspace still suggest the presence of economies of scale.

The magnitude of W1 and W2 is in line with the previous model and suggests an elasticity of approximately 0.3 (ie 3% increase in costs if one of the two labour input prices increases by 10%).

We note that the coefficient of the variable airspace controlled is now insignificant and that structural complexity has a counter-intuitive negative sign. Alternative measures of traffic complexity, not reported, had insignificant coefficients (both when using over flights share in total traffic or average flight level).

Additional background analysis on the efficiency scores suggests that the inclusion of environmental variables has a lower impact on the estimated inefficiencies and that different model specification have a somewhat limited impact on the efficiency scores (this is because environmental variables impact mostly the time invariant component which in the true random setting is not linked to inefficiencies).

Table 4: Regression results from the True Random Effects model

Variables	Coefficients [Standard errors]
Y	0.73*** [0.01]
W1	0.30*** [0.02]
W2	0.29*** [0.02]
W3	0.34
W4	0.07*** [0.01]
T	-0.03*** [0.00]
COMP	-0.06** [0.02]
BUS	-0.19*** [0.02]
VAR	0.90*** [0.08]
SIZE	-0.01 [0.01]
NET	-0.41*** [0.02]
Observations	254
Inefficiencies	13.4%

Standard errors in brackets. * significant at 10%; ** significant at 5%; *** significant at 1%.

Notes: Model fitted with a constant. There are fewer observations because the variable concentration has been included, estimation also excluded Moldavia due to some problems in convergence. Based on the investigation of alternative specifications the impact is negligible on the estimated coefficients and null on the inefficiencies. Source: CEG.

5.3 Interpretation of the results in terms of inefficiency

Naturally, the question arises to what extent the inefficiency measures obtained from the different models are of the same order of magnitude. Comparable inefficiency measures appear to be a requirement if strong conclusions are to be drawn from these measures.

It should be noted that:

- (a) the Random Effects model proposed by Pitt and Lee assumes that ANSPs inefficiency is invariant in time. This means that non-observed ANSP specificities which do not change over time will be considered as inefficiency. Therefore, in this model inefficiency is likely to be over-estimated if there is a high level of heterogeneity.

- (b) The true Random Effects model proposed by W. Greene assumes that ANSPs inefficiency is variant in time. This means that persistent differences across ANSPs due to inefficiency will be considered as heterogeneity and not as inefficiency. This means that in this model inefficiency is likely to be under-estimated if there is a high level of heterogeneity.

As expected, the estimated inefficiency level varies between the two different models. In the Pitt & Lee random effect model which assumes that all the time invariant elements are linked to inefficiency, the estimated system level inefficiency is around 60%. This is significantly different from the level of inefficiency estimated by the true random model effects model (13%) according to which all the time invariant elements are not considered as inefficiency but treated as non-observed heterogeneity.

It is likely that the “real” level of inefficiency is within the threshold provided by these two different models [13%-60%] since time invariant differences across ANSPs are probably due to both inefficiency and to specific factors reflecting local circumstances. Furthermore, it will be worth checking the hypothesis of “endogeneity” of ATCOs in OPS wages (see Section 3.3 above). Indeed, if ATCOs in OPS wages are endogenous the actual inefficiencies may be higher than estimated by the two models.

The econometric analysis shows that the assumptions taken on the error term u_i have a large impact on the inefficiency estimates and on the relative positions of individual ANSPs in the overall distribution of the inefficiency measure. For this reason, caution is needed with the interpretation of these results. However, the PRU will continue to collect and analyse data to investigate whether more robust conclusions can be drawn in future years. As the time series of data increases, the robustness of the panel techniques applied is also expected to increase.

6 NEXT STEPS

The PRU plans to progress on the econometric cost-benchmarking analysis by including the ACE 2010 data when these will be available and to check whether a more flexible functional form than the Cobb-Douglas (such as the translog cost function) and other estimation models (e.g. random coefficients) can be used.

The PRU also plans to test alternative assumptions and data to compute the non-staff operating input and the capital-related input. The potential “endogeneity” of ATCOs in OPS wages may affect the estimated cost-inefficiencies. Further investigation would be required in order to address this issue in the econometric analysis.

For the time being, the results provided in this report do not take into account the quality of service provided by the different ANSPs. It would therefore be important to develop a methodology to correlate ANSPs estimated inefficiency levels with the quality of service provided in future econometric analyses.

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ANNEX: ADDITIONAL ESTIMATION RESULTS

Table A: Additional econometric results based on Pitt and Lee Random Effects model

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	With business environment quality				Without business environment quality					
Y	0.62*** [0.06]	0.54*** [0.06]	0.69*** [0.05]	0.57*** [0.06]	0.36*** [0.05]	0.40*** [0.06]	0.49*** [0.04]	0.53*** [0.06]	0.65*** [0.05]	0.50*** [0.06]
W1	0.30*** [0.03]	0.30*** [0.03]	0.27*** [0.02]	0.28*** [0.02]	0.28*** [0.02]	0.28*** [0.02]	0.30*** [0.02]	0.30*** [0.02]	0.26*** [0.03]	0.31*** [0.03]
W2	0.28*** [0.02]	0.27*** [0.02]	0.28*** [0.02]	0.28*** [0.02]	0.26*** [0.02]	0.26*** [0.02]	0.27*** [0.02]	0.27*** [0.02]	0.29*** [0.02]	0.27*** [0.03]
W4	0.06*** [0.02]	0.06*** [0.02]	0.08*** [0.02]	0.07*** [0.02]	0.08*** [0.02]	0.08*** [0.02]	0.07*** [0.02]	0.07*** [0.02]	0.08*** [0.02]	0.06*** [0.02]
T	-0.03*** [0.00]	-0.02*** [0.00]	-0.03*** [0.00]	-0.02*** [0.00]	-0.02*** [0.00]	-0.02*** [0.00]	-0.02*** [0.00]	-0.02*** [0.00]	-0.03*** [0.00]	-0.02*** [0.00]
COMP	-0.11 [0.08]	-0.02 [0.09]	-0.12 [0.08]	-0.04 [0.09]		-0.16** [0.07]		-0.12 [0.08]	-0.13* [0.07]	-0.05 [0.08]
BUS	-0.19*** [0.05]	-0.17*** [0.05]	-0.24*** [0.04]	-0.22*** [0.04]						
VAR	1.32*** [0.19]	1.34*** [0.19]	1.16*** [0.22]	1.27*** [0.20]			1.38*** [0.19]	1.35*** [0.19]	1.41*** [0.23]	1.40*** [0.20]
SIZE		0.48*** [0.09]		0.28*** [0.11]	Variability significantly lowers the eff. scores, which is not the case complexity Variability also significantly impacts the size of the output coefficient			Including (in addition to variability) also either surface of concentration lowers the ineff. further		0.50*** [0.10]
NET			-0.46*** [0.06]	-0.34*** [0.09]						
Constant	3.67*** [0.70]	-0.82 [1.01]	7.28*** [0.76]	4.27*** [1.45]	6.53*** [0.53]	5.90*** [0.70]	4.75*** [0.52]	4.33*** [0.69]	7.78*** [0.82]	-1.03 [1.19]
Observations	268	268	261	261	268	268	268	268	261	268
Inefficiencies	108%	76%	60%	60%	156%	152%	125%	125%	60%	82%

Standard errors in brackets. * significant at 10%; ** significant at 5%; *** significant at 1% Source: CEG analysis of client data.

Table B True Random Effects model additional results

	Without business environment		With business environment				Variant of operating input prices
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Y	0.85*** [0.01]	0.86*** [0.01]	0.89*** [0.01]	0.63*** [0.01]	0.68*** [0.01]	0.73*** [0.01]	0.74*** [0.01]
W1	0.12*** [0.02]	0.19*** [0.02]	0.27*** [0.02]	0.27*** [0.02]	0.21*** [0.01]	0.30*** [0.02]	0.33*** [0.02]
W2	0.30*** [0.02]	0.33*** [0.02]	0.31*** [0.02]	0.27*** [0.02]	0.28*** [0.01]	0.29*** [0.02]	0.29*** [0.02]
W4	0.07*** [0.02]	0.04*** [0.02]	0.05*** [0.01]	0.06*** [0.01]	0.08*** [0.01]	0.07*** [0.01]	0.07*** [0.01]
T	-0.03*** [0.00]	-0.04*** [0.00]	-0.04*** [0.00]	-0.03*** [0.00]	-0.03*** [0.00]	-0.03*** [0.00]	-0.03*** [0.00]
COMP		-0.18*** [0.03]	-0.20*** [0.03]	0.09*** [0.02]	-0.18*** [0.02]	-0.06** [0.02]	0.04 [0.03]
BUS			-0.32*** [0.02]	-0.15*** [0.02]	-0.26*** [0.02]	-0.19*** [0.02]	-0.21*** [0.02]
VAR		1.45*** [0.08]	1.45*** [0.09]	0.95*** [0.07]	0.92*** [0.07]	0.90*** [0.08]	1.10*** [0.08]
NET					-0.45*** [0.02]	-0.41*** [0.02]	-0.40*** [0.02]
SIZE				0.24*** [0.01]		-0.01 [0.01]	0.07*** [0.01]
Constant	1.46*** [0.15]	0.94*** [0.18]	1.29*** [0.17]	1.57*** [0.16]	7.66*** [0.26]	6.81*** [0.28]	5.62*** [0.33]
Observations	268	268	268	268	254 [†]	254 [†]	254 [†]
ineff	13.4%	11.8%	12.3%	12.4%	13.2%	13.4%	13.7%

Standard errors in brackets. * significant at 10%; ** significant at 5%; *** significant at 1%.

[†] There are fewer observations because the variable Network concentration has been included and Moldova dropping out. Column (7) reports the results on the basis of the assumption that half of the prices for “other operating inputs” are common across ANSP.

Source : CEG