



European
Commission

JRC SCIENCE FOR POLICY REPORT

Efficiency of investment in compulsory education: empirical analyses in Europe

Tommaso Agasisti

Ralph Hippe and Giuseppe Munda

2017

This publication is a Science for Policy report by the Joint Research Centre (JRC), the European Commission's science and knowledge service. It aims to provide evidence-based scientific support to the European policy-making process. The scientific output expressed does not imply a policy position of the European Commission. Neither the European Commission nor any person acting on behalf of the Commission is responsible for the use which might be made of this publication.

Contact information

Tommaso Agasisti, Politecnico di Milano School of Management
Department of Management, Economics and Industrial Engineering
tommaso.agasisti@polimi.it

Ralph Hippe and Giuseppe Munda, European Commission, Joint Research Centre
Directorate B – Innovation and Growth, Unit JRC.B.4 – Human Capital and Employment
TP 361 – Via E .Fermi 2749 – I-21027 – Ispra (Va) – ITALY
ralph.hippe@ec.europa.eu
giuseppe.munda@ec.europa.eu

JRC Science Hub

<https://ec.europa.eu/jrc>

JRC106678

EUR 28607 EN

PDF ISBN 978-92-79-68863-8 ISSN 1831-9424 doi:10.2760/975369

Luxembourg: Publications Office of the European Union, 2017

© European Union, 2017

Reproduction is authorised provided the source is acknowledged.

How to cite: Tommaso Agasisti, Ralph Hippe and Giuseppe Munda; Efficiency of investment in compulsory education: empirical analyses in Europe; EUR 28607 EN. Luxembourg (Luxembourg): Publications Office of the European Union; 2017. JRC106678; doi:10.2760/975369

All images © European Union 2017

Title

Efficiency of investment in compulsory education: empirical analyses in Europe

Abstract

The current economic crisis has put ever more to the forefront the need to achieve educational goals in the most efficient way. Therefore, this report provides an empirical analysis of the efficiency in education in the EU. Efficiency is measured first by using two different but related traditional frontier approaches (Data Envelopment Analysis and Free Disposal Hull) and then the robustness of our findings is checked by means of multi-criteria evaluation. The analysis is based on a number of standard variables from the literature. The results show, among others, that not the amount, but the specific use of resources is what matters; and that the efficiency of an educational system could also contribute to long-term benefits in terms of adults' skills and competences.

Table of contents

Acknowledgements.....	5
Executive summary	6
1 Introduction: What we know about the efficiency of educational spending in Europe..	8
1.1 Efficiency of educational provision: comparison of spending and outputs at country-level	8
1.2 Efficiency of educational provision: comparison of inputs and outputs at single-institution level	9
2 Lessons learnt for advancing the study about the efficiency of educational public spending of European countries	11
3 Efficiency analysis of compulsory education in the EU Member States	13
3.1 About efficiency and effectiveness	13
3.2 Data and modelling	14
3.3 How do the efficiency scores correlate with the outputs?	19
3.3.1 Efficiency and PISA scores	19
3.3.2 Efficiency and early school leavers.....	20
3.3.3 Efficiency and NEET	21
3.4 How do the efficiency scores correlate with the inputs?	22
3.4.1 Efficiency and expenditure	22
3.4.2 Efficiency and the students:teachers ratio	24
3.5 Are the efficiency scores correlated with some variables describing key characteristics of the educational system?	25
3.5.1 Descriptive information on contextual variables.....	25
3.5.2 Efficiency and average teachers' age.....	26
3.5.3 Efficiency and average teachers' salaries	27
3.5.4 Efficiency and the proportion of immigrants	28
3.5.5 Efficiency and adult literacy	29
3.5.6 Efficiency and the adults' educational attainment.....	30
3.5.7 Efficiency and the proportion of public spending on education	31
3.5.8 Efficiency and equity	32
3.6 Robustness check: multi-criteria analysis	33
4 Concluding remarks and policy implications	35
4.1 The measurement of efficiency of education at country-level: conceptual issues	35
4.2 The characteristics of educational systems and the correlations with efficiency..	35
4.3 Future scenarios: the necessity for more data for better estimates of efficiency in education at country-level	39
References	41
ANNEX 1. Overview of efficiency studies in Europe	50
ANNEX 2. Overview of variables used	53
ANNEX 3. Robustness analysis: a multi-criterion approach	56

a) Analysis considering the expenses side only.....	56
b) Analysis considering the output side only	58
c) Integrated analysis considering both the expense and output sides	60
ANNEX 4: Pairwise comparisons	69
List of abbreviations and definitions.....	93
List of figures.....	94
List of tables.....	95

Acknowledgements

Comments by colleagues at JRC.B.4 and DG EAC on previous versions of this document have been very useful for its improvement.

Note

This technical report is part of CRELL VIII Administrative Arrangement agreed between DG EDUCATION and CULTURE (EAC) and DG JOINT RESEARCH CENTRE (JRC). In particular it refers to point 2.1 of the Technical Annex accompanying CRELL VIII.

Executive summary

Policy context

Education is considered an important factor of economic growth, employment and social inclusion. For this reason, improving educational outcomes is part of the Europe 2020 headline targets. Yet the current economic crisis has also put ever more to the forefront the need to achieve educational goals in the most efficient way. In fact, educational spending in EU Member States takes a share of about 10 % of total public expenditure, which translates to around 5 % of GDP. Thus, the discussion about efficiency of organizations and spending is crucial for the educational sector in Europe and has high policy relevance. For example, the Education and Training Monitor also identifies several challenges for education which are all, in different ways, related to the concept of efficiency.

Key conclusions

This report provides an empirical analysis of the efficiency in education in the EU. A number of conclusions can be drawn from the analysis. First, measuring efficiency is different from measuring academic performance. Some countries have students who obtain, on average, excellent results in terms of test scores, and whose educational system has been deemed as 'relatively inefficient', because of the use of an excessive amount of resources for getting these results. Conversely, there are countries where the educational system is 'relatively efficient' – i.e. the resources are used at their most, for getting the highest possible level of output – but still the academic results are unsatisfactory. The general aim of any educational policy should consist in reaching an adequate (high) level of outputs, with using the necessary amount of resources (and no more than such necessary level). Thus, instead of reducing the level of inputs, policymakers should find viable strategies for stimulating and getting higher results. In consequence, the specific use of resources is what matters.

Furthermore, the efficiency of an educational system is positively correlated with the competences of the adults. Thus, stimulating the efficiency of an educational system could also contribute to long-term benefits in terms of adults' skills and competences, and can stimulate a virtuous circle where higher levels of adults' human capital can foster current educational outputs, and vice versa.

In addition, policy makers may keep an eye on raising the average educational results, while having at the same time the objective of not leaving disadvantaged students behind.

Finally, the data availability for efficiency analyses at the EU level could be improved. To this end, an EU-wide project on generating additional and harmonising existing national school level data should be realised.

Main findings

This report analyses the efficiency of compulsory education. Efficiency is measured first by using two different but related traditional frontier approaches (Data Envelopment Analysis and Free Disposal Hull) and then the robustness of our findings is checked by means of multi-criteria evaluation. The analysis is based on a number of standard variables from the literature (among others, on the input side e.g., share of educational expenditure, and on the output side educational achievement scores). We consider several alternative specifications for calculating efficiency scores but we find that the main results are not sensitive to the specifically chosen model. We also correlate the efficiency scores with input, output and a number of contextual variables. First, we begin by correlating efficiency scores with output variables. We observe a positive statistical

relationship between efficiency and test scores (in mathematics), while the relationship with early school leavers and NEETs is less obvious, but a number of country groupings can be discerned. Second, we correlate efficiency with the inputs. On the one hand, efficiency scores are negatively correlated with expenditure per student and expenditure as a share of GDP. On the other hand, they are positively correlated with the students:teachers ratio. Finally, we introduce some contextual variables in the analysis. Overall, efficiency scores are negatively correlated with average teachers' age and equity, while they are positive related to adult literacy and share of natives. However, some country groupings appear not to follow these relationships. There is also no clear statistical pattern with teachers' salaries, adults' educational attainment and the proportion of public spending devoted to education.

Related and future JRC work

Closely related there is a Technical Report focussing on the methodology of efficiency analyses (Agasisti and Munda, 2017). The Technical Brief "Equity in education in Europe" is a useful complement.

Quick guide

This Report builds on the literature of previous empirical analyses on efficiency in educational systems. By using a new dataset and various econometric methods we assess the efficiency across European countries and derive a number of conclusions.

1 Introduction: What we know about the efficiency of educational spending in Europe

As discussed in the report on methodological aspects of efficiency analysis (Agasisti and Munda, 2017), there is no doubt that investments in human capital present positive benefits for economic growth and societal well-being. However, as in other categories of economic decisions, investments in education have to take into account their *opportunity cost* and try to answer difficult questions such as: How much of the national budget has to be devoted to education? Have all forms of education be financed equally? Is it better to invest in pre-schooling or in universities? Clearly, efficiency is a very important policy objective of any education system, and we begin this report by presenting a set of selected studies that deal with measuring and comparing efficiency of educational systems and institutions across Europe. The objective of this choice is to provide an overview of recent works that extended the empirical approach for analysing efficiency to a cross-country perspective; at the same time, reviewing these studies would help in having 'on-the-field', practical examples of variables actually used in empirical studies of this kind. The illustration is articulated in two sub-sections: one where the analysis is conducted at the country level (in the Annex 1, one can find a synthetic table summarizing the main variables used, countries and years of reference, including studies concerning higher education), and one that presents studies where the units of analysis are the single educational institutions.

The main criteria for including the studies in the selection have been the following:

- To be published in academic, international journals or in well-acknowledged series of working/discussion papers developed by research centres or institutions;
- The empirical analysis is comparative, i.e. the units analysed are cross-country.

This selection leads to a total of seven studies, of which five deal with comparisons at country level, and two are instead comparing efficiency of single educational institutions.

1.1 Efficiency of educational provision: comparison of spending and outputs at country-level

The first contribution in the field has been by Clements (2002), who conducted an empirical analysis on 18 countries. Estimates show that around 25% of spending on education in Europe can be reduced without altering the outputs produced, when benchmarked against other OECD countries' best practices. The countries within the EU that have been deemed relatively efficient are Finland, Greece and Ireland.

Afonso & St. Aubyn (2006) compared the efficiency of 25 countries in the provision of secondary education, using OECD-PISA test scores as outputs, and two measures of teaching intensity as inputs – number of teachers and teaching hours per year (averages by country). The results reveal that Finland and Korea turn out as the most efficient countries, and they constitute the benchmark against which they measure the other countries' efficiency. By regressing efficiency scores against two contextual variables, the results show that efficiency is positively correlated with country-level measures of parental education and GDP per capita.

Gimenez et al. (2007) measured the efficiency of primary/secondary education production in 31 countries, using TIMSS 1999 (TIMSS - Trends in International Mathematics and Science Study) as database. The findings show that contextual variables do play a major role in determining the level of educational production, and the countries' efficiency in educational spending. In the case of out-of-Europe, Anglo-Saxon countries (USA, Australia and New Zealand), efficiency should be reached by increasing test scores while at the same time reducing resources devoted to education. Countries

with the highest levels of efficiency are certain Asian countries and those with a Communist past. The authors do not provide any potential explanation for these findings. In our opinion, the two cases are very different: Asian countries show high level of spending in education, but coupled with very high (average) test scores. Ex-Communist countries, on the other side, have quite low test scores, but with a very low level of financial investment in education, so that they result being efficient in the ability of doing the most with their available resources.

Eugène (2008) assessed the efficiency of educational expenditure of 17 countries (14 'old' EU member States, plus USA, Japan and Poland). Expenditure refers to all the educational levels, from primary to tertiary (separately), so this paper is the first looking at the efficiency of the whole educational chain in the selected countries. Instead of using single measures of outputs (as PISA test scores, etc.) the author builds an aggregated indicator of outputs, which includes in addition to PISA scores the proportion of population that attained secondary and tertiary education, and the quality of the educational system at various levels, as judged by the World Economic Forum (WEF) and by the IMD World Competitiveness Yearbook – it is a particular example because of this choice to synthesize output in a single measure. The results situate four countries on the efficiency frontier: Poland, Ireland, the Netherlands and Finland. Two countries are particularly far from the educational efficiency frontier, namely Italy and USA. No clues are provided about the potential causes behind the efficiency differentials.

Agasisti (2014) analyses the efficiency of spending on primary and secondary education for 20 European countries. All data come from the OECD (Education at a Glance, various years); inputs are measured through students:teachers ratio and expenditures, while output is the PISA test score in mathematics in two subsequent editions (2006 and 2009). For the first time, such an efficiency analysis at country level is conducted in a "panel" version, that allows understanding how efficiency varies over time. A set of contextual variables, describing socioeconomic conditions of countries and educational systems' features, is used for a second-stage explorative analysis of factors associated with efficiency. The results identify two most efficient countries, Finland and Switzerland, and two very inefficient ones, Spain and Portugal. Between 2006 and 2009, the differences in scores between high-efficiency and low-efficiency countries diminished, although very slowly – and, overall, efficiency of spending did not increase in the period. Efficiency of educational expenditure is positively correlated with teachers' salaries and the digital literacy of students, confirming the strong role that these two 'factors' (students and teachers, and their quality) plays in affecting educational production.

1.2 Efficiency of educational provision: comparison of inputs and outputs at single-institution level

The presence of studies about the efficiency of single educational institutions in a cross-country perspective is still in its infancy, and is especially related to the availability of European-level datasets of microdata for HEIs, developed through three EU-funded projects (see below)¹. The only two studies that explicitly compare the efficiency of schools at primary/secondary educational levels used OECD PISA data for this purpose. Sutherland et al. (2010) use PISA 2003 data for computing efficiency scores of schools in the OECD countries, using computer availability, students:teachers ratio and students' SES as inputs, while considering PISA test scores as output. The results highlight that there is considerable variation in schools' efficiency within countries, much higher than

¹ Agasisti created a series of studies that compare the efficiency of universities in two countries at a time; we exclude them from this analysis, because we are interested here more on multi-country empirical analyses. Interested readers, however, can refer to: Agasisti & Johnes (2009); Agasisti & Perez Esparells (2010); Agasisti & Pohl (2012); Agasisti & Haelermans (2015) and Agasisti & Wolszczak-Derlacz (2015).

that across countries. In addition, the estimates demonstrate that inputs can be reduced by one third without having any effect on current output levels. Nevertheless, the study is accompanied by a country-level empirical analysis, which occupies most of the discussion of the results.

Agasisti & Zoido (2015) extend the previous work by using PISA 2012 data for estimating the efficiency of 8,640 schools in 30 OECD countries. The inputs and outputs used are analogous to those employed by Sutherland et al (2010), but the outputs are test scores in reading and mathematics simultaneously. The results again highlight much variation in efficiency scores within countries, definitely higher than that between countries. Therefore, some countries have a high proportion of schools that result to be efficient in the international comparison – and more specifically this is the case of south-east Asian countries. A second stage regression demonstrates that, on average, most efficient schools are those with a better school climate and stronger engagement of students. The paper also claims a positive relationship between efficiency and equity, in the sense that schools with higher efficiency scores are also those with lower proportion of students who are classified at very low proficiency level. Moreover, a quantile regression illustrates how the factors associated with higher/lower efficiency are different at different points of the efficiency's distribution – for instance, higher degrees of competition are associated positively with more efficient schools, and negatively with less efficient ones.

It is difficult to make general conclusions based on only two studies about the efficiency of single schools. In our view, it is actually crucial to create a European Database for data about primary and secondary schools. Many of the existent studies that investigate the determinants of students' performance highlight a specific role of schools, as well as the importance of the features of the educational systems (i.e. school autonomy, funding mechanisms, degree of competition, etc.) – see Luedemann et al. (2009) and Hanushek & Woessmann (2010). A very relevant field of research and analysis should be that of the interactions between school characteristics and system-level ones, as well as their evolution over time. This would require detailed data at the level of single institution (both directly collected or as the results of data integration from countries' Statistical Offices), but no systematic collection of administrative data about single schools exists today at the European level (this is why the only two existent studies rely on PISA data). With such data at hand, not only efficiency analyses could be conducted, but also and overall more precise studies about the influence of schools' features on students' achievement.

A different situation can be found when turning the attention to the efficiency of high education institutions (HEIs), where a richer and more developed field of study exists. We do not review this literature here, since our focus is on compulsory education.

2 Lessons learnt for advancing the study about the efficiency of educational public spending of European countries

In a policy perspective, the discussion about efficiency of organizations and spending is crucial for the educational sector in Europe. The Education and Training Monitor 2015 identifies several challenges for education in the continent, ranging from pre-primary schooling to HE: strengthening parental support measures, raising the quality of teachers, implementation of digital technologies in formal education, consolidation of language learning at school, establishing good links between vocational education and labour market, fostering learning mobility of HE students, a better use of digital learning in HEIs – see European Commission (2015; pp. 47-81). All these elements are somehow related with the concept of efficiency, in the sense that policy makers and educational managers are interested in understanding the ‘technology’ behind the transformation of inputs into outputs.

Here, we focus on three major points that, in our opinion, deserve a reflection when outlining the potential evolution of efficiency analysis of European education. A first point, already discussed in the methodological report (Agasisti and Munda, 2017), is about the *sensitivity of results to the choice of variables and methods*. If the intention of policy makers is to move the analysis from the area of academic studies to the arena of real policy use, then the results about single countries’ and institutions’ efficiency scores should be methodologically robust and empirically credible and defensible.

A golden standard of any system for measuring efficiency should consist in defining whether scores have the following two properties: (i) scores are robust to the selection of specific variables (inputs and outputs selection), and (ii) scores are robust to the selection of methods for efficiency analysis. As a basic requirement, the empirical analyses should show some robustness checks along these dimensions.

Another issue is that of the *internal heterogeneity of institutions*. The assumption that a single measure can reflect the “average” efficiency level of an educational institution can be hardly sustained, especially in contexts and situations where there exists a high degree of internal heterogeneity – within-institution. A typical case of such a situation is that of universities’ departments, which experience high level of autonomy and typically substantial variation in input usage and performance levels. For this reason, some scholars look directly at the efficiency of academic departments – instead of whole universities – as in Beasley (1990), Koksal & Nalcaci (2006), Kao & Hung (2008); Agasisti & Bonomi (2014) provide a comprehensive framework for assessing universities’ efficiency in presence of heterogeneity across academic departments and/or units within institutions. Such attention to intra-organizational differences should be promoted also in the research activities about primary and secondary schools. Indeed, the literature evidences that performance differentials across classes within schools are substantial (see evidence since Raudenbush & Willms, 1991 and Muthen, 1991) and so variation in efficiency within schools (i.e. between classes) is likely to exist²; estimates of school-level efficiency could be refined taking this heterogeneity into account.

A final remark is about the *study of the efficiency’s determinants*. Although most papers on efficiency analysis are concentrated on describing efficiency scores, the real interest for policy-making is in understanding which factors are likely to affect efficiency of spending and of institutions’ operations. Apart from the methodological issues related to

² The only exception should be constituted by a heterogeneous distribution of inputs/resources within schools that perfectly reflects output differentials. The research question thus should become how adequately measuring allocation of resources within schools (across classes) and the correlations of these measures with educational outputs.

the best way of modelling the impact of contextual variables on efficiency, the main point is about the identification and classification of the relevant variables. On one side, the desire of deriving information about the pure technical efficiency of educational institutions would suggest to consider many resources as actually contextual or at least non-discretionary in the use (see the interesting discussion in Ruggiero, 1998). For instance, in this perspective, the socioeconomic conditions of students are not a real input. On the other side, there is still no agreement about which are the main factors that are closely associated with (in)efficiency. As a consequence, any choice of contextual variables is subjected to the risk of discretion, and no steps are made towards a better comprehension of the efficiency determinants.

One of the main shortcomings in current research is the lack of more precise theories about what makes an institution abler than others in transforming its inputs (resources) into outputs (educational results somehow measured). In this vein, our idea is that the efficiency literature should integrate itself with three important streams that would help shed new lights on the mechanisms of (efficient) educational production:

- *Educational effectiveness.* A longstanding area of research is the one that investigates the determinants of successful school-level interventions, that goes under the name of "educational (or school) effectiveness" (see Sammons, 1995; Teddlie & Reynolds, 2000). This area of research, in addition to providing interesting evaluations of the effects of certain schools' characteristics and initiatives on results, suggests a comprehensive theoretical foundation to include certain schools' features among those that are likely to "matter" in influencing students' performance. Indications from this literature would help the efficiency approach to move away from a 'black box' attitude (where the educational institution simply transforms inputs into outputs) towards a better understanding of specific factors that must be considered to explore the efficiency differentials in a meaningful, theory-based setting.
- *Learning analytics.* Recent opportunities opened-up by a systematic collection of data produced by learners and by institutions offer the possibility to use a wider amount of data to better describe the educational process. As defined by Campbell et al (2012), "(...) Analytics marries large data sets, statistical techniques, and predictive modelling. It could be thought of as the practice of mining institutional data to produce 'actionable intelligence.'" This approach, applied to the case of educational institutions, would generate new informative power in the hands of analysts, who would be able to integrate new data sources in the efficiency analyses (such as, for instance, information about how students use the Learning Management Systems). It is not clear in which direction a more intense use of big data and analytics will lead the efficiency analyses, but it certainly will make new indicators available for describing inputs and outputs.
- *Quantitative policy evaluation.* As outlined by De Witte & Lopez-Torres (2015), too often the efficiency literature does not discuss the important distinction between correlations (i.e. factors associated with efficiency scores) and causation (i.e. mechanisms that drive higher/lower efficiency scores). A higher attention to the issues of endogeneity (intended in the econometric sense, that is to say the correlation between a variable under scrutiny and the error term) would make the efficiency analyses more robust and credible under an evaluative perspective – see the recent contribution by Cordero et al. (2015).

3 Efficiency analysis of compulsory education in the EU Member States

3.1 About efficiency and effectiveness

Before taking a closer look at the data, it seems useful to clarify in more detail what we can expect from such an efficiency analysis. For this reason, it is important to have a clear understanding of the difference between efficiency and effectiveness. It is of key importance understanding that efficiency alone cannot be a relevant policy objective. Effectiveness (i.e. the level of education output achieved) is at least equally important. Otherwise there is the risk to drive the education system towards a situation where efficiency means just “cheap”.

To clarify this point, let’s consider the following four situations obtained by combining efficiency with effectiveness:

Effective	A) Goals are achieved, e.g. good PISA scores, but too many resources are used. The education system is effective but there is a waste of resources.	B) Goals are achieved (e.g. good PISA scores) by using a reasonable amount of resources. Of course, this is the best situation.
Non-effective	C) Goals are not achieved (the education output is bad) and a lot of resources are used. This is the worst situation.	D) Goals are not achieved (poor education output) but the amount of resources used is low. The education system is efficient (because it uses wisely poor resources) but it is non-effective.
	Non-Efficient	Efficient

It is immediately evident that efficiency is a relevant policy objective only and only if it is considered in combination with effectiveness; two countries might present the same level of efficiency, with very different values for education output! According to the four situations described, policy priorities would be very different:

- A) The education system is providing a good output, its main problem is that it is too expensive (where too expensive means that other countries are achieving the same output by using less resources). Here there is room for improving the overall efficiency without any output deterioration.
- B) Ideal situation, the output is high and the amount of resources used is appropriate. Efficiency should not be a policy priority here. Policy-makers may think about further improvements of the education output by means of e.g. institutional reforms.

- C) This is the worst of all possible worlds, the system is not providing the desired output and it is very expensive! Both effectiveness and efficiency are important policy priorities.
- D) Under these conditions, there is an illusion of efficiency, but in reality there is a serious problem of lack of resources. The system is not providing the desired output. Here effectiveness should be a top policy priority (and possibly efficiency too). It is extremely important to understand that policies aimed at achieving efficiency only can lead to the situation under D easily. We reiterate that efficiency cannot be the unique policy goal of an education system.

These considerations have to be taking into account when looking at the data and the results in the next sections.

3.2 Data and modelling

The data that is used in this study is derived from Eurostat and OECD databases (for exact sources, see Annex 2). Whenever possible, preference has been given to Eurostat data because data are usually available for more countries. As our basic reference year we have chosen 2012, as most data series are available only up to 2013, so that the exercise cannot be performed for more recent years, and as the most relevant output variable, i.e. PISA scores, is available only for 2012 (not 2013). Equity and migrant share variables, both based on PISA data, also refer to 2012. Exceptions include data on teachers (age and salaries) which is only available for 2013. Where possible, we compute the average over the period 2010 to 2012 to avoid potential bias. In the case of expenditure data, Eurostat data provides two distinct datasets for the period before 2012 and after 2012, so that we could not calculate averages from the period 2010-2011-2012. In this case we chose to include only year 2012.

This study is about efficiency in compulsory education, so that we include data on primary and secondary education. In many cases, data is separately available for primary, lower and upper secondary education. For this reason, depending on the individual variable specification, we summed the various education levels or averaged them to get a measure for the entire primary and secondary education, in the latter case using weights to assign the appropriate relative share for each education stage (for example, we weighted by the number of pupils at each level). See Annex 2 for the specific weighting schemes applied in each case. The definition of primary and secondary education may vary depending on the variable. Ideally, we would include data on ISCED 1 to 3, but given data constraints in some cases levels 0 or 4 are also included. We present a synthetic description of the variables used in Table 1.

As a first step, we apply DEA and FDH approaches to input and output variables. Then we try to understand the relationship between the results obtained and some contextual variables. Table 2 describes the various DEA models used to carry out the efficiency analysis³. The choice of inputs and outputs is coherent with the methodological and empirical literature in the field, as summarized by the companion Report by Agasisti & Munda (2017). It must be highlighted that, from model 2 onwards, two measures of expenditure are included in the empirical specification. Although they are somehow related, they also tend to identify two different phenomena: i.e. the expenditure level available for educational purposes in absolute terms (expenditure per student) and the incidence of the expenditure level when considering a different level of economic wealth across countries (expenditure as a % GDP).

³ As explained in the manuals about DEA, different kinds of indicators (i.e. financial and non-financial) can be mixed in the estimation of efficiency scores, as the latter are obtained by linear programming techniques which standardize the various units of analyses.

Variable	Description	Year
<i>Input variables</i>		
Teacher ratio [teacherratio]	student/teacher ratio [ISCED 1-3]	average 2010-2012
Expenditure per student [expstud2avg]	Government expenditure per student in primary and secondary education (constant PPP\$)*	average 2010-2012
Expenditure as share of GDP [expgdp]	Total public expenditure on primary, lower and upper secondary education as % of GDP	2012
<i>Output variables</i>		
PISA reading score [pisa_read]	PISA reading scores	2012
PISA math score [pisa_math]	PISA mathematics scores	2012
Early school leavers share [esl]	100 - (share of early schooling leavers) [18-24 year olds]	average 2010-2012
NEET share [neet]	100 - (share of NEET) [15-34 year olds, non-employed persons not in education or training]	average 2010-2012
<i>Contextual variables</i>		
Teachers' age [teacheraage]	Average teachers' age, lower secondary (TALIS)	2013
Teachers' salaries [teachersalav g]	Teachers' Salaries (in Euro, converted using PPS for household final consumption expenditure), averaging primary, lower secondary and upper secondary education.	2013
Share of migrants [migr]	100 - (share of migrants among 15 year old pupils participating in PISA)	2012
PIAAC numeracy scores [piaac_num]	PIAAC numeracy scores	2012
Educational attainment [eduatt2]	Higher educational attainment level from 25 to 64 years, ISCED 5-8	average 2010-2012
Educational expenditures	Total public expenditure on primary, lower and upper secondary education as % of public expenditure (**)	2012

share of total [expsharetot ⁴]		
Equity [equity]	PISA Index of economic, social and cultural status	2012

Table 1. Overview of variables

Note: Given the short span of the period analysed, the use of constant prices (as expressed with PPP) instead of current prices should not represent a sensible change in the results of the empirical exercise.

Please note that all the models have been estimated assuming input-orientation and constant returns-to-scale (CRS)⁵.

Table 3 presents the correlation scores between the different model specifications. Figure 1 shows the relationship between DEA and FDH results. When considering the two main non-parametric models used in the literature about efficiency in education, namely DEA and FDH, the results obtained are in strict consonance. The main notable difference is that average scores in FDH are much higher – this is a feature of the technique. So, FDH is not able to make a clear distinction of the efficiency of educational systems of various countries which, instead, DEA indicates as differently efficient. The case of Austria and France, for instance, is illustrative of this situation as they have similar efficiency scores with FDH (.98) but very different ones when looking at DEA (around .7 and .9, respectively). Thus, these results can be considered robust, since by considering methods with similar assumptions, we find consonance between the results obtained, and we never see evident discrepancies which affect the “ranking” of most (in)efficient educational systems. We will further check the robustness of these results by means of multi-criteria evaluation, which is based on different and complementary assumptions.

⁴ A clarification is needed about the labelling of expsharetot as a contextual variable. This indicator shares the same numerator with expgdp (which is an input), while both denominators are largely beyond the reach of education policy makers. However, the intention of using expsharetot in a second stage is to check whether a different priority assigned to education (i.e. the “weight” of educational expenditure on total public budget) is somehow related with efficiency scores at country level.

⁵ The choice of input versus output orientation does not change the rankings of countries, but only modifies point estimates of efficiency scores. An input orientation seems more reasonable for the policy problem faces by governments, i.e. containing expenditures in the field without sacrificing the level of educational supply. Constant returns to scale are considered because no clear hypotheses about scale effects can be formulated about the production of educational services at country level – being so relevant the distribution of inputs and outputs across institutions to determine scale effects, more than their averages.

Model	Inputs	Outputs
Model_1 (DEA)	<ul style="list-style-type: none"> (inverse of) students:teachers ratio expenditure per student 	<ul style="list-style-type: none"> PISA test score, mathematics (100-) % early school leavers
Model_2 (DEA)	<ul style="list-style-type: none"> (inverse of) students:teachers ratio expenditure per student expenditure as % GDP 	<ul style="list-style-type: none"> PISA test score, reading (100-) % early school leavers
Model_3 (DEA)	<ul style="list-style-type: none"> (inverse of) students:teachers ratio expenditure per student expenditure as % GDP 	<ul style="list-style-type: none"> PISA test score, reading (100-) % NEET
Model_4 (DEA)	<ul style="list-style-type: none"> (inverse of) students:teachers ratio expenditure per student expenditure as % GDP 	<ul style="list-style-type: none"> PISA test score, mathematics (100-) % early school leavers (100-) % NEET
Model_5 (FDH)	<ul style="list-style-type: none"> (inverse of) students:teachers ratio expenditure per student expenditure as % GDP 	<ul style="list-style-type: none"> PISA test score, mathematics (100-) % early school leavers (100-) % NEET

Table 2. The models estimated for calculating efficiency scores

Panel A. Correlations between the efficiency scores obtained through the different models

	Model 1	Model 2	Model 3	Model 4	Model 5
Model 1	1				
Model 2	0.9484*	1			
Model 3	0.9227*	0.9875*	1		
Model 4	0.9540*	0.9971*	0.9812*	1	
Model 5	0.5277*	0.6629*	0.6599*	0.6550*	1

Panel B. Average efficiency scores obtained through the different models

	eff_1	eff_2	eff_3	eff_4	eff_5
Mean	0.8214	0.8614	0.8535	0.8544	0.9620

Table 3. The efficiency scores obtained through the different models

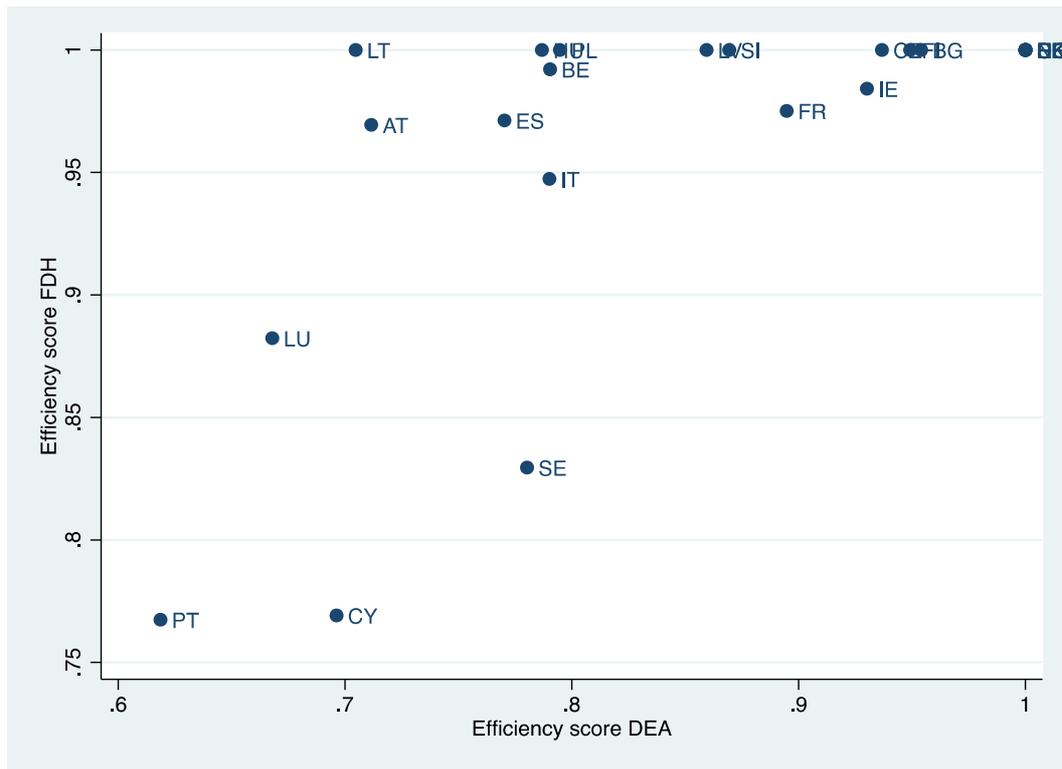


Figure 1. Assessing the robustness of the model: DEA vs FDH

The following table 4 reports the single efficiency scores for each country and for both techniques.

country	DEA	FDH	country	DEA	FDH
AT	0.70	0.98	IT	0.78	0.97
BE	0.76	0.98	LT	0.65	1.00
BG	0.95	1.00	LU	0.63	0.76
CY	0.70	0.77	LV	0.86	1.00
CZ	0.94	1.00	NL	1.00	1.00
DE	1.00	1.00	PL	0.79	1.00
EE	1.00	1.00	PT	0.63	0.77
ES	0.76	0.97	RO	1.00	1.00
FI	0.93	1.00	SE	0.77	0.83
FR	0.89	0.98	SI	0.87	1.00
HU	0.78	1.00	SK	1.00	1.00
IE	0.93	0.98	UK	1.00	1.00

Table 4. The efficiency scores by country, DEA and FDH

3.3 How do the efficiency scores correlate with the outputs?

Model 4 has been used as a baseline for the results presented in the following pages; it is preferred because it considers together the most representative inputs and outputs simultaneously (three inputs and three outputs). The purpose of this exercise is to check whether efficiency (synthetic measure) goes in the same direction of effectiveness, as measured through single indicators of output. It must be kept in mind that efficiency scores are obtained by weighting inputs and outputs, and that the weights do vary across countries, so no one single straightforward correlation can be derived by these plots. However, the exercise is useful to see if there is any output that, more than others, are related with the efficiency for a majority of countries – to anticipate the results, it does not seem to be the case.

3.3.1 Efficiency and PISA scores

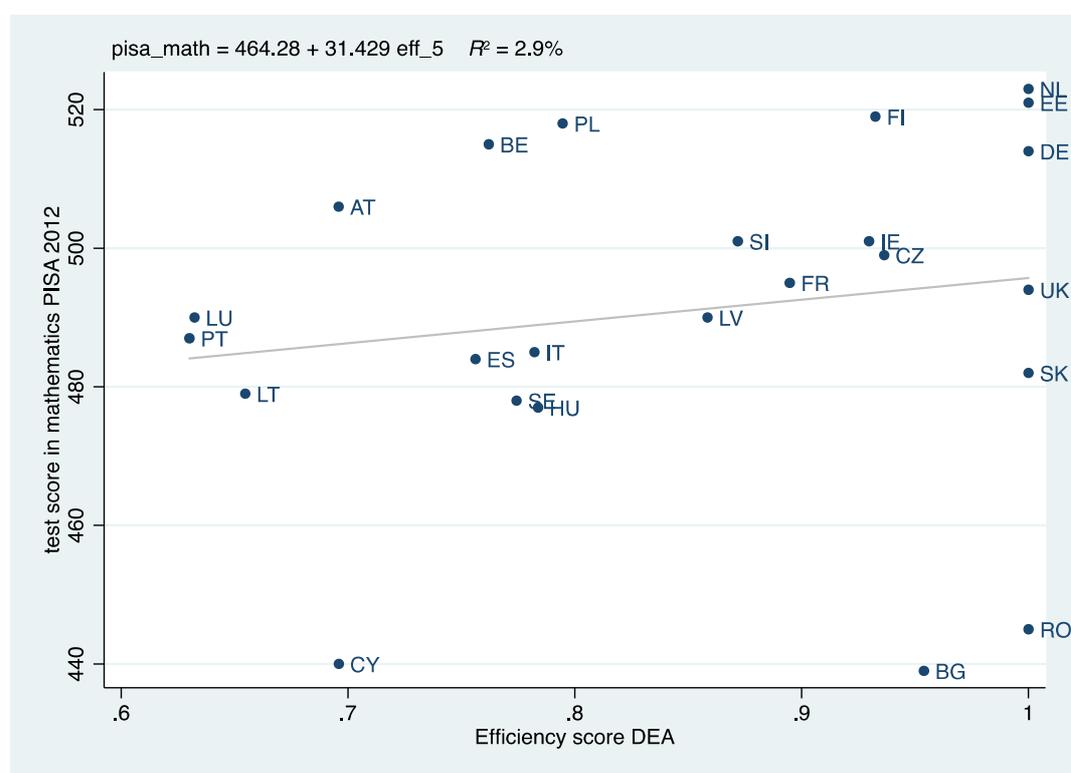


Figure 2. The relationship between efficiency and PISA test scores

We can observe a general, positive statistical relationship between the efficiency scores and test scores in mathematics, as measured by PISA 2012. However, three main groups of countries can be identified and described:

- a group with high efficiency and high test scores (NL, EE, DE, FI). In these countries, students obtain on average high test scores, and the educational production process is efficient.

- A second group comprises two countries (BG and RO). In these countries, the test scores obtained by students are quite low (i.e. well below these countries' average), but the efficiency of educational production is very high – this means that the educational system is making the most with the available resources (in other terms, the low scores are determined by other factors than pure inefficiency in the use of resources). These countries constitute a group where the characteristics of the educational systems' outputs are not fully desirable; although the systems are efficient, the absolute level of performance, i.e. its effectiveness, is not satisfactory (i.e. well below the EU average). It can be the case that the amount of educational inputs devoted to the educational activities is excessively low, and although the output produced through them is the efficient one, it would be necessary to invest more for increasing the output level from the observed current low level.
- A third group includes AT, BE and PL. Students in these countries have quite high test scores, but their educational systems turn out to be relatively inefficient – when compared with other counterparts, they could obtain the same high scores employing less resources.

Another interesting way of reading these results could be to compare countries with similar efficiency scores but different test scores (for example: HU, IT and PL), as well as countries with similar test scores but different efficiency scores (for example: LT, SE and SK).

3.3.2 Efficiency and early school leavers

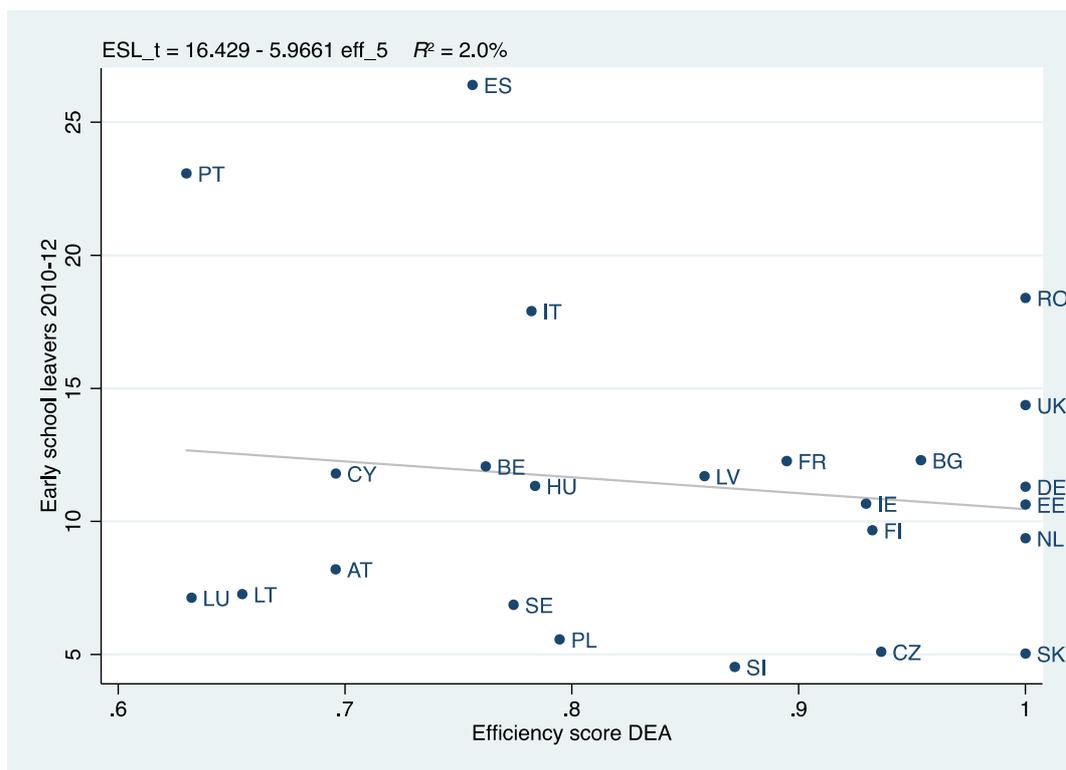


Figure 3. The relationship between efficiency and early school leavers

In this Figure 3, three clusters of countries can be identified as particularly interesting.

- There is a group of countries where the educational system is characterized by a high proportion of early school leavers (>15%) – PT, ES, IT and RO; in the first three countries the efficiency score of the educational systems is very low (and in the case of PT this is mostly evident), with the notable exception of RO, which is an efficient system (although driven more by the parsimony in the amount of inputs than by the results gained on the output side).
- Two educational systems are efficient and report very low levels of early school leavers: SK and CZ.
- A group of educational systems turn out to be somehow efficient although there is a noticeable proportion of early school leavers – see, for example, UK, BG, IE, FI, DE, EE, NL – in all these cases, the phenomenon is between 9% and 15%.
- In the group of countries whose educational system’s efficiency is between 0.75 and 0.8, there is a huge variability in the proportion of early school leavers – ranging from 5% of PL to around 20% of IT and ES.

3.3.3 Efficiency and NEET

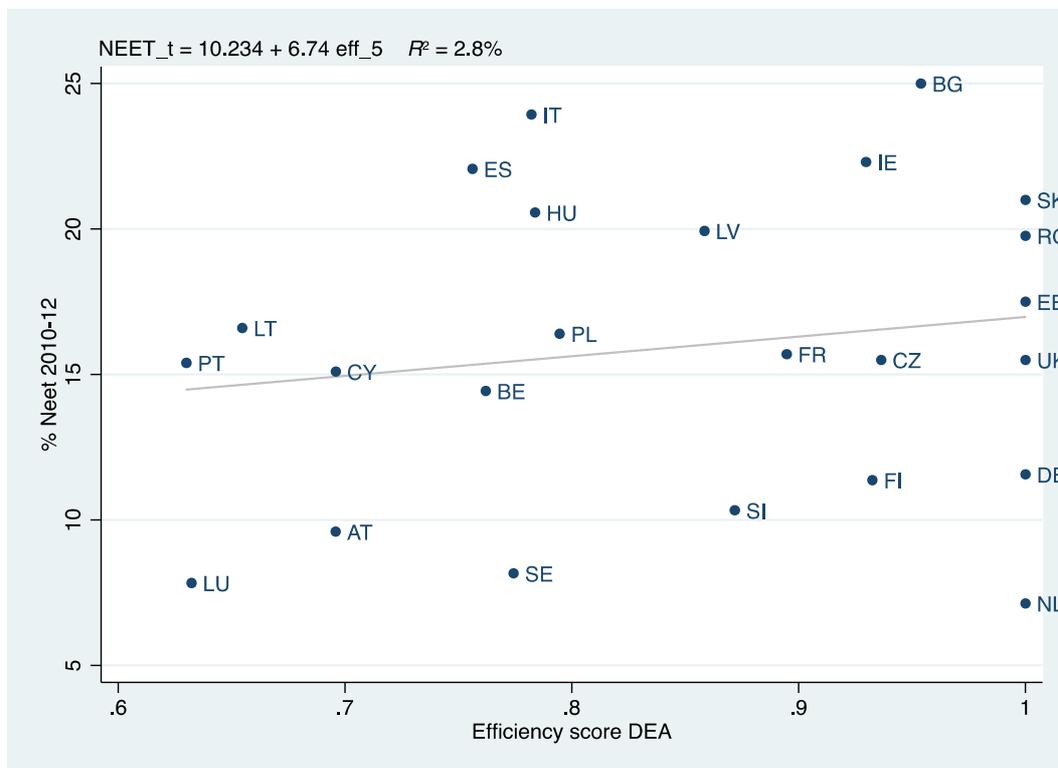


Figure 4. The relationship between efficiency and NEET

The patterns observed in Figure 4 mirror those already commented on in the previous Figure 3 when efficiency scores were related to early school leavers. All in all, it is rather difficult to detect any statistical strong correlation between the educational systems’ efficiency and the relevance of the phenomenon of NEET students.

More specifically, we can formulate the following considerations:

- Six countries where the educational system’s efficiency score is equal to 1 are characterized by very different proportion of NEET students, ranging from 21% in SK to around 7% in NL.

- The same heterogeneity holds for the countries where the educational system's efficiency is between 0.75 and 0.8; indeed, the range of variation is between 24% (IT) and 5% (SE).
- Two countries where the educational system is deemed to be inefficient also have a high proportion of NEET students (PT and LT, 15% and 16%, respectively).
- Two educational systems, although relatively efficient, are in countries where the proportion of NEET students is much higher-than-average (IE: 22%; BG: 25%).
- Two educational systems, despite being characterized by a small proportion of NEET students, are deemed to be relatively inefficient (LU and AT).

3.4 How do the efficiency scores correlate with the inputs?

In this section, we analyse how the efficiency scores are correlated with inputs. Overall, we expect negative correlations – that is to say, the higher is the level of available inputs (given a certain amount of outputs), the lower the efficiency scores will result. It is worth recalling that efficiency scores are obtained by weighting the various inputs and outputs, and so it is not possible to derive any straightforward correlation from these plots. Nevertheless, the aim of this exercise is to check whether some certain inputs are more likely to be those affecting efficiency scores. To anticipate the results, it seems to be the case with the students:teachers ratio in the expected direction: countries with a higher level of spending efficiency are those with lower number of teachers per student.

3.4.1 Efficiency and expenditure

a) *Expenditure per student.*

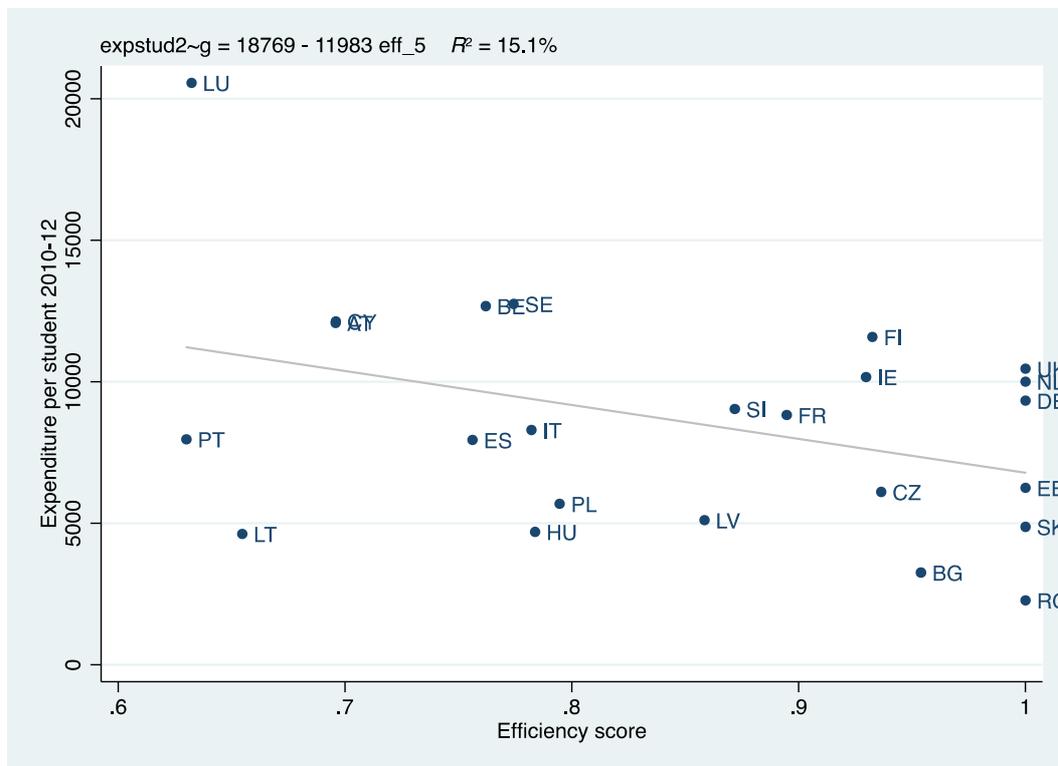


Figure 5. The relationship between efficiency and expenditure per student

As expected, there is a negative relationship between the estimated efficiency scores and the average expenditure per student. Nonetheless, three efficient educational systems are altogether characterized by high levels of expenditure (UK, NL and DE all have an expenditure per student around 10,000\$). Two other countries can be grouped with this set, namely FI and IE, which are among the highest spenders (>10,000\$) and whose educational system is relatively efficient (>0.9). Worth noticing is the case of RO, which has an efficient educational system and the lowest recorded expenditure per student (around 2,200\$); of course we re-iterate that effectiveness and efficiency are different concepts.

Three other groups of educational systems are interesting to be commented:

- One is constituted by relatively high-spenders, where the estimated efficiency score is <0.8 (BE, SE and – even more evidently – CY and AT).
- Another one are those countries where a low level of spending is associated with high relative efficiency scores (see, for example CZ and BG, where the spending per student is 6,100\$ and 3,100\$, respectively).
- Lastly, LT reports a very low level of expenditure per student, nonetheless its educational system turns out to be relatively inefficient (around 0.65).

b) *Expenditure on education as a share of GDP.*

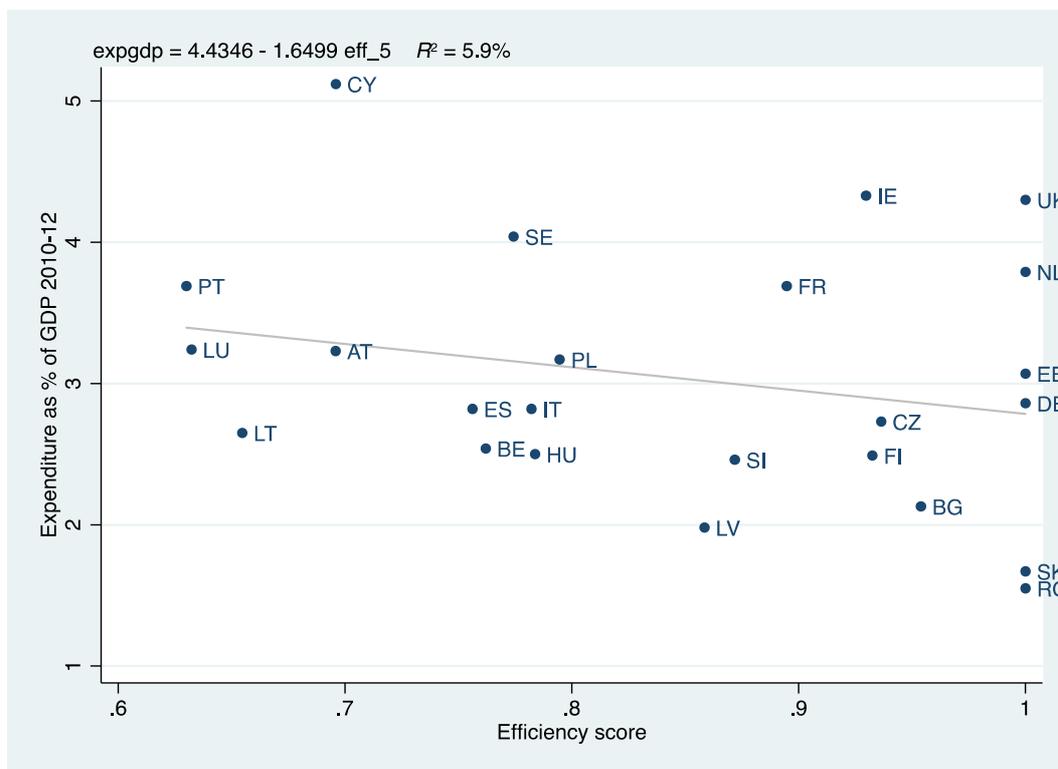


Figure 6. The relationship between efficiency and expenditure on education as % of GDP

The pattern of the relationship between efficiency scores and the expenditure on education as a share of GDP is similar to that with expenditure per student, but is less evident.

It can be useful to highlight some groups of countries, and more specifically:

- Some educational systems are efficient due to the very low level of spending (SK and RO, with less than 2% of GDP devoted to education).

- Some other educational systems are assessed as inefficient, despite the countries investing quite heavily in terms of % of GDP – see PT, LU and AT.
- A group of four educational systems is characterized by a high level of spending and at the same time by high efficiency scores (IE, UK, NL and FR – where spending is >3.5% of GDP)
- Some countries have an expenditure level around the sample average, and a corresponding estimated efficiency of educational system also being 'average' – i.e. around 0.75 and 0.8. Countries belonging to this set are: PL, ES, IT, BE and HU.

3.4.2 Efficiency and the students:teachers ratio

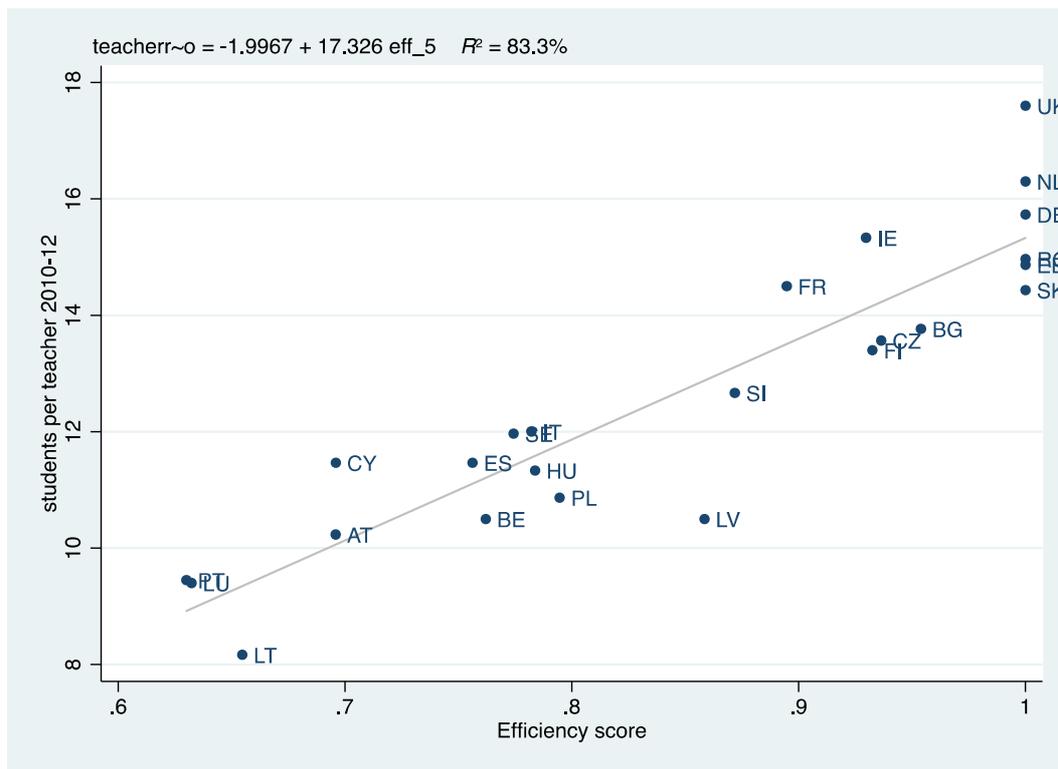


Figure 7. The relationship between efficiency and students:teachers ratio

This is the variable which is most correlated with efficiency scores, and is then the one which is 'determining' the estimates the most. By construction, higher students:teachers ratios are associated with higher efficiency scores. All the efficient educational systems (UK, NL, DE, RO, EE and SK) are characterized by a higher-than-mean ratio – in all cases, >14 (the mean is around 12).

Two interesting cases to be mentioned are LV, which has a relatively efficient educational system notwithstanding the quite low students per teachers ratio, and the UK, where the educational system is efficient despite having a very high ratio (around 18 students for each teacher).

It must be remembered here that no information is available about the distribution of these ratios by school, within countries.

3.5 Are the efficiency scores correlated with some variables describing key characteristics of the educational system?

3.5.1 Descriptive information on contextual variables

In the following table 6, we report the descriptive statistics of the variables that we use in the second-stage for providing evidence of correlations between the efficiency scores obtained in the previous step and some important characteristics of the educational system. The selection of these characteristics depends upon two factors: (i) the findings from existent literature and methodological review presented in (Agasisti and Munda, 2017) ; (ii) data shortage and availability.

Panel A. Descriptive statistics

Variables' label	Variable	Obs	Mean	Std. Dev.	Min	Max
Teachers age	Average age of teachers	15	44.5	2.7	39.2	48.9
Teachers salary	Average salary for teachers	15	29,223.8	18,386.5	9,329.0	80,789.5
% Non-native	% native students	16	88.8	10.7	53.6	99.3
PIAAC scores	Adults' test scores in PIAAC	16	267.6	12.2	245.8	282.2
% adults with TE	% adults (25-64) with a tertiary education degree	24	28.1	8.2	14.5	39.0
% spending	% public spending devoted to education	24	6.6	1.8	4.2	11.2
Equity	% of test scores explained by SES	24	16.2	4.4	8.6	24.6

Panel B. Statistical correlations across variables

	Efficiency score	Teachers age	Teachers salary	% Non-native	PIAAC scores	% adults with TE	% spending	equity
Efficiency score	1.00							
Teachers age	-0.31	1.00						
Teachers salary	-0.41	0.01	1.00					
% Non-native	0.49*	0.03	-0.90	1.00				
PIAAC scores	0.24	-0.10	-0.05	0.07	1.00			
% adults with TE	-0.02	-0.07	0.41	-0.43*	0.12	1.00		
% education spending	-0.20	-0.17	0.25	-0.36	-0.26	0.51*	1.00	
equity	0.33	-0.08	-0.19	0.23	0.31	0.04	0.16	1.00

Table 6. Some key characteristics of the educational system

3.5.2 Efficiency and average teachers' age

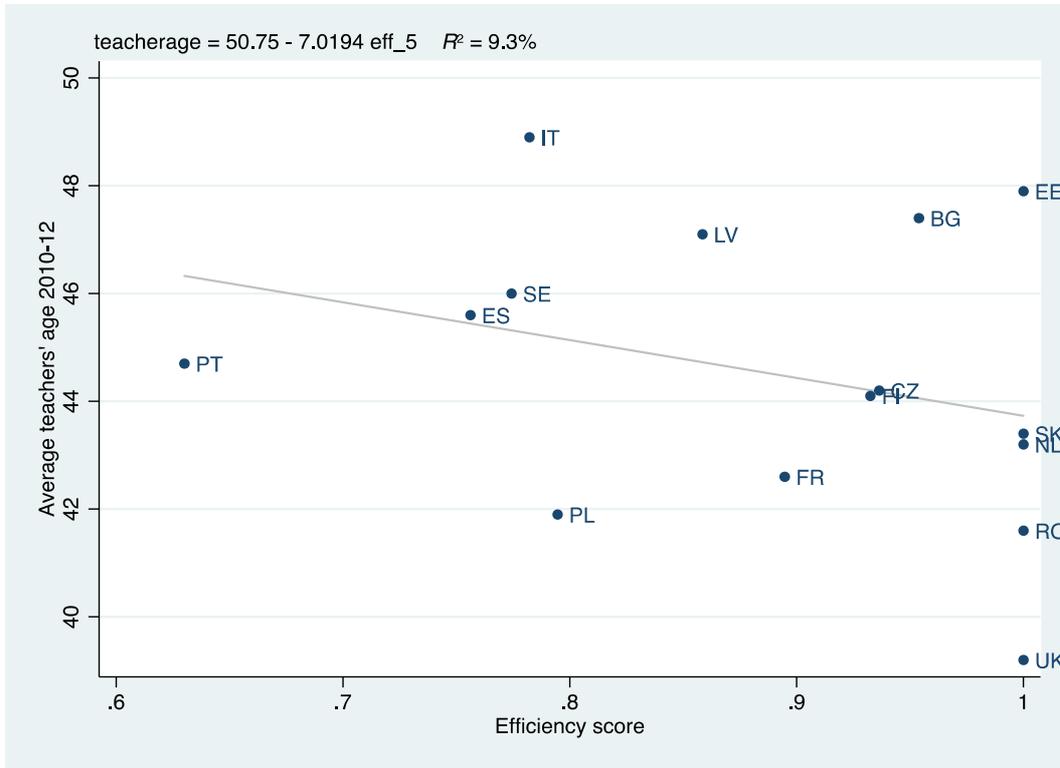


Figure 8. The relationship between efficiency and average teachers' age

The general pattern that emerges from this statistical correlation is that countries with higher efficiency scores have a younger body of teachers. The result points at suggesting a higher ability of a younger population of teachers in making the better use of the available resources. It should be noted, however, that together with the UK (a country with an efficiency score equal to 1 and the youngest teachers), EE is also among the most efficient educational systems, despite having an average age of teachers around 48. Two other situations that could be interesting to comment on are:

- IT and PL: their educational system reports a similar level of efficiency, although the average age of teachers is substantially different (around 49 and 42, respectively).
- PT: the educational system is relatively inefficient, despite the average age of teachers being close to the mean calculated with all countries where data are available.

3.5.3 Efficiency and average teachers' salaries

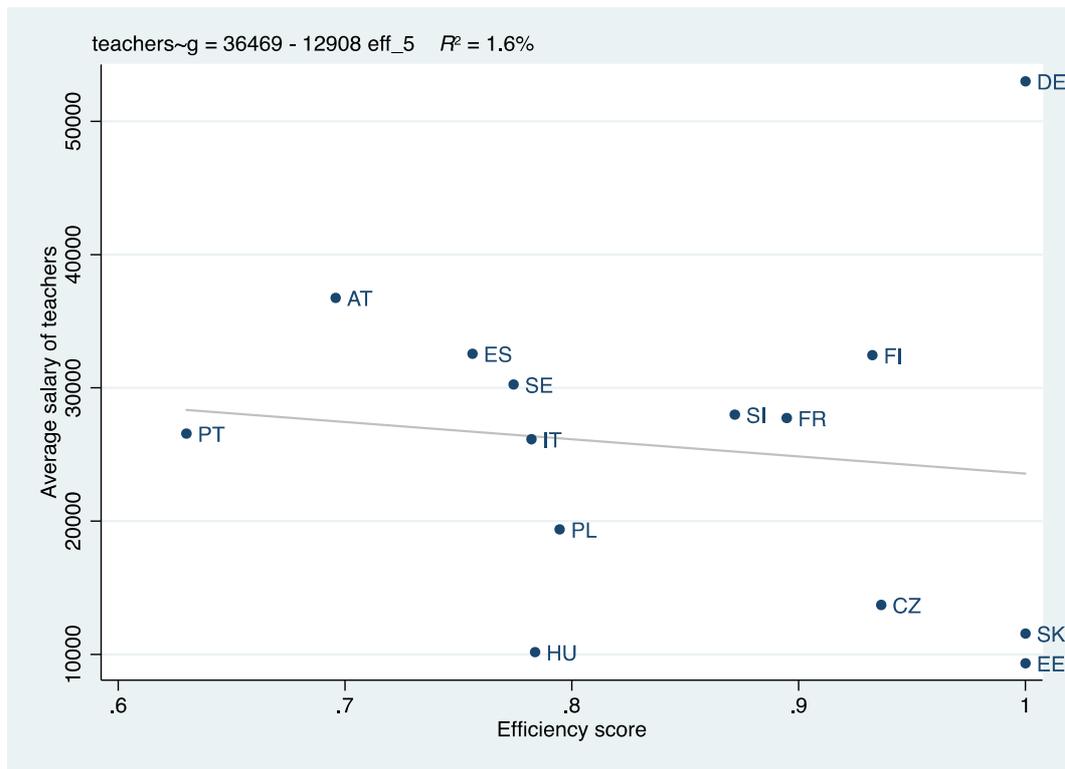


Figure 9. The relationship between efficiency and teachers' salaries

Another interesting aspect is that related with the average teachers' salary. In this case, it is hard to find any statistical correlation between this factor and the educational system's efficiency score. Therefore, some specific cases deserve attention.

- EE and SK report very low levels of teachers' salaries, so that at least part of the efficiency can be attributed to relative low prices of a key input, which allows the system to be relatively 'cheap' in gaining its academic results.
- On the other side of the spectrum, DE turns out to be an efficient educational system, despite high salaries being paid to teachers. In other words, teachers (and schools) are able to transform the inputs into academic results in an efficient way – and the higher salaries paid could be interpreted as a compensation for such efficiency. The same situation can be described for FI, although the teachers' salaries are somehow lower and the efficiency of the educational system slightly lower as well.
- Teachers in AT receive a quite high average salary, while the educational system's efficiency is relatively low. In this perspective, the higher salaries can be interpreted, all else equal, as one of the factors affecting inefficiency. Indeed, the expenditure per student is kept high because of high salaries, and at the same time the level of output is similar to that obtained by other countries with less resources.
- The reading of the figure by "column(s)" is suggestive. For instance, IT has an educational system that compensates teachers much less than ES and SE, but obtains comparable levels of efficiency; nonetheless, an analogous reasoning can be proposed using IT as a benchmark and individuating PL and HU as countries with similar efficiency scores, but with much lower average salaries for teachers.

- Lastly the reading of the figure by row(s) is equally instructive. Teachers in PT receive a similar salary as in IT, SI and FR; however, these four countries reveal very different levels of efficiency, with the latter being among the most efficient educational systems, and the former among the least efficient ones.

3.5.4 Efficiency and the proportion of immigrants

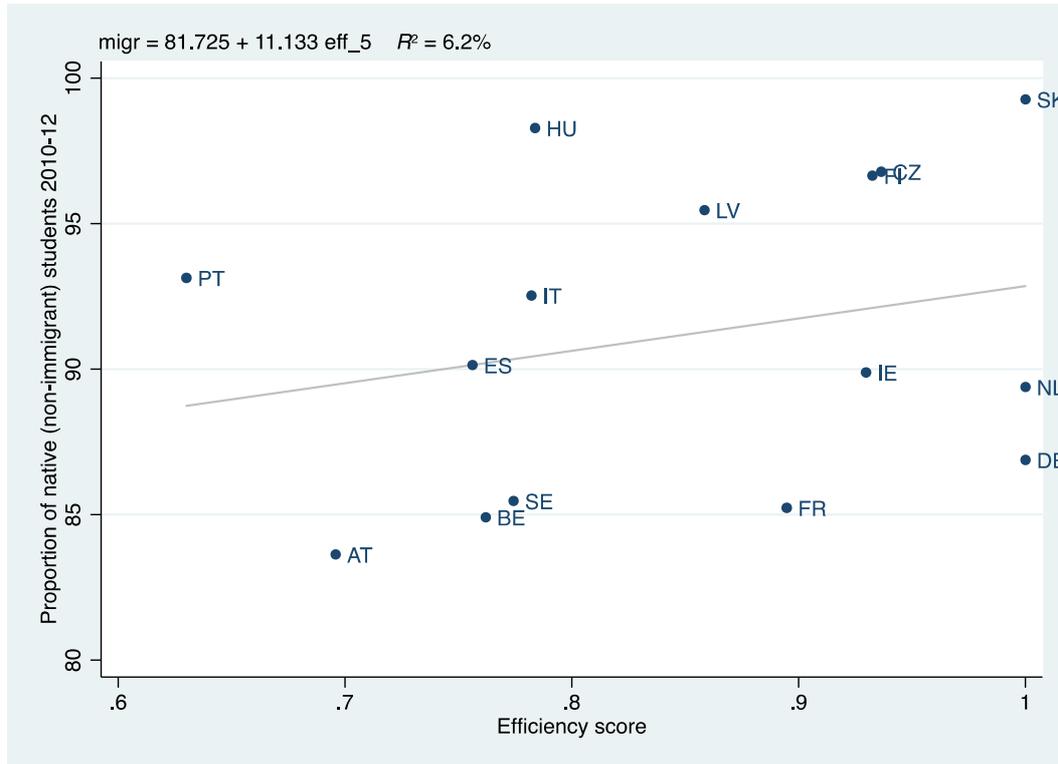


Figure 10. The relationship between efficiency and the proportion of immigrant students

Note: Luxembourg has been excluded because of the too-high proportion of non-native students

The general image emerging from this figure is one where the lower is the proportion of immigrant students, the higher is the efficiency of the educational system. It must be noted, however, that the definition of “immigrant” is very broad here, as it includes all the students who are not born in the relevant country, hence encompassing a wide range of potential families’ backgrounds, histories and cultures. In this sense, clearer indications about the relationship between efficiency of an educational system and the proportion of immigrants studying there would require much more detailed data. Some specific notes are worthwhile and based on these simple statistics, however, and they are listed in the following points.

- DE and NL have the most efficient educational systems in the sample considered, despite the system having a substantial proportion of immigrant students (13% and 11%, respectively).
- There is actually a group of countries where the educational system is characterized by both a high proportion of natives and a high efficiency score: LV, FI, CZ and SK. However, the case of HU points in the other direction; the educational system includes a small proportion of immigrants (<2%) but its efficiency score is relatively low.

- At a similar efficiency score level (between 0.75 and 0.8), there are countries with a very different proportion of non-native students: the already cited HU (<2%), IT and ES (between 8% and 10%), and also SE and BE (both around 15%).

3.5.5 Efficiency and adult literacy

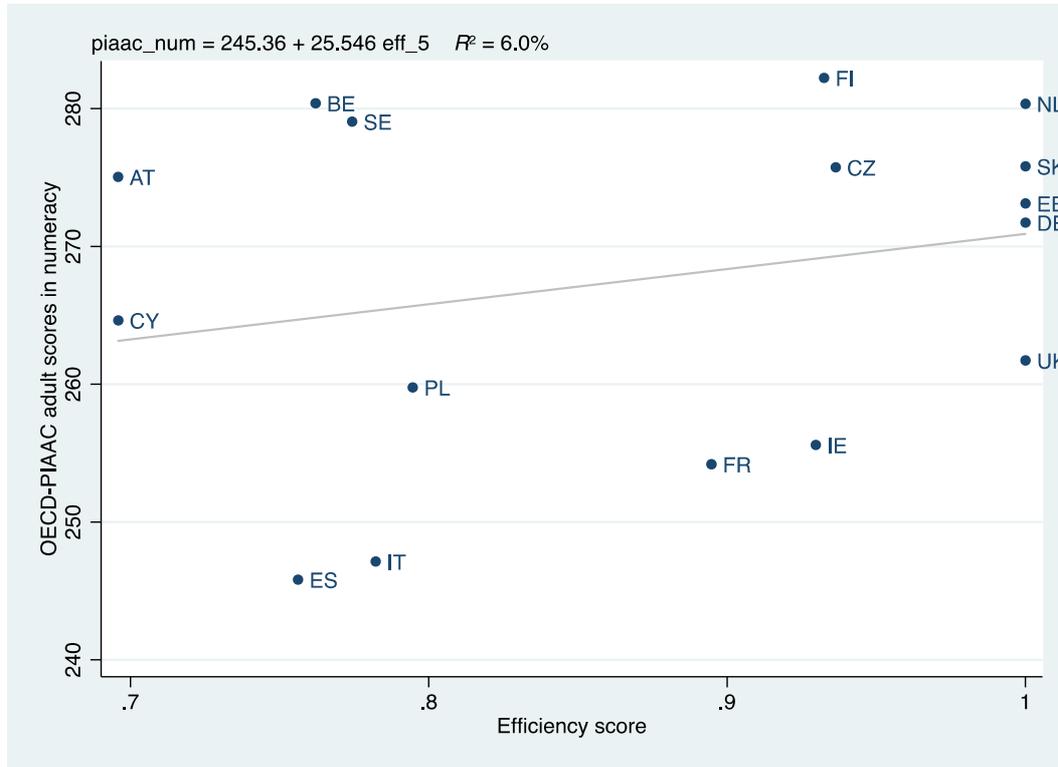


Figure 11. The relationship between efficiency and adult literacy – PIAAC (numeracy)

This Figure 11 sheds light on the relationship between the educational system of a country and test scores obtained by adults (as measured by OECD through PIAAC - Programme for the International Assessment of Adult Competencies). This relationship is substantially positive, and some remarks must be considered here.

- In almost all the countries where the educational system is efficient (=1), the level of competences measured through OECD's PIAAC is very high (see NL, SK, EE and DE). The only notable exception is UK; although the educational system is relatively efficient, the test scores of adults are not excellent, even though they are higher than the Programme's mean.
- There are some countries where the skills and competences of adults are very high, but the efficiency of the educational system is relatively low – as in BE, SE or absolutely low, as in AT.
- Three countries seem characterized by low efficiency of the educational system, accompanied by the particularly low levels of adults' competences and skills: ES, IT and – to a lower extent – PL.
- A particular case constitute FR and IE; their educational systems appear as relatively efficient (efficiency score >0.9), but the competences of adults are below PIAAC's average.

3.5.6 Efficiency and the adults' educational attainment

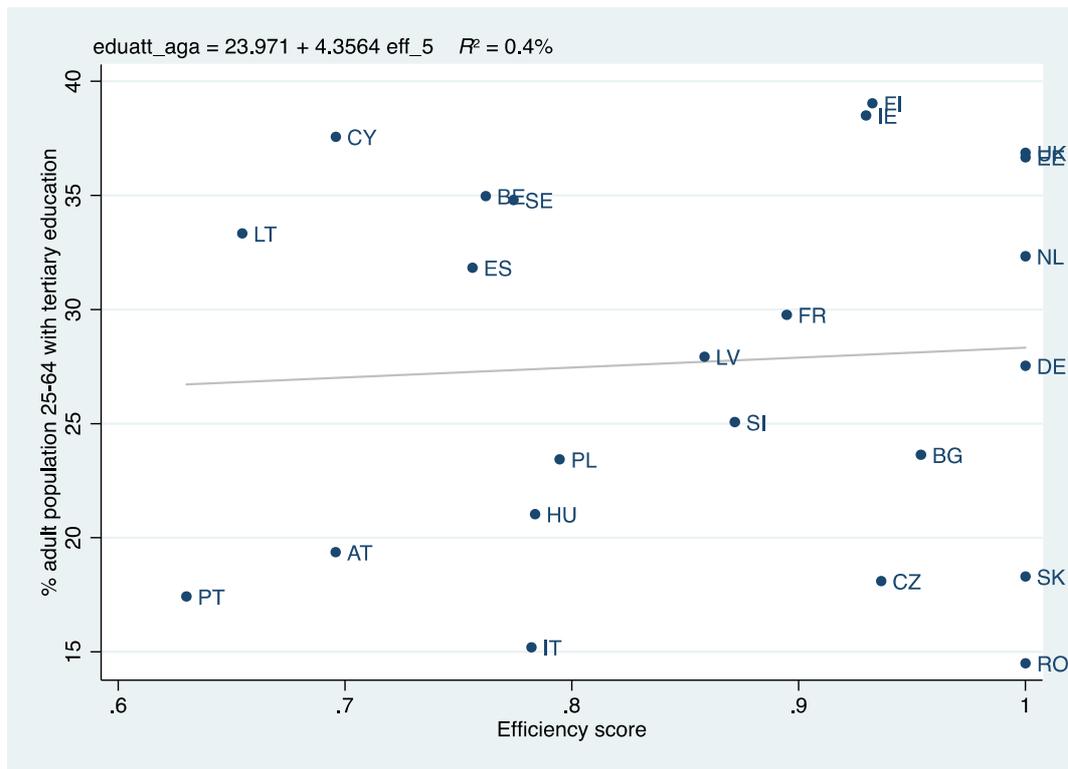


Figure 12. The relationship between efficiency and adults' educational attainment

Note: the variable about the adult population with tertiary education is defined as follows: the proportion of adult population (age 25-64) who own a tertiary education degree (both Type-A and Type-B, i.e. 'academic' and 'vocational', respectively).

While it is hard to find any clear pattern for the relationship between efficiency scores and the proportion of the adult population educated with tertiary education, it is interesting to look at four potentially similar group of countries.

- On one extreme, there are countries with a higher level of measured efficiency of their educational system, coupled with a high proportion (>30%) of educated adults – this is the case of the UK, EE, NL, EI and IE (and, to a certain extent, FR).
- On the other side, a converse group of countries is characterized by a lower proportion of graduates in the adult population (<20%) and low efficiency scores: PT, AT and IT – to a certain extent, PL and HU can also be classified here.
- Some countries have an efficient educational system, despite the 'stock' of human capital being quite low (i.e. the proportion of graduates is lower than 20%) – and this is the case of RO, SK, CZ and BG.
- Lastly a group of countries shows a higher-than-average proportion of educated adults (more than 30%), but the efficiency of the educational sector turns out to be comparatively low (i.e., <0.8): LT, CY, BE, SE and ES.

3.5.7 Efficiency and the proportion of public spending on education

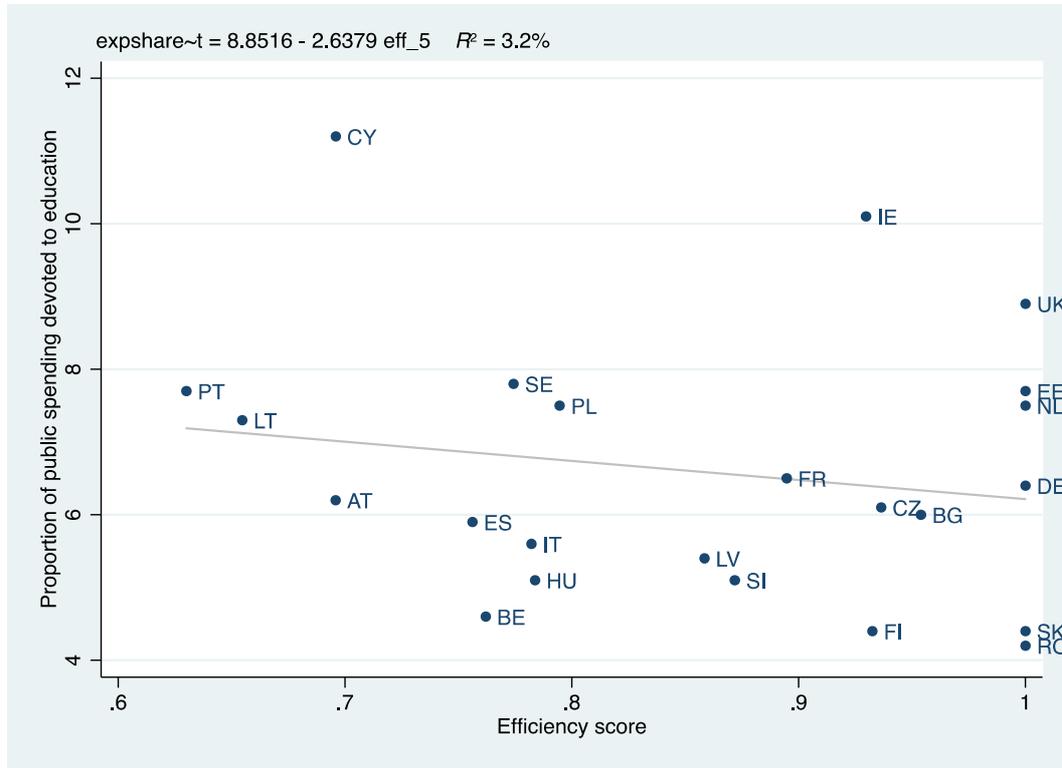


Figure 13. The relationship between efficiency and proportion of public spending devoted to education

Figure 13 highlights a general lack of correlation between efficiency scores and the proportion of public spending devoted to education, the latter being interpreted as a measure of policy priority for the field. Excluding some 'extreme' situations, however, some interesting patterns do emerge.

- Many countries where the educational system is efficient are characterized by a low proportion of public spending in education – see FI, SK and RO where this is below 5%.
- Conversely, in the UK – a country where the educational system is efficient – the proportion of public spending devoted to education is among the highest in the sample (8.9%).
- A group of countries is characterized by a relatively high proportion of spending channelled to education (>7.5%), and by a low level of efficiency of the educational system: SE and PL and, even more evidently, PT and LT. It must be said here that two countries with a similar proportion of resources dedicated to education stand out for their efficient educational system: EE and NL.
- There is a group of countries which appears to have similar efficiency levels in their educational systems (between 0.75 and 0.8) with sharp heterogeneity in the proportion of public spending allocated to education. This group includes SE, PL, ES, IT, HU and BE; with the proportion of public spending for education ranging between 7.8% (SE) and 4.6% (BE).

3.5.8 Efficiency and equity

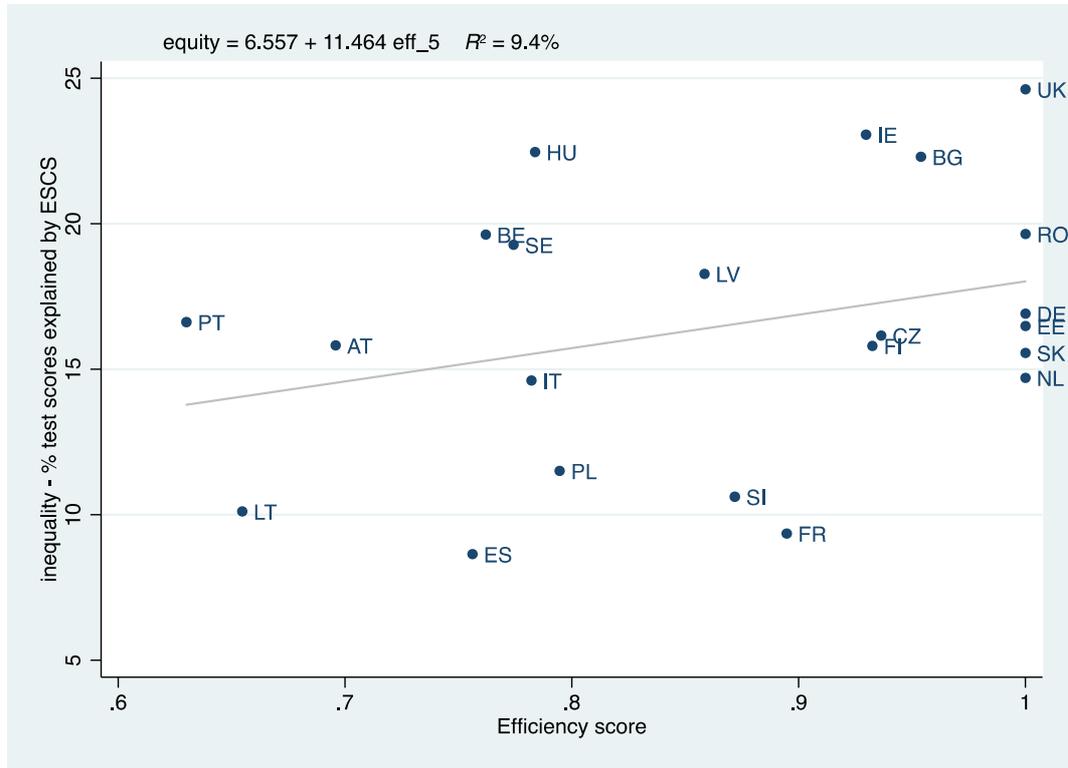


Figure 14. The relationship between efficiency and equity index

Note: the index for inequality in the educational system is defined as the proportion of PISA test scores accounted for by the Index of Economic, Social and Cultural Status (ESCS)

The findings reveal a statistical correlation between educational systems' efficiency score and the index for educational (in)equality. Although the Figure seems to indicate that a lower level of educational equality would be statistically associated with a higher level of efficiency, some points must be noted for a more correct and complete interpretation of the evidence.

- While it is certainly true that one of the efficient educational systems is characterized by the highest level of inequality (UK), it is also evident that four other efficient ones have an average level of inequality – see DE, EE, SK and NL in which the proportion of PISA test scores 'explained' by the ESCS is between 15% and 18%, in line with the EU average (i.e. there does not appear to be an equity vs efficiency trade off).
- In the group of countries whose educational system's efficiency is between 0.75 and 0.8, there is wide heterogeneity in the index of educational equity – with a range of proportion of test scores' explained by SES from 8.6% (ES) to 22.5% (HU).
- There are some countries whose educational system's high efficiency is also associated with high levels of equity (see SI and FR); also there is one country with high level of equality, despite a lower-than-average efficiency level (LT).

3.6 Robustness check: multi-criteria analysis

One should remember that if the objective of an efficiency study is its real policy use, there is no doubt that the results should be methodologically robust and defensible. Efficiency analyses, as any other evaluation study, may present a number of risks, such as oversimplification, wrong policy conclusions due to model misspecification, and biased results caused by hidden subjective judgments in the design process. Uncertainty and sensitivity analysis can help to gauge the robustness of the results obtained, to increase the transparency of the ranking system, to identify how countries that improve or decline under certain assumptions, and to help the framing of the debate around the conceptual framework used, i.e. which representation of reality has been considered.

In the framework of education policy, the desirability of the peculiar characteristics of multi-criteria evaluation has been advocated by various authors (see Agasisti and Munda, 2017 for an overview). While continuous approaches are still related to DEA and can be considered an attempt of improving DEA techniques, discrete multi-criteria methods are based on complete different assumptions. From this point of view, they can be considered a complementary approach, particularly useful for testing robustness of DEA results. In fact, when the set of alternatives is a finite one, it makes sense the use of mathematical aggregation procedures that do not exclude dominated alternatives a priori; in the framework of efficiency analysis, this implies that results obtained through traditional frontier methods should always be corroborated by also using non-frontier based mathematical approaches, such as multi-criteria methods. In particular here, we use the so-called NAIADE approach (Munda, 1995). The NAIADE method can be considered particularly useful for efficiency analyses in the field of education for four main reasons:

1. It has been explicitly designed for public policy applications;
2. it is flexible, since it can deal with different source of information on the criterion scores;
3. compensability⁶ can be controlled fully;
4. it can also be used for benchmarking exercises.

The whole NAIADE mathematical aggregation procedure can be divided into three main steps:

1. pair wise comparison of alternatives according to each criterion,

⁶ The mathematical aggregation of several criteria implies taking a position on the fundamental issue of compensability. Compensability refers to the existence of trade-offs, i.e. the possibility of offsetting a disadvantage on some criteria by a sufficiently large advantage on another criterion, whereas smaller advantages would not do the same. Thus a preference relation is non-compensatory if no trade-off occurs and is compensatory otherwise. It is important to understand that compensability means that in an education efficiency assessment exercise, an improvement in one of the spending side criteria can easily compensate a worsening in an output criterion such as e.g. PISA scores in science! An important related point to consider is that the existence of preference independence is a necessary condition to use a full compensatory linear aggregation rule. From an operational point of view this means that an additive aggregation function permits the assessment of the marginal contribution of each criterion separately (as a consequence of the preference independence condition). The marginal contribution of each criterion can then be added together to yield a total value. This implies that, for example, among the different aspects of the output variables there are no phenomena of synergy or conflict, i.e. preference independence considers each single score being fully unrelated with all the others, but indeed can courage be evaluated as a positive characteristic of a person, without knowing if he/she is a dedicated criminal or an enthusiastic medical doctor? From an education policy point of view, this implies that, for example, interaction among PISA scores in reading and mathematics are not possible. This is rather unrealistic from a scientific point of view, thus we can safely state that complete compensability is not desirable for efficiency assessment of education systems.

2. aggregation of all criteria,
3. ranking of alternatives.

Any attempt of measuring efficiency should deal with the following two questions: (i) are results robust to the selection of specific variables (inputs and outputs selection)? and (ii) are results robust to the selection of a specific method for efficiency analysis? To answer these two questions, NAIADE is first applied to all available input information. The idea is to evaluate which countries are spending less for education, by considering the plurality of available data sources. Then we take into account the output side. Again, we take advantage of the multi-criteria characteristic by using various output measures simultaneously (a difference with the previous DEA analyses is that here some contextual variables, such as educational attainment, are considered output variables). Finally, we carry out a multidimensional evaluation, where the various input and output items are integrated all together. This last analysis can be considered an alternative measure of efficiency of the education systems at country level; this is aimed at answering question two.

We have done this analysis to check the robustness of our results. In our specific application multi-criteria analysis corroborates the results obtained by means of traditional frontier methods. However, some changes exist but these are at the extremes of the distribution only. The full set of analyses is presented in Annex 3.

In Annex 4, NAIADE is also used for benchmarking exercises, since it allows the pairwise comparisons between all the countries considered. The various countries are compared to the top performer. These comparisons may have a policy value since one can be fully aware of the mutual weaknesses and strengths on each single evaluation criterion and some policy priorities can be derived.

4 Concluding remarks and policy implications

This section illustrates some conclusions and derives some policy suggestions. Although all analyses here have been done at country level, we avoid drawing conclusions on single Member States: all conclusions are derived for the aggregate as general options for potential improvement.

All our results are based on efficiency analyses which are descriptive in nature, thus the relationships between efficiency scores and contextual variables must be interpreted as correlational, and not causal.

4.1 The measurement of efficiency of education at country-level: conceptual issues

We reiterate that measuring efficiency is different from measuring effectiveness (academic performance measured by test scores and graduation rates). Some countries have students who obtain, on average, excellent results in terms of test scores in mathematics, for example PL and BE, and whose educational system has been deemed as 'relatively inefficient' in this analysis, because of the use of an excessive amount of resources for getting these results – more precisely, other countries in the sample employ lower levels of resources for obtaining a comparable level of performance. Conversely, there are countries where the educational system is 'relatively efficient' – i.e. the resources are used at their most, for getting the highest possible level of output – but still the academic results are unsatisfactory, for example students' results in PISA are still very low – see the examples of RO and SK. The interpretation of results must take the definition of "efficiency" into account, then. From a policy perspective, an educational system is not desirable if it produces lower educational outputs, although it does it efficiently, that is to say with low levels of resources employed in the process. The general aim of any educational policy should consist in reaching an adequate (high) level of outputs, with using the necessary amount of resources (and no more than such necessary level). Thus, instead of reducing the level of inputs, policymakers should find viable strategies for stimulating and getting higher results. A recent good example is given by Portugal, which experienced a considerable improvement in both PISA and TIMSS 2015 scores, while the total expenditure in education did not increase at all⁷.

In this vein, the present study offers some insights about statistical correlations between country-level efficiency scores and characteristics of the educational systems. It is of a key importance remembering that such results should not be interpreted in a strict causal sense; instead, they should raise questions and reflections about the features that can inspire policies for improving educational outputs. The efficiency perspective adds to the traditional approach of looking at the performance, by considering how many resources are needed to reach those performances.

4.2 The characteristics of educational systems and the correlations with efficiency

Investing more resources on educational systems is not enough to guarantee better results; an efficient use of those resources is a prerequisite for raising the overall qualitative level of the systems themselves. In this perspective, the better approach for policy-making is not allocating more public and private money to education tout court, but instead searching for those interventions and activities which are more related with better results. Resources should then go hand-in-hand with methods for assessing the results achieved; and in the current age of tight budgets, the evaluation of the dynamics of expenditures' growth should be based on the benchmarking of results (i.e. by

⁷ See Pordata (2016).

comparing practices and characteristics of educational systems with similar spending levels, and different level of outputs produced). In this sense, our findings are consistent with evidence provided by existing literature pointing at demonstrating that the specific use of resources matters for affecting educational outputs, more than the absolute level of spending. This is a typical improvement in policy making brought by adopting an efficiency approach; instead of claiming for more investments per se, prioritisation of budget allocations must follow evidence about the 'value for money' of specific interventions and systems' characteristics.

There is a positive correlation between students:teachers ratio and the estimated efficiency of an educational system. This finding is suggestive of the negative relationship between the amount of (human) resources available and efficiency (holding the output constant). The policy interpretation of this finding is far from being straightforward, however. For sure, educational policy-makers cannot intend this finding as a justification for reducing the teaching labour force, neither they can consider it as a suggestion for increasing average class sizes. Instead, the result only corroborates the intuition that a higher investment for hiring more teachers is not necessarily conducive to higher levels of educational results. For pursuing this objective, instead, human resources should work in a productive manner. The available data at country level does not allow researchers to take into account quality differentials in the average teachers' workforce, which could be responsible for at least part of the efficiency differentials that emerge across countries. Apart from these average differences, it can also be the case that differences within countries do exist, and lead to an overall difference in the efficiency use of human resources. Thus, no further strong conclusions can be easily derived unless exploring the distribution of students:teachers ratio by school, within countries – something which is well beyond the scope of this analysis.

The problem of high proportions of early school leavers and NEET individuals is plaguing various educational systems. However, it is hard to find any evident statistical correlation between the efficiency scores attributed to the educational system and the incidence of these two phenomena. In this perspective, there are some countries with low proportions of early school leavers and NEET individuals, which can be more efficient in using their resources, for instance by attempting to improve test scores. Conversely, some educational systems are already efficient although they present a high proportion of early school leavers and NEETs, and they could invest more resources to solve this problem, and this could result in short-run deviations from the efficient frontier. This last eventuality holds important policy implications. If a country considered investing more financial resources for programs specifically designed to reduce the incidence of NEET phenomena, this would lead to lower levels of efficiency in educational spending, all else equal – indeed, the results eventually obtained by these policies take time to materialise. If policy makers at national level were strictly forced to follow indications from efficiency analyses, the perverse incentive for them would be to limit investments in these areas, and to simply take a conservative approach that does not induce a visible increase of NEETs. To contrast this unintended result, efficiency analyses should take into account temporary, ad hoc investments in policy areas that are considered a political priority at national and European level.

The educational systems where the teachers are younger also are, on average, more efficient. Although no causal claims can be derived from the present study, this statistical correlation is helpful for stimulating institutional reflections at country level; in fact two different explanations may exist.

The first one is that a younger body of teachers can help the efficient use of available resources. For instance, younger teachers can be more motivated or equipped with most 'updated' skills, and can employ the resources in a more efficient way, so that the number of teachers necessary for obtaining the expected outcomes can be lower than in the past. If this is the case, policy makers should reflect on three important steps that

deal with policies about (teaching) human resources. First, plans and incentives to assume younger teachers, and to favour a turnover between older teachers and younger ones, could be welcome and justified under an efficiency argument. Second, studies and analyses about the differences in the use of time and resources by teachers of different ages could be helpful for informing more efficient practices and habits. Third, salaries and economic incentives could be directed towards the remuneration of more productive young teachers; indeed, reducing the amount of money attributed on the basis of teachers' age and experience, and improving that allocated to more productive efficiency, can result into improving the efficiency of an educational system, all other else equal. However, in the literature some studies suggest that older and more experienced teachers may lead to a higher performance of students; although this is not a strictly linear relationship, as the very oldest seem to perform again on a lower level. A possible explanation is that in some countries, older teachers have more power to select which class they take, so that they may opt for the classes with the better (and easier) students.

The second explanation is that younger teachers are simply paid less; all else equal (i.e. assuming equal productivity along the curve of teachers' age), this would result in lower expenditures per student, in front of the same academic results. Data support a negative relationship between a country's average salary paid to teachers, and its educational system's efficiency score. In terms of policy implications, this would result in completely different suggestions than those formulated above. At system level, it would not be desirable to keep the salaries artificially low (i.e. beyond the productivity ratio) just for pursuing a more efficient process of educational production. Albeit this approach can have a positive payoff in the short-run, when the average levels of educational outputs do not experience negative shocks, it can instead be the case that negative effects appear in the medium-long run. For example, teachers could be demotivated by persistent low salaries, and their productivity could drop year after year – eventually, the best part of them could even leave the profession. Furthermore, low salaries can create a barrier preventing the attraction and retention of promising young talents and productive teachers, undermining the positive effects for system-level educational efficiency associated with having a composition of the teachers' body more skewed towards the younger ones. On the other side, policy makers of those countries where teachers (even the younger ones) are paid more should assess which initiatives must be taken to stimulate a more productive use of teaching human resources, including the opportunity of lifelong training and the consideration of more performance-oriented incentives and salaries (although the academic literature in these areas is quite sceptical about the real effectiveness of these approaches).

Countries where a higher proportion of students are natives (i.e., non-immigrants) have, on average, a more efficient educational system. This negative correlation between the proportion of immigrants and the educational system's efficiency can be explained by higher cost associated with educating non-natives, because of obstacles due to culture, background, history and practices – overcoming these obstacles is, by the way, an explicit aim of various educational policies in Europe. As it often happens, this is a clear case where efficiency and equity objectives are potentially conflictual. This finding at country level comes with stimulating important policy implications. The political aim of promoting social inclusion for students who are not natives is strong enough to justify some inefficiency stemming from having a high proportion of immigrant students. However, policy makers and educational leaders should challenge themselves to identify institutional approaches and educational practices which can maximize the productivity of the resources invested for the social (and educational) inclusion of immigrant students. For example, it can be the case that the inefficiency of the educational systems derives from allocating money to some practices and initiatives which are not stimulating the educational experience of immigrant students, and their subsequent educational performance. In the same vein, different initiatives could be developed for guaranteeing the current educational performance of immigrant students with less money invested.

Overall, given that policy makers opted for investing resources directed at including immigrant students, educational experts and teaching leaders should devote their efforts towards using the available additional money for raising the educational performances of these students. The analyses based on the efficiency approach, in this context, could provide a good guide to check whether the available resources – that are invested altogether, for reasons that are beyond any efficiency consideration and instead follow equity priorities – are used in the most productive directions.

The efficiency of an educational system is positively correlated with the competences of the adults, at country level, as measured through the OECD program called PIAAC - Programme for the International Assessment of Adult Competencies. Stimulating the efficiency of an educational system is then not only worthwhile because of the responsibility in the best possible use of public resources; this could also contribute to long-term benefits in terms of adults' skills and competences (on the other hand adults with better skills and competences contribute to the education system's overall efficiency by providing a better family background to students). This finding also constitutes a justification for posing again attention to policies for improving the lifelong learning (LL) in various countries. The traditional argument for LL is that adults need a continuous update of their competences to fully live a society and economy that continuously requires new skills – and this is certainly true. However, our study points at the existence of a 'spillover' effect. Indeed, more educated adults can work in a more productive way towards the creation of those positive conditions that favour a more productive use of educational resources, which leads to better educational current outputs, and impacts positively on the subsequent efficiency of the educational system.

The amount of public spending on education, as a proportion of total public spending, is not statistically correlated with the education system's efficiency of a country. However, many efficient educational systems are in countries where the proportion of public spending on education is relatively low; as mentioned above, our findings suggest that probably the way of employing the available resources matter more for efficiency than the prioritization of education in public spending. At the same time, policy considerations should also take into account that there are countries where educational spending is high, and efficiency of the system is also high. These are countries in which high levels of spending did result into higher-than-average performance, and can secure future prosperity to the country through their high level of educational outputs. These countries should represent the desirable benchmark, more than those countries which are deemed as efficient mainly because they spend relatively little on education (without getting high educational performance). In the light of policy-making, educational leaders should aim at understanding how high-spending high-results countries employ their resources, so that new requests of funding can be channelled through initiatives for improving the efficiency of the overall educational systems.

Equity and efficiency are not necessarily set in a trade-off setting. Although we reveal that, in some countries, high efficiency comes at the cost of lower equality, there are also cases where the two dimensions (efficiency and equity) go hand-in-hand. In this sense, it is likely that internal characteristics of the educational system's design can affect the relative importance of equity and efficiency, and the potential for their co-existence. From a policy perspective, optimal conditions arise when higher levels of educational output can be obtained without sacrificing the ability of disadvantaged students to obtain good results. Such conditions can be achieved when not only the average results are satisfying, but also the distribution around the average results is quite narrow; indeed, in these circumstances, the majority of students are able to get high educational outputs. Policy makers should seek to create those conditions which conduce to use the resources in the most productive way; reducing spending while keeping outputs constant is a risky approach, because it is likely to reproduce social inequalities between students with different socioeconomic backgrounds. In this sense, resources should be allocated to the support of disadvantaged students; such an

approach could work simultaneously for improving the efficiency and the equity of the educational system. In other words, the results of our efficiency analyses suggest that policy makers could keep an eye to raise the average educational results, while having at the same time the objective of not leaving disadvantaged students behind.

4.3 Future scenarios: the necessity for more data for better estimates of efficiency in education at country-level

Finally, we would like to stress the importance of data for proper efficiency analyses. Although we made all efforts to use reliable and complete data, there is no doubt that the data availability could be improved significantly. When considering the possibility of comparing performance and efficiency of the European primary and secondary schools, the first step should be the realization an EU-level large project, with the aim of defining the relevant variables to be constantly monitored and updated. Starting with a baseline and simplified version of the educational process, schools can be represented by using human and financial resources as inputs. In this sense, the following input variables should be routinely collected: number of teaching and support staff; expenditures by type; facilities available (number of computers, space in teaching rooms, etc.); characteristics of teaching staff (age, qualifications, etc.). In this group, the characteristics of school management staff should also be included; limiting the focus to the school principal, the relevant information should consider his/her age, qualification, field of study, years spent in the institution, etc.

All these data are in many cases already available at country level, so the main objective when creating the "Input" section of a possible European Database deals with the integration of existing data – this, of course, leads to a series of problems like alignment of dates, timing for transferring data, common glossaries, etc.

The attempt of collecting comparable information about outputs, instead, is quite different and much more challenging. Of course, national statistical offices have data about some phenomena that are more 'administrative' and can be considered as outputs, such as pass rates, retention rates, dropout, etc. – in these cases, once verified that school-level variables can be built around these phenomena, the only issue would be the integration into a European Database, with the focal points depicted above. Therefore, it would be necessary to administer annually standardized test scores, to measure and analyse school-level differences in skills, competences and knowledge acquired. This attempt would be heroic (and probably completely unfeasible) if the active commitment of each school is not guaranteed.

The most similar exercises currently realized, namely PISA, TIMSS and PIRLS⁸, share three characteristics that are detrimental for the type of assessment that we are proposing here: they are conducted on a sample of schools, periodically (typically, every three years) and are often conducted only on a single grade.⁹ To be part of a systematic collection of useful data for a European Database, the tests should be administered every year, to all the schools, and possibly on several grades (to build Value-Added measures, where performance in year $t+n$ is modelled as a function of the performance in year t). In discussing this hypothesis, we are also making the (hard) assumption that a convergence of opinions can be reached about the opportunity of testing only three domains, reading, mathematics and science – as PISA does. We are aware that this is

⁸ The meaning of these three acronyms is as follows: PISA – Programme for International Student Assessment is administered by OECD; and International Association for the Evaluation of Educational Achievement [IEA] administers the Trends in International Mathematics and Science Study (TIMSS) and Progress in International Reading Literacy Study (PIRLS).

⁹ TIMSS has been conducted in some countries for the 4th and the 8th grade.

likely to be unrealizable, due to the prohibitive financial and organizational costs (at least, at the present technological conditions). With a marked difference to the case of Higher Education, then, the definition of efficiency for each school should reside on different outputs than test scores¹⁰. In this direction, the main conceptual effort at the beginning of such a project should be devoted to reach an agreement about the indicators that can be considered as acceptable for measuring school outputs, other than test scores.

An important help can come from literature reviews, as the one proposed by De Witte & Lopez-Torres (2015), in which, however, the problem of identifying widely used indicators of this kind remains. Most probably, indicators about dropouts and passing rates will be the best candidates for measuring school outputs, at least in the short time. Obviously, this choice would lead space to researchers for continuing studies about the efficiency of schools selected as part of the samples tested by PISA, TIMSS and PIRLS, because in this case better measures of outputs will be available and usable (i.e., test scores) – maybe, in this spirit, an institutional collaboration with OECD and IEA would lead to a better design of the sample for conducting research and analysis at school level.

A further topic deserves a discussion, and it is related to the choice – and collection of – data about contextual variables. While some of them are clearly impossible to be obtained routinely (as, for example, the managerial practices and attitudes of school principal, the school climate – all these issues being better covered through ad hoc periodic questionnaires), others could be easily extracted from pre-defined statistical systems. Examples of this kind are: ownership, type of institution, share of private funding, number of schools in the same region, etc. Of course, a substantial work of aligning definitions and metrics would be necessary to assure comparability between indicators across countries also in this case.

Summarizing, the work of collecting comprehensive indicators about inputs, (some) outputs and contextual variables of primary and secondary school would be extremely hard, but not impossible. Certainly, this would require some changes in the way Statistical Offices collect the information, and an organizational project with a long term effort. The experience matured with similar projects in the Higher Education field, however, should make this attempt a bit easier and policy makers more optimistic about the potential results.

¹⁰ However, research work should be done to improve the way in which PISA, TIMSS and PIRLS do collect relevant information about the outputs, for instance by developing measures of prior achievement of students, with the aim of developing more credible measures of Value Added at school level.

References

- Afonso, A., & Aubyn, M. S. (2006). Cross-country efficiency of secondary education provision: A semi-parametric analysis with non-discretionary inputs. *Economic Modelling*, 23(3), 476-491.
- Agasisti T. and Giuseppe Munda (2017). Efficiency of investment in compulsory education: An Overview of Methodological Approaches; EUR 28608 EN. Luxembourg (Luxembourg): Publications Office of the European Union; JRC106681.
- Agasisti, T., & Salerno, C. (2007). Assessing the cost efficiency of Italian universities. *Education Economics*, 15(4), 455-471.
- Agasisti, T. (2009). Market forces and competition in university systems: theoretical reflections and empirical evidence from Italy. *International Review of Applied Economics*, 23(4), 463-483.
- Agasisti, T., & Johnes, G. (2009). Beyond frontiers: comparing the efficiency of higher education decision-making units across more than one country. *Education Economics*, 17(1), 59-79.
- Agasisti, T., & Pérez-Esparrells, C. (2010). Comparing efficiency in a cross-country perspective: the case of Italian and Spanish state universities. *Higher Education*, 59(1), 85-103.
- Agasisti, T., and G. Johnes (2010). Heterogeneity and the evaluation of efficiency: the case of Italian universities. *Applied Economics*, 42: 1365-75.
- Agasisti, T. (2011). Performances and spending efficiency in higher education: a European comparison through non-parametric approaches. *Education Economics*, 19(2), 199-224.
- Agasisti, T., & Pohl, C. (2012). Comparing German and Italian public universities: Convergence or divergence in the higher education landscape?. *Managerial and Decision Economics*, 33(2), 71-85.
- Agasisti, T., Bonomi, F., & Sibiano, P. (2014). Measuring the "managerial" efficiency of public schools: a case study in Italy. *International Journal of Educational Management*, 28(2), 120-140.
- Agasisti, T., & Belfield, C. (2014). Efficiency in the community college sector: Stochastic frontier analysis. CCRC Working Papers, Teachers College Columbia University.
- Agasisti, T. (2014). The efficiency of public spending on education: An empirical comparison of EU countries. *European Journal of Education*, 49(4), 543-557.
- Agasisti, T., & Bonomi, F. (2014). Benchmarking universities' efficiency indicators in the presence of internal heterogeneity. *Studies in Higher Education*, 39(7), 1237-1255.
- Agasisti, T., & Haelermans, C. (2015). Comparing efficiency of public universities among European countries: Different incentives lead to different performances. *Higher Education Quarterly*.
- Agasisti, T., & Wolszczak-Derlacz, J. (2015). Exploring efficiency differentials between Italian and Polish universities, 2001-11. *Science and Public Policy*, scv026.
- Aghion, P., Dewatripont, M., Hoxby, C., Mas-Colell, A., & Sapir, A. (2010). The governance and performance of universities: evidence from Europe and the US. *Economic Policy*, 25(61), 7-59.
- Aigner, D., Lovell, C. K., & Schmidt, P. (1977). Formulation and estimation of stochastic frontier production function models. *Journal of Econometrics*, 6(1), 21-37.

- Alberta Oliveira, M., & Santos, C. (2005). Assessing school efficiency in Portugal using FDH and bootstrapping. *Applied Economics*, 37(8), 957-968.
- Alexander, W. R. J., Haug, A. A., & Jaforullah, M. (2010). A two-stage double-bootstrap data envelopment analysis of efficiency differences of New Zealand secondary schools. *Journal of Productivity Analysis*, 34(2), 99-110.
- Banker, R. D., Janakiraman, S., & Natarajan, R. (2004). Analysis of trends in technical and allocative efficiency: An application to Texas public school districts. *European Journal of Operational Research*, 154(2), 477-491.
- Barr, N. (2004). Higher education funding. *Oxford Review of Economic Policy*, 20(2), 264-283.
- Barro, R. J. (2001). Human capital and growth. *American Economic Review*, 12-17.
- Battese, G. E., & Coelli, T. J. (1995). A model for technical inefficiency effects in a stochastic frontier production function for panel data. *Empirical Economics*, 20(2), 325-332.
- Baumol, W.J., J.C. Panzar and R.D. Willig (1982). *Contestable Markets and the Theory of Industry Structure*, New York: Harcourt Brace Jovanovich.
- Beasley, J. E. (1990). Comparing university departments. *Omega*, 18(2), 171-183.
- Benhabib, J., & Spiegel, M. M. (1994). The role of human capital in economic development evidence from aggregate cross-country data. *Journal of Monetary Economics*, 34(2), 143-173.
- Berlinski, S., Galiani, S., & Gertler, P. (2009). The effect of pre-primary education on primary school performance. *Journal of Public Economics*, 93(1), 219-234.
- Bland, C. J., Center, B. A., Finstad, D. A., Risbey, K. R., & Staples, J. (2006). The impact of appointment type on the productivity and commitment of full-time faculty in research and doctoral institutions. *Journal of Higher Education*, 89-123.
- Bloom, N., Lemos, R., Sadun, R., & Van Reenen, J. (2015). Does management matter in schools?. *The Economic Journal*, 125(584), 647-674.
- Bolli, T., Olivares, M., Bonaccorsi, A., Daraio, C., Aracil, A. G., & Lepori, B. (2016). The Differential Effects of Competitive Funding on the Production Frontier and the Efficiency of Universities. *Economics of Education Review*.
- Bonaccorsi, A., & Daraio, C. (Eds.). (2007a). *Universities and strategic knowledge creation: Specialization and performance in Europe*. Edward Elgar Publishing.
- Bonaccorsi, A., & Daraio, C. (2007b). The differentiation of the strategic profile of higher education institutions. New positioning indicators based on microdata. *Scientometrics*, 74(1), 15-37.
- Bonaccorsi, A., Daraio, C. & Simar L. (2007). Efficiency and productivity in European universities: exploring trade-offs in the strategic profile. Chapter in Bonaccorsi & Daraio (2007a).
- Bonaccorsi, A. (Ed.). (2014). *Knowledge, Diversity and Performance in European Higher Education: A Changing Landscape*. Edward Elgar Publishing.
- Bordons, M., Fernández, M., & Gómez, I. (2002). Advantages and limitations in the use of impact factor measures for the assessment of research performance. *Scientometrics*, 53(2), 195-206.
- Bratti, M., Checchi, D., & De Blasio, G. (2008). Does the expansion of higher education increase the equality of educational opportunities? Evidence from Italy. *Labour*, 22(s1), 53-88.
- Campbell, J. P., & Oblinger, D. G. (2007). Academic analytics. *EDUCAUSE Review*, 42(4), 40-57.

- Cazals, C., Florens, J. P., & Simar, L. (2002). Nonparametric frontier estimation: a robust approach. *Journal of Econometrics*, 106(1), 1-25.
- Charnes, A., Cooper, W. W., Lewin, A. Y., & Seiford, L. M. (Eds.). (2013). *Data envelopment analysis: Theory, methodology, and applications*. Springer Science & Business Media.
- Chowdry, H., Crawford, C., Dearden, L., Goodman, A., & Vignoles, A. (2013). Widening participation in higher education: analysis using linked administrative data. *Journal of the Royal Statistical Society: Series A (Statistics in Society)*, 176(2), 431-457.
- Clements, B. (2002). How efficient is education spending in Europe?. *European Review of Economics and Finance*, 1(1), 3-26.
- Coelli, T. J., Rao, D. S. P., O'Donnell, C. J., & Battese, G. E. (2005). *An introduction to efficiency and productivity analysis*. Springer Science & Business Media.
- Cohn, E., Rhine, S. L., & Santos, M. C. (1989). Institutions of higher education as multi-product firms: Economies of scale and scope. *The Review of Economics and Statistics*, 284-290.
- Cohn, E., & Cooper, S. T. (2004). 15 Multi-product cost functions for universities: economies of scale and scope. *International handbook on the economics of education*, 579.
- Coleman, J. S., Campbell, E. Q., Hobson, C. J., McPartland, J., Mood, A. M., Weinfeld, F. D., & York, R. (1966). *Equality of educational opportunity*. Washington, DC, 1066-5684.
- Cooper, W. W., Seiford, L. M., & Zhu, J. (Eds.). (2011). *Handbook on data envelopment analysis (Vol. 164)*. Springer Science & Business Media.
- Cordero-Ferrera, J. M., Pedraja-Chaparro, F., & Salinas-Jiménez, J. (2008). Measuring efficiency in education: an analysis of different approaches for incorporating non-discretionary inputs. *Applied Economics*, 40(10), 1323-1339.
- Cordero Ferrera, J. M., Cebada, E. C., Chaparro, F. P., & González, D. S. (2011). Exploring educational efficiency divergences across Spanish regions in PISA 2006. *Revista de Economía Aplicada*, 19(57), 117-146.
- Cordero, J. M., Santín, D., & Sicilia, G. (2015). Testing the accuracy of DEA estimates under endogeneity through a Monte Carlo simulation. *European Journal of Operational Research*, 244(2), 511-518.
- Cunha, M., & Rocha, V. (2012). On the efficiency of Public higher education institutions in Portugal: An exploratory study. *FEP Economics and Management, Working Paper*.
- Daouia, A., & Simar, L. (2005). Robust nonparametric estimators of monotone boundaries. *Journal of Multivariate Analysis*, 96(2), 311-331.
- Daraio, C., & Simar, L. (2005). Introducing environmental variables in nonparametric frontier models: a probabilistic approach. *Journal of Productivity Analysis*, 24(1), 93-121.
- Daraio, C., & Simar, L. (2007). *Advanced Robust and nonparametric methods in efficiency analysis: methodology and applications*. Springer Science & Business Media.
- Daraio, C., Bonaccorsi, A., Geuna, A., Lepori, B., Bach, L., Bogetoft, P., ... & Fried, H. (2011). The European university landscape: A micro characterization based on evidence from the Aquameth project. *Research Policy*, 40(1), 148-164.
- Darling-Hammond, L. (2000). Teacher quality and student achievement. *Education Policy Analysis Archives*, 8, 1.
- De la Torre, E., Agasisti T. & Perez-Esparrells C. (2016). How including third mission indicators do change universities' efficiency scores: empirical evidence on Spanish universities, Working Paper – to be presented at the 2016 Annual Conference of the Association for Education Finance and Policy (AEFP).

- De Witte, K., & López-Torres, L. (2015). Efficiency in education: a review of literature and a way forward. *Journal of the Operational Research Society*.
- Di Liberto, A., Schivardi, F., & Sulis, G. (2015). Managerial Practices and Students' Performance. *Economic Policy*, 30(84), 683-728.
- Dill, D. D. (1997). Higher education markets and public policy. *Higher Education Policy*, 10(3-4), 167-185.
- Dronkers, J., & Robert, P. (2008). Differences in scholastic achievement of public, private government-dependent, and private independent schools: a cross-national analysis. *Educational Policy*, 22(4), 541-577.
- Emrouznejad, A., Parker, B. R., & Tavares, G. (2008). Evaluation of research in efficiency and productivity: A survey and analysis of the first 30 years of scholarly literature in DEA. *Socio-Economic Planning Sciences*, 42(3), 151-157.
- Essid, H., Ouellette, P., & Vigeant, S. (2014). Productivity, efficiency, and technical change of Tunisian schools: a bootstrapped Malmquist approach with quasi-fixed inputs. *Omega*, 42(1), 88-97.
- Etzkowitz, H., & Leydesdorff, L. (2000). The dynamics of innovation: from National Systems and "Mode 2" to a Triple Helix of university-industry-government relations. *Research Policy*, 29(2), 109-123.
- Eugène, B. (2008). The efficiency frontier as a method for gauging the performance of public expenditure: a Belgian case study. *National Bank of Belgium Working Paper*, (138).
- European Commission (2015). *Education and training monitor 2015*. Publications Office of the European Union.
- Fandel, G. (2007). On the performance of universities in North Rhine-Westphalia, Germany: Government's redistribution of funds judged using DEA efficiency measures. *European Journal of Operational Research*, 176(1), 521-533.
- Farrell, M. J. (1957). The measurement of productive efficiency. *Journal of the Royal Statistical Society. Series A (General)*, 120(3), 253-290.
- Figlio, D. N. (1999). Functional form and the estimated effects of school resources. *Economics of Education Review*, 18(2), 241-252.
- Fried, H. O., Lovell, C. K., & Schmidt, S. S. (Eds.). (2008). *The measurement of productive efficiency and productivity growth*. Oxford University Press.
- Giménez, V., Prior, D., & Thieme, C. (2007). Technical efficiency, managerial efficiency and objective-setting in the educational system: an international comparison. *Journal of the Operational Research Society*, 996-1007.
- Glass, J. C., McKillop, D. G., & Hyndman, N. (1995). Efficiency in the provision of university teaching and research: an empirical analysis of UK universities. *Journal of Applied Econometrics*, 10(1), 61-72.
- Golany, B., & Tamir, E. (1995). Evaluating efficiency-effectiveness-equality trade-offs: a data envelopment analysis approach. *Management Science*, 41(7), 1172-1184.
- Greene, W. (2005). Reconsidering heterogeneity in panel data estimators of the stochastic frontier model. *Journal of Econometrics*, 126(2), 269-303.
- Greene, W. H. (2008). The econometric approach to efficiency analysis. In *The measurement of productive efficiency and productivity growth*, 92-250.
- Greenwald, R., Hedges, L. V., & Laine, R. D. (1996). The effect of school resources on student achievement. *Review of Educational Research*, 66(3), 361-396.

- Grosskopf, S., Hayes, K. J., Taylor, L. L., & Weber, W. L. (2001). On the determinants of school district efficiency: Competition and monitoring. *Journal of Urban Economics*, 49(3), 453-478.
- Grosskopf, S., & Moutray, C. (2001). Evaluating performance in Chicago public high schools in the wake of decentralization. *Economics of Education Review*, 20(1), 1-14.
- Gulbrandsen, M., & Slipersaeter, S. (2007). The third mission and the entrepreneurial university model. In *Universities and strategic knowledge creation*, 112-143.
- Gundlach, E., Wossmann, L., & Gmelin, J. (2001). The decline of schooling productivity in OECD countries. *The Economic Journal*, 111(471), 135-147.
- Haelermans, C., & De Witte, K. (2012). The role of innovations in secondary school performance—Evidence from a conditional efficiency model. *European Journal of Operational Research*, 223(2), 541-549.
- Haelermans, C., & Ruggiero, J. (2013). Estimating technical and allocative efficiency in the public sector: A nonparametric analysis of Dutch schools. *European Journal of Operational Research*, 227(1), 174-181.
- Hanushek, E. A. (1979). Conceptual and empirical issues in the estimation of educational production functions. *Journal of Human Resources*, 351-388.
- Hanushek, E. A. (1986). The economics of schooling: Production and efficiency in public schools. *Journal of Economic Literature*, 1141-1177.
- Hanushek, E. A. (1997). Assessing the effects of school resources on student performance: An update. *Educational evaluation and policy analysis*, 19(2), 141-164.
- Hanushek, E. A., & Luque, J. A. (2003). Efficiency and equity in schools around the world. *Economics of Education Review*, 22(5), 481-502.
- Hanushek, E. A. (2006). School resources. *Handbook of the Economics of Education*, 2, 865-908.
- Hanushek, E. A., & Woessmann, L. (2008). The role of cognitive skills in economic development. *Journal of Economic Literature*, 607-668.
- Hanushek, E. A., & Woessmann, L. (2010). The economics of international differences in educational achievement (No. w15949). National Bureau of Economic Research.
- Hanushek, E. A., & Woessmann, L. (2012). Do better schools lead to more growth? Cognitive skills, economic outcomes, and causation. *Journal of Economic Growth*, 17(4), 267-321.
- Hashimoto, K., & Cohn, E. (1997). Economies of scale and scope in Japanese private universities. *Education Economics*, 5(2), 107-115.
- Haveman, R., & Wolfe, B. (1995). The determinants of children's attainments: A review of methods and findings. *Journal of Economic Literature*, 1829-1878.
- Hicks, D. (2012). Performance-based university research funding systems. *Research Policy*, 41(2), 251-261.
- Izadi, H., Johnes, G., Oskrochi, R., & Crouchley, R. (2002). Stochastic frontier estimation of a CES cost function: the case of higher education in Britain. *Economics of Education Review*, 21(1), 63-71.
- James, E. (1978). Product mix and cost disaggregation: A reinterpretation of the economics of higher education. *Journal of Human Resources*, 157-186.
- Johnes, G., & Johnes, J. (1993). Measuring the research performance of UK economics departments: an application of data envelopment analysis. *Oxford economic papers*, 332-347.

- Johnes, J., & Johnes, G. (1995). Research funding and performance in UK university departments of economics: a frontier analysis. *Economics of Education Review*, 14(3), 301-314.
- Johnes, G. (1997). Costs and industrial structure in contemporary British higher education. *The Economic Journal*, 107(442), 727-737.
- Johnes, J. (2004). Efficiency measurement. *International Handbook on the Economics of Education*, chapter 16.
- Johnes, J., Thanassoulis, E., Lenton, P., & Emrouznejad, A. (2005). An exploratory analysis of the cost structure of higher education in England. DfES publications.
- Johnes, G., Johnes, J., & Thanassoulis, E. (2008). An analysis of costs in institutions of higher education in England. *Studies in Higher Education*, 33(5), 527-549.
- Johnes, G., and J. Johnes (2009). Higher education institutions' costs and efficiency: taking the decomposition a further step. *Economics of Education Review*, 28: 107-13.
- Johnes, G., and A. Schwarzenberger (2011). Differences in cost structure and the evaluation of efficiency: the case of German universities. *Education Economics*, 19: 487-500.
- Johnes, G. (2015). Evaluating the efficiency of public services. *IZA World of Labor*.
- Johnson, A. L., & Ruggiero, J. (2014). Nonparametric measurement of productivity and efficiency in education. *Annals of Operations Research*, 221(1), 197-210.
- Johnstone, D. B. (2004). The economics and politics of cost sharing in higher education: comparative perspectives. *Economics of Education Review*, 23(4), 403-410.
- Jongbloed, B., & Vossensteyn, H. (2001). Keeping up performances: An international survey of performance-based funding in higher education. *Journal of Higher Education Policy and Management*, 23(2), 127-145.
- Joumady, O., & Ris, C. (2005). Performance in European higher education: A non-parametric production frontier approach. *Education Economics*, 13(2), 189-205.
- Kao, C., & Hung, H. T. (2008). Efficiency analysis of university departments: An empirical study. *Omega*, 36(4), 653-664.
- Kempkes, G., & Pohl, C. (2010). The efficiency of German universities—some evidence from nonparametric and parametric methods. *Applied Economics*, 42(16), 2063-2079.
- Köksal, G., & Nalçacı, B. (2006). The relative efficiency of departments at a Turkish engineering college: A data envelopment analysis. *Higher Education*, 51(2), 173-189.
- Koshal, R. K., & Koshal, M. (1995). Quality and economies of scale in higher education. *Applied Economics*, 27(8), 773-778.
- Koshal, R. K., & Koshal, M. (1999). Economies of scale and scope in higher education: a case of comprehensive universities. *Economics of Education Review*, 18(2), 269-277.
- Koshal, R. K., & Koshal, M. (2000). State Appropriation and Higher Education Tuition: what is the relationship?. *Education Economics*, 8(1), 81-89.
- Krueger, A. B. (2003). Economic considerations and class size. *The Economic Journal*, 113(485), F34-F63.
- Kuo, J. S., & Ho, Y. C. (2008). The cost efficiency impact of the university operation fund on public universities in Taiwan. *Economics of Education Review*, 27(5), 603-612.
- Laband, D. N., & Lentz, B. F. (2003). New estimates of economies of scale and scope in higher education. *Southern Economic Journal*, 172-183.
- Ladd, H. F. (Ed.). (1996). *Holding schools accountable: Performance-based reform in education*. Brookings Institution Press.

- Laredo, P. (2007). Revisiting the third mission of universities: toward a renewed categorization of university activities?. *Higher Education Policy*, 20(4), 441-456.
- Levin, H. M., & McEwan, P. J. (2001). *Cost-effectiveness analysis: Methods and applications* (Vol. 4). Sage.
- Luedemann, E., Schuetz, G., Woessmann, L., & West, M. R. (2009). *School accountability, autonomy and choice around the world*. Edward Elgar.
- Mancebón, M. J., Calero, J., Choi, Á., & Ximénez-de-Embún, D. P. (2012). The efficiency of public and publicly subsidized high schools in Spain: Evidence from PISA-2006. *Journal of the Operational Research Society*, 63(11), 1516-1533.
- McDonald, J. (2009). Using least squares and tobit in second stage DEA efficiency analyses. *European Journal of Operational Research*, 197(2), 792-798.
- Mensah, Y. M., & Werner, R. (2003). Cost efficiency and financial flexibility in institutions of higher education. *Journal of Accounting and Public Policy*, 22(4), 293-323.
- Moed, H. F., Burger, W. J. M., Frankfort, J. G., & Van Raan, A. F. (1985). The use of bibliometric data for the measurement of university research performance. *Research Policy*, 14(3), 131-149.
- Molas-Gallart, J., & Castro-Martínez, E. (2007). Ambiguity and conflict in the development of 'Third Mission' indicators. *Research Evaluation*, 16(4), 321-330.
- Moore, M. H. (1995). *Creating public value: Strategic management in government*. Harvard University Press.
- Munda, G. (1995) *Multicriteria evaluation in a fuzzy environment*. Physica-Verlag, Contributions to Economics Series, Heidelberg.
- Muthén, B. O. (1991). Multilevel factor analysis of class and student achievement components. *Journal of Educational Measurement*, 28(4), 338-354.
- Nigsch, S., & Schenker-Wicki, A. (2015). Frontier efficiency analysis in higher education. In *Incentives and Performance* (pp. 155-170). Springer International Publishing.
- OECD (2002). *Education at a Glance 2002 - Glossary*, OECD, Paris.
- OECD (2014). *PISA 2012 Results in focus. What 15-year-olds know and what they can do with what they know*, OECD Paris.
- Parteka, A., & Wolszczak-Derlacz, J. (2013). Dynamics of productivity in higher education: cross-European evidence based on bootstrapped Malmquist indices. *Journal of Productivity Analysis*, 40(1), 67-82.
- Perelman, S., & Santin, D. (2011). Measuring educational efficiency at student level with parametric stochastic distance functions: an application to Spanish PISA results. *Education Economics*, 19(1), 29-49.
- Perry, L., & McConney, A. (2010). Does the SES of the school matter? An examination of socioeconomic status and student achievement using PISA 2003. *The Teachers College Record*, 112(4), 7-8.
- Pinheiro, R., Langa, P. V., & Pausits, A. (2015). The institutionalization of universities' third mission: introduction to the special issue. *European Journal of Higher Education*, 5(3), 227-232.
- Pordata (2016). *Despesas do Estado em educação: execução orçamental - Portugal*, <http://www.pordata.pt/Portugal/Despesas+do+Estado+em+educa%c3%a7%c3%a3o+e+xecu%c3%a7%c3%a3o+or%c3%a7amental-866>.
- Powell, B. A., Gilleland, D. S., & Pearson, L. C. (2012). Expenditures, efficiency, and effectiveness in US undergraduate higher education: A national benchmark model. *The Journal of Higher Education*, 83(1), 102-127.

- Raudenbush, S. W., & Willms, J. D. (Eds.). (1991). *Schools, classrooms, and pupils: International studies of schooling from a multilevel perspective*. Academic Press.
- Ray, S. C. (1991). Resource-use efficiency in public schools: a study of Connecticut data. *Management Science*, 37(12), 1620-1628.
- Robst, J. (2001). Cost efficiency in public higher education institutions. *Journal of Higher Education*, 730-750.
- Romer, P. M. (1990). Human capital and growth: theory and evidence. In *Carnegie-Rochester Conference Series on Public Policy* (Vol. 32, pp. 251-286). North-Holland.
- Ruggiero, J. (1998). Non-discretionary inputs in data envelopment analysis. *European Journal of Operational Research*, 111(3), 461-469.
- Ruggiero, J., & Vitaliano, D. F. (1999). Assessing the efficiency of public schools using data envelopment analysis and frontier regression. *Contemporary Economic Policy*, 17(3), 321.
- Ruggiero, J. (2004). Performance evaluation in education. In *Handbook on data envelopment analysis* (pp. 323-346). Springer US.
- Ryan, J. F. (2004). The relationship between institutional expenditures and degree attainment at baccalaureate colleges. *Research in Higher Education*, 45(2), 97-114.
- Sacerdote, B. (2011). Peer effects in education: How might they work, how big are they and how much do we know thus far?. *Handbook of the Economics of Education*, 3, 249-277.
- Sammons, P. (1995). *Key characteristics of effective schools: A review of school effectiveness research*. B & MBC Distribution Services.
- Sarrico, C. S., & Dyson, R. G. (2000). Using DEA for planning in UK universities—an institutional perspective. *Journal of the Operational Research Society*, 51(7), 789-800.
- Sarrico, C. S., Teixeira, P. N., Rosa, M. J., & Cardoso, M. F. (2009). Subject mix and productivity in Portuguese universities. *European Journal of Operational Research*, 197(1), 287-295.
- Sarrico, C. S., Rosa, M. J., & Coelho, I. P. (2010). The performance of Portuguese secondary schools: An exploratory study. *Quality Assurance in Education*, 18(4), 286-303.
- SCRGSP (Steering Committee for the Review of Government Service Provision) 2006, *Report on Government Services 2006*, Productivity Commission, Canberra.
- Simar, L., & Wilson, P. W. (2000). Statistical inference in nonparametric frontier models: The state of the art. *Journal of Productivity Analysis*, 13(1), 49-78.
- Simar, L., & Wilson, P. W. (2007). Estimation and inference in two-stage, semi-parametric models of production processes. *Journal of Econometrics*, 136(1), 31-64.
- Smith, P. C., & Street, A. (2005). Measuring the efficiency of public services: the limits of analysis. *Journal of the Royal Statistical Society: Series A (Statistics in Society)*, 168(2), 401-417.
- St. Aubyn, M. S., Garcia, F., & Pais, J. (2009). Study on the efficiency and effectiveness of public spending on tertiary education (No. 390). Directorate General Economic and Monetary Affairs (DG ECFIN), European Commission.
- Stevens, P. A. (2005). A stochastic frontier analysis of English and Welsh universities. *Education Economics*, 13(4), 355-374.
- Sutherland, D., Price, R., & Gonand, F. (2010). Improving public spending efficiency in primary and secondary education. *OECD Journal: Economic Studies*, 2009(1), 1-30.

- Tajnikar, M., & Debevec, J. (2008). Funding system of full-time higher education and technical efficiency: case of the University of Ljubljana. *Education Economics*, 16(3), 289-303.
- Teddlie, C., & Reynolds, D. (2000). *The international handbook of school effectiveness research*. Psychology Press.
- Thanassoulis, E., Kortelainen, M., Johnes, G., & Johnes, J. (2011). Costs and efficiency of higher education institutions in England: a DEA analysis. *Journal of the Operational Research Society*, 62(7), 1282-1297.
- Todd, P. E., & Wolpin, K. I. (2007). The production of cognitive achievement in children: Home, school, and racial test score gaps. *Journal of Human Capital*, 1(1), 91-136.
- Tone, K. (2004). Malmquist productivity index. In *Handbook on Data Envelopment Analysis* (pp. 203-227). Springer US.
- Tsionas, E. G. (2002). Stochastic frontier models with random coefficients. *Journal of Applied Econometrics*, 17(2), 127-147.
- Tsionas, E. G., & Kumbhakar, S. C. (2014). Firm heterogeneity, persistent and transient technical inefficiency: a generalized true random-effects model. *Journal of Applied Econometrics*, 29(1), 110-132.
- Van Raan, A. F. (2005). Fatal attraction: Conceptual and methodological problems in the ranking of universities by bibliometric methods. *Scientometrics*, 62(1), 133-143.
- Veiderpass, A., & McKelvey, M. (2015). Evaluating the performance of higher education institutions in Europe: a nonparametric efficiency analysis of 944 institutions. *Applied Economics*, 1-11.
- Webber, D. A., & Ehrenberg, R. G. (2010). Do expenditures other than instructional expenditures affect graduation and persistence rates in American higher education?. *Economics of Education Review*, 29(6), 947-958.
- Wößmann, L., & Schütz, G. (2006). *Efficiency and equity in European education and training systems*. Analytical report for the European commission prepared by the European expert network on economics of education (EENEE) to accompany the communication and staff working paper by the European commission under the same title, 26.4, 1, 2007-2013.
- Woessmann, L. (2007). International evidence on school competition, autonomy, and accountability: A review. *Peabody Journal of Education*, 82(2-3), 473-497.
- Woessmann, L. (2008). Efficiency and equity of European education and training policies. *International Tax and Public Finance*, 15(2), 199-230.
- Wolszczak-Derlacz, J., & Parteka, A. (2011). Efficiency of European public higher education institutions: a two-stage multicountry approach. *Scientometrics*, 89(3), 887-917.
- Worthington, A. C. (2001). An empirical survey of frontier efficiency measurement techniques in education. *Education Economics*, 9(3), 245-268.
- Worthington, A. C., & Dollery, B. E. (2002). Incorporating contextual information in public sector efficiency analyses: a comparative study of NSW local government. *Applied Economics*, 34(4), 453-464.
- Worthington, A. C., & Higgs, H. (2011). Economies of scale and scope in Australian higher education. *Higher Education*, 61(4), 387-414.
- Zhu, J. (Ed.). (2015). *Data Envelopment Analysis: A Handbook of Models and Methods* (Vol. 221). Springer.

ANNEX 1

Table A.1 An overview of the main studies about the efficiency of education in Europe, country-level studies

Paper	Data source	Variables	Method	Countries
Clements, B. (2002). How efficient is education spending in Europe?. <i>European Review of Economics and Finance</i> , 1(1), 3-26.	OECD	Inputs: spending in \$, spending as % GDP Output: percentage of population that completes secondary education at a normal graduation age; test scores (TIMSS)	FDH (Free Disposable Hull)	18 countries: Austria, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Korea, Netherlands, Portugal, Spain, Sweden, United States
Afonso, A., & Aubyn, M. S. (2006). Cross-country efficiency of secondary education provision: A semi-parametric analysis with non-discretionary inputs. <i>Economic modelling</i> , 23(3), 476-491.	OECD	Inputs: teachers per 100 students, hours per year in school Outputs: PISA test scores Contextual variables: Parent education attainment, GDP per capita	DEA (Data Envelopment Analysis) + second-stage Tobit	25 countries: Australia, Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Indonesia, Ireland, Italy, Japan, Korea, Netherlands, New Zealand, Norway, Portugal, Slovak Republic, Spain, Sweden, Thailand, Turkey, Uruguay
Giménez, V., Prior, D., & Thieme, C. (2007). Technical efficiency, managerial efficiency and objective-setting in the educational system: an international comparison. <i>Journal of the Operational</i>	TIMSS 1999	Inputs: intensity of teaching resources, facilities, materials and quality of teachign staff Outputs: test scores in mathematics and science Contextual variables: literacy rate of adult population, GDP, employment rate, indexes for students' attitude towards	DEA (Data Envelopment Analysis)	31 countries: Belgium, Bulgaria, Chinese Taipei, Russian Federation, Hong Kong, Hungary, Italy, Latvia, Morocco, Moldova, Netherlands, Czech Republic, Korea, Romania, Singapore, Thailand, Slovenia, Tunisia,

Research Society, 996-1007.		mathematics and science, students' home possessions, time spent studying mathematics		Indonesia, Macedonia, Jordan, South Africa, Lithuania, Australia, Canada, Malaysia, United States, New Zealand, Chile, Cyprus, Philippines
Eugène, B. (2008). The efficiency frontier as a method for gauging the performance of public expenditure: a Belgian case study. National Bank of Belgium Working Paper, (138).	OECD, World Economic Forum	Inputs: monetary values - expenditure on education Outputs: a synthetic indicator that aggregates various measures of output, as PISA test scores and % adults with high education	FDH (Free Disposable Hull)	17 countries: 14 'old' EU members USA, Japan and Poland
Paper	Data source	Variables	Method	Countries
St. Aubyn, M. S., Garcia, F., & Pais, J. (2009). Study on the efficiency and effectiveness of public spending on tertiary education (No. 390). Directorate General Economic and Monetary Affairs (DG ECFIN), European Commission.	OECD, Eurostat	Inputs: academic staff, students, expenditures (%GDP and \$) Outputs: graduates, QS rankings, published articles, citations Contextual variables: characteristics of tertiary educational systems, PISA scores	DEA (Data Envelopment Analysis) + second-stage Tobit; SFA (Stochastic Frontier Analysis)	28 countries: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Germany, Denmark, Estonia, Greece, Spain, Finland, France, Hungary, Ireland, Italy, Japan, Lithuania, Latvia, Malta, the Netherlands, Poland, Portugal, Romania, Sweden, Slovenia, Slovak Republic, UK, USA
Agasisti, T. (2011). Performances and spending efficiency in higher education: a European comparison through non-parametric	OECD	Inputs: expenditures, entry rates, students:teachers ratio Outputs: population attainment, graduation rates, employment, foreign students Contextual variables: students in	DEA (Data Envelopment Analysis) + second-stage Tobit; FDH	18 countries: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Netherlands, Norway,

approaches. Education Economics, 19(2), 199-224.		public institutions, % public funds, subsidies to students		Poland, Slovak Republic, Portugal, Spain, Sweden, Switzerland, UK
Agasisti, T. (2014). The efficiency of public spending on education: An empirical comparison of EU countries. European Journal of Education, 49(4), 543-557.	OECD	Inputs: students:teachers ratio and expenditures Outputs: PISA test scores 2006 and 2009 Contextual variables: GPD per capita, teachers' salaries, internet at school, % public spending, instructional time	Bootstrap DEA + Tobit analysis	20 European countries: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, Netherlands, Norway, Poland, Slovak Republic, Portugal, Spain, Sweden, Switzerland, UK

Contributions are presented in chronological order of publication

ANNEX 2

Table A.2 Detailed overview of variables used in this study

Variable	Description	Year	Source	Comments
pisa_read	PISA reading scores	2012	National Center for Education Statistics (NCES) (2016), PISA International Data Explorer. http://nces.ed.gov/surveys/pisa/idepisa , last accessed 22 November 2016	
pisa_math	PISA mathematics scores	2012	National Center for Education Statistics (NCES) (2016), PISA International Data Explorer. http://nces.ed.gov/surveys/pisa/idepisa , last accessed 22 November 2016	
piaac_num	PIAAC numeracy scores	2012	National Center for Education Statistics (NCES) (2016), U.S. PIAAC International Data Explorer. http://nces.ed.gov/surveys/piaac/ideuspiaac , last accessed 22 November 2016	
esl	100 - (share of early schooling leavers) [18-24 year olds]	average 2010-2012	Eurostat (2016), Dataset t2020_40, last accessed 22 November 2016	
neet	100 - (share of NEET) [15-34 year olds, all non-employed persons]	average 2010-2012	Eurostat (2016), Dataset edat_ifse_20, last accessed 22 November 2016	
teacherratio	student/teacher ratio [ISCED 1-3]	average 2010-2012	Eurostat (2016), Dataset educ_iste, last accessed 22 November 2016	
migr	100 - (share of migrants among 15 year old pupils participating in PISA)	2012	OECD (2013), PISA 2012 Results: Excellence through Equity (Volume II): Giving Every Student the Chance to Succeed, Annex B1, Chapter 3	
expstud2avg	Government expenditure per student in primary and secondary education (constant PPP\$)	average 2010-2012	UNESCO (2016), UIS.Stat, Dataset education, indicator Government expenditure per primary student (constant PPP\$), indicator Government expenditure per secondary student (constant PPP\$), last accessed 22 November 2016	Weighted by number of pupils at each level. Source UNESCO (2016), Dataset education, indicator Enrolment in primary education, both sexes (number), indicator Enrolment in secondary education, both sexes (number), last accessed 22 November 2016
expgdp	Total public expenditure on primary, lower and upper secondary	2012	Eurostat (2016), Dataset educ_uoe_fine06, last accessed 22 November 2016	Sum of primary, lower and upper secondary education.

	education as % of GDP			
eduatt2	Higher educational attainment level from 25 to 64 years, ISCED 5-8	average 2010-2012	Eurostat (2016), Dataset edat_lfse_03, last accessed 22 November 2016	This variable has an alternative age definition (25-64 years) of the variable above
teachersalavg	Teachers' Salaries (in Euro, converted using PPS for household final consumption expenditure), averaging primary, lower secondary and upper secondary education.	2013	Costa, P. & Araújo, L. (2015), Teacher Costs. Luxembourg: Publications Office of the European Union. DOI: 10.2760/250728	Weighted by number of teachers at each level. Source: Eurostat (2015), Dataset educ_pers1t, last accessed 22 November 2016
expsharetot	Total public expenditure on primary, lower and upper secondary education as % of public expenditure	2012	Eurostat (2016), Dataset educ_uoe_fine08, last accessed 22 November 2016	
teacherage	Average teachers' age, lower secondary (TALIS)	2013	OECD (2016), OECD.Stat, Dataset TALIS Indicators, indicator mean age of teachers, last accessed 22 November 2016	
equity	PISA Index of economic, social and cultural status	2012	OECD (2015), Education Policy Outlook 2015: Making Reforms Happen, OECD Publishing, Paris. DOI: http://dx.doi.org/10.1787/9789264225442-en	The lower this index is, the higher is equity

Table A.3 Dataset

country	teacherratio	expstud2avg	expgdp	expsharetot	pisa_read	pisa_math	pisa_sci	esl	neet	teacherage	teachersalavg	migr	piaac_num	eduatt2	equity
AT	10	12080	3	6	490	506	506	92	90		36751	84	275	19	16
BE	11	12675	3	5	509	515	505	88	86	39	41195	85	280	35	20
BG	14	3260	2	6	436	439	446	88	75	47				24	22
CY	11	12135	5	11	449	440	438	88	85				265	38	
CZ	14	6109	3	6	493	499	508	95	85	44	13706	97	276	18	16
DE	16	9334	3	6	508	514	524	89	88		53003	87	272	28	17
DK		12557	3	6	500	496	498	90	92	45		91	278	34	16
EE	15	6253	3	8	516	521	541	89	83	48	9329		273	37	9
EL	9				477	453	467	87	75			89		25	15
ES	11	7945	3	6	488	484	496	74	78	46	32561	90	246	32	16
FI	13	11584	2	4	524	519	545	90	89	44	32447	97	282	39	9
FR	15	8827	4	7	505	495	499	88	84	43	27733	85	254	30	22
HR	11				485	471	491	95	80	43				18	12
HU	11	4697	3	5	488	477	494	89	79		10165	98		21	23
IE	15	10169	4	10	523	501	522	89	78			90	256	39	15
IT	12	8295	3	6	490	485	494	82	76	49	26137	93	247	15	10
LT	8	4626	3	7	477	479	496	93	83					33	14
LU	9	20564	3	8	488	490	491	93	92		80789	54		37	18
LV	11	5109	2	5	489	490	502	88	80	47		95		28	15
MT	10	10774	5	11				77	86					16	
NL	16	10008	4	8	511	523	522	91	93	43		89	280	32	12
PL	11	5687	3	8	518	518	526	94	84	42	19375		260	23	17
PT	9	7968	4	8	488	487	489	77	85	45	26564	93		17	20
RO	15	2279	2	4	438	445	439	82	80	42				15	19
SE	12	12751	4	8	483	478	485	93	92	46	30246	85	279	35	11
SI	13	9040	2	5	481	501	514	95	90		27987			25	16
SK	14	4875	2	4	463	482	471	95	79	43	11562	99	276	18	25
UK	18	10461	4	9	499	494	514	86	85	39			262	37	12

Note: the data are rounded values of the original dataset. Data for UK refers to the UK, England or England and Wales. Data for BE refers to Belgium or its Flemish part.

ANNEX 3. Robustness analysis: a multi-criterion approach

a) Analysis considering the expenses side only

In this analysis, we include all the expenditure variables; this is a comparative advantage of using multi-criteria evaluation in comparison with traditional frontier methods. In particular, we use expenditure on education as a share of GDP (in two specific definitions, expgdp and expgdp-2), the expenditure on education as a share of total expenditure (expshare), and the educational expenditure per student (exp-stud2) in the analysis. Note that we have used data on all EU countries where available. In practice, this meant that we could not include MT, EL and HR because of lacking data coverage. The dataset for this analysis is presented in Table A4 (data is taken from Annex 2, here it is presented again for reasons of clarity).

Criteria \ Alternatives	AT	BE	BG	CY	CZ	DE	DK	EE	ES	FI	FR	HU	IE	IT	LT
EXP GDP	3.230000	2.540000	2.130000	5.120000	2.730000	2.860000	3.440000	3.070000	2.820000	2.490000	3.690000	2.500000	4.330000	2.820000	2.650000
EXP SHARE	6.200000	4.600000	6.000000	11.200000	6.100000	6.400000	5.800000	7.700000	5.900000	4.400000	6.500000	5.100000	10.100000	5.600000	7.300000
EXP GDP-2	3.384520	4.250470	2.212590	4.921570	2.546480	2.814110	4.802950	3.202450	2.400580	3.140750	3.634680	2.601570	4.096150	2.822640	2.910970
EXP-STUD-2	12079.700000	12675.200000	3259.520000	12135.100000	6108.820000	9333.660000	12556.800000	6252.990000	7944.620000	11583.900000	8826.770000	4697.300000	10168.700000	8295.270000	4625.000000

LU	LV	NL	PL	PT	RO	SE	SI	SK	UK
3.240000	1.980000	3.790000	3.170000	3.690000	1.550000	4.040000	2.460000	1.670000	4.300000
7.500000	5.400000	7.500000	7.500000	7.700000	4.200000	7.800000	5.100000	4.400000	8.900000
3.307900	3.109140	3.554920	3.208180	3.745670	1.613910	3.909590	2.936280	2.595440	4.413240
20563.900000	5109.390000	10007.900000	5687.390000	7960.160000	2279.000000	12751.500000	9039.910000	4874.910000	10461.100000

Table A4. Data used for input evaluation

By applying NAIADÉ see (Agasisti and Munda, 2017), we have obtained the ranking shown in Figure A1. Each option is characterised by its strength (positive flow) and weakness (negative flow). The intersection between these two evaluations is providing the final ranking. When two options are not connected by an arrow, the situation described is a so-called *incomparability relation*, i.e. according to the information available, no clear relation of preference or indifference between these two options can be derived. Overall, we may safely state that the three groups of less spending countries (higher part of the ranking) and medium and bottom (countries which spend more) are clear. They are as follows:

Low Spending = (RO, SK, BG, HU, LV)

Medium Spending = (ES, LT, SI, CZ, IT, FI, DE, PL, EE, FR, AT, BE)

High Spending = (PT, NL, LU, DK, IE, UK, SE, CY)

Of course, this is not an evaluation; spending more or less per se is not something positive or negative without knowing the output obtained.

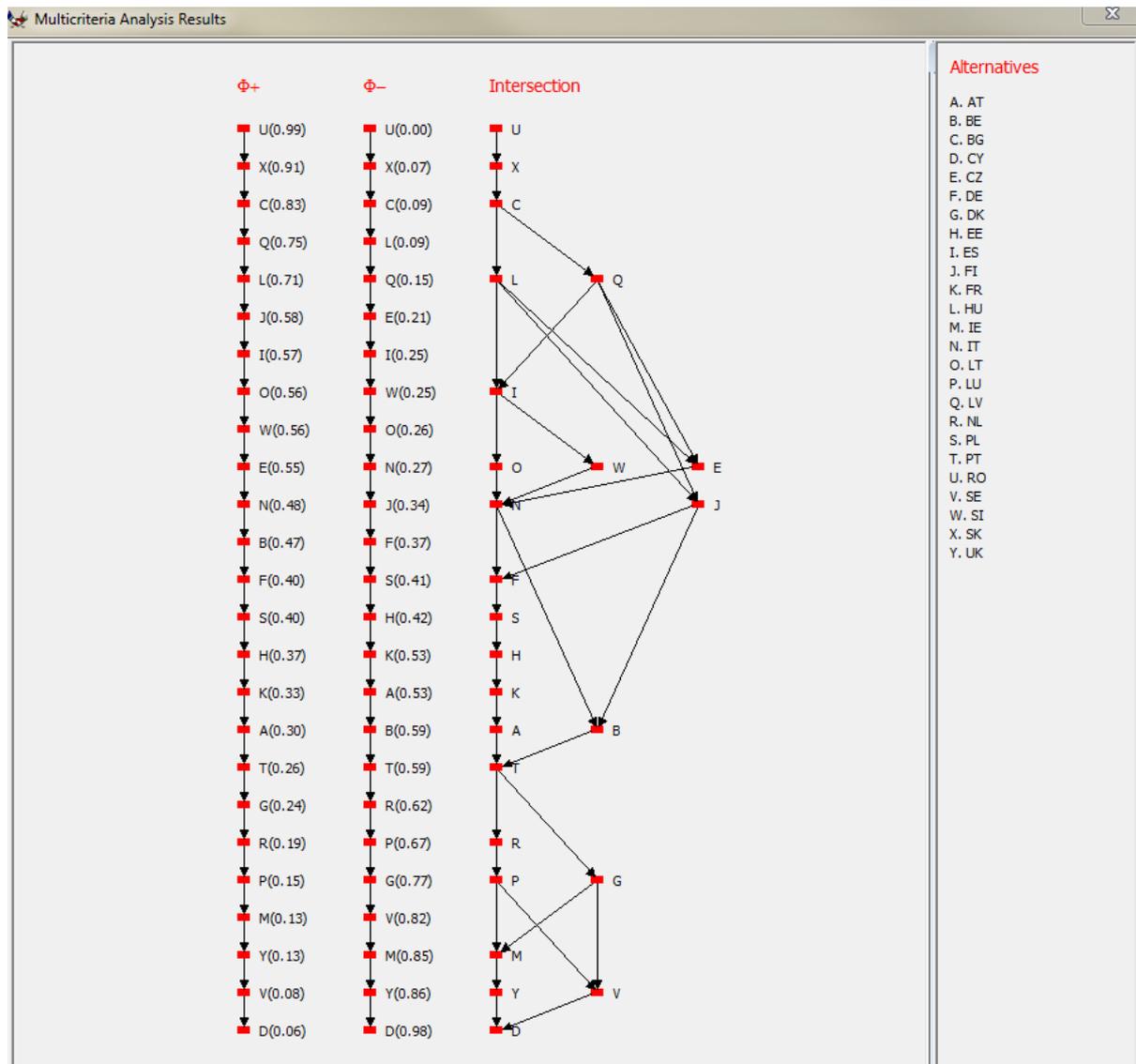


Figure A1. Multi-criteria ranking according to expenses
 (Countries in the top positions are the least spending ones)

b) Analysis considering the output side only

We repeat here the multi-criterion exercise for the output criteria. For the same reasons mentioned above, we could not include MT, EL and HR. The data used are shown in Table A5. Here too, the objective is to evaluate if we can determine with a reasonable degree of certainty, which countries perform better than others on the output side. The ranking obtained is presented in Figure A2. Leaving aside uncertainty in some pair-wise comparisons, the overall clustering in top, medium and low performer countries appears very clear and stable. It is:

High Output = (FI, NL, EE, PL, IE, DE, BE, DK, SI)

Medium Output = (LU, AT, CZ, UK, FR, SE)

Low Output = (LT, LV, CY, ES, PT, HU, SK, IT, BG, RO)

One can easily see that all low spending countries also present low outcomes. However, there are also cases of high spending countries with low outcomes; clearly an issue of efficiency spending appears here.

Criteria \ Alternatives	AT	BE	BG	CY	CZ	DE	DK	EE	ES	FI	FR	HU	IE	IT	LT
PISA READING	490.000000	509.000000	436.000000	449.000000	493.000000	508.000000	500.000000	516.000000	488.000000	524.000000	505.000000	488.000000	523.000000	490.000000	477.000000
PISA MATH	506.000000	515.000000	439.000000	440.000000	499.000000	514.000000	496.000000	521.000000	484.000000	519.000000	495.000000	477.000000	501.000000	485.000000	479.000000
PISA SCIEN	506.000000	505.000000	446.000000	438.000000	508.000000	524.000000	498.000000	541.000000	496.000000	545.000000	499.000000	494.000000	522.000000	494.000000	496.000000
EARSCHELEV	91.800000	87.933300	87.700000	88.200000	94.900000	88.700000	90.100000	89.366700	73.600000	90.333300	87.733300	88.666700	89.333300	82.100000	92.733300
NEET	90.400000	85.566700	75.000000	84.900000	84.500000	88.433300	91.633300	82.500000	77.933300	88.633300	84.300000	79.433300	77.700000	76.066700	83.400000
EDUATTAIN	83.533300	69.233300	79.833300	66.400000	84.233300	76.033300	72.033300	68.866700	70.733300	67.700000	73.100000	81.966700	66.400000	86.666700	72.233300

LU	LV	NL	PL	PT	RO	SE	SI	SK	UK
488.000000	489.000000	511.000000	518.000000	488.000000	438.000000	483.000000	481.000000	463.000000	499.000000
490.000000	490.000000	523.000000	518.000000	487.000000	445.000000	478.000000	501.000000	482.000000	494.000000
491.000000	502.000000	522.000000	526.000000	489.000000	439.000000	485.000000	514.000000	471.000000	514.000000
92.866700	88.300000	90.633300	94.433300	76.066700	81.600000	93.133300	95.466700	94.966700	85.633300
92.166700	80.066700	92.866700	83.600000	85.000000	80.233300	91.833300	89.666700	79.000000	84.500000
68.233300	76.133300	71.900000	79.600000	84.633300	87.266700	70.833300	78.433300	83.900000	66.800000

Table A5. Data used for output evaluation

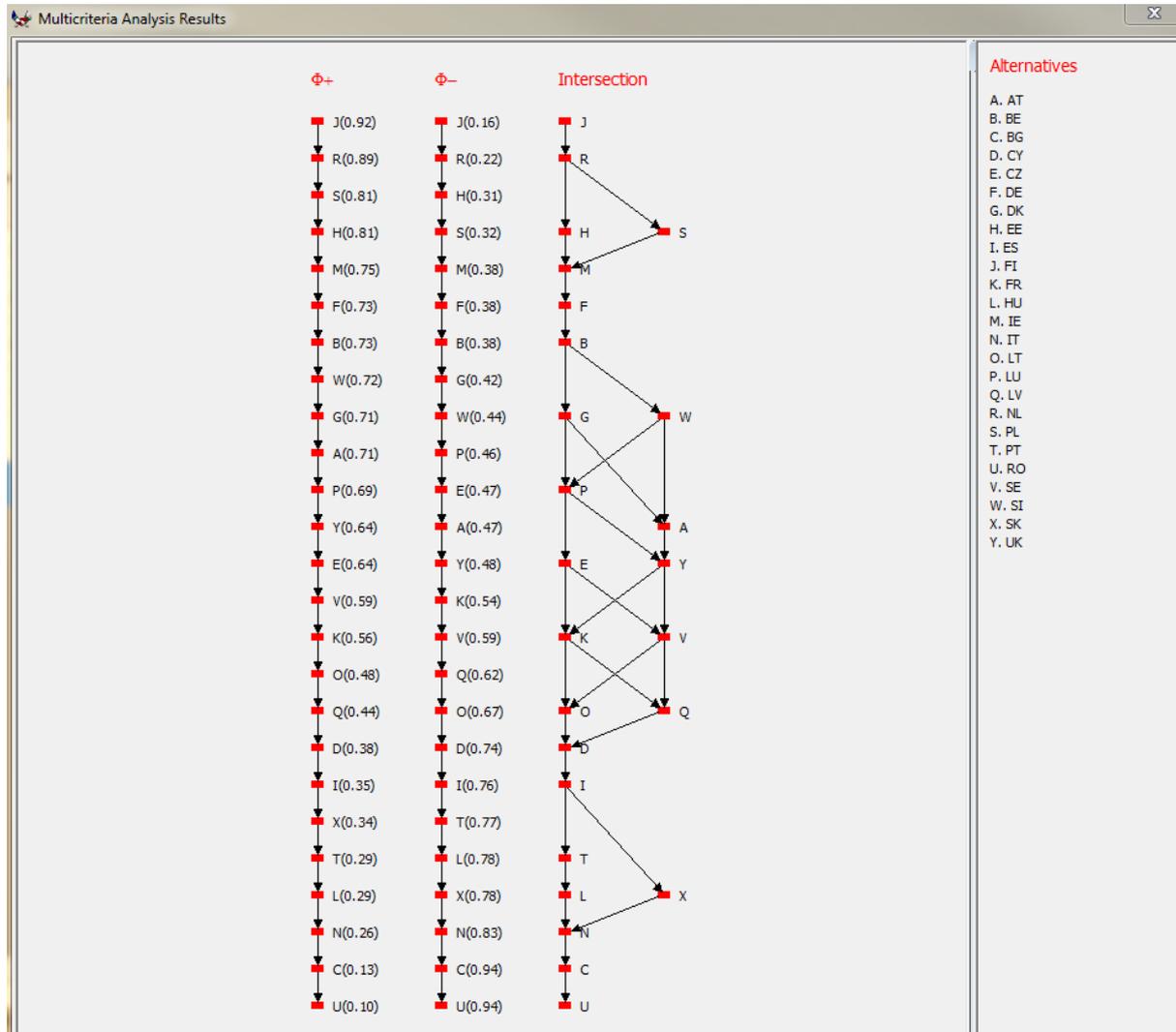


Figure A2. Multi-criteria ranking according to output
 (Countries in the top positions are the ones presenting better overall output scores)

c) Integrated analysis considering both the expense and output sides

Finally, we include all data used from both input and output sides. For the same reasons mentioned above, we could not include MT, EL and HR. Table A6 presents the dataset. In multi-criteria terms, efficiency can be defined as a compromise solution between inputs and outputs. The ranking presented in Figure A3 can therefore be considered a multidimensional measure of country efficiency. This ranking has been derived by limiting the compensability among criteria as much as possible. As we have already discussed in the methodological report, a low degree of compensability can here be considered a desirable property. However, in the search of the assessment of result robustness, we also test how the final ranking varies if one allows higher degrees of compensability. Figures from A4 to A9 show how country rankings vary if higher and higher degrees of compensability are allowed in the mathematical aggregation procedure. With the exception of the extreme case where the maximum degree of compensability is used, the country ranking appears very stable.

Overall the following three groups of countries appear:

High Efficiency = (FI, SI, EE, PL, CZ, DE, NL)

Medium Efficiency = (BE, LV, SK, AT, LT, HU, DK, LU, RO, IE)

Low Efficiency = (ES, FR, BG, UK, SE, IT, PT, CY)

In the case of maximum compensability which, we reiterate is not a desirable property, the ranking is as follows:

High Efficiency = (FI, SI, SK, CZ, LV, HU, RO)

Medium Efficiency = (BG, DE, BE, LT, ES, IT, EE, PL)

Low Efficiency = (NL, AT, LU, DK, IE, SE, PT, UK, CY, FR)

Criteria \ Alternatives	AT	BE	BG	CY	CZ	DE	DK	EE	ES	FI	FR	HU	IE	IT	LT
PISA READING	490.000000	509.000000	436.000000	449.000000	493.000000	508.000000	500.000000	516.000000	488.000000	524.000000	505.000000	488.000000	523.000000	490.000000	477.000000
PISA MATH	506.000000	515.000000	439.000000	440.000000	499.000000	514.000000	496.000000	521.000000	484.000000	519.000000	495.000000	477.000000	501.000000	485.000000	479.000000
PISA SCIEN	506.000000	505.000000	446.000000	438.000000	508.000000	524.000000	498.000000	541.000000	496.000000	545.000000	499.000000	494.000000	522.000000	494.000000	496.000000
EARSCHLEAV	91.800000	87.933300	87.700000	88.200000	94.900000	88.700000	90.100000	89.366700	73.600000	90.333300	87.733300	88.666700	89.333300	82.100000	92.733300
NEET	90.400000	85.566700	75.000000	84.900000	84.500000	88.433300	91.633300	82.500000	77.933300	88.633300	84.300000	79.433300	77.700000	76.066700	83.400000
EXPGDP	3.230000	2.540000	2.130000	5.120000	2.730000	2.860000	3.440000	3.070000	2.820000	2.490000	3.690000	2.500000	4.330000	2.820000	2.650000
EXPSHARE	6.200000	4.600000	6.000000	11.200000	6.100000	6.400000	5.800000	7.700000	5.900000	4.400000	6.500000	5.100000	10.100000	5.600000	7.300000
EXPGDP-2	3.384520	4.250470	2.212590	4.921570	2.546480	2.814110	4.802950	3.202450	2.400580	3.140750	3.634680	2.601570	4.096150	2.822640	2.910970
EDUATTAIN	83.533300	69.233300	79.833300	66.400000	84.233300	76.033300	72.033300	68.866700	70.733300	67.700000	73.100000	81.966700	66.400000	86.666700	72.233300
EXP-STUD-2	12079.700000	12675.200000	3259.520000	12135.100000	6108.820000	9333.660000	12556.800000	6252.990000	7944.620000	11583.900000	8826.770000	4697.300000	10168.700000	8295.270000	4625.000000

LU	LV	NL	PL	PT	RO	SE	SI	SK	UK
488.000000	489.000000	511.000000	518.000000	488.000000	438.000000	483.000000	481.000000	463.000000	499.000000
490.000000	490.000000	523.000000	518.000000	487.000000	445.000000	478.000000	501.000000	482.000000	494.000000
491.000000	502.000000	522.000000	526.000000	489.000000	439.000000	485.000000	514.000000	471.000000	514.000000
92.866700	88.300000	90.633300	94.433300	76.066700	81.600000	93.133300	95.466700	94.966700	85.633300
92.166700	80.066700	92.866700	83.600000	85.000000	80.233300	91.833300	89.666700	79.000000	84.500000
3.240000	1.980000	3.790000	3.170000	3.690000	1.550000	4.040000	2.460000	1.670000	4.300000
7.500000	5.400000	7.500000	7.500000	7.700000	4.200000	7.800000	5.100000	4.400000	8.900000
3.307900	3.109140	3.554920	3.208180	3.745670	1.613910	3.909590	2.936280	2.595440	4.413240
68.233300	76.133300	71.900000	79.600000	84.633300	87.266700	70.833300	78.433300	83.900000	66.800000
20563.900000	5109.390000	10007.900000	5687.390000	7960.160000	2279.000000	12751.500000	9039.910000	4874.910000	10461.100000

Table A6. Data used for efficiency evaluation

The effects of complete compensability are very evident. While countries such as FI, SI and CZ are still top performers and some others continue to be at the bottom, there are countries that present a completely different performance in comparison with lower compensatory degrees. For example, NL is now evaluated as a bottom performer while ES and IT become medium efficiency countries. The reason why this happens is that, in a complete compensatory framework, spending inputs (if medium-high) can completely overcompensate good outcomes (this is the case for e.g. NL, AT, LU) or (if medium-low) bad outcomes (e.g. IT or ES).

Although multi-criteria analysis is based on completely different methodological assumptions than DEA and FDH, overall the results are corroborated by all the three approaches. Thus we can safely state that the efficiency assessment presented in this report is very stable. Only exceptions being BG, which DEA and FDH evaluate as a top performer while multi-criteria analysis considers it as a bottom performer, and FR and the UK which DEA and FDH evaluate much better than MCA (in one approach UK is a top country while in the other is consistently considered a bottom one). Probably here the explanation has to be found in the fact that both DEA and FDH allow for a higher degree of compensability than MCA.

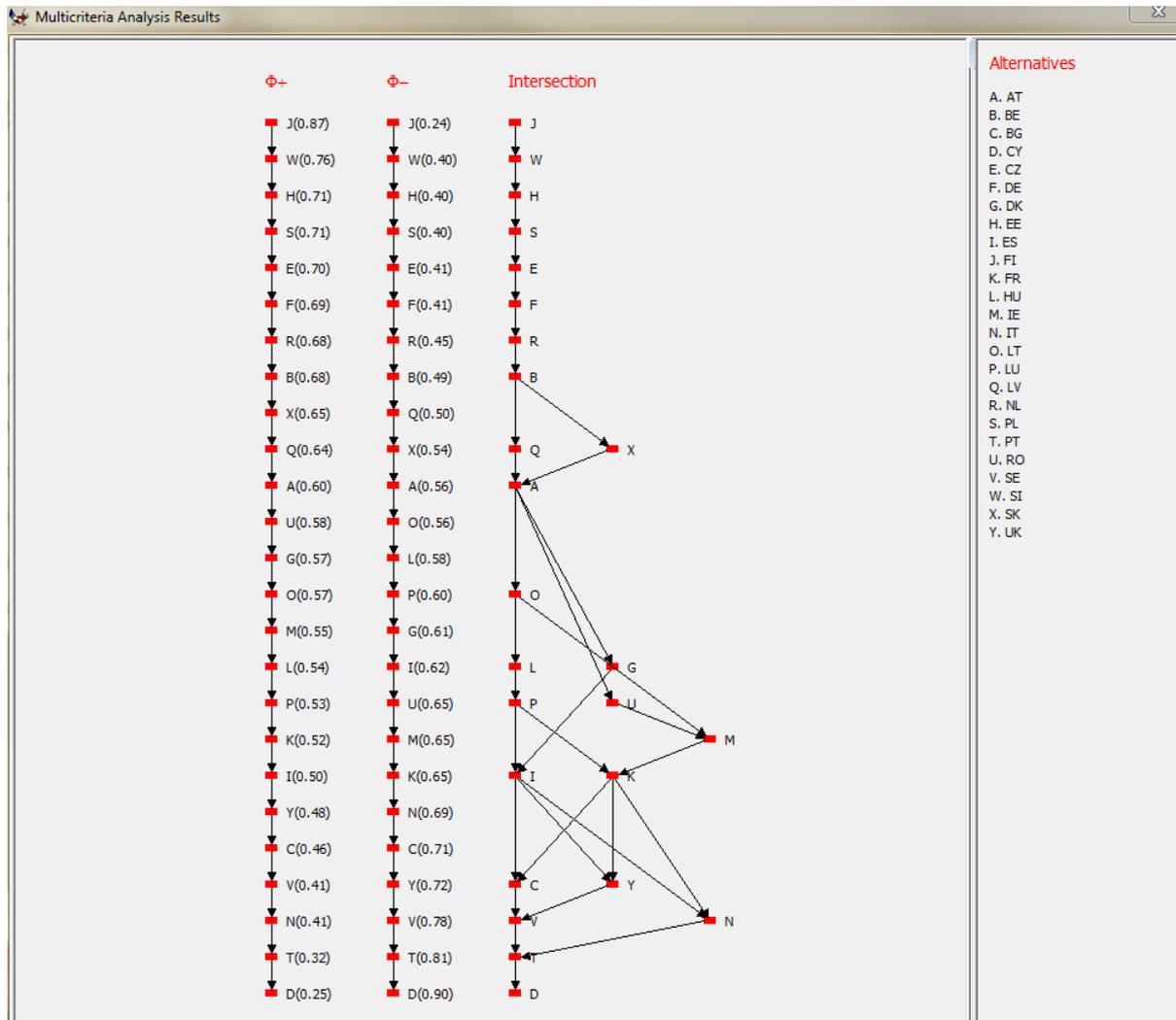


Figure A3. Multi-criteria ranking according to input and output items. Compensability = minimum (Countries in the top positions are the ones presenting better overall efficiency scores)

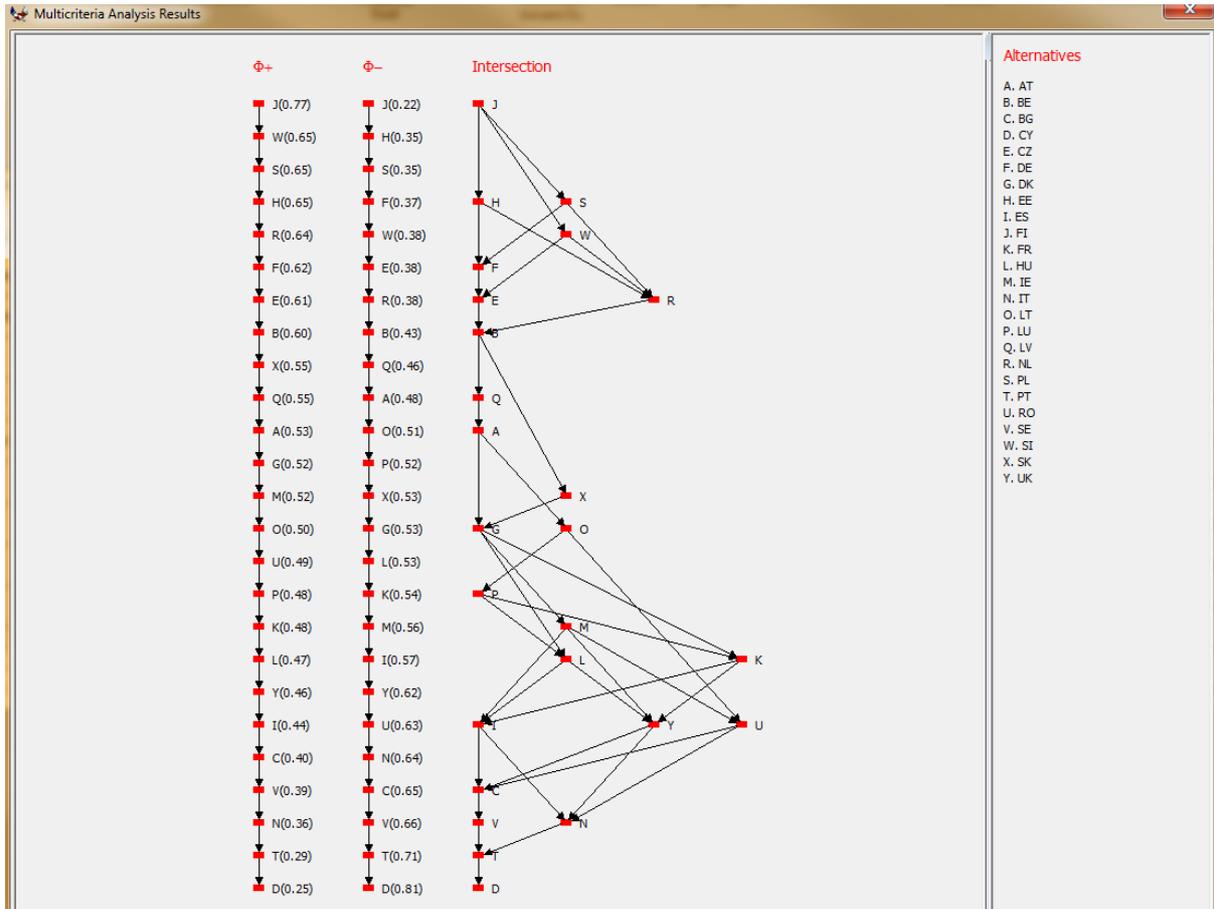


Figure A4. Multi-criteria ranking according to input and output items. Compensability = very low (Countries in the top positions are the ones presenting better overall efficiency scores)

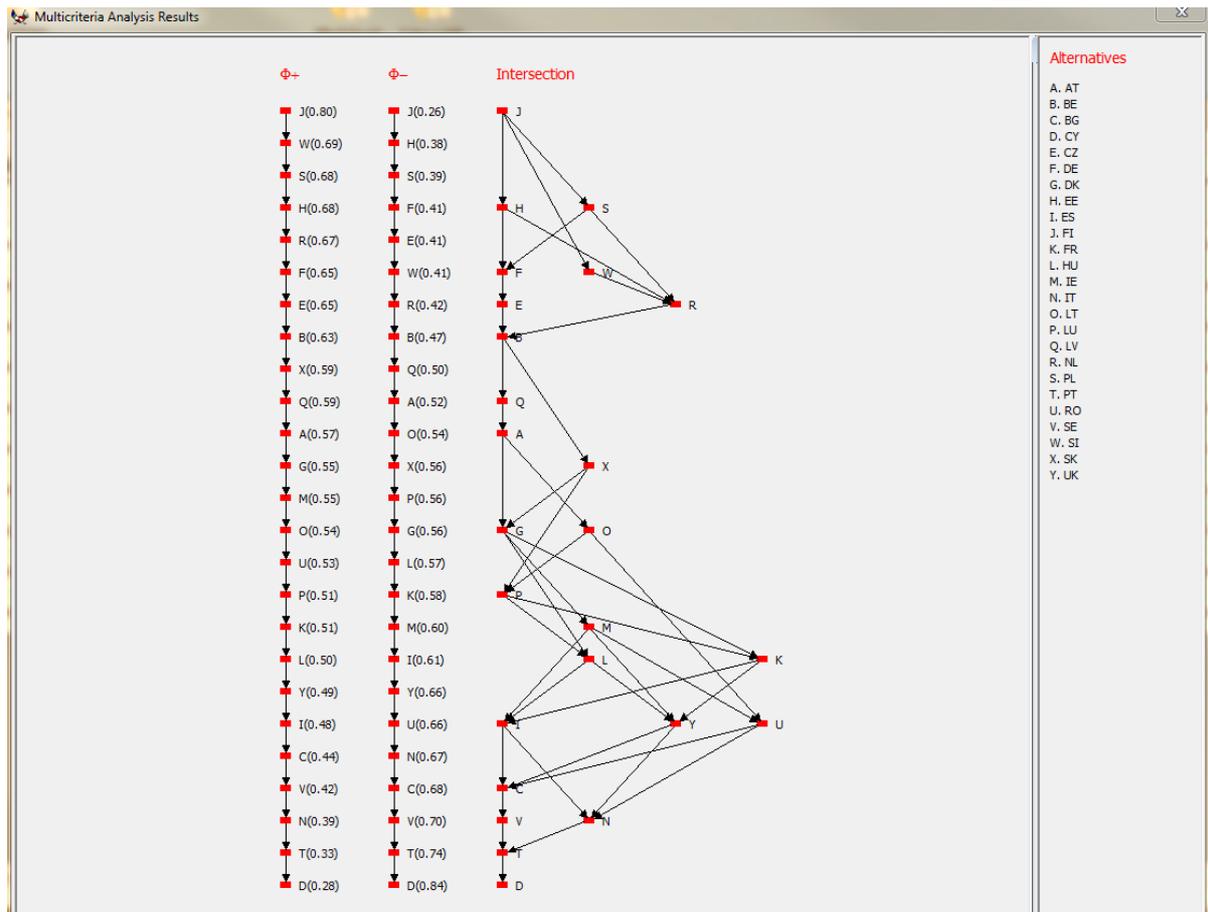


Figure A5. Multi-criteria ranking according to input and output items. Compensability = low (Countries in the top positions are the ones presenting better overall efficiency scores)

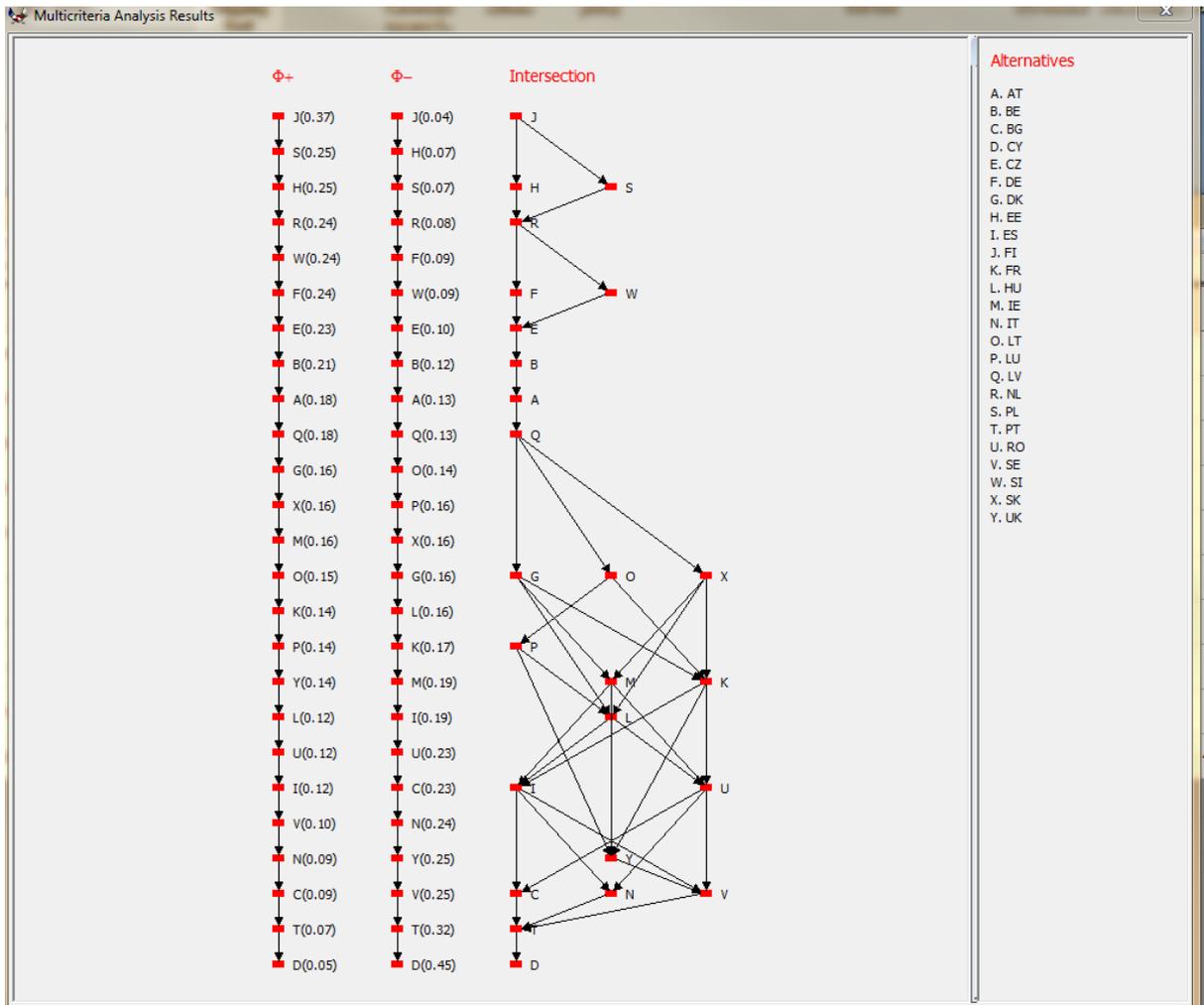


Figure A6. Multi-criteria ranking according to input and output items. Compensability = moderate (Countries in the top positions are the ones presenting better overall efficiency scores)

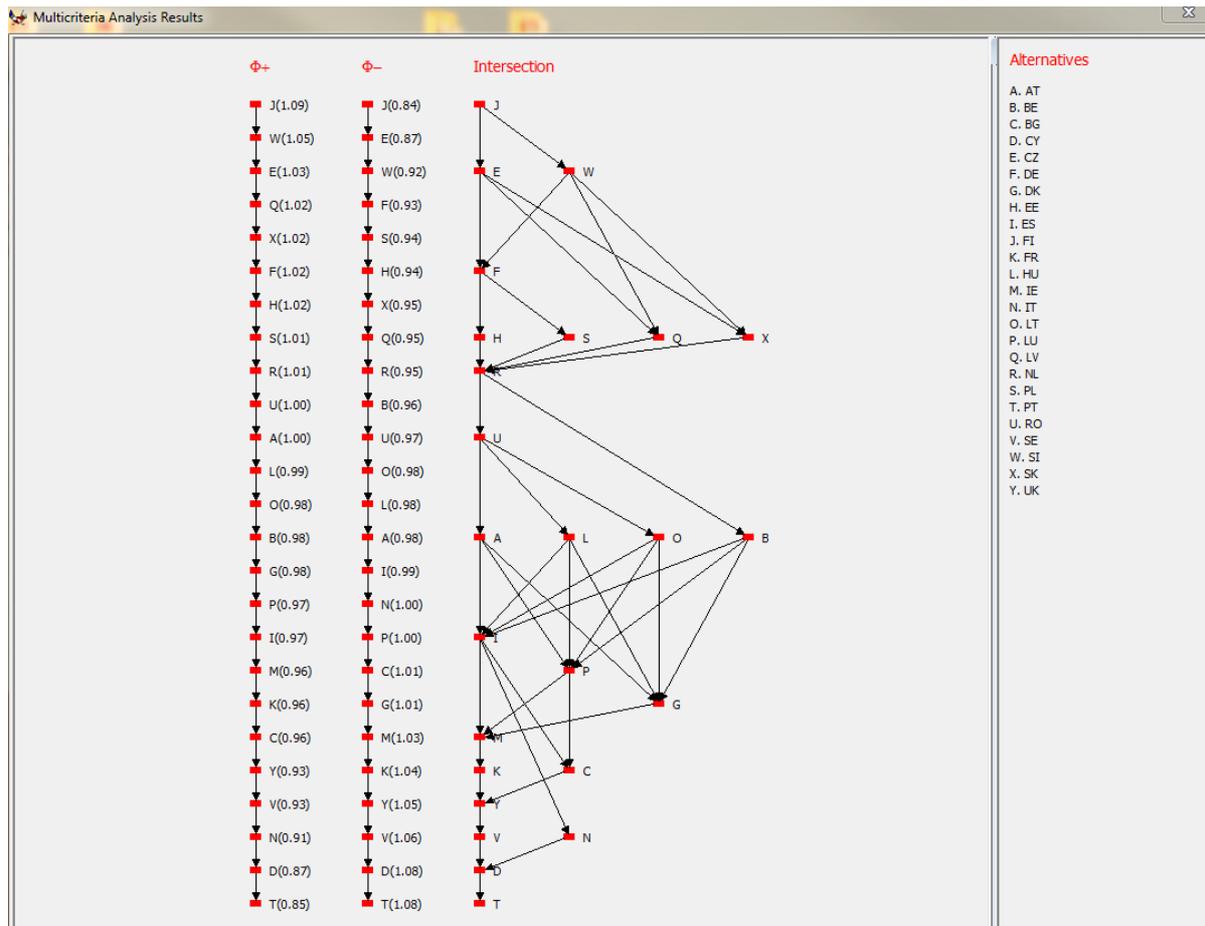


Figure A7. Multi-criteria ranking according to input and output items. Compensability = high (Countries in the top positions are the ones presenting better overall efficiency scores)

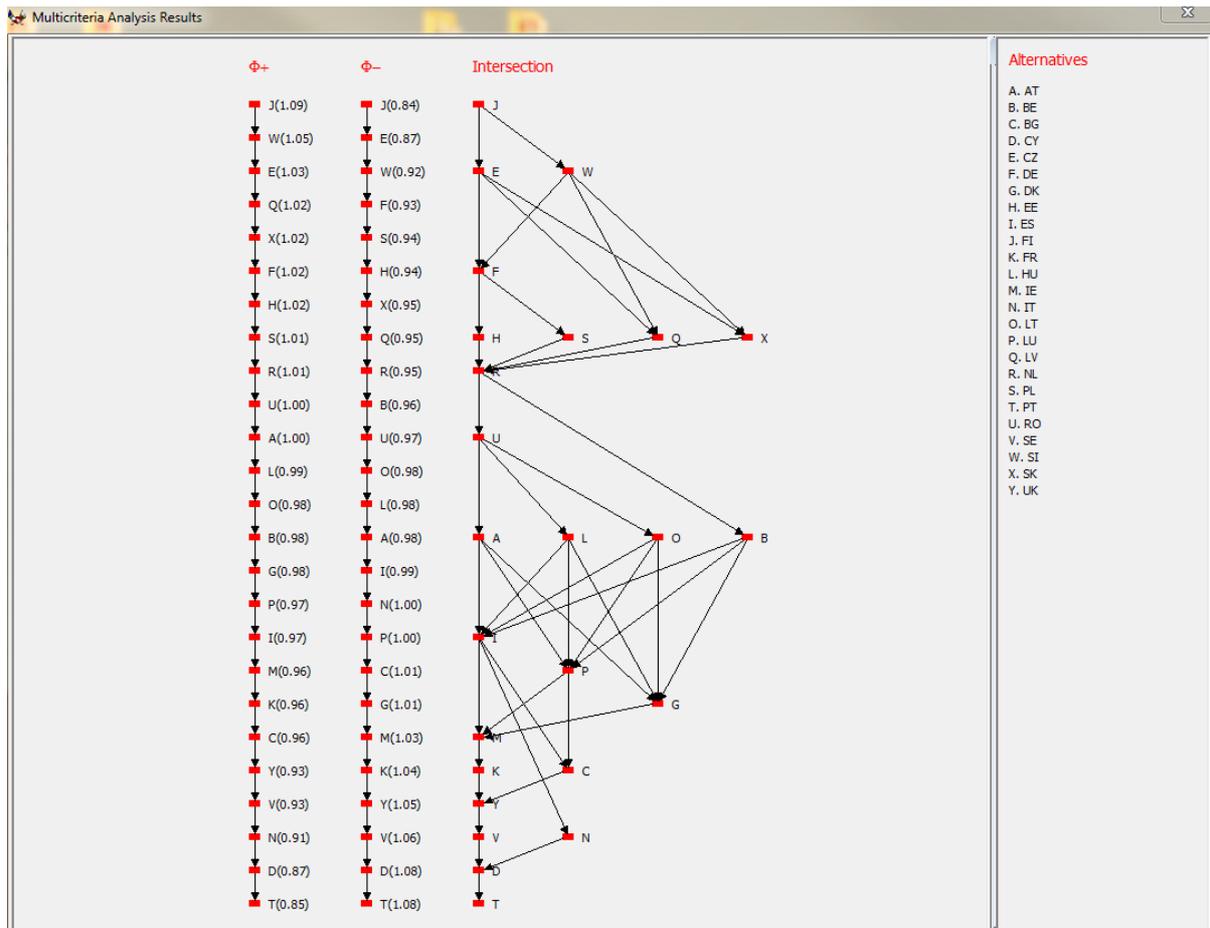


Figure A8. Multi-criteria ranking according to input and output items. Compensability = very high (Countries in the top positions are the ones presenting better overall efficiency scores)

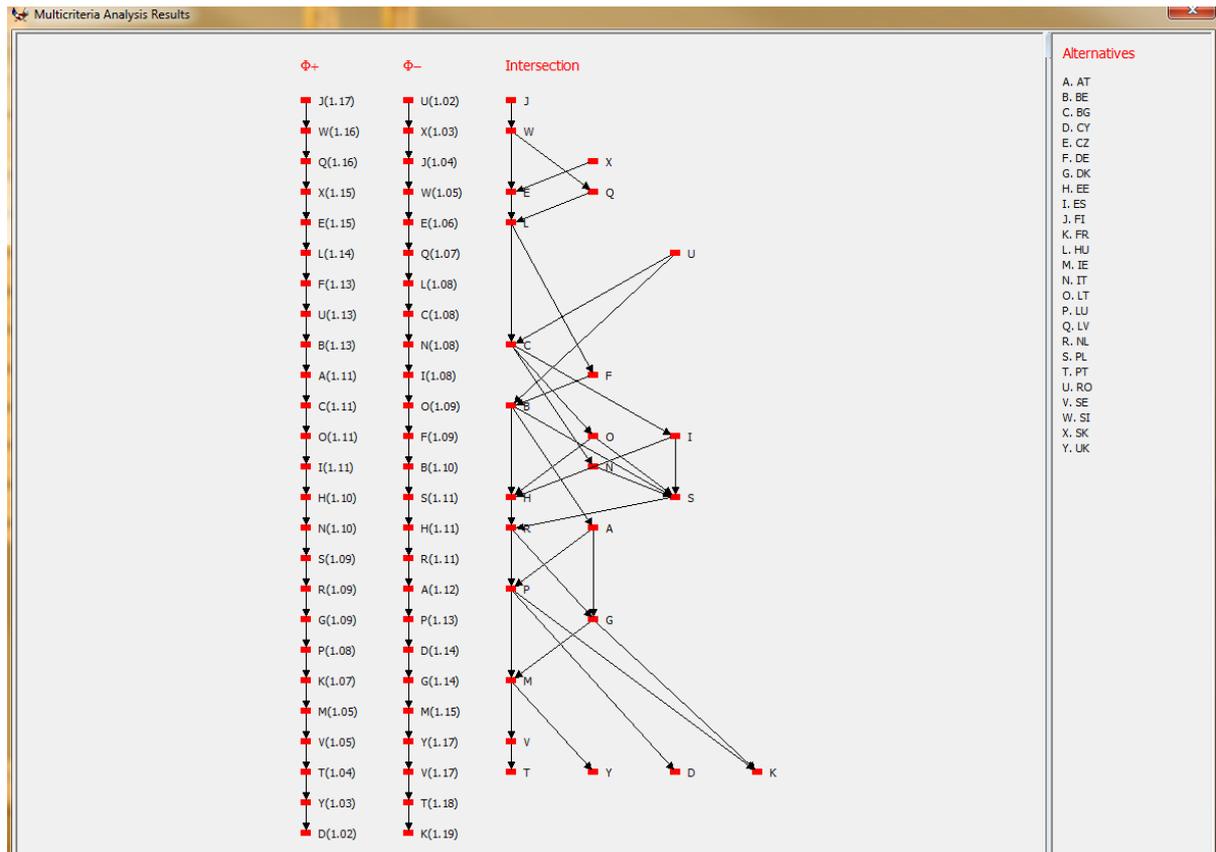
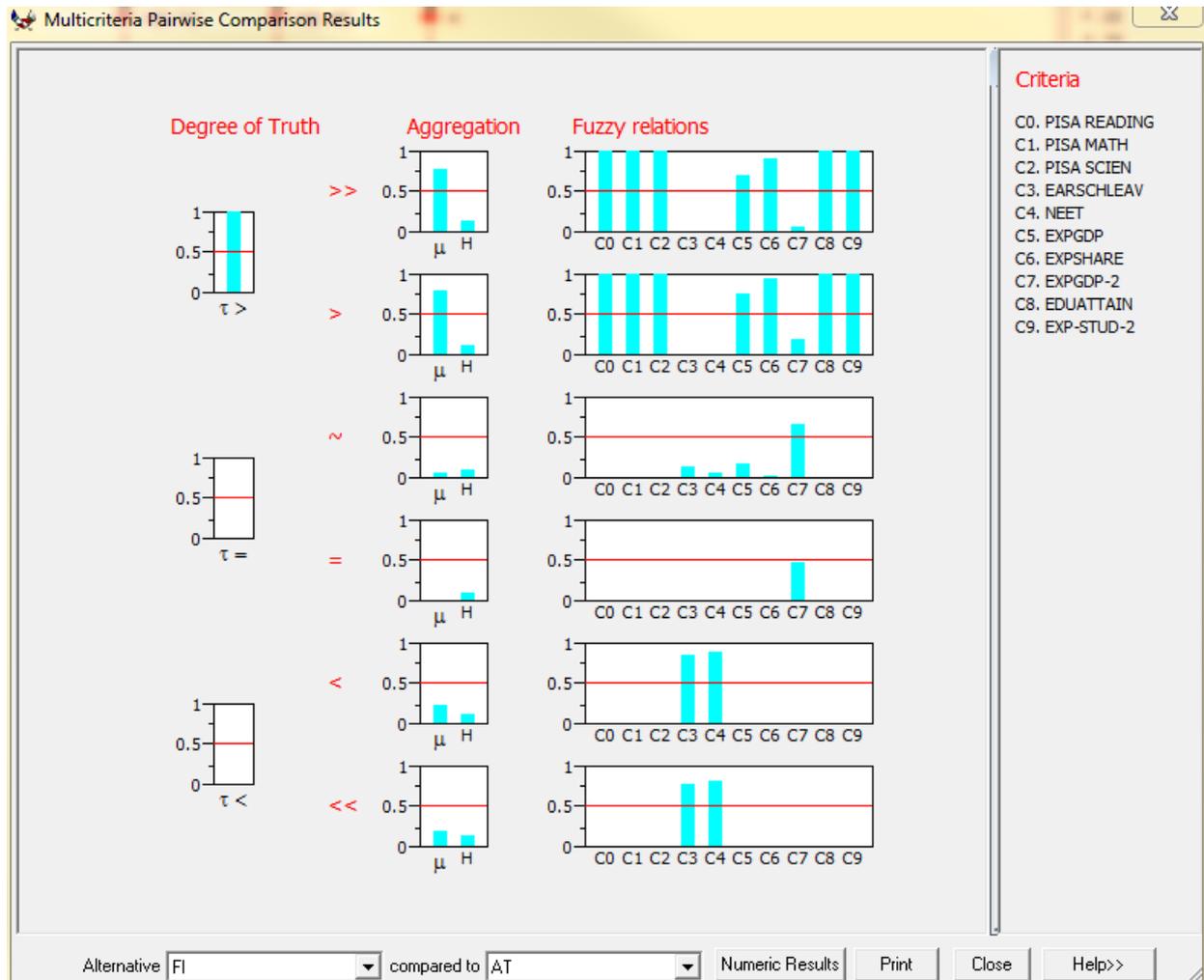


Figure A9. Multi-criteria ranking according to input and output items. Compensability = maximum (Countries in the top positions are the ones presenting better overall efficiency scores)

ANNEX 4: Pairwise comparisons

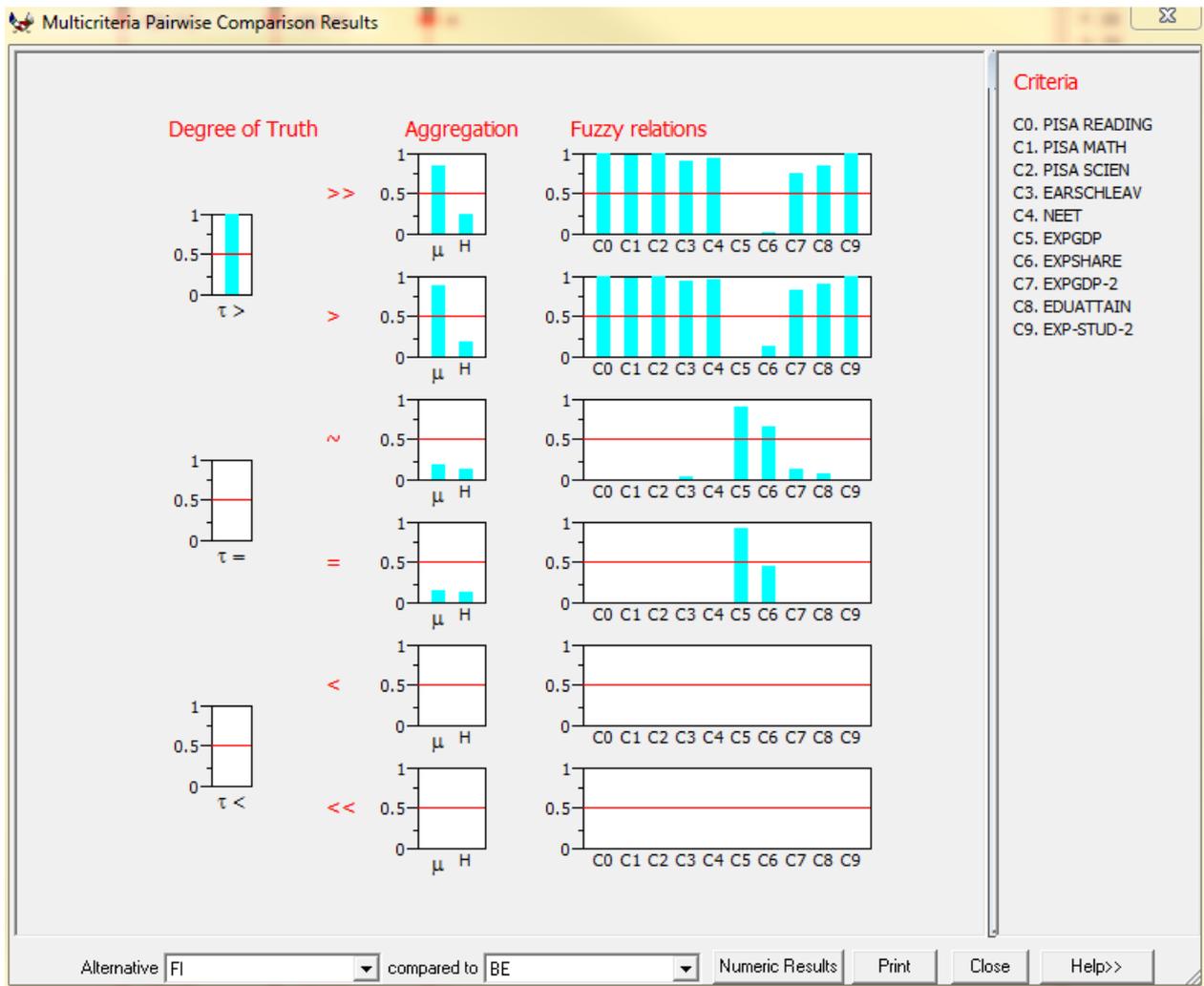
Here all countries are compared to the top performer, i.e. Finland. The objective is to help policy-makers in deriving some possible policy priorities. To guide the reading of this Annex, we comment the case shown below (comparison between FI and AT).

a) FI and AT

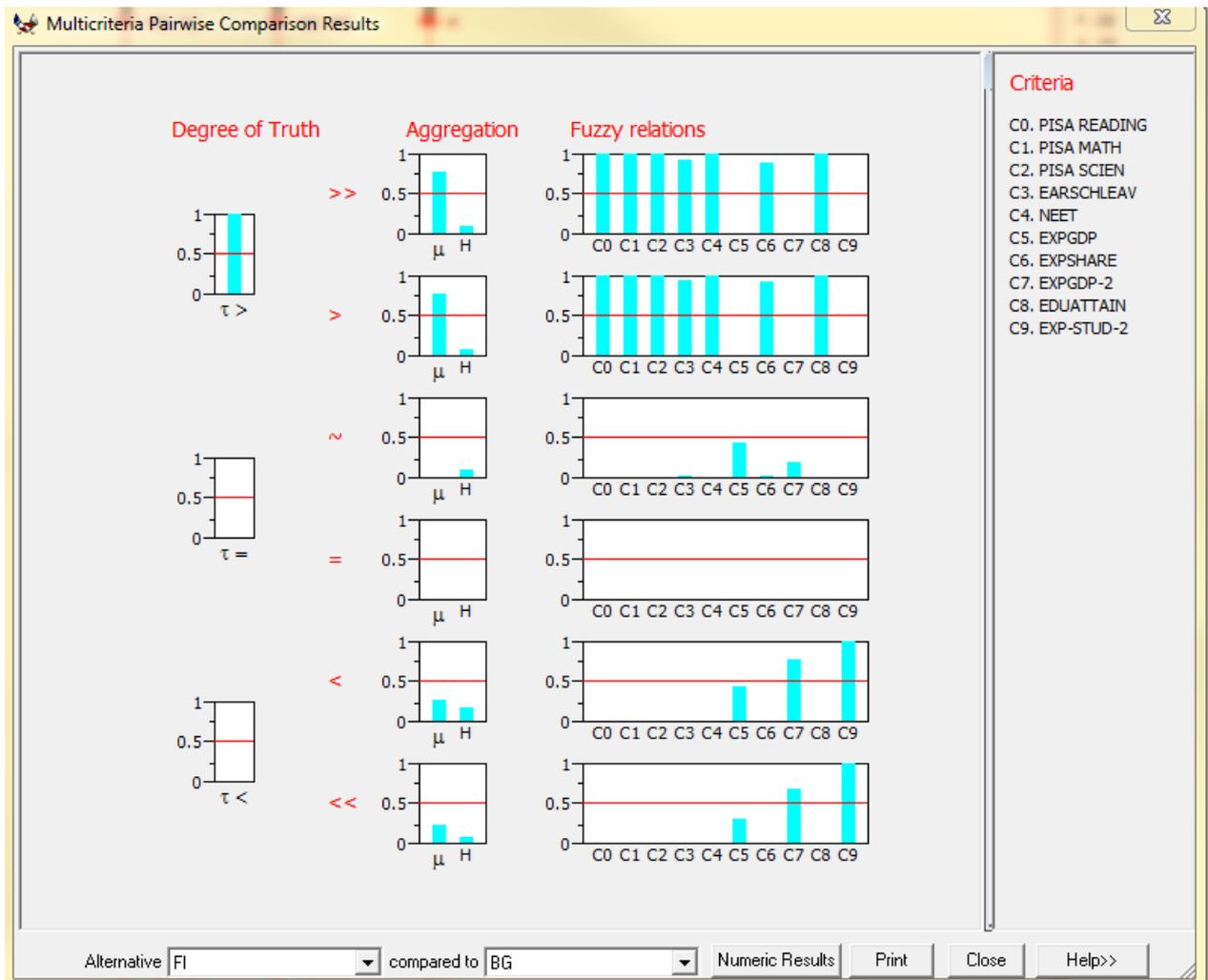


In general an assessment is considered “credible” if its “degree of truth” is higher than 0.5. In this case, the first two columns are corroborating the statement that overall Finland is a more efficient country than Austria. However, if one looks at the performance on each of the single criteria used, it is possible to see that on criteria 3 and 4 Austria is performing better than Finland, and on criterion 7 is almost equal, thus policy-makers should not consider e.g. early school leavers or NEET as policy priority since they are performing well in this respect. On the other hand, AT is performing definitely worse than FI on all the other criteria considered, which should then be considered as possible policy priorities.

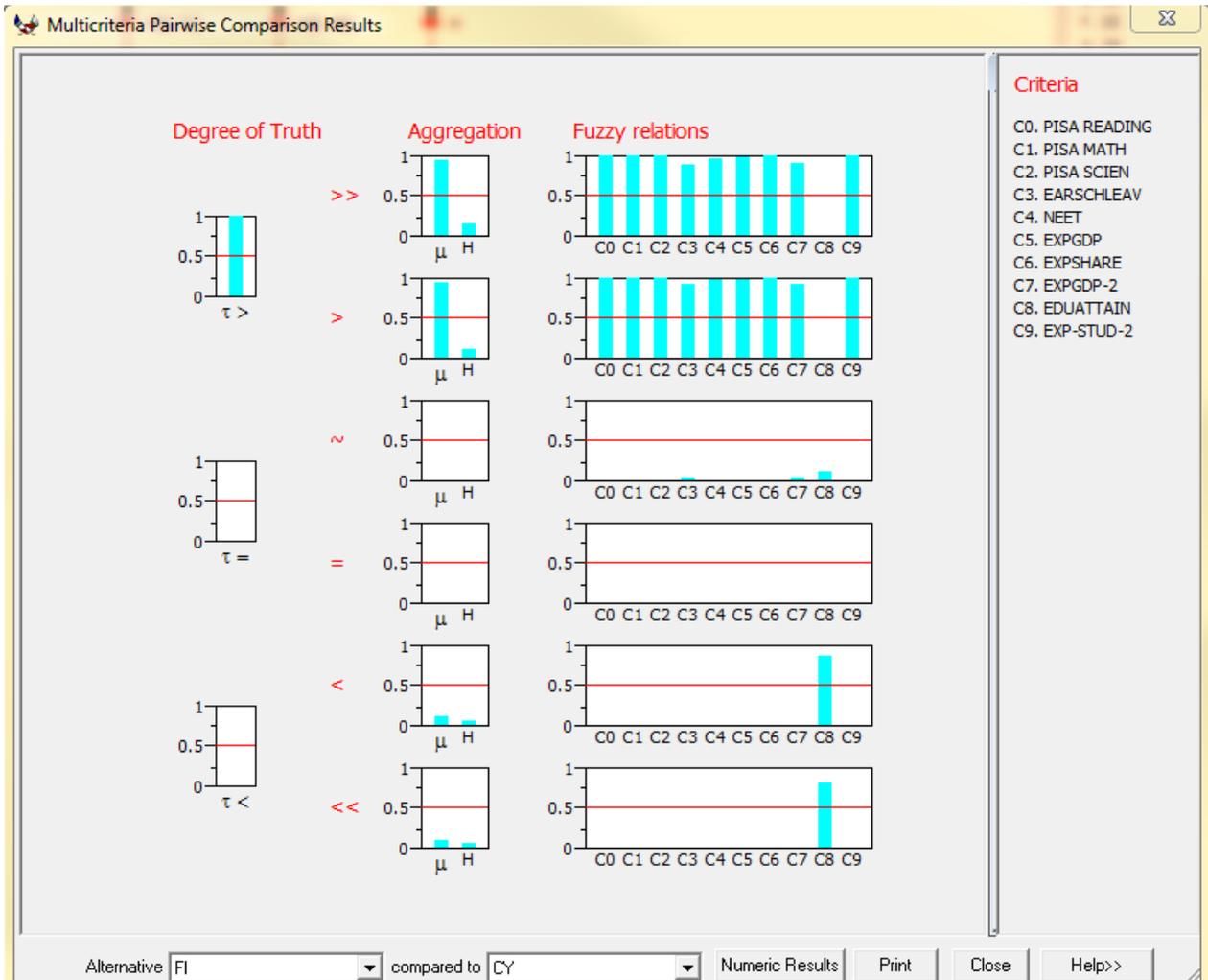
b) FI and BE


Alternative FI compared to BE
Numeric Results
Print
Close
Help>>

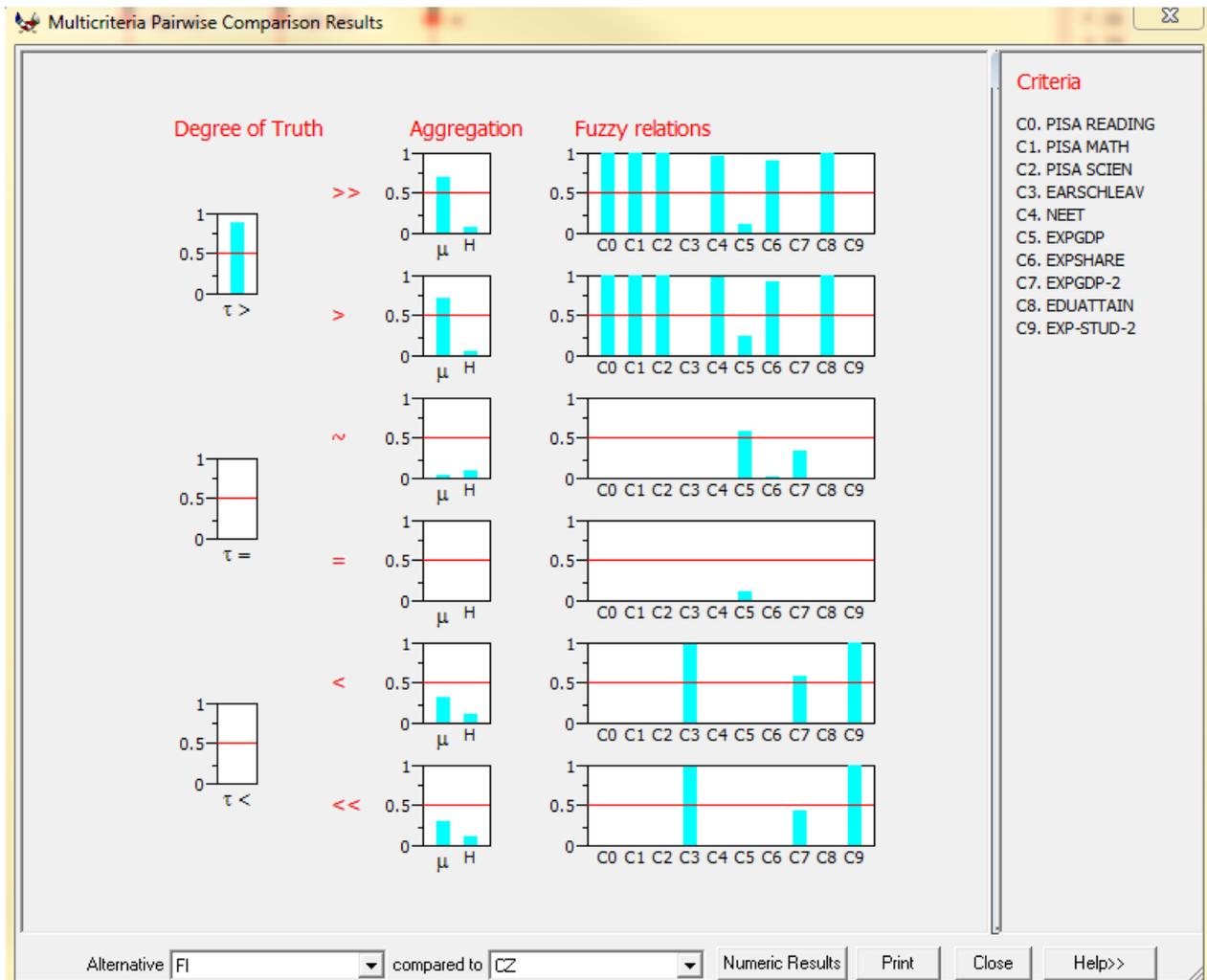
c) FI and BG



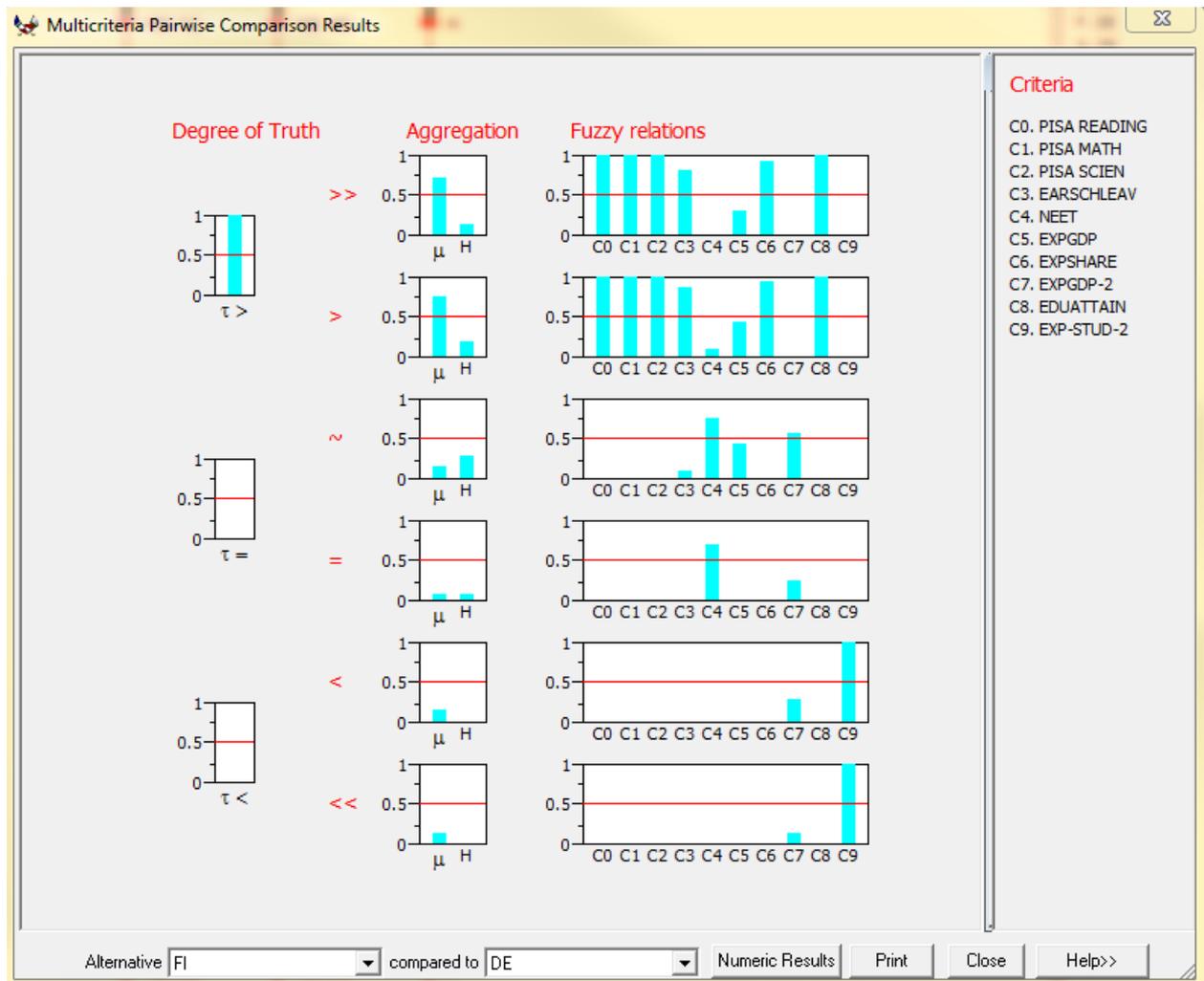
d) FI and CY



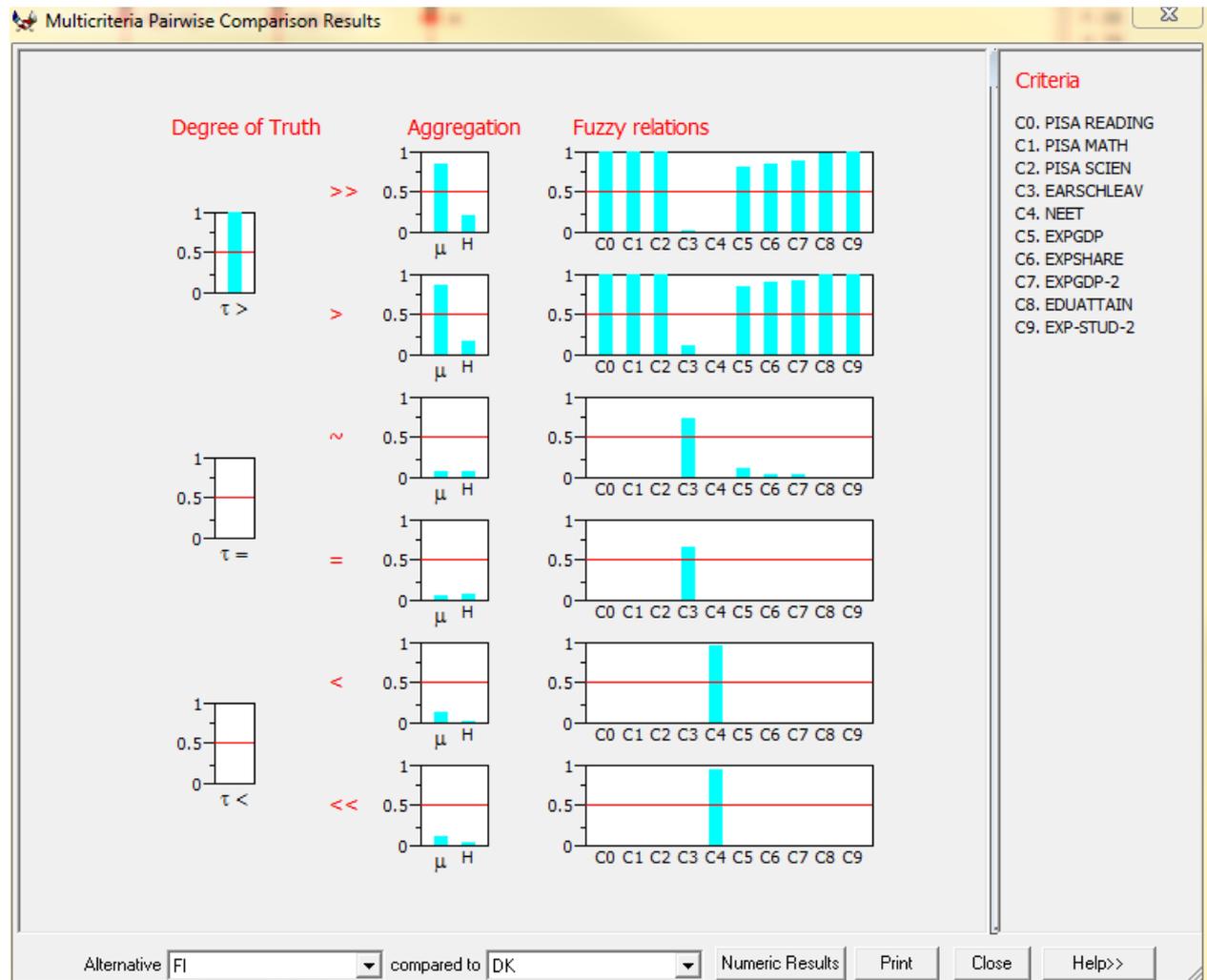
e) FI and CZ



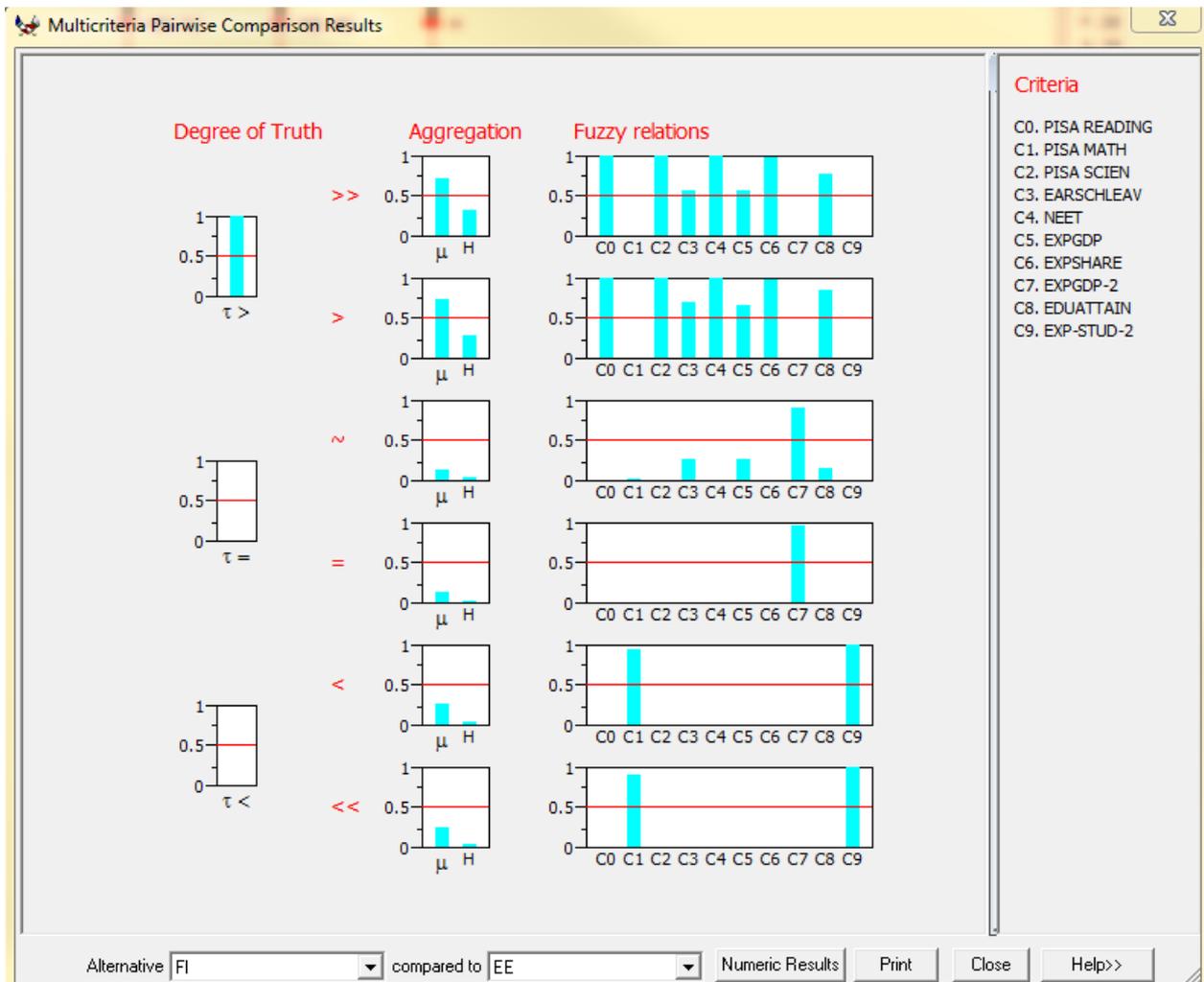
f) FI and DE



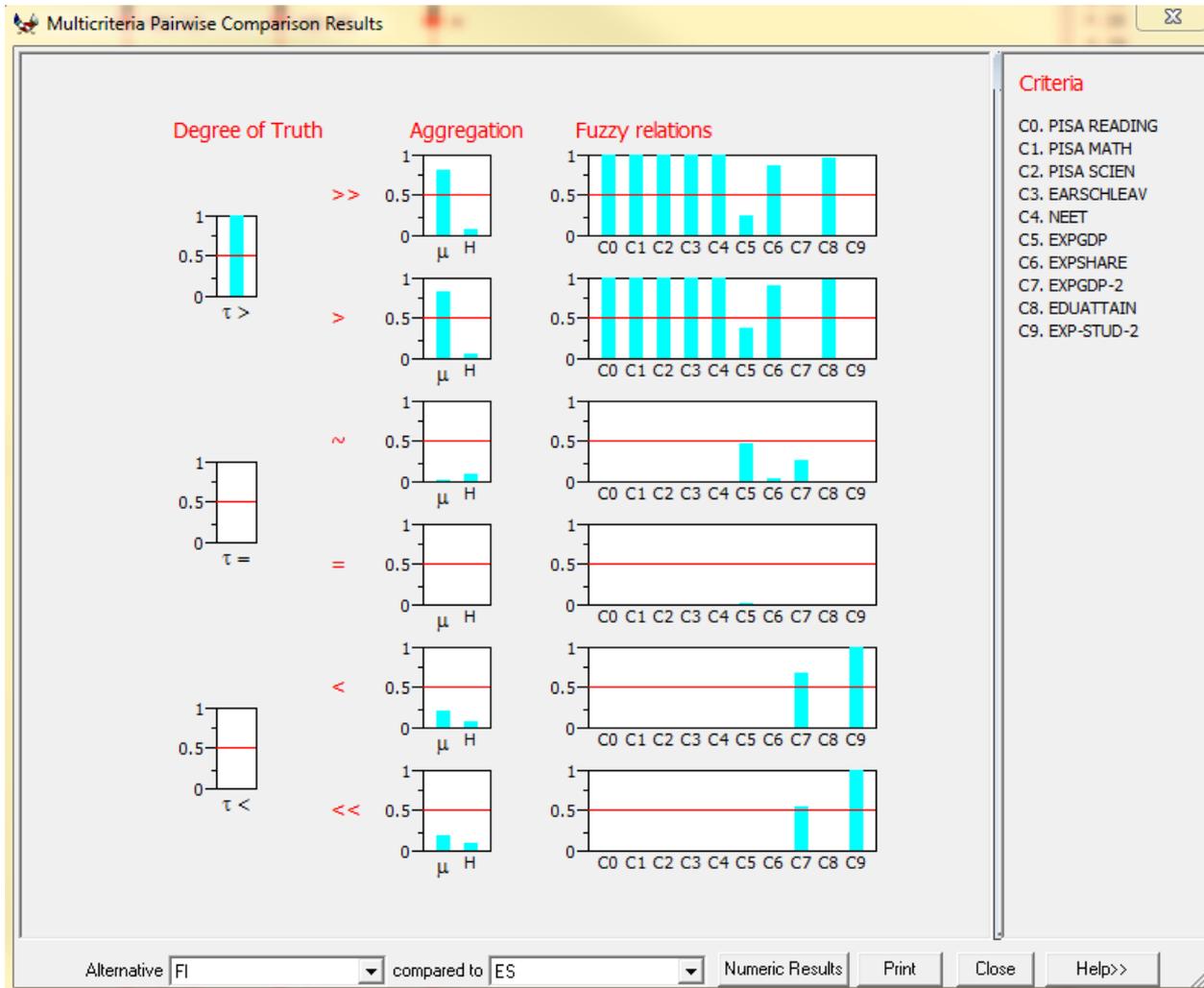
g) FI and DK



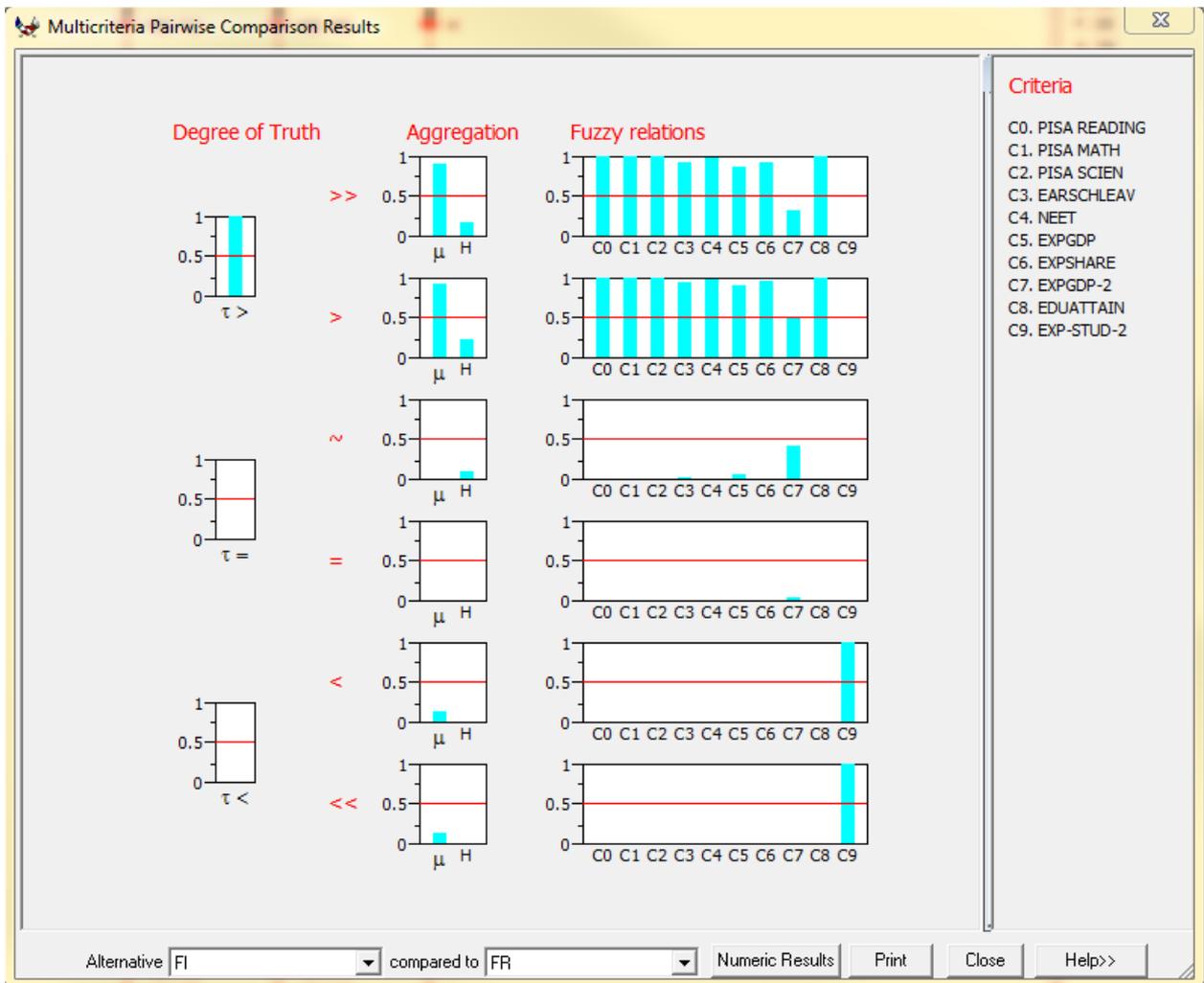
h) FI and EE



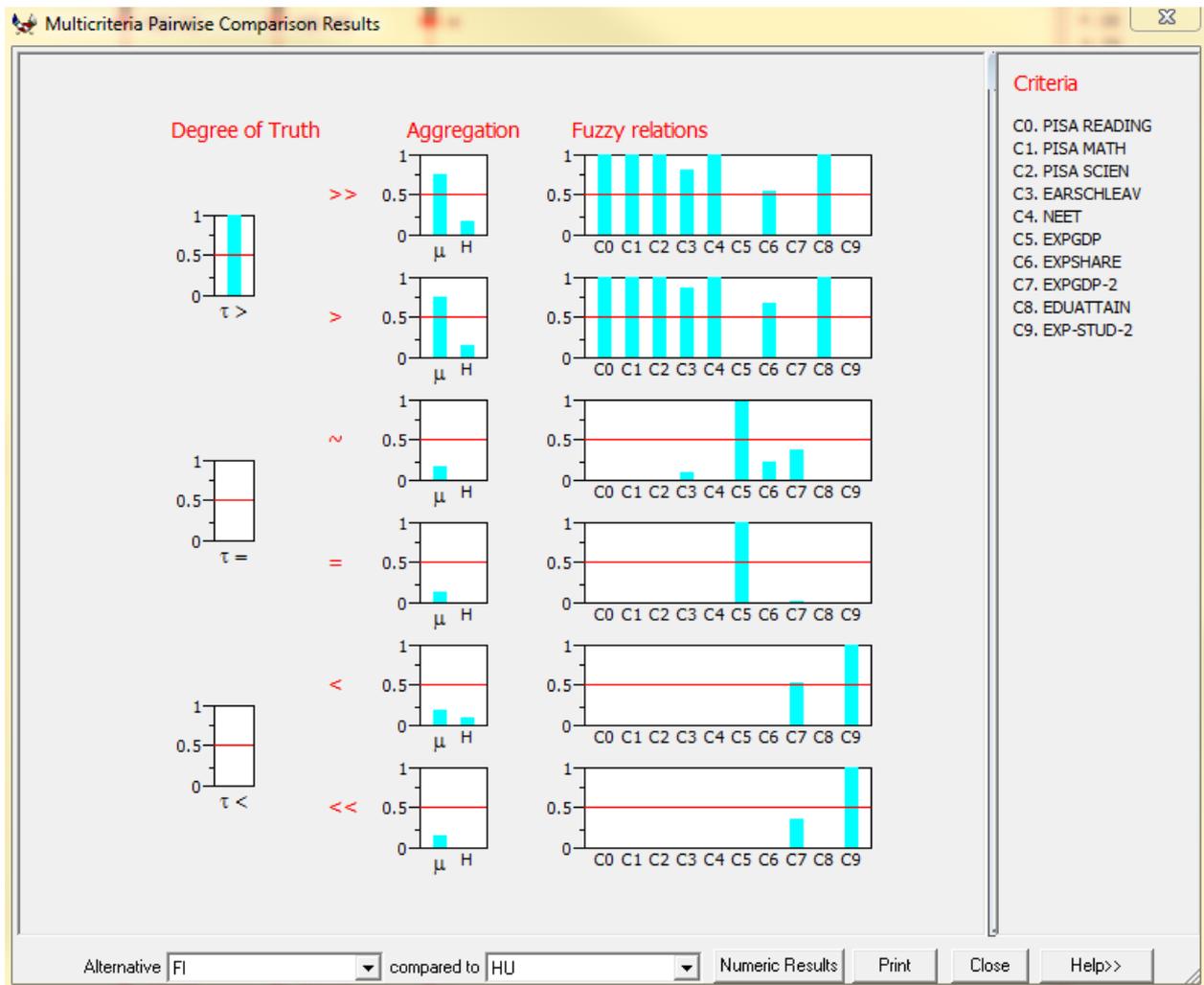
i) FI and ES



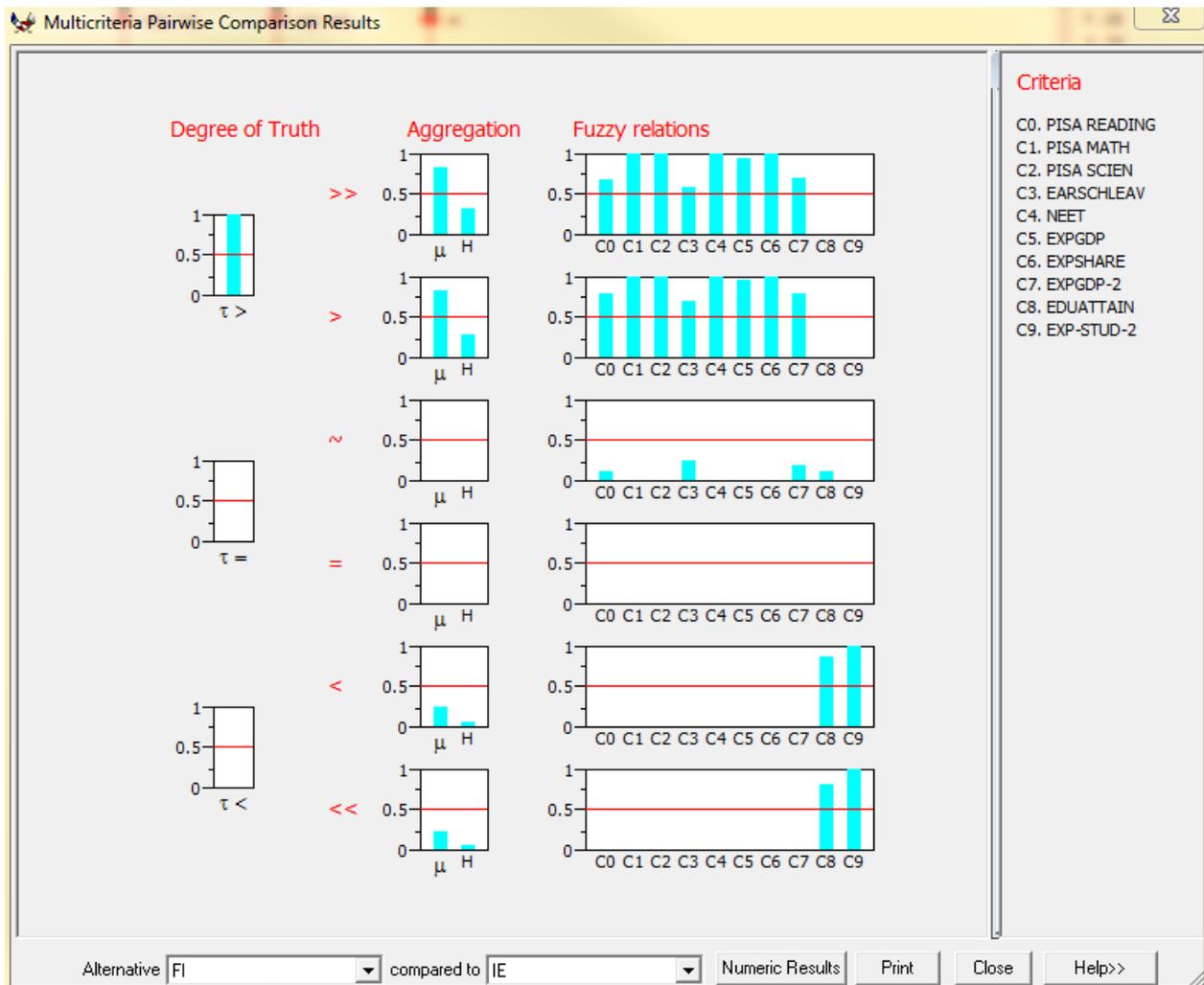
j) FI and FR



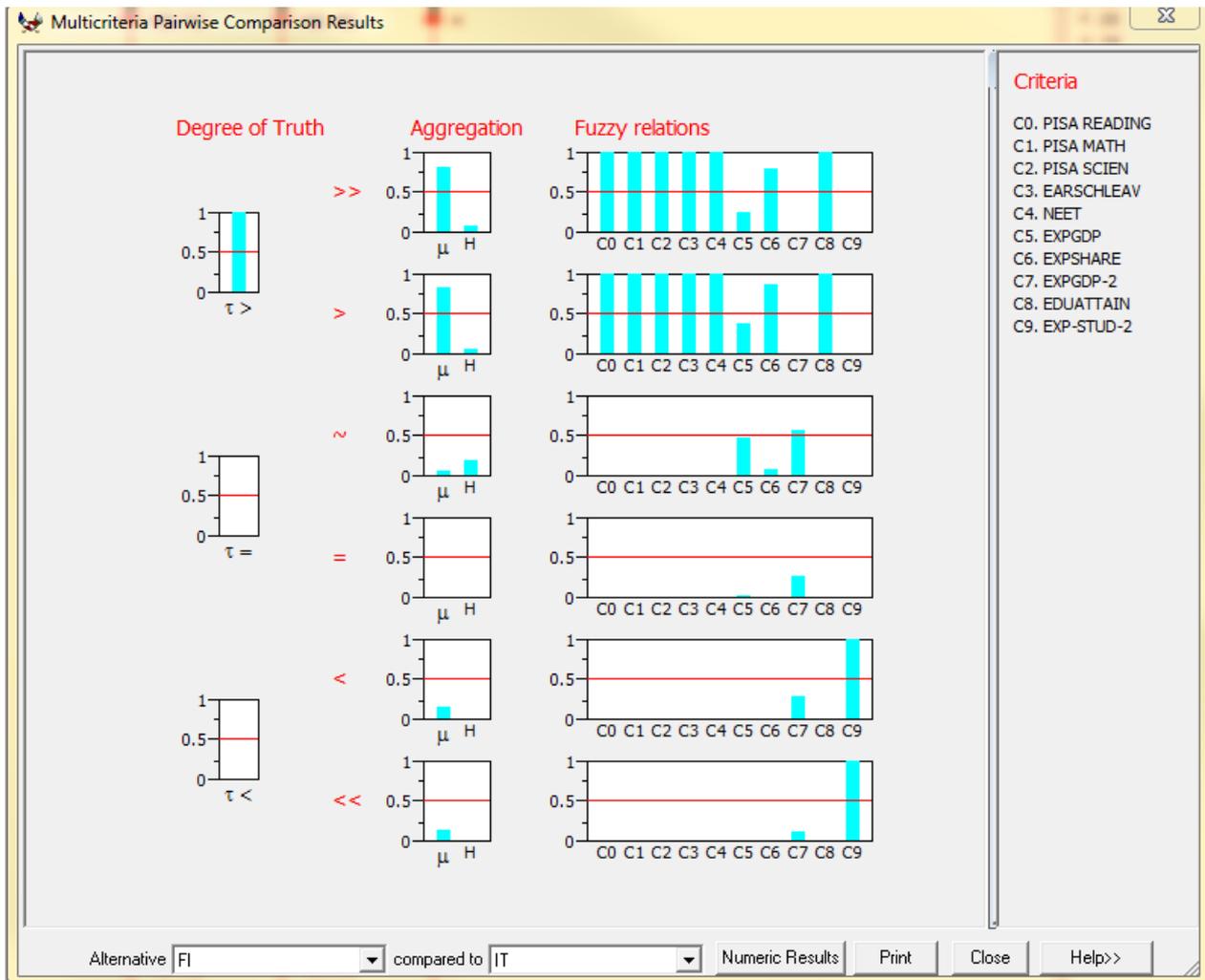
k) FI and HU



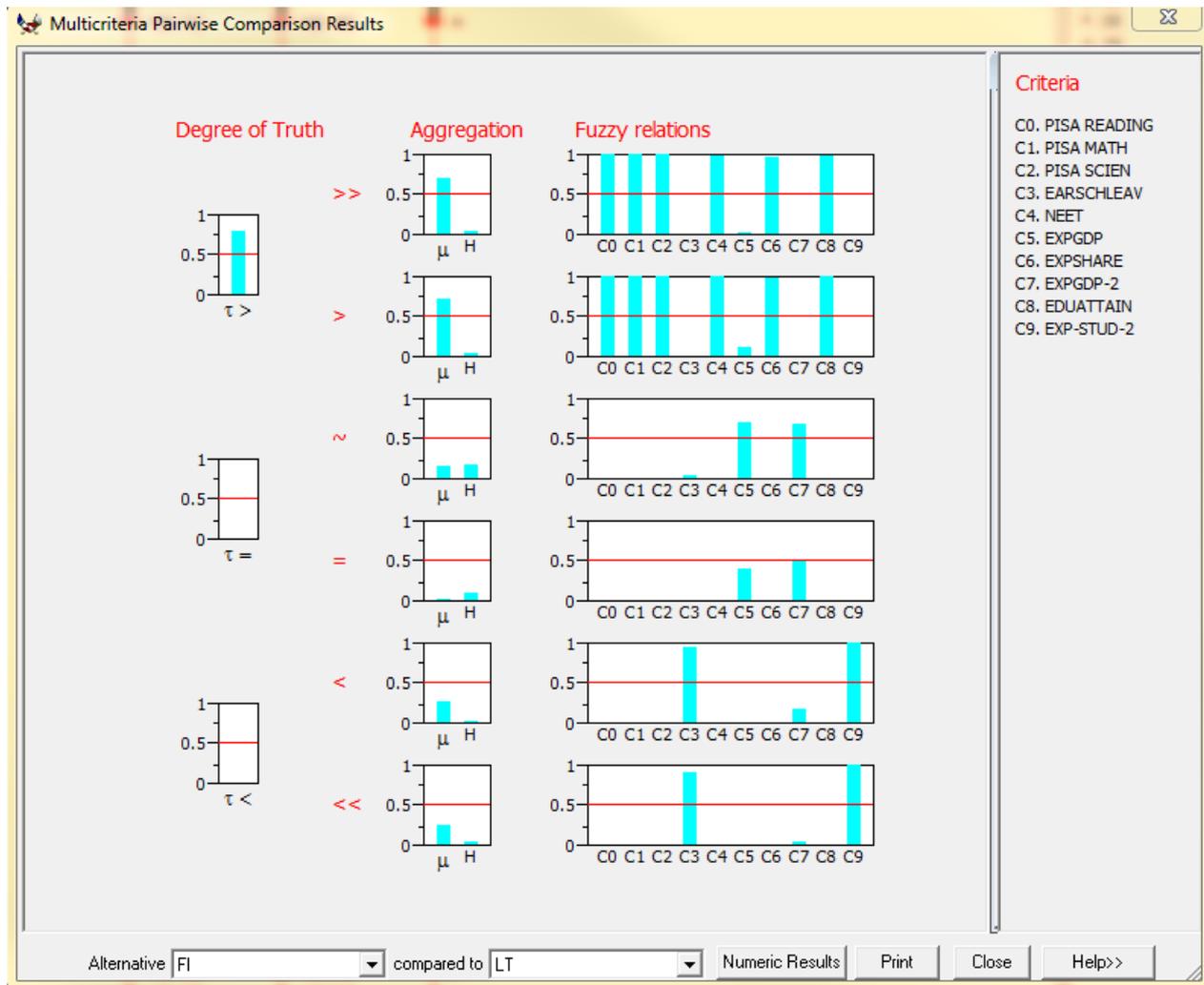
I) FI and IE



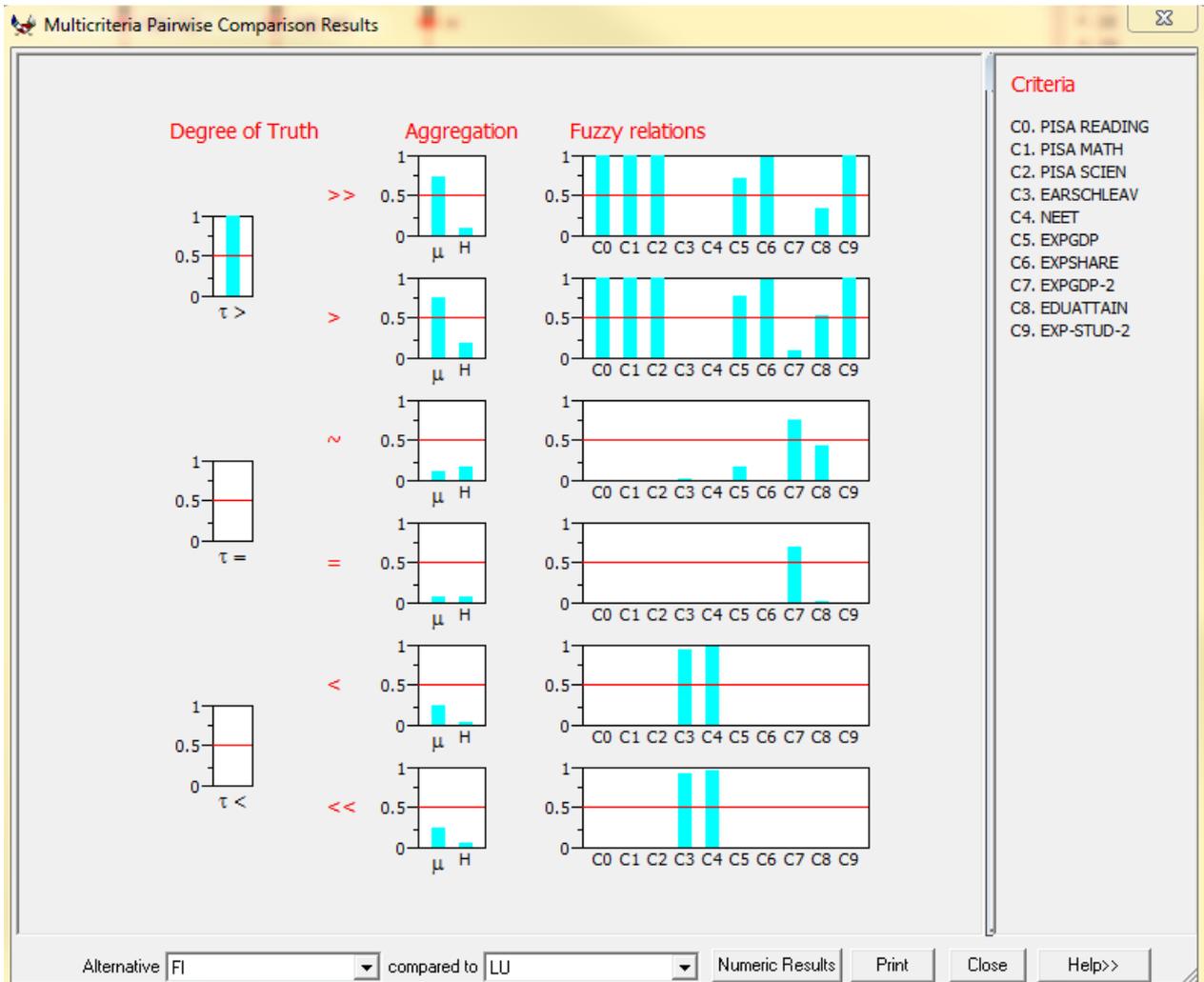
m) FI and IT



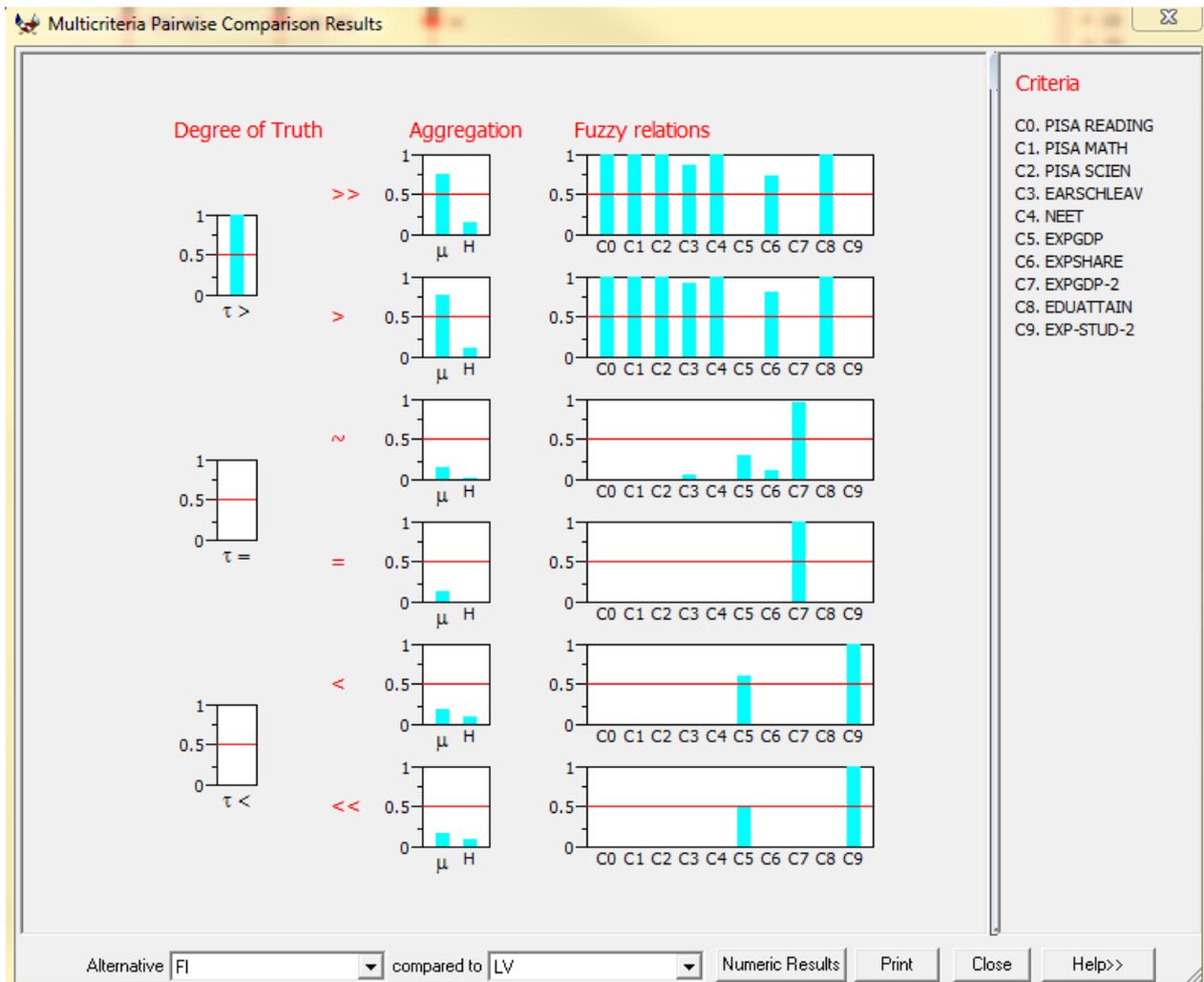
n) FI and LT



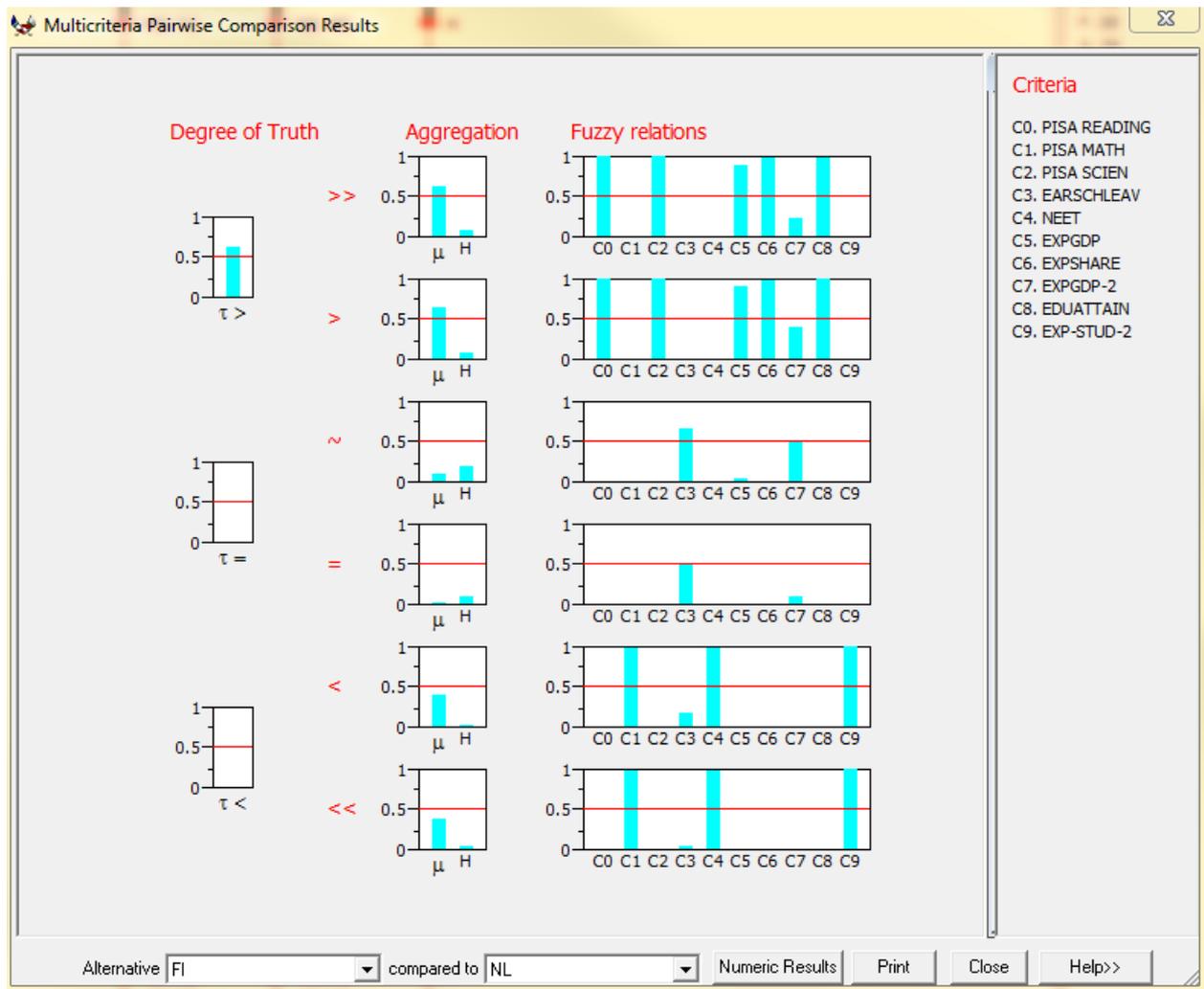
o) FI and LU



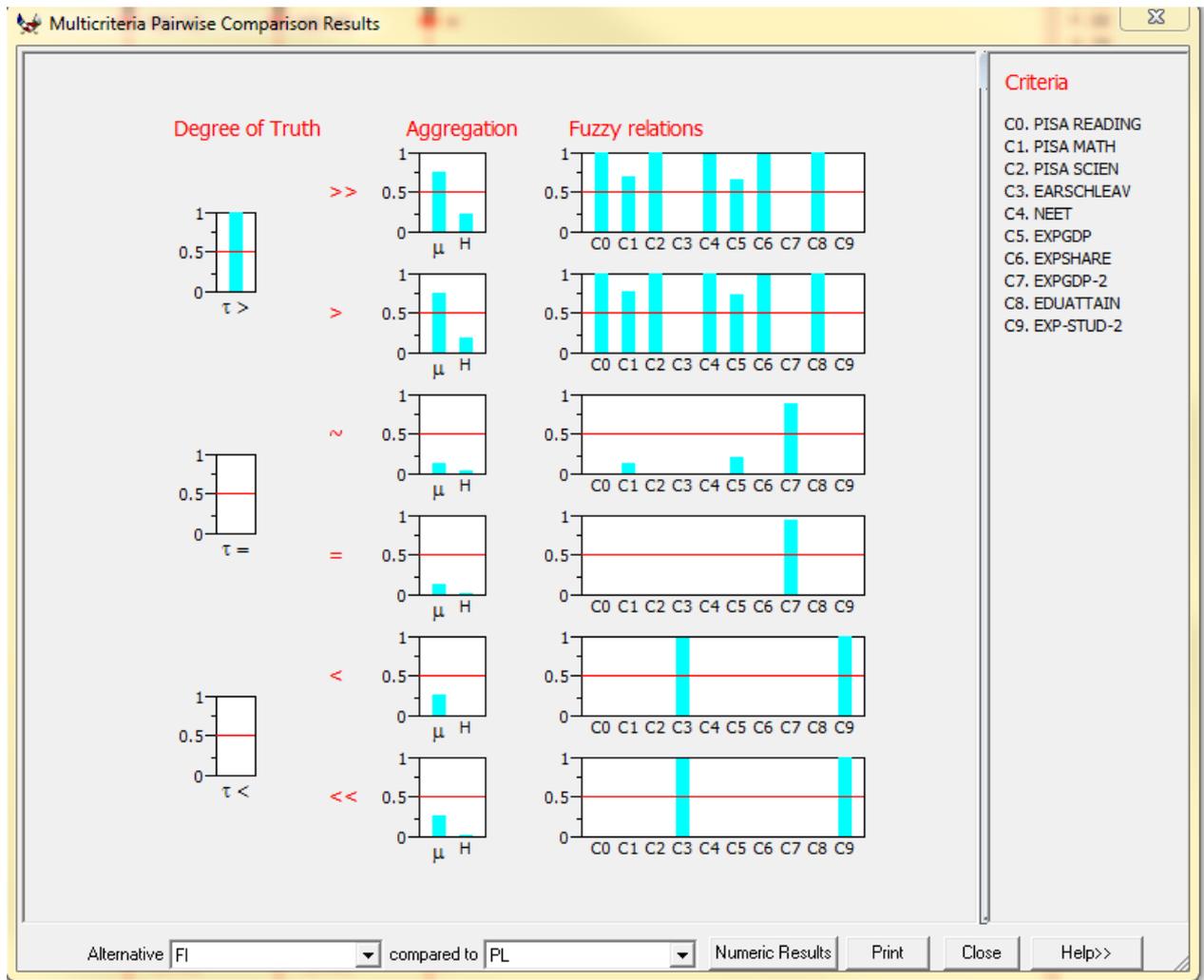
p) FI and LV



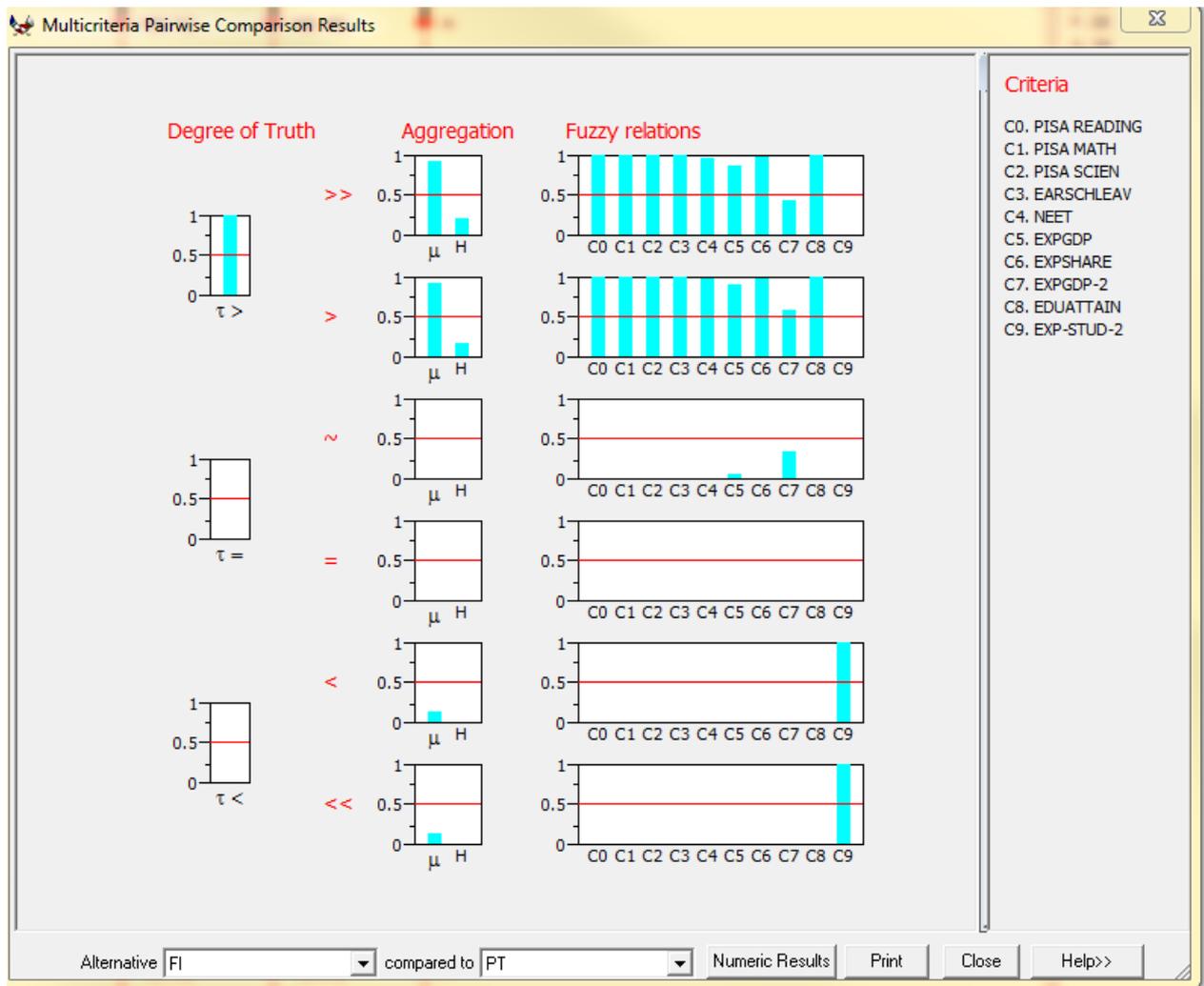
q) FI and NL



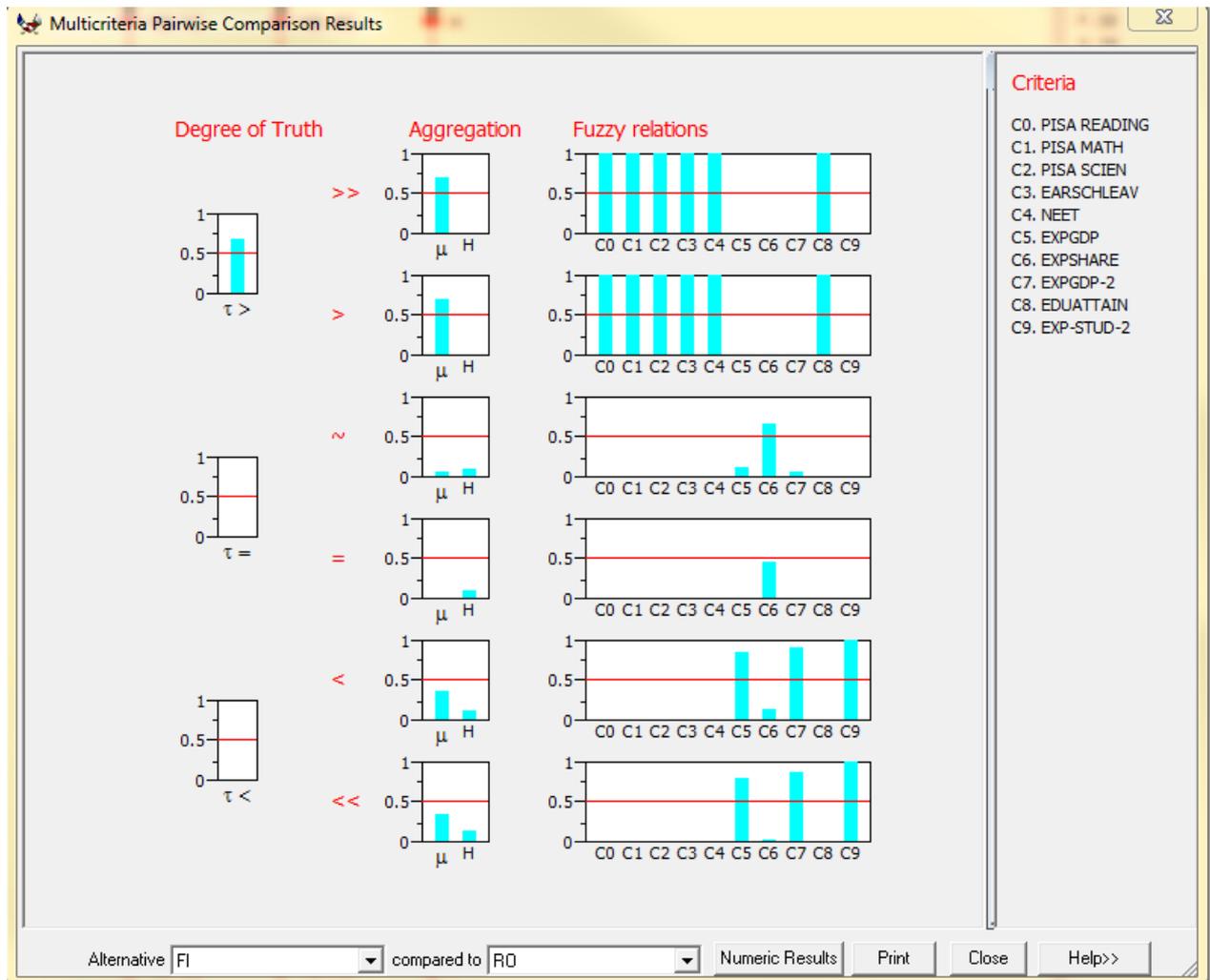
r) FI and PL



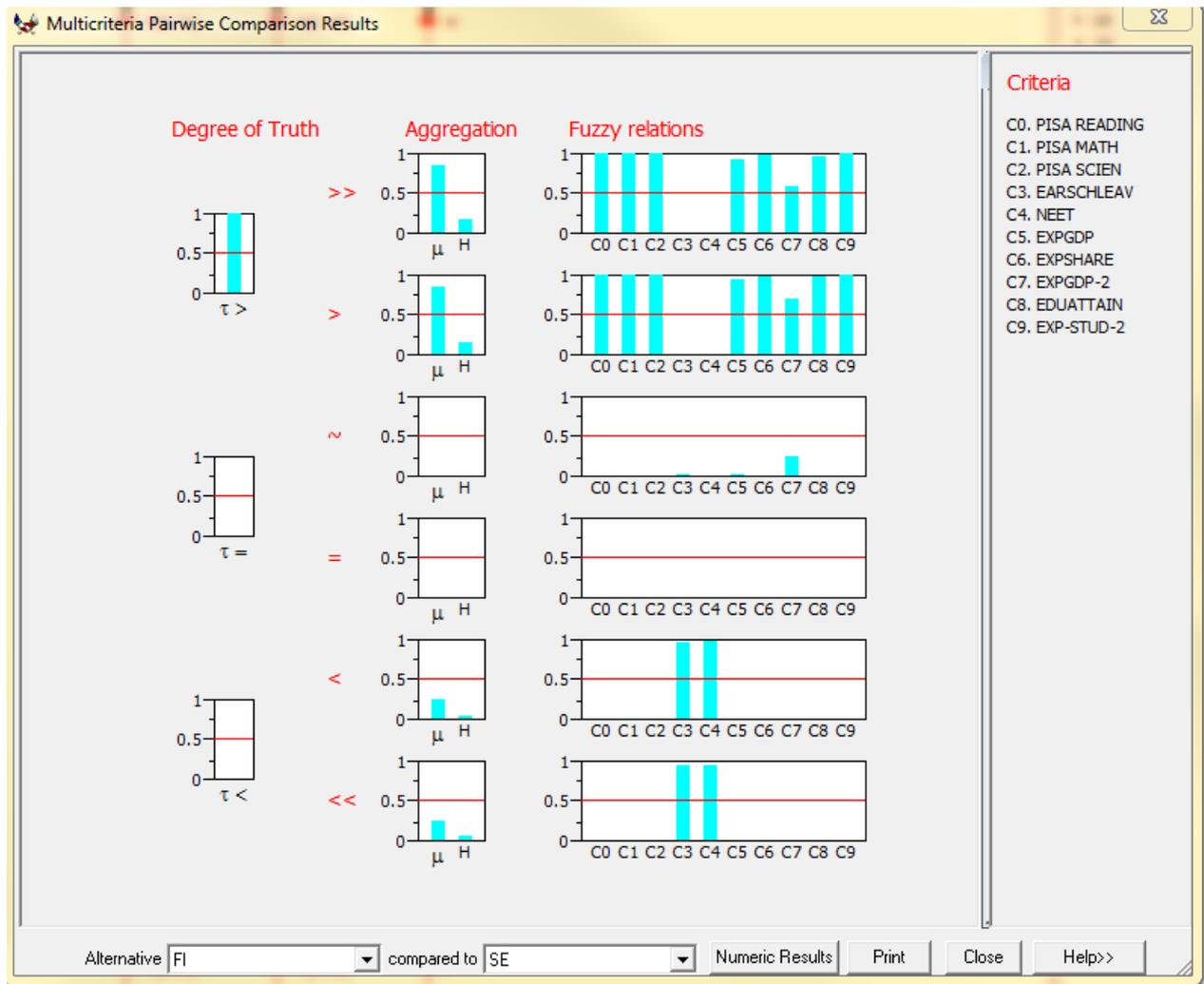
s) FI and PT



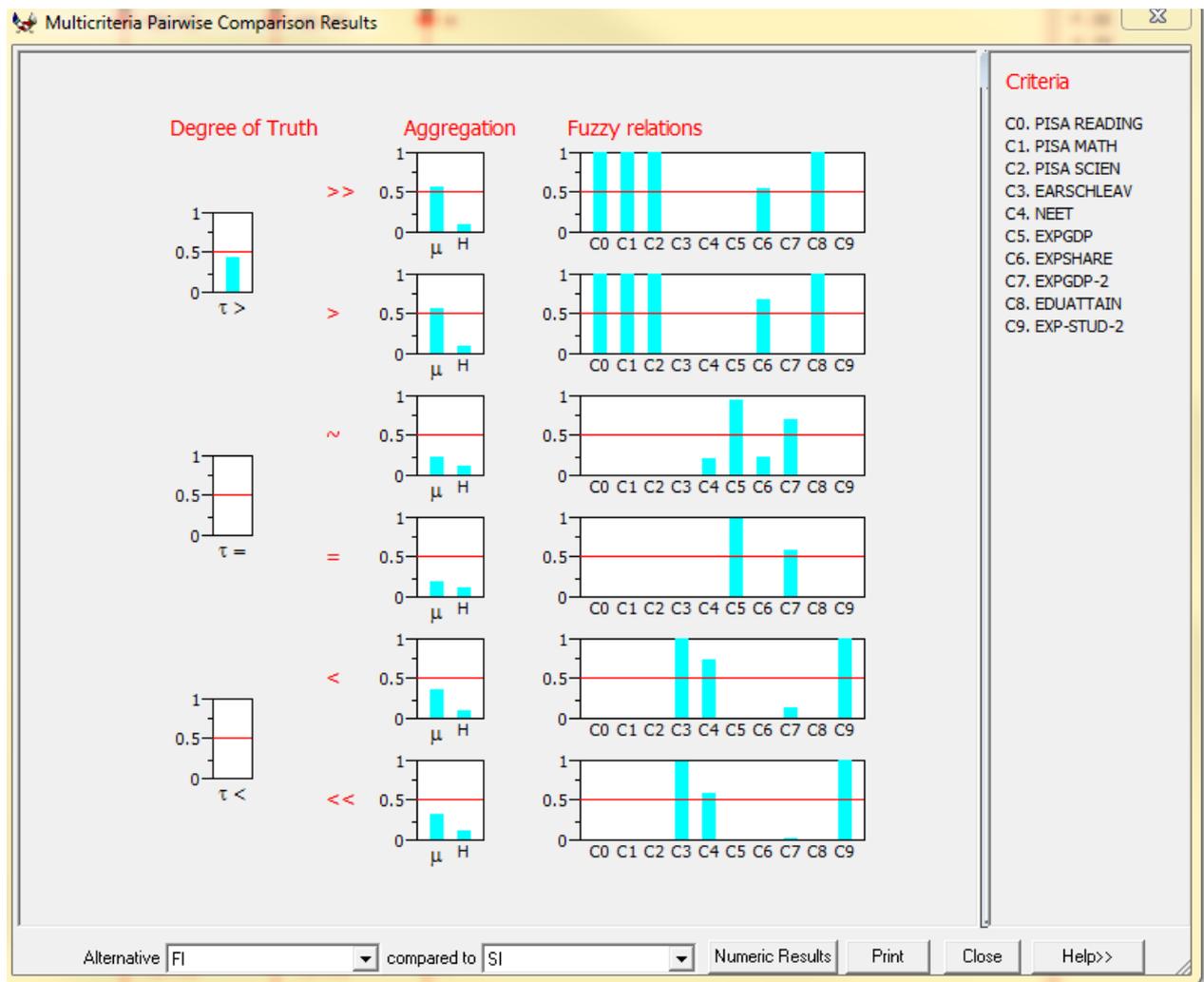
t) FI and RO



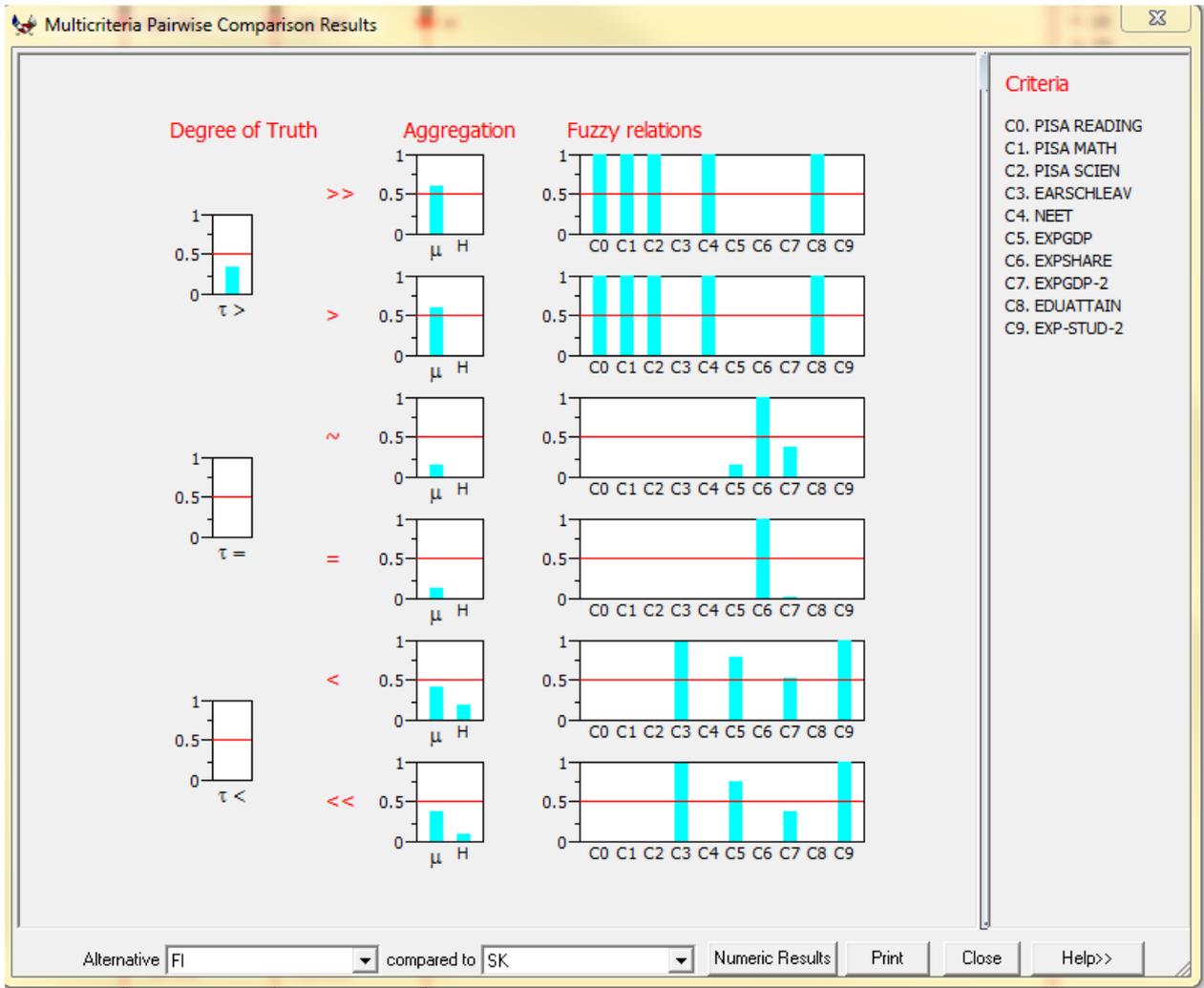
u) FI and SE



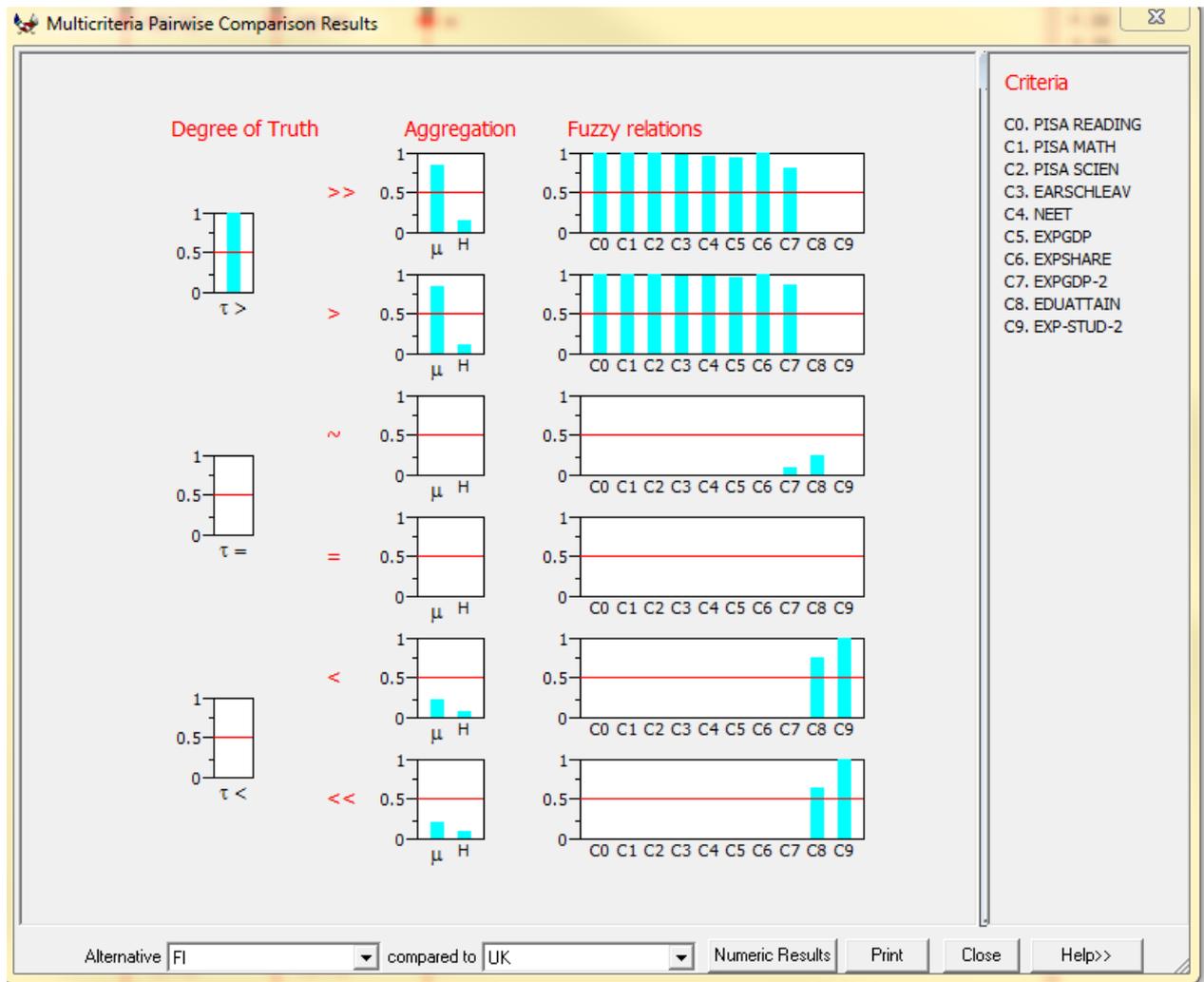
v) FI and SI



w) FI and SK



x) FI and UK



List of abbreviations and definitions

Abbreviation	Definition
CRS	Returns to scale
DEA	Data Envelopment Analysis
EAC	DG Education and Culture
ESCS	Economic, Social and Cultural Status
EU	European Union
FDH	Free Disposal Hull
FTE	Full-time equivalent
GDP	Gross domestic product
HE	Higher education
HEI	Higher education institution
ISCED	International Standard Classification of Education
JRC	DG Joint Research Centre
MCA	Multi-criteria analysis
NEET	Not in Education, Employment or Training
OECD	Organisation for Economic Development and Co-Operation
PIAAC	Programme for the International Assessment of Adult Competencies
PISA	Programme for International Student Assessment
PPP	Purchasing power parity
PPS	Purchasing power standard
SES	Social-economic status
SFA	Stochastic Frontier Analysis
TALIS	Teaching and Learning International Survey
TIMMS	Trends in International Mathematics and Science Study
USA	United States of America

List of figures

Figure 1. Assessing the robustness of the model: DEA vs FDH	18
Figure 2. The relationship between efficiency and PISA test scores.....	19
Figure 3. The relationship between efficiency and early school leavers.....	20
Figure 4. The relationship between efficiency and NEET	21
Figure 5. The relationship between efficiency and expenditure per student.....	22
Figure 6. The relationship between efficiency and expenditure on education as % of GDP.....	23
Figure 7. The relationship between efficiency and students:teachers ratio.....	24
Figure 8. The relationship between efficiency and average teachers' age	26
Figure 9. The relationship between efficiency and teachers' salaries	27
Figure 10. The relationship between efficiency and the proportion of immigrant students	28
Figure 11. The relationship between efficiency and adult literacy – PIAAC (numeracy) 29	
Figure 12. The relationship between efficiency and adults' educational attainment	30
Figure 13. The relationship between efficiency and proportion of public spending devoted to education	31
Figure 14. The relationship between efficiency and equity index	32

List of tables

Table 1. Overview of variables	16
Table 2. The models estimated for calculating efficiency scores.....	17
Table 3. The efficiency scores obtained through the different models	17
Table 4. The efficiency scores by country, DEA and FDH	18
Table 6. Some key characteristics of the educational system	25

Europe Direct is a service to help you find answers to your questions about the European Union

Free phone number (*): 00 800 6 7 8 9 10 11

(*): Certain mobile telephone operators do not allow access to 00 800 numbers or these calls may be billed.

A great deal of additional information on the European Union is available on the Internet.

It can be accessed through the Europa server <http://europa.eu>

How to obtain EU publications

Our publications are available from EU Bookshop (<http://bookshop.europa.eu>), where you can place an order with the sales agent of your choice.

The Publications Office has a worldwide network of sales agents. You can obtain their contact details by sending a fax to (352) 29 29-42758.

JRC Mission

As the science and knowledge service of the European Commission, the Joint Research Centre's mission is to support EU policies with independent evidence throughout the whole policy cycle.



EU Science Hub

ec.europa.eu/jrc



[@EU_ScienceHub](https://twitter.com/EU_ScienceHub)



[EU Science Hub - Joint Research Centre](https://www.facebook.com/EU_ScienceHub)



[Joint Research Centre](https://www.linkedin.com/company/eu-science-hub)



[EU Science Hub](https://www.youtube.com/EU_ScienceHub)

