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Economists' Musings on Human Capital Investment: How Efficient is Public Spending on Education in EU Member States?

Erik Canton, Anna Thum-Thysen and Peter Voigt

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How Efficient is Public Spending on Education in EU Member States?

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Abstract

In this paper we perform stochastic frontier analyses to assess the quality of public spending on education in Europe. To measure the corresponding efficiency, three dimensions are taken into account: (1) quantity (tertiary educational attainment), (2) quality (PISA scores in the area of science), and (3) inclusiveness (proxied by the inverse of young people not in employment, training or education (NEET rates)). All EU Member States are covered over the period 2002 – 2015. Based on pooled and fixed effects regressions, the EU Member States' efficiency scores are assessed both with a view at an EU-wide frontier to allow for cross-country comparisons as well as concerning country-specific frontiers to identify individual trends and possibly remaining deficiencies. The results reveal that some Member States manage to achieve high efficiency in all observed output dimensions 'quantity', 'quality' and 'inclusion', such as e.g. the Netherlands and the United Kingdom - which implies that there is not necessarily a trade-off between the individual output dimensions. Evidence suggests, moreover, that most Member States made remarkable progress over time in terms of efficient use of public resources in reaching large numbers of highly educated young adults. With a view at quality and inclusiveness of public spending on education, however, in many Member States seems to remain still room (and need) for further improvements.

JEL Classification: I2 (I21, I26, I28), H52, O15.

Keywords: human capital, quality of public finance, investment on education, efficiency analysis

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1. INTRODUCTION

Human capital[1] is seen as ever more important for boosting productivity and pivotal for innovativeness, economic growth and societal welfare.[2] Accordingly, stimulating investment in human capital tends to occupy an increasingly central place in the ongoing policy debates. Moreover, while education decisions and education policy typically have a long-term horizon - as it takes time to build up human capital - there could also be a relationship between an economy's stock of skilled workers and its resilience to economic shocks. In fact, better qualifications arguably increase the capability to adjust to an ever faster changing world, thus helping individuals to reduce the risk of becoming unemployed.

In this paper we analyse the performance of the European public sectors in enhancing human capital by asking how efficient public spending on education is. To set the scene, the paper first outlines the general need (and economic rationale) for investing in human capital and provides a clear logic for government intervention. The efficiency analyses will illustrate that, however, the performance of public intervention can vary largely across EU Member States.

The core of the paper is a comprehensive Stochastic Frontier Analysis (SFA) to assess the efficiency of public spending on the basis of the distance to the estimated optimal production – the (education) production frontier. To measure the corresponding efficiency, three dimensions are taken into account: (1) quantity (tertiary educational attainment), (2) quality (PISA scores in the area of science), and (3) inclusiveness (proxied by the inverse of young people not in employment, training or education, (NEET rates)). All EU Member States are covered over the period 2002 – 2015. Conceptually, two types of frontier analyses will be conducted – both allowing for interesting policy perspectives. The first is based on a pooled regression where it is assumed that all countries have theoretically similar possibilities to generate educational outcomes (cross-country benchmarking and illustrating corresponding trends) while the second captures country-specifics in terms of individual education systems (by means of country fixed effects) and, therefore, allows to benchmark the efficiency of public spending on education in each country and with a view at each of analysed output dimensions.

The paper is structured as follows: Section 2 sets the scene by providing stylised facts on where Europe stands in terms of human capital and education (spending) and by making the case for investment in education including a discussion of the rationale for public intervention. Section 3 reflects the relevant literature with a view at previous findings on the efficiency of public spending on education. Section 4 and 5 outline the conceptual framework for the empirical assessments of the efficiency of public spending on education and discuss the corresponding methodological implications, respectively. Section 6 presents and discusses the empirical findings and Section 7 concludes.

1 Following the OECD (1998), human capital is defined here as "the knowledge, skills, competencies and other attributes embodied in individuals or groups of individuals acquired during their life and used to produce goods, services or ideas in market circumstances."

2 Bakhshi *et al*. (2017).

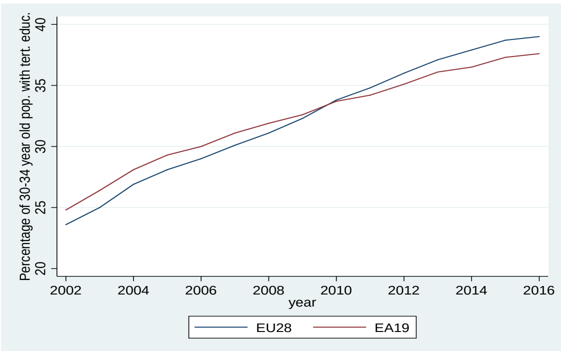
2. SETTING THE SCENE: WHY IS IT IMPORTANT TO INVEST IN HUMAN CAPITAL?

Spending on education is a genuine and decisive investment in the sense that the expected returns are quite high (and may materialise over a long period). This holds both for individuals (private returns) as well as for the society at large (social returns), as human capital accumulation is a key driver for economic and productivity growth, innovation activities and also the resilience of an economy in times of crises. Seen from an EU perspective, human capital accumulation is critical for EMU deepening and for promoting economic and social convergence in the EU. Moreover, next to economic returns, education is also an effective remedy to fight poverty and to flatten the income distribution, i.e. many education policies are expected to deliver a double-dividend. The right to quality and inclusive education is part of the European Pillar of Social Rights and represents a common goal. Accordingly, investment in education is vital for Europe. But, where does the EU currently stand in terms of spending on education (compared to historical figures and/or other regions in the world) and on educational outcomes? Below, we present some stylised facts and then turn to reviewing the arguments for public investment in education discussed in the economics of education literature.

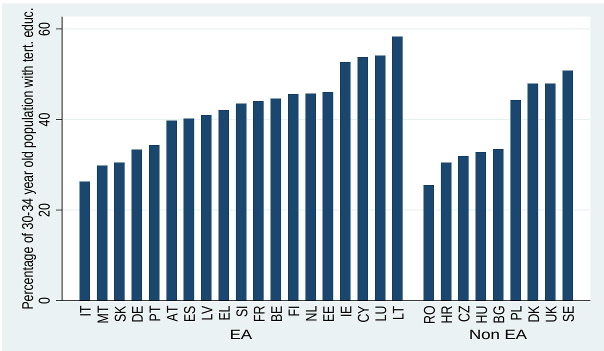
2.1. WHERE DOES EUROPE STAND IN TERMS OF EDUCATION: STYLISED FACTS

To provide a picture of where Europe stands in terms of education, we assess the EU's position (and that of its Member States) in terms of tertiary educational attainment; the quality of education as measured by PISA scores[3]; employability by skill level; the share of young not in employment, education or training and public spending on education. Educational attainment in the EU28 has increased over time, but remains fairly heterogeneous across Member States.[4] Graph 1a shows that the share of population reaching tertiary education has increased overall. However, as shown in Graph 1b, there are significant differences across countries, with Lithuania and Luxembourg displaying the highest share of young adults achieving third level education, followed by Cyprus, Ireland and Sweden.

Graph 1a: **Evolution of tertiary education attainment in the EU**



Graph 1b: **Tertiary educational attainment in EU Member States, 2016**

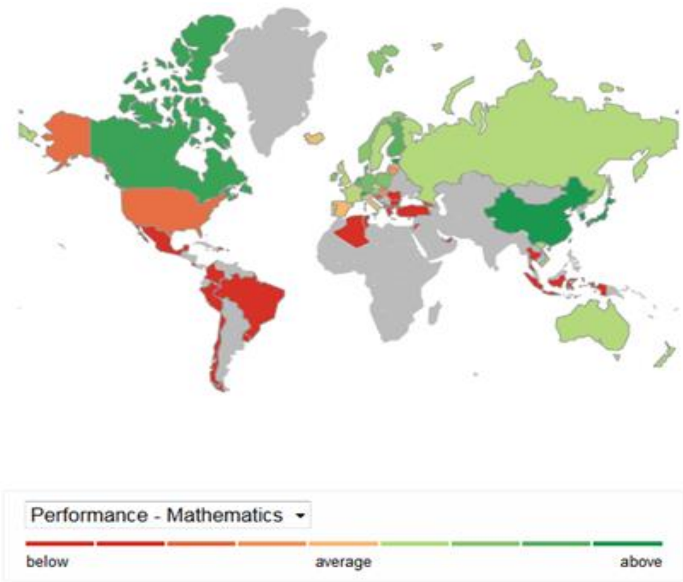


Source: Eurostat

[3] The Programme for International Student Assessment (PISA) is a triennial international survey which aims to evaluate education systems worldwide by testing the skills and knowledge of 15-year-old students. OECD, PISA. Other international surveys are available too, e.g. since 1995: TIMS (Trends in International Mathematics and Science Study). Note that PISA measures basic competences used in daily life.

[4] Note that the EU has set some targets in the field of education – reducing school drop-out rates below 10% by 2020; at least 40% of 30-34 years-old completing third level education by 2020. These EU targets are translated into targets at national level and are subject to annual assessment in the light of the European Semester country reports.

Graph 2: **World map – PISA scores in mathematics, 2015**



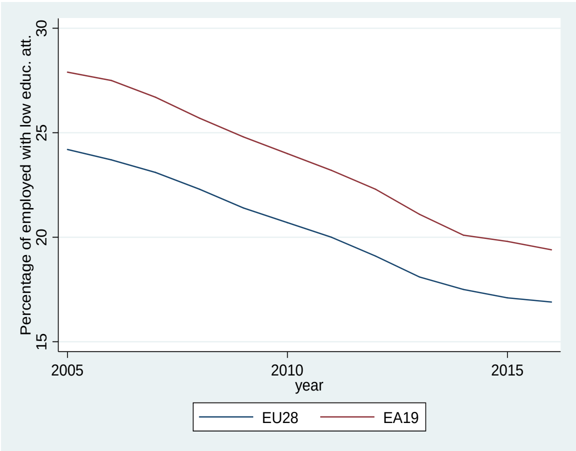
In terms of education quality (esp. building up cognitive skills) – as measured by PISA scores – Europe is just in the midfield rather than a leading world region (see Graph 2).

In fact, PISA scores in mathematics show that Europe is not leading among developed countries. The same is true for scores in sciences and in terms of reading.

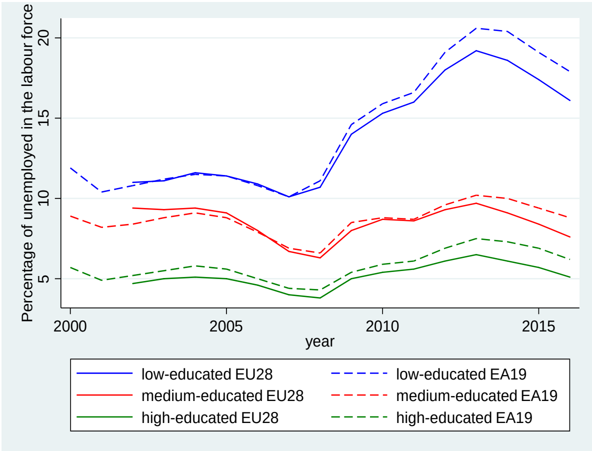
Source: OECD PISA data, http://www.oecd.org/pisa/

Regarding the employability by skill level, a general trend of qualification upgrading of the labour force can be observed (Graph 3a), i.e. the share of low-educated in total employment has decreased over time.[5] And the low-educated labour force has been systematically more exposed to the risk of unemployment, which has become even more apparent during the crisis period when the unemployment rate among the low-educated has sharply increased (Graph 3b). Moreover, whereas the unemployment rate among the medium- and high-educated labour force has more or less returned to pre-crisis levels, this is not the case for the low-educated workers. Hence, skills become increasingly important for employability and can enhance individual resilience.

Graph 3a: **Evolution of employment of low educated in the EU and the EA**



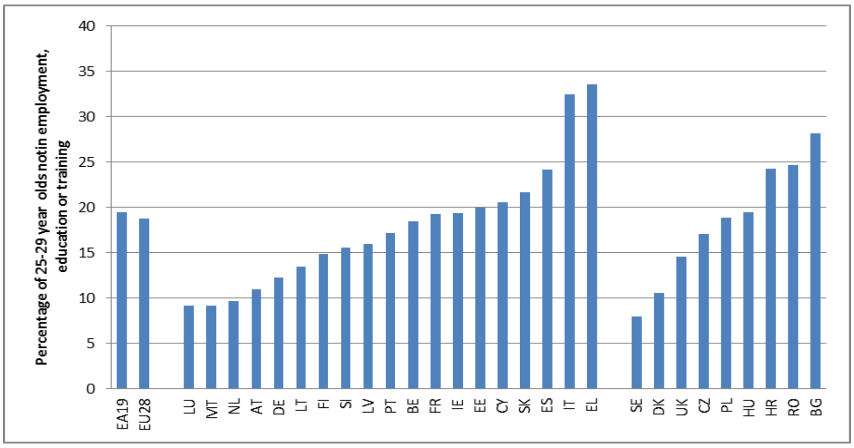
Graph 3b: **Evolution of unemployment in the EU and the EA, by educational attainment levels**



Source: Eurostat.

5 There are relatively more low-qualified workers in the EA than in the EU28. The share of high-qualified workers in total employment is fairly similar in the EA and the EU28 (33.7% vs. 34.5% in 2016). However, there are somewhat less medium-qualified workers in the EA compared with the EU28 (46.6% and 48.4%, respectively, in 2016).

Graph 4: **Young adults Not in Employment, Education or Training [NEET] in the EU, 2016**

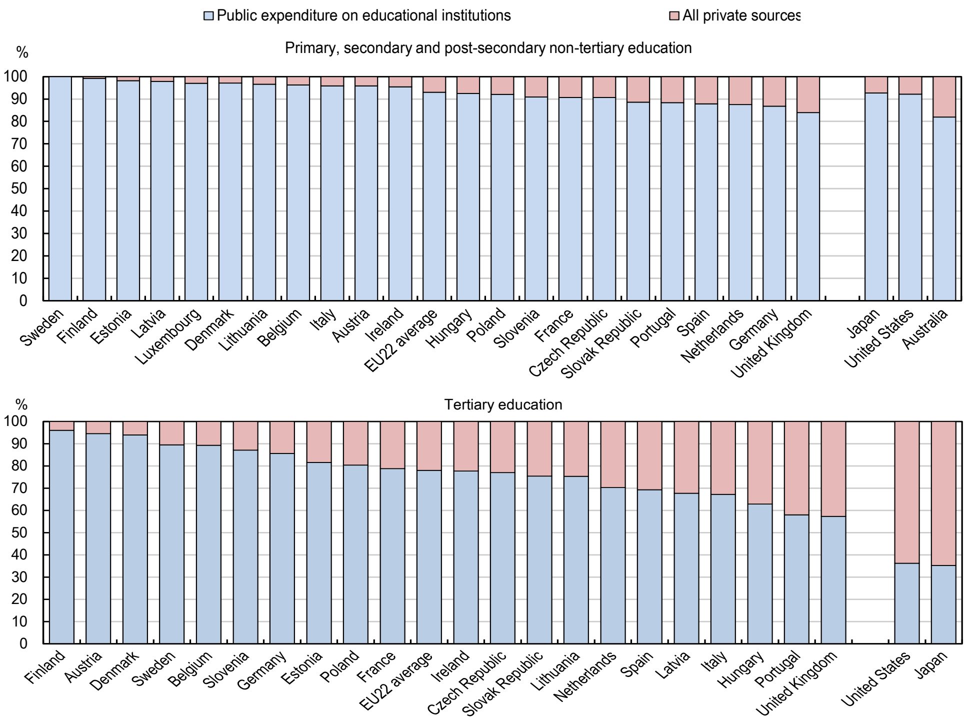


In 2016, the share of young people neither currently employed, in training or in education (NEET) was close to 20% in the euro area (with crisis-hit Member States, such as Greece, Italy and Spain scoring highest). Overall, Denmark and Sweden display the lowest NEET rates with values around 10%.

Source: Eurostat.

Next we turn to an assessment of where Europe stands in terms of public spending on education. Public funding is the key source of spending on education in Europe, in particular in the primary and secondary level (Graph 5). However, the situation is more contrasted in tertiary education, where the private funding plays a relative higher role in some Member States (e.g. Hungary, Portugal, and the United Kingdom). The share of private funding in non-EU countries (e.g. the Australia, Japan and the US) tends to be significantly higher.

Graph 5: **Distribution of public and private expenditure on educational institutions by level of education in selected EU Member States, 2013**

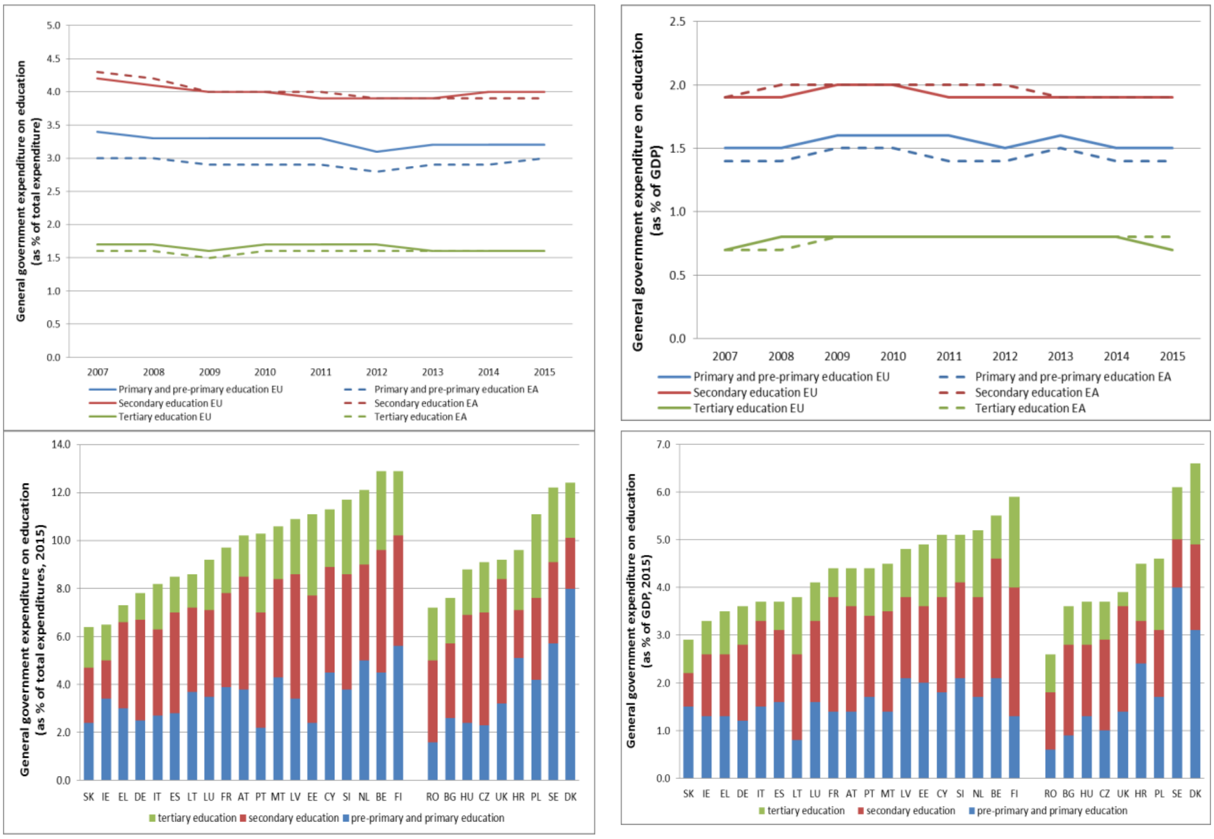


Source: OECD (2017), 'Education at a Glance', originally from the UNESCO-OECD-Eurostat joint data collection on educational statistics.

Notes: Private sources include some contributions to educational institutions received from public sources. Data was not available for Bulgaria, Cyprus, Croatia, Greece, Luxembourg, Malta and Romania.

Graph 6 shows general government expenditure on education over time and reveals that spending on education has been about stable during the years of crisis although it makes overall only a rather small share of the total government expenditures (at ca. 10% in both EA and EU28). Spending on secondary education is overall the largest spending block, followed by primary and then tertiary education.[6] Some EU countries – in particular Greece, Ireland, Italy, Portugal, Romania and Spain – experienced temporary declines in educational spending that could be attributed to the crisis.

Graph 6: **General government expenditure on education in the EU (2007-2015), per Member State (2015)**



Source: Eurostat

Note: For further facts and figures on education (spending) see e.g. 'The Human Capital Report 2016' (WEF) or with specific focus on EU countries the Euroean Commission's Education and Training Monitor (European Commission, 2017).

In sum, from looking at the empirical figures and trends, some positive messages arise. For instance, educational attainment in Europe has increased remarkably over the last two decades (although it remains fairly heterogeneous across Member States) and also the overall spending on education remained relatively resilient to budget cuts during the years of crisis. However, beyond mere 'quantity' aspects, in terms of 'quality' (esp. building up cognitive skills), Europe is currently just in the midfield rather than a leading world region and also with a view at 'inclusiveness' some reason for concerns and arguably room for improvement remain. In this light, below, the economic case for investing in human capital and also the rationale for public intervention in this regard is reflected in brief.

[6] For a discussion of international benchmarks for education spending and the somewhat problematic nature of such figures see e.g. Worldbank (2017), pp. 30ff.

2.2. THE ECONOMIC CASE FOR INVESTING IN HUMAN CAPITAL

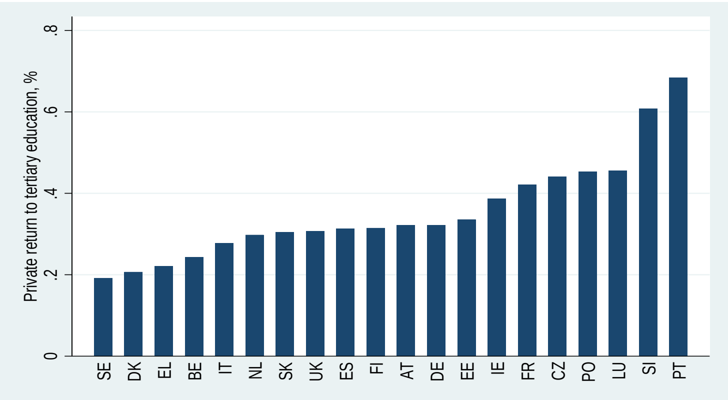
Outlining the economic rationale for investing in education is straightforward: education typically pays off, both for the individual and for society at large.[7] At individual level, getting educated and acquiring skills makes people more productive and these productivity gains translate into wage increases (this is referred to as the private return to education). At macro level, a well-educated labour force contributes to economic and productivity growth and advances the innovative capacity of a society which altogether helps increasing the standard of living for the entire population (referred to as the social return to education).[8] Furthermore, investing in education may avoid some costs commonly associated with the low-qualified stratum of society (unemployment, health issues, etc.).[9]

2.2.1 Private returns to education

The private returns to education conflate the financial gains accruing to the individuals as a result of their educational investments (i.e. money and time spent by individuals for their education, including foregone earnings from alternative employment during the education period relative to the income gains induced by education).

There is ample empirical literature on private returns to education which has consistently shown that education tends to be a rather good investment for individuals. The financial gains are mostly expressed in terms of wage increases associated with building up of human capital. A typical finding in empirical research is that one additional year of schooling tends to increase a worker's long-term average wage by something between 5% and 15%.[10]

Graph 7: **Private returns to tertiary education programmes in selected EU Member States, 2005**



Estimated private returns to tertiary education vary considerably across EU countries according to a recent study published by JRC.[11]

The highest returns are measured in Portugal and Slovenia, while the returns are relatively modest in Denmark and Sweden (Graph 7).

Source: Badescu *et al*. 2011, based on the EU-SILC dataset of 2005. Data not available for later years.

Note: An approximation of the annualised private return to tertiary education would be to divide the private return reported in the Graph by 4 (in case of a 4-year tertiary education programme). This would yield a private return in the range of 5-16% for each additional year of education.

[7] See also European Commission (2014).

[8] Note that in official statistics and also the System of National Accounts (SNA), the spending on education is accounted as expenditure, not as investments, while – following the rationale outlined above – one could well argue that spending on education and human capital formation is an investment since it is assumed to pay off in future periods. For this paper, disentangling the exact meaning of 'spending on education' (expenditure vs. investment) is avoided, i.e. 'spending on education' and 'investment in education' are seen as synonyms. It is however important to keep in mind that education spending is not part of the investment figures as provided e.g. by ESTAT.

[9] Cedefop (2017).

[10] Psacharopoulos and Patrinos (2004). See Box 1 for further details.

[11] Badescu *et al*. (2011). The estimates of private returns to education are based on a Mincer equation as described in Box 1.

However, while significant private returns are essential incentives for individuals to invest in education, excessively high private returns may point to bottlenecks in the education system (e.g. limited access for disadvantaged groups) and/or the labour market (e.g. in case of sheltered professions which effectively reduce competition and give professionals a certain market power enabling them to charge inflated prices for their services).[12]

Box 1: ESTIMATING PRIVATE RETURNS TO EDUCATION

This box provides a concise introduction on the commonly-used methodology to calculate the private returns to education. Starting point is the idea that schooling is an investment in human capital, and this investment would generate a future return in the form of a higher wage for the individual. This idea relates to the seminal work of Jacob Mincer.[13] The approach is empirically implemented by explaining the logarithm of the wage of a worker from her/his educational attainment and labour market experience (which is another source of human capital formation), while controlling for a set of background characteristics such as gender, type of labour contract (e.g. full-time or part-time, fixed term or tenure), and sector of economic activity:

$$\log(w_{i,t}) = \alpha + \beta S_i + \gamma X_{i,t} + \varepsilon_{i,t}$$

where w is the gross hourly wage of worker i in year t, X includes background characteristics, γ is the regression coefficient of these background characteristics, α is a constant term, and ε is an error term. The term S indicates the schooling level of the individual, and regression coefficient β measures the private return to investment. The schooling level S is often measured as the number of years of education. In that case the quasi-elasticity β has a straightforward interpretation: it measures the % increase in the person's wage when (s)he would take an additional year of schooling. As mentioned in the text, existing estimates of β are in the range of 5 to 15%.

Two heavily debated issues are worth mentioning: Firstly, educational attainment may suffer from measurement error. For example, the researcher often does not observe the quality of the school. These measurement difficulties introduce noise in S, which leads to a downward bias of the estimated regression coefficient β. Secondly, regression coefficient β can suffer from selection bias. Technically this means that S is not exogenous, but depends on unobserved background characteristics. For example, if persons who stay longer at school are also more motivated and/or have higher inherent ability, then β would pick up both the effect of additional schooling and of the individual's motivation/inherent ability. As such, regression coefficient β would suffer from upward bias, and the "true" private return to schooling would be lower. This notion of selection bias has triggered a large literature based on experimental methods, where for example data on identical twins are used to rule out as much as possible the role of unobserved factors. According to Krueger and Lindahl (2001), the upward "ability" bias is of about the same order of magnitude as the downward bias due to measurement error.[2] Therefore, standard ordinary least squares estimates of the private returns to education could be assumed to give indeed a fairly reliable number.

2.2.2 Social returns to education

The social rate of return compares the costs and benefits for the country as a whole. It refers to what education really costs, rather than to what students actually pay out of pocket, and what is the mid- to long-term benefit for society. To estimate these social returns in a broad sense, researchers have also looked at the impact on health, safety, participation in democratic processes, etc. For the sake of simplicity, here we take a more narrow perspective by briefly reviewing main findings related to the relationship with economic growth.

There is indeed a vast literature on the empirics of economic growth with an explicit role for the education sector. Education may generally affect economic and productivity growth through different channels (see Lucas, 1988 or Barro, 2001), for instance by increasing the innovation capacity and the general quality of the workforce, which also leads to higher absorption of new techniques and

12 See for example Badescu (2011).

13 See for example Mincer (1974).

technologies. Consequently, a country's level of human capital (commonly approximated by the educational attainment of the labour force) can have an impact on productivity levels (referred to as a "level-level" effect) and/or on the rate of productivity growth (a "level-growth" effect). A typical finding of the former strand in the literature is that if the average educational attainment of the work force increases by one year, labour productivity would rise by approximately 7-10%.[14]

In turn, the "level-growth" literature emphasises the interaction between the human capital stock and technological change. For instance, Benhabib and Spiegel (1994) suggest that a 1% larger stock of human capital (proxied by years of schooling and enrolment rates)[15] corresponds to an increase in GDP growth rate(s) by about 0.13% via an increase in productivity growth (and also innovativeness). The authors find, moreover, that countries with a larger human capital stock show faster technological catch-up.

The major difference between the two strands relates to the actual transmission channels at work: while the first emphasises the productivity-enhancing effects of schooling (and the associated skill-upgrading of the labour force), the second strand stresses the adoption and innovation channels (shifting the boundaries of the production possibilities outwards due to technological progress). Both channels work in parallel. Which one tends to be more conducive to growth appears to be country-specific. As demonstrated by Vandenbussche *et al.* (2006)[16], an optimal composition of public spending on education depends on the corresponding economy's relative distance to the technological frontier. And since the latter is changing over time and also relative to other countries, any national policy mix should anticipate technological advancements and gradually adjust education spending accordingly. This includes striking the right balance between emphasis on education and vocational training.

And even the distribution of education funding across disciplines seems to matter for potential socio-economic returns. Among others, Murphy *et al.* (1991) studied this question and found evidence that countries with a higher proportion of engineers tend to grow faster, while countries with a higher proportion of law graduates tend to grow slower. Glocker and Storck (2012) analysed returns to various fields of study (from German micro data) and concluded that graduating in business yields higher expected returns than for example majoring in mathematics.[17]

Having outlined the economic case for investing in human capital – both on the individual and on the social level – we now turn to discussing the economic case for public intervention.

[14] See e.g. Mankiw *et al.* (1992) or Soto (2002). An overview is provided e.g. in Lindahl and Canton (2007).

[15] Approximated according to Kyriacou (1991) based on estimating the relationship between educational attainment of the labour force (years of schooling) and past values of human capital investments (such as enrolment in primary, secondary and tertiary education). See also Behabib and Spiegel (1994), p. 168 and Table 7 for details.

[16] The authors distinguish the innovation and imitation channel when analysing the contribution due to human capital. Imitation thus refers to the adoption of technologies developed elsewhere. If innovation is a relatively more skill-intensive activity than imitation, skilled labour and a generally higher average education level of the society tend to have a stronger impact on economic growth for countries closer to the technological frontier. The authors found evidence supporting this hypothesis for OECD countries.

[17] Such characteristic differences in returns across study fields (and countries) may well be taken into account when allocating public funds for education and these aspects could also have implications for tuition fee policies (which can be used to narrow the discrepancy between private and social returns to education). Note, however, that many countries in Europe currently do not charge different tuition fees across study fields, while cost differences can be substantial (i.e. the costlier studies are relatively more subsidised).

2.3. THE ECONOMIC CASE FOR PUBLIC INTERVENTION

The logic for public intervention in the field of education is derived from both market failures[18] and redistribution/equal opportunities concerns (see Poterba, 1996).

2.3.1 Market failures

Two forms of market imperfections have been emphasised in the economics of education literature: human capital spill-overs (which are generally associated with knowledge production and human capital accumulation) and capital market imperfections.

Human capital spill-overs imply that benefits from education accrue not only to the people making the investment, but also to others.[19] Hence, human capital spill-overs drive a wedge between the private and social return to education, possibly leading to under-investment in education since individuals making the investment cannot appropriate the full returns. Public intervention can address this market failure by public provision of education and/or by subsidising education systems or parts of it (mostly in form of direct financing of education institutes).

Students may have difficulties to finance their education on the private capital market due to capital market imperfections. Educational investments can be costly and financing such expenditures through the private capital market tends to be difficult mainly because of information asymmetries (it is costly for banks to observe a student's talent and effort) while human capital cannot be collateralised. Moreover, capital market imperfections tend to create unequal access to education, thus limiting vertical social mobility (e.g. children from economically disadvantaged families would face difficulties to enter higher education). The standard remedy to cope with these capital market imperfections is the provision of publicly backed student loans. Often such loan schemes also have a subsidy element as loans are typically provided under rather attractive conditions (e.g. interest rates below market rates).[20]

2.3.2 Income distribution and equal opportunities

Besides addressing market failures, another objective of public education is to provide equal access to education (as a matter of societal fairness). Parental resources differ and, even faced when banks are willing to offer student loans, children from less advantaged families may be discouraged to go to school (Poterba, 1996). In most countries, primary and secondary education is the responsibility of central or regional government and aims to provide a fair access to all.

Re-distributional aspects therefore provide a further rationale for public intervention. In fact, there is an inter-linkage of education with an economy's income distribution. The idea is that the skill premium will fall when educated workers become more abundant.[21] Indeed, when low-skilled employees become scarcer, their wages will be raised relative to the wages of high-skilled workers. This compresses the income distribution, and reduces the private returns to education. Some empirical studies indeed seem to support this idea.[22] However, a stimulus of higher education could also generate an opposite effect, in the sense that the larger stock of skilled workers may induce skill-biased

[18] A market failure leads to a situation in which the allocation of goods and services is not efficient, i.e. there exists another conceivable outcome where an individual may be made better-off without making someone else worse-off. Market failures arise for example due to information-asymmetries, market power, and external effects.

[19] This happens for example when people learn from each other in social interactions at the workplace. People thus benefit from the presence of skilled colleagues, and these are gains outside the usual market transactions.

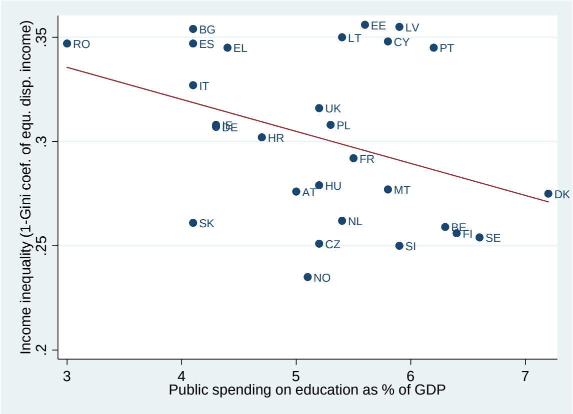
[20] The above outlined capital market imperfections can, for instance, be rather efficiently corrected for by means of so-called social loan schemes, inspired by the Australian student loan system with income-contingent repayments. Such a scheme also provides some insurance against low returns to investment, as graduates are (partly) exempted from servicing their debt when they receive a low income.

[21] Tinbergen (1975).

[22] Dur and Teulings (2001).

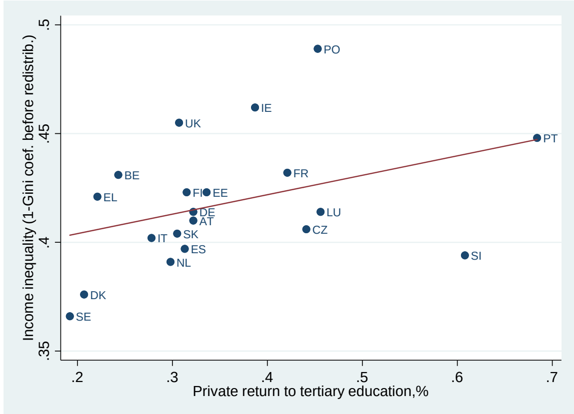
technological change, i.e. development of new technologies that are complementary to skilled workers. Such skill-biased technological change also leads to an increased relative demand for skilled workers, which would then tend to push up again the skill premium in wage formation processes. Therefore, depending on which effect is dominating, adjusting the emphasis of education policy (thus affecting income distribution *ex ante*) and possibly using further instruments (such as e.g. tax policy, i.e. correcting the distribution *ex post*) can be necessary to achieve an income distribution in line with societal preferences.

Graph 8a: **Public spending on education and income inequality in the EU Member States, 2014**



Source: Eurostat.

Graph 8b: **Private returns to schooling and income inequality in selected EU Member States, 2005**



Source: OECD (Gini coefficients before redistribution) and Badescu *et al*. (2011)[23], based on the EU-SILC dataset of 2005 (private returns to tertiary education).

Notes: Data pertain to 2005 as data for later years was not available (see also Section 3.1).

Empirical evidence confirms that EU countries which are spending more on education also tend to have a more equal income distribution (see Graph 8a). Countries such as Denmark, Sweden, Finland and Belgium feature relatively high spending on education in combination with a relatively equal income distribution. In contrast, Bulgaria, Romania and Spain have relatively low public spending on education and a rather uneven distribution of income.[24] Moreover, evidence also suggests a link between private returns to schooling and income inequality (before taxes), see e.g. Graph 8b. In line with the argument above, the countries with the lowest private returns to education (Denmark and Sweden) also have the lowest income inequality in the EU.

Although there is arguably ample reason for investing in human capital and also an economic case for comprehensive public intervention, the fact that Europe lags behind other world regions in terms of education, as outlined above, gives rise to the question whether we invest simply too little on education or whether this is rather due to inefficiencies in the corresponding spending on education. The following Sections will analyse this question more closely, beginning with a reflection on what the relevant literature tells us in this regard (see next Section).

[23] The estimates of private returns to education are based on a Mincer equation as described in Box 1.

[24] There are, however, also clear exceptions to this pattern, notably in the Baltics, Cyprus and Portugal, where income inequality remains relatively high despite higher than average spending on education.

3. THE EFFICIENCY OF PUBLIC SPENDING ON EDUCATION: EVIDENCE FROM THE LITERATURE

The literature on the efficiency of public spending on education can be split into two groups of studies (see also Mandl, 2008). Studies pertaining to the first group typically consider public spending on education as input in the education production function. These studies often focus on the efficiency of public spending and distinguish different government functions such as health and/or education (see e.g. Medeiros and Schwierz, 2015). According to Agasisti (2014) this approach implies that the definition of efficiency is limited to the resources invested in education. In turn, studies pertaining to the second group often postulate an education production function with a wider spectrum of input factors, including both monetary and non-monetary input factors. Below we give an overview of some previous findings in the two fields. In Section 4 we explain that while our work can rather be attributed to the first group (considering public spending as the only input factor, i.e. the public finance literature), we take other potentially relevant (non-monetary) input factors into account as environmental factors and also justify why we have decided to do so.

3.1. PUBLIC SPENDING ON EDUCATION AS INPUT FACTOR IN THE EDUCATION PRODUCTION FUNCTION

Clements (2002) was among the first to systematically assess efficiency of public spending on education in Europe. He defines public spending on primary and secondary education as input variable and educational attainment levels and performance on international examinations as output variables. He finds 25 percent of education spending in the EU to be wasteful and concludes that, in Europe, improving efficiency of education spending is more important than increasing outlays. Previously, Clements (1999) had conducted a similar analysis to evaluate efficiency in Portugal, assuming public spending on education per student in purchasing-power adjusted U.S. dollars at primary and secondary level as input and the ratio of secondary graduates to population at typical graduation rate as output. Gupta and Verhoeven (2001) assess efficiency of spending in the domain of primary and secondary school enrolment and adult literacy in 85 African, Asian and Western countries using PPP-adjusted per capita spending on primary and secondary level education as input and educational attainment at primary school level and enrolment at secondary level as outputs. The authors find that improvements in educational attainment in African countries require more than higher budgetary allocations. Belhocine *et al.* (2013) assess the efficiency of public spending on secondary schooling in Iceland by relating it to PISA scores and find that annual savings in education up to the secondary level could reach 3.3 percent of GDP in Iceland. Grigoli (2014) determines efficiency of public spending on education in emerging and developing economies based on secondary education expenditure per student in purchasing-power parities as inputs. He finds that improving efficiency could achieve large potential gains in enrolment rates, especially in lower-income economies, in particular in Africa.

3.2. MULTIPLE MONETARY AND NON-MONETARY INPUT FACTORS

Gimenez *et al.* (2017) provide an extensive overview of the literature on the performance of education systems demonstrating the variety of (monetary and non-monetary) input and output variables used in the literature. While most studies focus on primary and secondary education, some studies examine the efficiency of tertiary education. Regarding the first group of studies, Afonso and St. Aubyn (2005, 2006) define instructional hours per year and teachers per 100 students in secondary schools as inputs and average educational achievement in science, reading and mathematics (PISA scores) as output. To account for environmental variables, the obtained efficiency scores are regressed on GDP per capita and parental educational attainment in a second-stage regression. Sutherland *et al.* (2007) define the ratio of teaching staff per 100 students as well as the school-average of socio-economic status in secondary schools as inputs and PISA scores as outputs. Scippacercola and Ambra (2014) estimate the relative efficiency of secondary schools based on a set of school resource variables as inputs, a set of environmental factors and the number of students who passed the final exams in secondary school with a score higher than 80 out of 100 as output variable. Agasisti (2014) takes PISA scores as an approximation for education output and as inputs the overall education expenditure per student and student-teacher ratios (to measure human resources involved in education). Contextual variables (such as e.g. GDP per capita, unemployment rates, etc.) and structural characteristics of the educational system are tested in a second analytical step as explanatory variables affecting the (in)efficiency scores obtained in step one. Focussing on spending on health care, secondary education and general public services, a recent analysis conducted by the OECD estimates the efficiency of public spending for a sample of OECD countries (Dutu and Sicari, 2016). For the evaluation of efficiency in public spending on education the authors use PPP-adjusted spending per student in secondary education and the PISA index of economic, social and cultural status (ECSC) as input variables and PISA scores as output variables.

With a view at public spending on tertiary education, St Aubyn *et al.* (2009) and the European Commission (2010) concluded that autonomy is an important driver of efficiency of tertiary education in Europe. The authors' analysis is conducted on the basis of a cost function relating inputs especially relevant for tertiary education to the number of graduates and the number of academic publications. On a national level, Kempkes and Pohl (2006) study the efficiency of spending in German universities using parametric and non-parametric methods, Abbott and Doucouliagos (2003) study the efficiency of spending in Australian universities, and Kocher *et al.* (2005) assess the productivity of research in economics.

In the next sections we turn to discussing our methodological approach for analysing the efficiency of public spending on education in Europe. We start by presenting the framework for identification of an efficient boundary of investment in education and then turn to discussing the empirical estimation methodology to be employed.

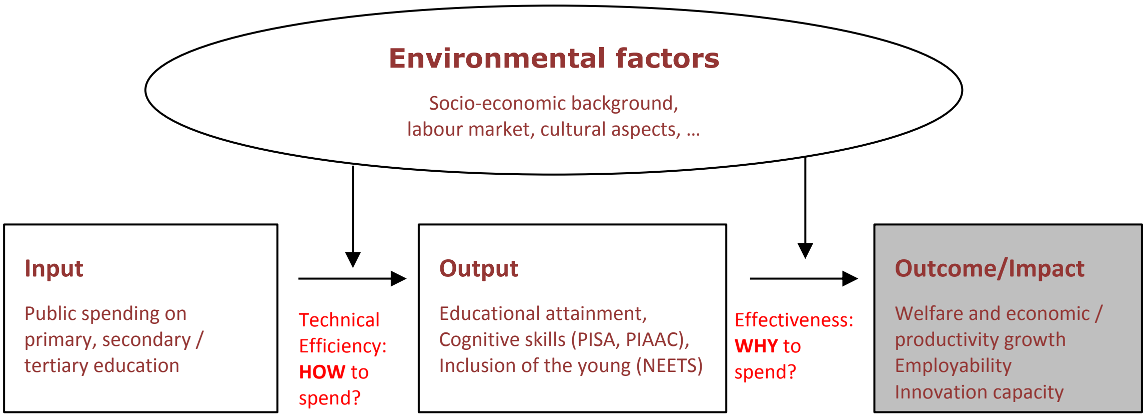
4. IDENTIFYING THE EFFICIENT FRONTIER OF INVESTMENT IN EDUCATION

To investigate the efficiency of spending on education, commonly a production function is specified that links public spending on education (i.e. input) to educational outputs (such as the number of graduates or cognitive skills) by means of a certain production technology.[25] Efficiency is then assessed by the distance to the production frontier determined by the production technology. The aim is to separate gains in efficiency from quality improvements in the input set by estimating a production frontier that makes it possible to distinguish between virtual moves towards or away from the frontier (efficiency gains/losses) and possible technical change (shift of the frontier or change in its shape; e.g. due to new teaching techniques, new tools/technical equipment).

Graph 9 illustrates our conceptual understanding of education production. St Aubyn *et al.* (2009) note that the literature does not provide a clear indication of which input- and output- variables should be chosen to measure efficiency in public spending on education. Below we discuss our choice for these factors and Table A.I.1 presents a detailed overview of the selected input-output pairs and the data used. We further discuss the role of environmental factors and potential caveats.

[25] For a discussion of education production functions see e.g. Hanushek (2007).

Graph 9: **Framework for analysing the efficiency of public spending on education**



Source: Adapted from Mandl (2008).

Note: The grey shaded part is not captured in the presented analysis as this paper concentrates on 'efficiency' not on 'effectiveness'.

4.1. CHOOSING INPUT INDICATORS

While input variables can be either measured by the invested monetary value or as a non-monetary value created by public spending in education (i.e. teaching time, instruction hours or student/teacher ratios), in this paper we concentrate on the former type of variables. It should be noted, however, that in terms of monetary variables, it is not easy to track down public expenditure on all the different types of relevant input (Trujillo *et al.*, 2007). In particular indirect costs, such as opportunity costs of using government owned buildings or higher tax burdens due to higher expenditure, are hard to capture (Mandl *et al.*, 2008). While the most important component of education expenditure is teacher salaries, such spending also includes intermediate consumption, contributions and social transfers such as subsidies or social benefits, and capital investment.

The invested monetary value is measured by public spending on education and should be taken in per student terms in order to control for demographic developments (e.g. a declining number of students that result from ageing in populations requires less spending). Spending should also be normalised by GDP per capita values to control for the degree of economic development as well as the size of the country.

The two available main data sources on public education spending are National Accounts' Classification of the Functions of Government (COFOG) and the Unesco-OECD-Eurostat joint data collection (UOE)[26]. For the purpose of computing per-student expenditure, it would be best to use the UOE's expenditure on educational institutions, as the OECD (2017) does e.g. in its 'Education at a Glance'. However, these series have some flaws as, for instance, they are updated only up to 2014, data is not available for all Member States and there is some risk of double-counting transfers.

Finally, spending on education can generally either rely on public or on private sources (e.g. individuals, households, private educational institutions). However, as outlined above in Section 2.1 across the EU, the educational systems tend to be based mainly on public resources (Mandl *et al*. 2008). In fact, with a view across Europe and all education levels up to non-tertiary education, most of the Member States display private interventions of less than 15% of the total spending on education with the United Kingdom being at about 17%. In tertiary education the EU22 average of public spending in total spending on education is at 78% (see Graph 5). It is therefore reasonable to

[26] See: http://ec.europa.eu/eurostat/statistics-explained/index.php/UNESCO_OECD_Eurostat_(UOE)_joint_data_collection_%E2%80%93_methodology

concentrate the analysis of the efficiency of spending on education on the corresponding public expenditures.

4.2. CHOOSING OUTPUT INDICATORS

Public spending on education serves a number of objectives, as mentioned above, in particular being a key driver for economic or productivity growth, innovation activities and also the resilience of an economy in times of crises by means of ensuring a rather highly and adequately skilled population as well as safeguarding fairness and openness across the society. And, next to economic returns, education is also an effective remedy to fight poverty and flatten the income distribution. These policy objectives can be grouped into three measurable outputs *quantity* (tertiary educational attainment), *quality* (cognitive skills, approximated by PISA scores) and *inclusion* (proxied by NEET rates). In order to assess the overall quality of public spending on education analytically, these three dimensions need to be observed in parallel. Hence, a country is considered to perform well if it is efficient in terms of all these dimensions.[27].

While efforts to maximise these three main education outputs and thus delivering on all mentioned policy objectives might be mutually reinforcing, it may arguably appear difficult to achieve all at once (especially in case of tight budgetary constraints). In this context, the individual education systems across Europe have emerged over a long time with a view to address possible trade-offs in terms of education policy priority setting, resulting in a significant heterogeneity in the individual features of each national/regional education system and also in remarkable differences in delivering on the three mentioned objectives. However, with a view at spending smartly on human capital and achieving different objectives at once (i.e. good quality public spending), it is all about finding an appropriate balance in the education policy mix which delivers well on all dimensions.[28]

4.3. THE ROLE OF ENVIRONMENTAL FACTORS

The relationship between public spending on education and educational outputs may be affected by various factors. One relevant factor is arguably parental background. In fact, children tend to perform better in the classroom when their parents are well-educated and supportive to their children's school career. Since parental background represents what happens outside the classroom – while public spending represents what happens inside the school – it is classified as an environmental factor. For a discussion on the location of factors outside the discretion of the "producer" see Pereira and Moreira (2007). Other factors such as cultural aspects, the labour market or policy-related factors may also play a role. Such features can be accounted for in the analysis as environmental factors but are often difficult to measure.

4.4. CAVEATS

Unfortunately, analyses of all three definitional elements of efficiency shown in Graph 9 (inputs, outputs, and the functional relation of the two) may be affected by severe conceptual and measurement problems (see e.g. Lovell, 2002). And this is particularly true with a view at the public sector. We outline some of the main caveats and to the extent possible these difficulties are taken into account in the analysis as specified below.

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[27] One could ask whether efficiency should not be measured in terms of the production of skills that are considered 'useful' for the economy (i.e. the massification of tertiary education may not be desirable in terms of employment rates). However, it can be argued that a workforce with a high number of tertiary qualifications (no matter in which discipline) possesses a set of competences that can be used flexibly across different sectors of the labour market. The signalling power of tertiary degrees is also considered to play an important role.

[28] See for instance Hanushek and Kimko (2000) on the link between schooling, labour-force quality and the economic growth of nations. The authors find that labour force quality (measured by comparative tests of mathematics and scientific skills) has a robust relationship with economic / productivity growth. In addition, they find that quality differences cannot simply be explained by differences in investing resources in schools.

Firstly, when analysing public spending on education, one is dealing with a multi-input – (e.g. infrastructure, wages for teachers, equipment, etc.) – multi-output relation (graduates, knowledge/ideas, etc.), in which inputs as well as outputs might be heterogeneous and sometimes not even comparable. It is therefore suggested to concentrate analytically on one specific area of public activity, as we do in this paper, since this facilitates the identification of input, output and outcome (see European Commission (2012) and also Mandl *et al.* (2008)).

Furthermore, time, history and stochastic influence may affect the system and the effect on output generally is lagged (Edquist, 1997). We take this effect into account by lagging the input variables.

Data quality is also a crucial issue. The identification of appropriate input and output indicators is often challenging since measurement may entail data availability issues. Also the identification of the appropriate contextual factors is not straightforward. Mandl *et al*. (2008) again point out that in that respect it is better to focus on a well-defined area of public spending – as we do in our analysis – rather than looking at public spending as a whole. As efficiency analyses are very sensitive to outliers, which would strongly affect the empirical results, an estimation technique that is relatively less sensitive to outliers would be advantageous (see Section 5 for more details).

Finally, the individual observation points for conducting an efficiency analysis – i.e. the decision making units (DMU) – are considered to be the entire public education systems in each of the observed EU Member States. This definition entails some questions: education systems are typically public, private-government dependent or private-independent. However, the available data does not allow distinguishing the percentage of funds the private government-dependent institutions receive from the government. St Aubyn *et al*. (2009) therefore check the Member States' education systems for the importance of public, government-dependent private and independent private institutions based on which they consider either only public or public and government-dependent private institutions. We consider that in most EU countries (apart from the UK) purely private spending on education (which does not include government-subsidies) is considered small enough to be discarded in the efficiency analysis.

5. ESTIMATION OF THE EFFICIENT FRONTIER

There are two general approaches to determining efficiency: (1) an approach based on estimation of a parametric model, such as Stochastic Frontier Analysis (SFA; see e.g. Kumbhakar and Lovell, 2000),[29] and (2) an approach based on linear programming and non- or semi-parametric models, such as Data Envelopment Analysis (DEA; see e.g. Cooper *et al*., 1999) or Free Disposal Hull (FDH; Deprins *et al*., 1984).[30] Both general approaches have been developed straightforwardly with considerable model-specific enhancements of the basic frontier concept and are frequently applied to empirical analyses (Cherchye, 2001; Martin *et al*., 2004). Since SFA allows testing for statistical hypotheses, taking account of statistical noise, providing parameter estimates of production factors, elasticities and controlling for relevant country-specific effects (see Section 5.2), we apply the parametric stochastic frontier technique.

[29] SFA is a parametric approach and requires specifying a functional form for the production function. It precludes assessing multiple inputs and outputs. Stochastic production frontier models used in SFA were first developed by Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broek (1977). Kumbhakar and Lovell (2000) provide an excellent introduction to SFA.

[30] DEA (Farrell 1957; Charnes *et al*. 1978) is a non-parametric approach based on linear programming, which consists of constructing a frontier for the best performers to be used as a point of reference for other observations/countries (i.e. a maximisation problem with respect to a set of constraints). The production function is assumed to be common across all units. Input-output combinations which are not on the frontier are considered as inefficient combinations. FDH is a variant of DEA in which the convexity assumption made in the DEA framework is relaxed. Several software packages allow performing DEA, e.g. the FEAR package in R.

5.1. STOCHASTIC FRONTIER ANALYSIS

The stochastic frontier problem for country i in year t can be written as follows:

$$y_{it} = f(x_{it-1}, \beta)\varepsilon_{it}(z_{it})\exp(\omega_{it})$$

where y_{it} denotes an educational output, x_{it-1} public spending on education with a lagged effect[31], and $f(.,.)$ an (education) production function for country i in time t. β represents a (set of) parameter to be estimated while ε_{it} represents the level of efficiency which depends on the environmental factors z_{it}. $exp(\omega_{it})$ denotes a set of random shocks.

If $\varepsilon_{it} = 1$, country i achieves the optimal output given the production technology $f(.,.)$. If $\varepsilon_{it} < 1$, country i is not using its inputs optimally given the production technology. Technical efficiency ε_{it} is assumed to be positive with the boundaries $0 < \varepsilon_{it} \leq 1$.

Taking natural logarithms of the equation above yields:

$$\ln(y_{it}) = \ln\{f(x_{it-1}, \beta)\} + \ln\big(\varepsilon_{it}(z_{it})\big) + \omega_{it}$$

Assuming k inputs (indexed by j) and, moreover, that the production function is log-linear and defining $u_{it}(z_{it}) = -\,ln(\varepsilon_{it}(z_{it}))$, we can write:

$$\ln(y_{it}) = \beta_0 + \beta_j \ln(x_{it-1}) - u_{it}(z_{it}) + \omega_{it}$$

with $u_{it} \geq 0$ as $0 < \varepsilon_{it} \leq 1$.[32]

When estimating the equation above, a key question is how to identify the inefficiency term $(-u_{it})$ through distributional assumptions on u_{it} and ω_{it}.[33] The econometric model is estimated on the basis of a panel dataset as the inclusion of time-variation allows relaxing the assumption of time-invariant inefficiencies.[34] The operational command for panel SFA in STATA is "xtfrontier". However, the user-written command by Belotti *et al.* (2013) "sfpanel" allows the inclusion of explanatory factors of the inefficiency term as well as a wider range of time-varying inefficiency models. For an overview and a brief discussion of available panel data stochastic frontier models see, for instance, Rashidghalam *et al.* (2016). Assuming a truncated normal distribution for the inefficiencies[35], technical inefficiencies are estimated based on the model by Battese and Coelli (1995) and respective on Greene (2005)[36]

[31] When empirically assessing the returns to spending on education one should be aware that often significant time lags occur between the actual spending and obtaining measurable results, such as e.g. achieving a degree, i.e. the latter is subject to accumulated spending over a longer time span and/or building upon earlier education and skill levels. This lag structure is proxied by one year-lag to still keep the number of observations large enough.

[32] Note that Kumbhakar and Lovell (2000) show that the cost function equivalent to the production function can be derived in a similar way. However, since data availability and measurement related to outputs of the education system are an important constraint; here the focus is on the production function problem.

[33] See Kumbhakar and Lovell (2000) for more details on how to identify these two error components.

[34] For cross-sectional output indicators such as the PIAAC indicator we choose the traditional model implemented in STATA's "frontier" command, which also allows specifying environmental factors determining inefficiency scores.

[35] Note that to use the "cluster" option in the STATA command – which computes standard errors accounting for intragroup correlation – it is argued that we need enough clusters for the asymptotic approximation to be reliable (views diverge how to define it; e.g. Angrist and Pischke (2008) define 40-50 clusters to be enough for reliability). As we have a small number of clusters (28) compared to our overall sample size (around 400) it is possible that the standard errors may be overestimated. We therefore estimate our results without the "cluster" option. "Cluster" modifies the standard error estimate but does not modify the parameter estimate.

[36] The use of the methodology proposed in Greene (2005) is appropriate if T is larger or equal to 10 (we typically have T between 11 and 16) to avoid inconsistent estimation of the error variances. The bias is also larger the larger N is compared to T. Since we have a macro panel with N=28 or N=19, we may not have such a severe bias as if we were estimating a firm panel with more than 1000 firms and only few Ts. The problem of inconsistent estimation of the error variances stems from the incidental parameter problem: a problem of statistical inference arising when the number of

when including fixed effects in the production function. The data used in the analysis and the respective data sources are presented in Annex I.

5.2. STOCHASTIC FRONTIER VS. DATA ENVELOPMENT ANALYSIS

The parametric approach (SFA) is based on econometric estimation methods, where technical inefficiencies are obtained from a compound error term, and makes it possible to test hypotheses, takes account of statistical noise, and provides parameter estimates of production factors, elasticities, etc. for possible further interpretation. An additional advantage of SFA is that it can be set up to include environmental factors directly in a one-step estimation procedure. SFA maximum likelihood estimation also allows for an unbalanced panel. Finally, SFA is less sensitive to outliers than DEA.

By contrast, the non-parametric approach (a mathematical programming technique), which has been traditionally assimilated into Data Envelopment Analysis (DEA), relies on a minimum of assumptions about the shape of the production possibility frontier (i.e. convexity and variable returns to scale) and does not require assumptions concerning the functional form or distributions of error terms. It is, overall, comparably easy to calculate. However, limitations remain in terms of considering time series, slacks, inbuilt attribution of inefficiencies to exploratory variables, etc.[37] General drawbacks of the DEA are also that corresponding results depend on the size and composition of the sample. In addition, outliers, measurement errors and statistical noise tend to bias significantly the results. Conceptually, the number of efficient units may be overestimated, i.e. existing inefficiencies may be underestimated[38] especially if (compared to the sample size) a relatively large amount of inputs and outputs are included. Bootstrapping can be used to address this issue.

5.3. POOLED REGRESSION VS. FIXED EFFECTS

Econometric estimation of efficiency via SFA also allows controlling for country specificities via fixed effects. Considering a common cross-country frontier (i.e. not controlling for fixed effects) is relevant under the assumption that the technology of the education production function is perfectly transferable across countries, i.e. country-specificities do not matter. While this may be true to some extent (in the sense that smart education policies are certainly at least partly exportable and countries can learn from good practices implemented elsewhere), it is arguably a fairly strong assumption. Including fixed effects allows relaxing this assumption and evaluating the efficiency of Member States controlling for their country-specific institutional settings. The latter approach is based on the idea that national education systems are all more or less specific and not easy to be changed in a short period as they have usually evolved over long time with evidence of strong path dependencies. Results for both specifications (analysing efficiency across countries and time as well as controlling for fixed effects and analysing efficiency within countries) are presented in order to provide a picture of both extreme cases with the actual space for efficiency improvements situated in between.

The SFA including fixed effects relies upon fewer variables since time-invariant (structural) factors are taken into account by the fixed effects. Such factors could be country-specific school systems, economic systems but to some extent also socio-economic background since it changes only slowly over the observed sample period and is therefore highly correlated with fixed effects. The SFA without fixed effects would require controlling explicitly for the environmental factors outlined above.

units (or cross-sections) is relatively large compared to the length of the panel, i.e. if T is fixed and N tends towards infinity (as is the case in micro panels), there are only few T units used to estimate N parameters. The within-transformation (or first differencing), as is done in the standard FE estimator (coded in xtreg, fe), is a solution to this problem and Belotti *et al*. (2013) have coded such an estimator also for stochastic frontier analysis. However, this estimator is difficult to implement.

37 See e.g. Coelli *et al*. (2005) for a general introduction to efficiency and productivity analysis.

38 Note that inefficiency may also be underestimated by assuming that the countries on the frontier are efficient (in the sense of best practice performers representing the best possible solution). See e.g. Dutu and Sicari (2016).

However, apart from family background, this data is hard to obtain and precisely due typically low variation over time often either not significant or posing problems for the convergence of the numerical optimisation algorithms. Therefore, for the model specification without fixed effects, it was decided to control only for family background.

6. EMPIRICAL RESULTS

This section discusses the estimated efficiency scores evaluated first across countries over time ('common EU frontier', i.e. no country specifics taken into account) and then within countries over time (i.e. controlling for the specifics of each country's education system by means of fixed effects).[39] An evaluation against these two different frontiers allows providing a picture of two extreme cases: A common EU frontier allows evaluating efficiency assuming that education systems are transferable across countries while a country-specific frontier allows relaxing this assumption by considering national education systems as country-specific, i.e. not easily changeable especially not in a short period. The actual space for efficiency improvements is situated between these two extreme cases.

To reflect the dimensions of educational outputs considered as most important, three input-output pairs are looked at: (1) total public spending on all education levels (pre-primary up to tertiary) and tertiary educational attainment (measure of 'quantity'), (2) public spending on compulsory schooling (pre-primary up to secondary) and PISA science scores[40] (proxy for 'quality') and (3) total public spending on all education levels and the rate of the 25-29 year old not in employment, education or training (NEETs)[41] (as a measure of 'inclusion').

6.1. ANALYSING EFFICIENCY ACCROSS COUNTRIES (COMMON EU FRONTIER)

Empirical results indicate that public spending on education is positively related with the quantity and quality of educational outputs. This finding holds across several measures of input-output pairs. (see Graphs 10-12 and Annex II). Graphs 10-12 show log-linearised production frontiers and respective Member States' distances to this frontier for all three output dimensions. The production functions shown in the graphs depict deterministic production functions derived from the SFA by removing the stochastic error component.

Moreover, according to the results obtained from the frontier estimations, some Member States manage to achieve high efficiency in all observed dimensions 'quantity', 'quality' and 'inclusion' such as e.g. the Netherlands and the United Kingdom. It should be noted, however, that the share of private sources in total spending on education is highest in the United Kingdom among the EU Member States as shown in Graph 5, both at the primary + secondary level and also at the tertiary level. This may improve efficiency and should be taken into account.[42]

Other countries strike a favourable balance in terms of two out of three dimensions, such as e.g. Germany or Sweden. The former is situated relatively close to the frontier both in terms of PISA scores and NEET rates but not so well in terms of tertiary educational attainment. It should be noted

[39] Further regression results related to additional input-output pairs are presented in Annex II.

[40] PISA scores do not only measure whether students can reproduce knowledge but also whether students can use their knowledge and can apply it to novel settings (inside and outside of school). We argue that the mathematics score among the PISA scores is the most easily comparable internationally. However, while PISA maths scores are strongly related with spending on secondary education, they are weakly related with the spending on pre-primary to secondary education (which is an indicator more likely to measure all the schooling that is relevant for PISA).

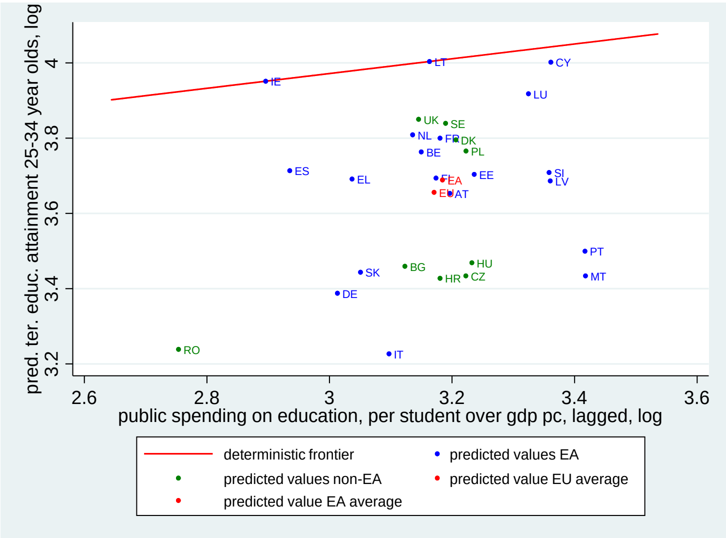
[41] The interpretation of the NEET indicator requires caution. It touches upon several areas such as unemployment, early school leaving or labour market discouragement. See Elder (2015) for a discussion on its interpretation.

[42] Furthermore, despite doing well on the three dimensions assessed here, in the United Kingdom evidence suggests that there may still be room for improvement in young adults' basic skill levels and in social mobility.

that the Austrian and the German systems may represent special cases in that respect due to the importance of the dual education system combining apprenticeships and vocational education. This system has proven successful in combating youth unemployment,[43] i.e. enhancing inclusion. However, the degrees typically offered are not classified as tertiary educational attainment.[44] In contrast, for instance, Bulgaria, Italy and Romania perform relatively weakly in terms of most of the three dimensions. And Cyprus and Lithuania are relatively striking cases as they perform quite efficiently in terms of producing high levels of tertiary attainment while these countries score much lower with regard to producing high levels of cognitive skills and inclusion.

In terms of tertiary educational attainment rates, in 2015, Ireland and Lithuania are setting the frontier as these countries achieve among the highest tertiary educational attainment rates in the sample while spending relatively moderately. With respect to Lithuania and some other Member States, it should be noted that the number of students is on a decreasing trend due to demographic developments, which could pose a question as to whether resources should be adapted (this may not be visible in the data as teacher wages are relatively low). Italy, Malta and Romania all have relatively low rates of tertiary educational attainment but differ in terms of their efficiency levels: While in Malta also the spending is relatively high in Romania it is comparably low.

Graph 10: **Tertiary educational attainment and spending on pre-primary to tertiary education, 2015**



Reading the graph: The graphical distance of the depicted observations to the frontier represents inefficiency (to be read as: 'how much more tertiary educational attainment could be achieved in a country given the same amount of spending on education but avoiding any wastes'). Blue and green dots represent EA and non-EA Member States respectively and red dots represent EU and EA aggregates.

Note: The estimation is based on panel data taking into account annual data per country (2002 – 2015), but the Graph represents the distance to the frontier in 2015 only.

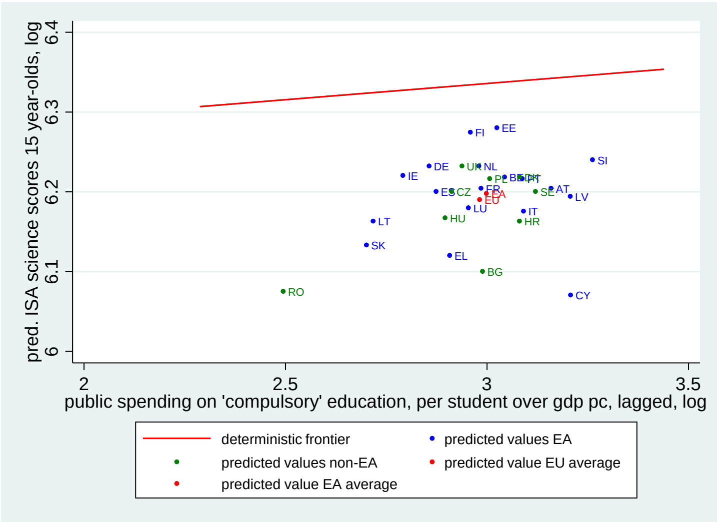
In terms of quality (PISA scores), no country is on the frontier in 2015. This implies that the frontier is set by observations in earlier years and efficiency has on average declined over time. Estonia and Finland are closest to the frontier, while Cyprus and Romania with very low levels of PISA scores – but high levels of spending in the case of Cyprus – are furthest.[45]

[43] See e.g. Eichhorst (2015).

[44] Indeed, the figures of tertiary educational attainment are comparably low in Austria and Germany, which is likely to be due to differences in reporting as many degrees classified as upper secondary levels are actually equivalent to tertiary levels in other countries. Note that Austria and Germany, when setting their national targets based on the EU2020 targets, decided to include ISCED 4 in the category of tertiary attainment (see http://ec.europa.eu/europe2020/pdf/annexii_en.pdf).

[45] Despite low levels of spending, Romania is not considered as efficient because the common production frontier is estimated to be at a high level even for low amounts of spending.

Graph 11: **PISA scores and spending on pre-primary to secondary education, 2015**

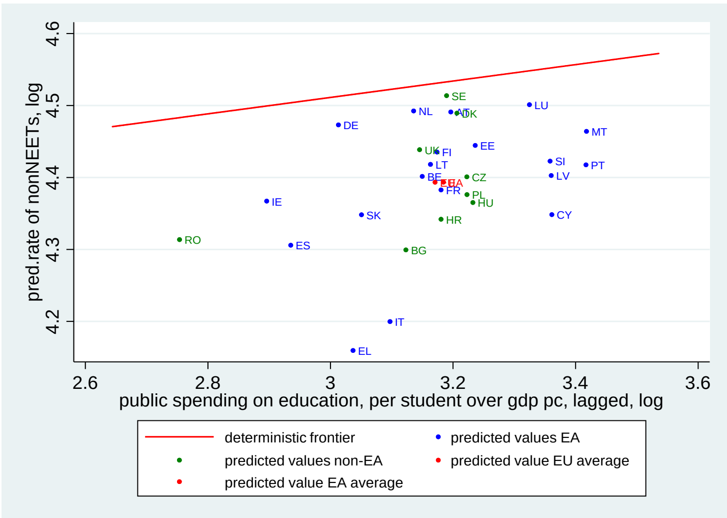


Reading the graph: The graphical distance of the depicted observations to the frontier represents inefficiency (to be read as: 'how much more in terms of cognitive skills could be achieved in a country given the same amount of spending on education but avoiding any wastes'). Blue and green dots represent EA and non-EA Member States respectively and red dots represent EU and EA aggregates.

Note: The estimation is based on panel data taking into account annual data per country (2002 – 2015), but the Graph represents the distance to the frontier in 2015 only.

In terms of NEET rates, the frontier is set by observations in earlier years implying a decline of efficiency in 2015 compared to earlier periods. Germany, the Netherlands and Sweden are closest to the frontier while Greece and Italy with very high NEET rates (i.e. low non-NEET rates) are relatively far away from the common frontier. The latter points to the fact that NEET rates, beyond the efficiency of spending on education, are driven also by a series of other factors which cannot be captured in the presented education production function framework (e.g. NEET rates driven by economic and financial crisis). Nevertheless, in the mid- to long-run, the empirical relation between education spending and NEET rates appears robust.

Graph 12: **NEET rates and spending on pre-primary to tertiary education, 2015**



Reading the graph: The graphical distance of the depicted observations to the frontier represents inefficiency (to be read as: 'how much more in terms of inclusion could be achieved in a country given the same amount of spending on education but avoiding any wastes'). Blue and green dots represent EA and non-EA Member States respectively and red dots represent EU and EA aggregates.

Note that for simplification here NEET rates are expressed as their negative (100–NEET rate). The estimation is based on panel data taking into account annual data per country (2002 – 2015), but the Graph represents the distance to the frontier in 2015 only.

Finally, parental education, considered as an environmental factor, was found to be generally important for efficiency of public spending on education (Annex II, 1-4). In particular, family background was found most relevant for achieving tertiary educational attainment, but less so for PISA scores and NEET rates).[46] Parents play certainly an important role in motivating / pushing their children to achieve a diploma, but, more importantly, this can also reflect a rising trend in the importance of higher education diplomas that has already set in among the parental generation.

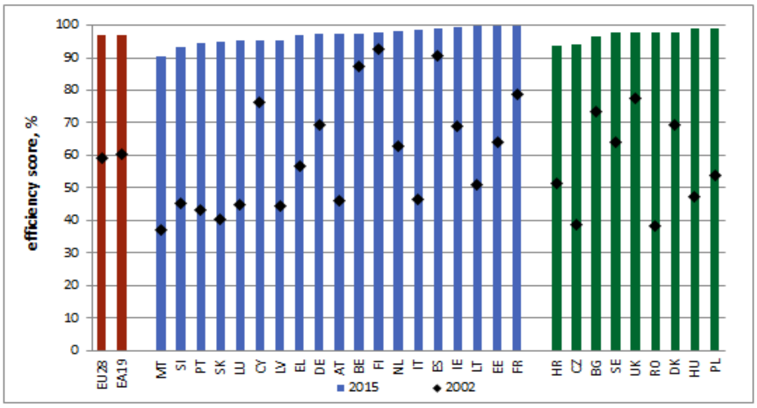
6.2. ANALYSING EFFICIENCY WITHIN EACH OF THE EU MEMBER STATES (COUNTRY SPECIFIC FRONTIERS)

Countries have their own characteristics and efficiency can be evaluated with respect to their own country-specific frontier. Graphs 13-15 below show efficiency scores obtained from a model where fixed effects are included and assumed to control for time-invariant country-specific characteristics such as institutional settings, involvement of different government levels, cultural specificities. Such aspects can be assumed as time-invariant at least in the short- and medium-term since corresponding changes evolve rather slowly over time and the empirical analysis covers only 13 years. It should be noted, however, that these fixed effects may also capture a measure of time-invariant inefficiency.

Public spending on education in EU Member States became more and more efficient over recent years, in particular in increasing the number of people with tertiary education. In fact, in terms of tertiary educational attainment rates, EU countries are close to their corresponding production frontiers in 2015 (see Graph 13). Hence, to improve further (i.e. increase tertiary educational attainment rates) the country-specific frontier would need to be shifted outwards by changing the production technology, i.e. amending the national education systems and/or introducing new education techniques.

In turn, the empirical results of the efficiency analyses suggest that there remains room for further improvement in terms of quality and inclusion. In contrast to the picture in terms of tertiary educational attainment rates, there is no common trend across all EU Member States in terms of PISA scores or NEET rates. In fact, efficiency has decreased in some countries while it has increased in others. Accordingly, an answer to the question where to put further emphasis in terms of education policy mix (quantity, quality and/or inclusion) must be country specific, while taking into account the observed best-practice examples from other countries.

Graph 13: **Efficiency scores related to tertiary educational attainment and spending on pre-primary to tertiary education**



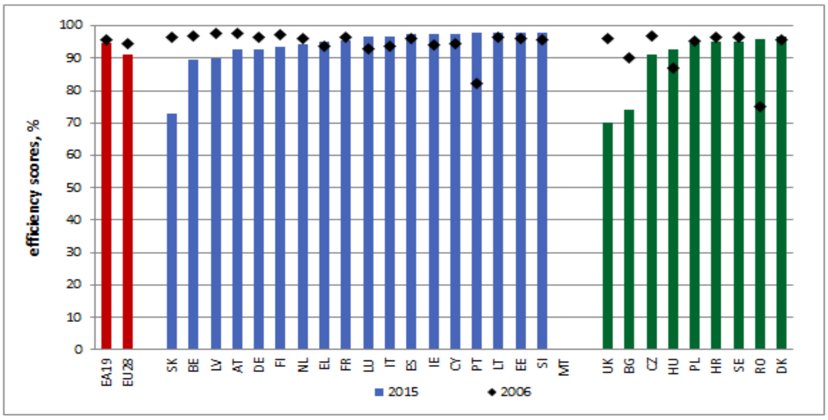
Notes: 2004 data for HR and PL.
EU28 and EA averages are unweighted as all indicators involved in the estimation of the efficiency scores are measured per population or per GDP per capita.

In terms of tertiary educational attainment rates, efficiency improvements were tremendous between 2002 and 2015, while spending remained comparably stable (Graph 13). For instance, in Malta tertiary educational attainment rose from 9% to 31% while spending remained at around 5%; similar numbers apply to Romania. In France, in turn, the efficiency improvements were not as large as tertiary educational attainments were already relatively high in 2002. All countries are very close to their individual frontier in

[46] It appeared, however, to be less influential with a view at achieving high PISA scores or low NEET rates.

2015, i.e. further significant improvements can only be made by amending the education system and thus shifting the country-specific frontiers outwards (changing the boundaries of the established national education system).

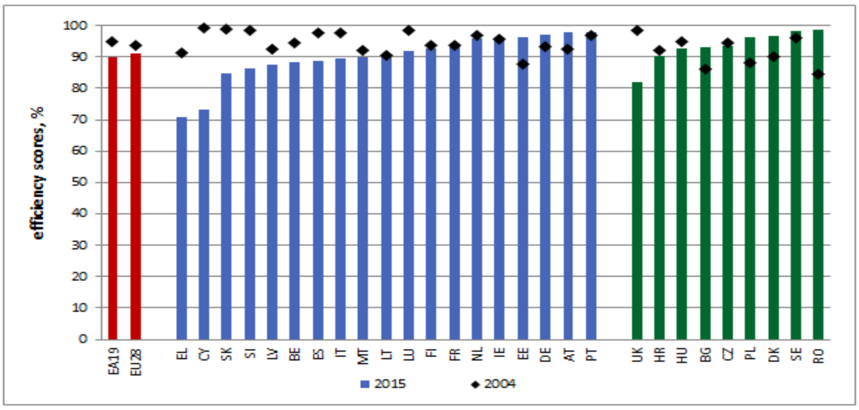
Graph 14: **Efficiency scores related to PISA science scores and spending on pre-primary to secondary education**



Notes: 2006 is used as it gives a higher geographical coverage (23 countries). 2008 values used for LV and RO; 2011 value for Ireland; 2012 value for Cyprus. Data not available for Malta (PISA science scores).
The EU and EA averages are weighted using population weights for 2006 and 2015 as outlined in the data annex in OECD (2012), "Quality Matters in Early Childhood Education and Care" where weights of skills assessment scores for Belgium based on its three different provinces are also based on population figures.

In terms of quality (PISA scores), about one third of the countries in the sample experience decreasing efficiency scores over time (Graph 14). This is quite alarming. However, a remarkable exception from this trend is Portugal which has improved efficiency considerably. Estonia is an interesting example as it rather close both to its own frontier and the common frontier. Empirical results suggest that all countries have room to improve efficiency when compared against their own frontier.

Graph 15: **Efficiency scores related to (non-)NEET rates and spending on pre-primary to tertiary education**



Notes: 2005 and 2009 values for HR and IE.
Non-weighed averages for the EU and the EA as all indicators involved in the estimation of the efficiency scores are measured per population or per GDP per capita.

With a view at NEET rates – i.e. looking at inclusion – evidence suggests that about two thirds of Member States experienced decreasing efficiency scores over time, i.e. also this trend goes arguably in the wrong direction. Empirical results suggest that Cyprus and Greece seem to have room to improve efficiency scores even when taking structural features as given while Romania and Sweden are found to be close to their own frontiers. While this points to the fact that Sweden is performing relatively well in terms of inclusion (since the country is also the closest to the common frontier in terms of NEET rates), for Romania the corresponding finding suggests that there is room for further improvement with a view at the best performing European countries. However, the empirical results suggest that further improvement in terms of inclusion in Romania (as far as determined by education spending) cannot be achieved with the current setting of the national education system (*inter alia* driven by removing inefficiencies in the system).

Overall, the empirical results indicate that some countries do well compared to a common frontier but could do even better as revealed by comparing them against their individual country-specific frontier and for some countries the opposite is true. For example, results would imply that the UK could improve efficiency in terms of PISA scores when it is compared to its own frontier while the country is found to 'do well' compared to the cross-country common frontier. Other countries are found to do well compared to their own frontier but appear to lack behind in a cross-country comparison, i.e. results suggest that further improving their efficiency given the existing education system comes to a limit and they could only improve their efficiency by making structural changes (i.e. shifting outwards their individual frontier and thus catching up with the common frontier). For example, Romania is found to be close to its own frontier in terms of NEET rates but appears to have room for improvement compared to a common frontier.

7. CONCLUSION

The empirical results presented in this paper illustrated that only a few countries in Europe currently spend public money on education fully efficiently, i.e. they get the maximum possible results with regard to all three observed dimensions (quantity, quality and inclusion). There is a number of countries which do well in terms of one or two of these aspects, but achieving the best results in all three appears difficult and may require rethinking of the existing education-policy mix. Depending on the reason that holds back further improvements – i.e. either wastes in spending on education (remaining inefficiencies) or operating close to boundaries of the country-specific education system (capacity constraints) – an appropriate policy response would be different. And there is arguably no blueprint for an ideal education-policy mix since the national education systems are all fairly specific (and not easy to change in short term); i.e. there is no one-size fits all solution for education policy making.

Nevertheless, empirical analyses like the one presented in this paper can help figures out where a country currently stands (1) relative to its own education systems' possibilities and (2) compared to other Member States. Policy recommendations can then be derived from comparing individual solutions and learning about best practices in terms of education policy and the design of the education system in countries that appear to be appropriate peers. And this could be particularly relevant in case of educational aspects which pose new challenges to Europe's existing education systems in terms of new learning needs and methods triggered e.g. by globalisation and/or disruptive technological progress (including digitalisation).[47] In this context, to foster both efficiency and equity[48], public spending policies need to be properly designed for each stage of the life-cycle (ranging from early childhood education to adult learning),[49] which should come together with a regulatory framework ensuring accountability and sufficient funding. Adult learning is an important complementary piece, including both private and public provision as well as diverse (formal, non-formal and informal) forms of learning, each of which require specific policy and cost-sharing arrangements between the

[47] The growing need for new skills warrants that education provides highly-relevant content, which means permanently updating curricula and possibly adjusting content to fit emerging requirements. In fact, the rapid digital transformation of the economy brought that many jobs now require some level of digital skills (as does participation in society at large). And beyond mere technical skills, the collaborative economy is changing business models, opening up opportunities and new routes into work, demanding different skill sets, and bringing challenges such as accessing upskilling opportunities. Access to services, including e-services, is changing and requires that users, providers and public administrations have sufficient digital skills. Yet, digital skills are lacking in Europe at all levels. Member States, businesses and individuals need to rise to the challenge and invest more in digital skills formation (including coding / computer science) across the whole spectrum of education and training, possibly starting already from early childhood education.

[48] Woessmann (2008) suggests an analytical conceptual framework to assess this issue. Note that this analysis is short on presenting empirical evidence. According to the authors this is due to poor data availability at the micro level.

[49] Note that there is some literature emphasising the importance of early childhood interventions, stressing that a person's educational performance is strongly shaped by early childhood learning (cf. the work of Heckman and co-authors at https://heckmanequation.org/resource/4-big-benefits-of-investing-in-early-childhood-development/).

government, businesses and individuals. Continuously updating and possibly adjusting curricula is another.

The main take-away messages arising from the presented analysis are the following:

As shown in our presentation of stylised facts, **educational attainment has increased in Europe** over the last two decades although it remains fairly heterogeneous across Member States. However, in terms of qualiy – building cognitive skills, Europe is just in the midfield rather than a leading world region. In fact, PISA scores in mathematics show that Europe is not leading among developed countries. The same is true for scores in sciences and reading. Moroever, in 2016, a significant proportion of young people was not employed, nor in training or education (20% of 25-29 years old in the Euro area).

Furthermore, we provided evidence that **education matters as the resilience of the labour force has been lower for low qualified during the crisis**, both for the EA and the EU28. The low-educated labour force has been systematically more exposed to the risk of unemployment, which has become even more apparent during the crisis period when the unemployment rate among the low-educated has sharply increased. Moreover, whereas the unemployment rate among the medium- and high-educated labour force has more or less returned to pre-crisis levels, this is not the case for the low-educated workers.

Our discussion of the literature on the economic case for investment in human capital and public intervention shows that **spending on education is a genuine and decisive public investment** in the sense that the expected returns are quite high (and may materialise over a long period). This holds both for individuals (private returns) as well as for the society at large, as human capital accumulation is a key driver for economic/productivity growth, innovation activities and also the resilience of an economy in times of crises. Moreover, next to economic returns, education is also an effective remedy to fight poverty and flatten the income distribution, i.e. many education policies are expected to deliver a double-dividend for the society at large.

Our analysis of the efficiency of public spending on education implies that **reinforcing human capital formation in Europe is not necessarily about spending more (public) money on education rather than spending it more efficiently**. In fact, according to the presented analyses, in terms of education attainment, efficiency of public spending has increased notably over the last 20 years. However, results suggest as well that significant room for improvement remains in many countries in terms of 'quality' and 'inclusion'. It is remarkable that some Member States have managed to achieve high efficiency in all observed dimensions 'quantity', 'quality' and 'inclusion', thus demonstrating that this is feasible and there is not necessarily a trade-off between achieving high scores in all relevant aspects. In some cases, rethinking national education policies (possibly implying structural reform) appears necessary to attain better performance.[50]

Our analysis also implies that **how to spend smartly and efficiently on human capital will in any case be country-specific**. Instrumental in assessing and improving the country-specific policy mix could be conducting comprehensive sectoral spending reviews on education (proved to be an appropriate instrument to identify and remove inefficiencies and/or achieve savings).[51] Indeed, spending reviews on education have been recently conducted or are ongoing in several Member States, i.e. they are completed in Malta and Slovenia and are on-going in Portugal. Moreover, learning from countries/regions that are seen as appropriate peers – i.e. benchmarking individual solutions against

[50] See Varga and in 't Veld (2014, esp. Figure 4, p.16) for the results of a QUEST simulation of the possible impact due to structural reforms in the field of human capital investments (resulting in changing skills compositions of the labour force). In a comparison of reform areas and their corresponding potential impacts, reforms in the education system (aside of labour market reforms) stand out as generating the most significant increases in GDP in the mid to long-run.

[51] See e.g. Vandierendonck (2014) for a valuable discussion on design, conduct and implementation of spending reviews.

other countries' / regions' best practices – appears to be vital. Closing the gap with the best-performing countries should be the ambitious goal.

Overall, the paper and its empirical findings are designed to provide a basis for an intensified debate on the highly pertinent issue of the efficiency of public spending on education. It could be a starting point for a number of avenues for further work on the topic – partly already touched upon throughout the paper. These could include for example (i) a deeper discussion of financing modes for education (public versus private), related to private versus social returns to education i.e. going beyond our focus on public spending, (ii) discussing the possibility of decreasing marginal returns to formal education and the rising need for upskilling and retraining and (iii) further analysing the 'quality drivers' of education systems.

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ANNEX I - Input and Output pairs and environmental factors

Table A.I.1: **Input-output pairs and environmental factors**[52]

Monetary input variables		**Output variables**		**Environmental factors**	
Public expenditure on total education per students over GDP per capita[53]	Expenditure data taken from COFOG; available 1995-2015; number of enrolled students taken from UOE; available 2000-2015; total population taken from AMECO	- tertiary educational attainment among the 25-34 population - PIAAC - young people not in employment, education or training among the 25-29 year-old population[54]	Eurostat (LFS); available 1995-2015 OECD; available 2015; people aged 16-65 Eurostat; available 2004-2016	- country-specific features such as education culture, main government level involved in educational spending etc. (captured by fixed effects) - [for NEETS:] GDP growth rate - parental education: the share of parents with tertiary education (we follow Dragomirescu-Gaina and Weber (2013) in proxying parental education by the educational attainment of the "parental cohort"; we define the parental cohort as a 20 year interval around an average childbirth age of 30 (constrained by the available maximum current age of 64) of youths aged between 15-34 (on average 25), which results in the age cohort 45-64; we subtract non-response observations).	GDP in constant prices (AMECO; 1961-2018) Eurostat (LFS); available 1995-2015
Public expenditure on (1) pre-primary and primary (ISCED 0-1[55]), (2) secondary (ISCED 2-3[56]) or (3)"compulsory"[57] (ISCED 0-3) schooling – per students over GDP per capita	Expenditure data taken from COFOG; available 1995-2015; number of enrolled students taken from UOE; available 2000-2015; total population taken from AMECO	- early school leavers among the 18-24 year-old population[58] - PISA[59]	Eurostat; available 1992-2016 OECD; available 2000-2015; 15-year olds, interpolated		
Public expenditure on tertiary education	ISCED 5-6; per students over GDP per capita; COFOG; available 1995-2015	- tertiary educational attainment among the 25-34 year old population - PIAAC	Eurostat (LFS); available 1995-2015 for OMS OECD; available 2015		

52 Variables need to be taken in logs in line with the derived model presented above. Environmental variables may be logged or not according to our belief on the relationship. Total spending is missing for Ireland from 2002 to 2006.

53 PPS correction is arguably insufficient to correct for the real-term differences in wages. This is a result of the composition of the commodity basket which is the basis for PPS-calculation. In particular, it includes non-tradable and tradable goods. The latter are often priced equally across countries.

54 "The indicator young people neither in employment nor in education and training, abbreviated as NEET, corresponds to the percentage of the population of a given age group and sex who is not employed and not involved in further education or training. The numerator of the indicator refers to persons meeting these two conditions: (1) they are not employed (i.e. unemployed or inactive according to the International Labour Organisation definition); (2) they have not received any education or training in the four weeks preceding the survey. The denominator is the total population of the same age group and sex, excluding the respondents who have not answered the question 'participation to regular education and training'." See: http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Young_people_neither_in_employment_nor_in_education_and_training_%28NEET%29).

55 In the COFOG database it seems that it is not possible to separate pre-primary and primary educational spending.

56 Secondary education refers to lower and upper secondary education (https://unstats.un.org/unsd/cr/registry/regcs.asp?Cl=4&Lg=1&Co=09.2)

57 To construct a proxy for spending on compulsory education (though upper secondary education is not compulsory) pre-primary to secondary education was added up.

58 "Early leaver from education and training, previously named early school leaver, refers to a person aged 18 to 24 who has completed at most lower secondary education and is not involved in further education or training." (see http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Early_leaver_from_education_and_training)

59 Note that COFOG expenditure on secondary education includes upper secondary education; 15 year-olds may not yet have reached the upper secondary education level. Note also that data for Malta on the PISA science score is only available in 2012.

ANNEX II – Regression results

Table A.II.1: **Stochastic Frontier Analysis based on Battese and Coelli (1995); EU**

	(1) Tertiary educational attainment of 25-34 year old population	(2) nonNEETs among the 25-29 year old population	(3) PIAAC numerical score (16-65 year old population)	(4) Tertiary educational attainment of 25-34 year old population	(5) PIAAC numerical score (16-65 year old population)	(6) PISA science score of 15 year old population	(7) nonESLs among the 18-24 year old population	(8) PISA science score of 15 year old population	(9) nonESLs among the 18-24 year old population	(10) PISA science score of 15 year old population	(11) nonESLs among the 18-24 year old population
Production function equation											
Total education expenditure per student over GDP per capita in % (1 lag; log)	0.196***	0.114***	0.198***								
	(0.00182)	(0.0248)	(2.06e-05)								
Tertiary education expenditure per student over GDP per capita in % (1 lag; 2 lags in case of PIAAC; log)				0.0738***	0.0432***						
				(0.0271)	(5.40e-06)						
Preprimary, primary+secondary education expenditure per student over GDP per capita in % (1 lag; log)						0.0407***	0.0277**				
						(0.0134)	(0.0118)				
Preprimary+primary education expenditure per student over GDP per capita in % (1 lag; log)								-0.0140	0.0299***		
								(0.00858)	(0.00589)		
Secondary education expenditure per student over GDP per capita in % (1 lag; log)										0.0202***	-0.0241***
										(0.00624)	(0.00589)
Constant	3.077***	4.169***	5.014***	3.411***	5.501***	6.214***	4.452***	6.293***	4.446***	6.192***	4.606***
	(0.00597)	(0.0789)	(6.58e-05)	(0.0973)	(1.70e-05)	(0.0395)	(0.0363)	(0.0253)	(0.0184)	(0.0190)	(0.0178)
Time trend	0.0191***	-	-	0.0226***	-	-	-	-	-	-	-
	(2.97e-05)			(0.00156)							
Ineffiency equation (a negative coefficient indicates a positive effect on efficiency)											
Constant	2.657***	0.226***	-	2.518***	-	0.287***	2.804***	0.391***	2.796***	0.373***	2.597***
	(0.102)	(0.0167)		(0.118)		(0.0205)	(0.717)	(0.148)	(0.699)	(0.123)	(0.627)
Share of parents with tertiary education in % (actual value or log)	-0.758***	-0.00485***	model does not converge	-0.726***	model does not converge	-0.0527***	-1.252***	-0.156*	-1.246***	-0.146**	-1.146***
	(0.0365)	(0.000821)		(0.0434)		(0.00682)	(0.363)	(0.0860)	(0.353)	(0.0690)	(0.315)
GDP growth in %	-	-0.00478***	-	-	-	-	-	-	-	-	-
		(0.00143)									
Variance of inefficiencies (usigma)	-2.871***	-4.962***	-5.367***	-2.823***	-5.574***	-6.090***	-2.959***	-5.006***	-2.999***	-5.121***	-3.083***
	(0.0889)	(0.126)	(0.316)	(0.103)	(0.316)	(0.0828)	(0.367)	(0.677)	(0.361)	(0.559)	(0.349)
Variance of random error term (vsigma)	-20.77**	-9.112***	-38.25	-7.874***	-36.63	-20.12	-7.078***	-7.002***	-7.135***	-7.044***	-7.145***
	(10.21)	(1.320)	(348.9)	(0.691)	(181.7)	(16.78)	(0.195)	(0.172)	(0.190)	(0.161)	(0.182)
Likelihood ratio test of usigma=0	-	-	0.002	-	0.009	-	-	-	-	-	-
Signal-to-noise ratio	7716.23***	7.962296***	13900000***	12.49557***	5532054***	1113.652***	7.844069***	2.713543***	7.907964***	2.615621***	7.621263***
Observations	437	360	20	412	20	339	406	339	406	349	416
Average number of years	15.6	12.9	1	14.7	1	12.1	14.5	12.1	14.5	12.5	14.9
Number of countries	28	28	20	28	20	27	28	27	28	27	28

Notes: (1) Standard errors in parentheses and *** p<0.01, ** p<0.05, * p<0.1; (2) results are expressed in terms of elasticities; (3) results are robust to taking further lags of the spending variables; (4) significant standard deviations of the ineffiency terms (usigma) and significant signal to noise ratios indicate the existence of ineffiencies. In the case of cross-sectional regressions employed with PIAAC scores a likelihood ratio test is reported to test for the signifiance of the inefficiencies; (5) model (5) is estimated using the STATA command "frontier" as it is a cross-sectional rather than a model based on panel data; (6) PISA data is unavailable for Malta; (7) dependent variables are expressed in logs of %. PISA and PIAAC results are reported as log of value on a scale constructed using a generalised form of the Rasch model as described by Adams, Wilson and Wang (1997). For each domain (reading, mathematics and science), a scale is constructed with a mean score of 500 and standard deviation of 100 among OECD countries. (8) parental background is taken in logs for the regression reported in column (2).

Table A.II.2: **Stochastic Frontier Analysis based on Greene (2005) – including country fixed effects; EU**

	(1) Tertiary educational attainment of 25-34 year-old population	(2) nonNEETs among the 25-29 year old population	(3) Tertiary educational attainment of 25-34 year old population	(4) PISA science score of 15 year old population	(5) nonESLs among the 18-24 year old population	(6) PISA science score of 15 year old population	(7) nonESLs among the 18-24 year old population	(8) PISA science score of 15 year old population	(9) nonESLs among the 18-24 year old population
Production function equation									
Total education expenditure per student over GDP per capita in % (1 or 2 lags; log)	0.291***	0.733***							
	(1.44e-05)	(0.00979)							
Tertiary education expenditure per student over GDP per capita (1 lag)			-0.0337***						
			(0.00326)						
Preprimary, primary +secondary education expenditure per student over GDP per capita (1 lag)				0.930***	0.692***				
				(0.0107)	(0.00662)				
Preprimary+primary education expenditure per student over GDP per capita (1 lag)						0.819***	0.711***		
						(0.0161)	(0.00906)		
Secondary education expenditure per student over GDP per capita (2 lags)								1.044***	0.720***
								(2.52e-06)	(3.48e-06)
Inefficiency equation (a negative coefficient indicates a positive effect on efficiency)									
Variance of inefficiencies (usigma)	-2.605***	-4.985***	-2.791***	-5.038***	-5.138***	-4.283***	-11.33***	-3.437***	-3.984***
	(0.0957)	(0.259)	(0.0989)	(0.191)	(0.169)	(0.196)	(3.962)	(0.111)	(0.101)
Variance of random error term (vsigma)	-35.81	-7.696***	-38.10	-6.149***	-6.693***	-5.665***	-4.336***	-37.14	-38.18
	(94.54)	(0.831)	(177.1)	(0.213)	(0.239)	(0.257)	(0.0733)	(197.7)	(259.4)
Signal-to-noise ratio	16300000***	3.878902***	46400000***	1.742953***	2.176371***	1.995399***	0.0303433***	20900000***	26600000***
Observations	437	358	412	338	406	338	406	327	391
Average number of years	15.6	12.9	14.7	12.5	14.5	12.5	14.5	12.1	14.9
Number of countries	28	28	28	27	28	27	28	27	28

Notes: (1) Standard errors in parentheses and *** p<0.01, ** p<0.05, * p<0.1; (2) results are expressed in terms of elasticities; (3) results are robust to taking further lags of the spending variables; (4) significant standard deviations of the ineffiency terms (usigma) and significant signal to noise ratios indicate the existence of ineffiencies. (5) model (5) is estimated using the STATA command "frontier" as it is a cross-sectional rather than a model based on panel data; (6) PISA data is unavailable for Malta; (7) dependent variables are expressed in logs of %; PISA and PIAAC results are reported as log of value on a scale constructed using a generalised form of the Rasch model as described by Adams, Wilson and Wang (1997); for each domain (reading, mathematics and science), a scale is constructed with a mean score of 500 and standard deviation of 100 among OECD countries.

Table A.II.3: **Stochastic Frontier Analysis based on Battese and Coelli (1995); EA**

	(1) Tertiary educational attainment of 25-34 year old population	(2) nonNEETs among the 25-29 year old population	(3) PIAAC numerical score (16-65 year old population)	(4) Tertiary educational attainment of 25-34 year old population	(5) PIAAC numerical score (16-65 year old population)	(6) PISA science score of 15 year old population	(7) nonESLs among the 18-24 year old population	(8) PISA science score of 15 year old population	(9) nonESLs among the 18-24 year old population	(10) PISA science score of 15 year old population	(11) nonESLs among the 18-24 year old population
Production function equation											
Total education expenditure per student over GDP per capita in % (1 lag; log)	0.196***	0.148***	0.0973								
	(0.00103)	(0.0289)	(0.0891)								
Tertiary education expenditure per student over GDP per capita in % (1 lag; 2 lags in case of PIAAC; log)				0.0949***	0.0432***						
				(0.0276)	(5.16e-06)						
Preprimary, primary+secondary education expenditure per student over GDP per capita in % (1 lag; log)						0.0135	0.00373				
						(0.0142)	(0.0115)				
Preprimary+primary education expenditure per student over GDP per capita in % (1 lag; log)								-0.0168	0.0438***		
								(0.0124)	(0.00776)		
Secondary education expenditure per student over GDP per capita in % (1 lag; log)										0.00992	-0.0233***
										(0.00784)	(0.00724)
Constant	3.077***	4.025***	5.287***	3.347***	5.501***	6.272***	4.520***	6.346***	4.409***	6.283***	4.601***
	(0.00366)	(0.0927)	(0.338)	(0.101)	(1.61e-05)	(1.009)	(0.0345)	(0.999)	(0.0232)	(1.104)	(0.0223)
Time trend	0.0191***	-	-	0.0226***	-			-	-		
	(7.98e-05)			(0.00176)							
Ineffiency equation (a negative coefficient indicates a positive effect on efficiency)											
Constant	2.539***	0.155***	-	2.389***	-	0.287	1.923***	0.260	1.871***	0.282	1.932***
	(0.129)	(0.0371)		(0.151)		(1.008)	(0.316)	(0.999)	(0.304)	(1.104)	(0.311)
Share of parents with tertiary education in % (actual value or log)	-0.732***	-0.00525**	-	-0.702***	-	-0.0621***	-0.772***	-0.0579***	-0.745***	-0.0601***	-0.776***
	(0.0465)	(0.00216)		(0.0564)		(0.00680)	(0.150)	(0.00726)	(0.143)	(0.00668)	(0.147)
GDP growth in %	-	-0.0114**	-	-	-	-		-	-	-	-
		(0.00462)									
Variance of inefficiencies (usigma)	-2.793***	-4.537***	-8.452	-2.693***	-5.438***	-8.574	-3.629***	-9.014	-3.616***	-8.535	-3.695***
	(0.115)	(0.312)	(30.77)	(0.137)	(0.365)	(20.39)	(0.270)	(28.68)	(0.263)	(18.60)	(0.266)
Variance of random error term (vsigma)	-22.15	-7.302***	-6.270***	-8.192***	-37.00	-6.590**	-7.309***	-6.547***	-7.851***	-6.638**	-7.294***
	(17.88)	(0.713)	(1.308)	(0.652)	(216.4)	(2.806)	(0.229)	(2.433)	(0.348)	(2.793)	(0.198)
Likelihood ratio test of usigma=0	-	-	0.489	-	0.045	-	-	-	-	-	-
Signal-to-noise ratio	15966.46***	3.984337 ***	0.34	15.63092***	7135258***	0.3708523**	6.295154***	0.2911495	8.308967***	0.387379**	6.047397***
Observations	298	243	15	281	15	219	276	219	276	229	276
Average number of years	15.7	12.8	1	14.8	1	11.5	14.5	11.5	14.5	12.1	15.1
Number of countries	19	19	15	19	15	19	19	19	19	19	19

Notes: (1) Standard errors in parentheses and *** p<0.01, ** p<0.05, * p<0.1; (2) results are expressed in terms of elasticities; (3) results are robust to taking further lags of the spending variables; (4) significant standard deviations of the ineffiency terms (usigma) and significant signal to noise ratios indicate the existence of ineffiencies. In the case of cross-sectional regressions employed with PIAAC scores a likelihood ratio test is reported to test for the signifiance of the inefficiencies; (5) model (5) is estimated using the STATA command "frontier" as it is a cross-sectional rather than a model based on panel data; (6) PISA data is unavailable for Malta; (7) dependent variables are expressed in logs of %. PISA and PIAAC results are reported as log of value on a scale constructed using a generalised form of the Rasch model as described by Adams, Wilson and Wang (1997). For each domain (reading, mathematics and science), a scale is constructed with a mean score of 500 and standard deviation of 100 among OECD countries.

Table A.II.4: **Stochastic Frontier Analysis with fixed effects based on (Greene 2005); EU**

	(1) Tertiary educational attainment of 25-34 year-old population	(2) nonNEETs among the 25-29 year old population	(3) Tertiary educational attainment of 25-34 year old population	(4) PISA science score of 15 year old population	(5) nonESLs among the 18-24 year old population	(6) PISA science score of 15 year old population	(7) nonESLs among the 18-24 year old population	(8) PISA science score of 15 year old population	(9) nonESLs among the 18-24 year old population
				Production function equation					
Total education expenditure per student over GDP per capita in % (1 or 2 lags; log)	1.288***	0.740***							
	(0.153)	(0.00602)							
Tertiary education expenditure per student over GDP per capita (1 lag)			-0.0565***						
			(2.64e-06)						
Preprimary, primary +secondary education expenditure per student over GDP per capita (1 lag)				0.649***	-1.278***				
				(0.00641)	(0.0110)				
Preprimary+primary education expenditure per student over GDP per capita (1 lag)						0.569***	0.682***		
						(0.00898)	(0.00867)		
Secondary education expenditure per student over GDP per capita (2 lags)								0.933***	-0.616***
								(0.0102)	(0.00968)
				Inefficiency equation (a negative coefficient indicates a positive effect on efficiency)					
Variance of inefficiencies (usigma)	-3.836***	-4.824***	-2.825***	-6.310***	-4.316***	-12.92*	-5.243***	-5.402***	-4.538***
	(0.381)	(0.186)	(0.119)	(0.278)	(0.196)	(7.237)	(0.228)	(0.298)	(0.190)
Variance of random error term (vsigma)	-4.136***	-8.445***	-36.93	-7.066***	-5.452***	-5.846***	-5.875***	-6.007***	-8.128***
	(0.314)	(0.721)	(255.8)	(0.272)	(0.222)	(0.0999)	(0.198)	(0.270)	(0.967)
Signal-to-noise ratio	1.162259***	6.115616***	25500000***	1.459423***	1.764014***	0.0291249***	1.371544***	1.353467***	6.016661 ***
Observations	298	242	281	218	276	218	276	215	269
Average number of years	15.7	12.7	14.8	12.1	14.5	12.1	14.5	11.9	14.2
Number of countries	19	19	19	18	19	18	19	18	19

Notes: (1) Standard errors in parentheses and *** p<0.01, ** p<0.05, * p<0.1; (2) results are expressed in terms of elasticities; (3) results are robust to taking further lags of the spending variables; (4) significant standard deviations of the ineffiency terms (usigma) and significant signal to noise ratios indicate the existence of ineffiencies. (5) model (5) is estimated using the STATA command "frontier" as it is a cross-sectional rather than a model based on panel data; (6) PISA data is unavailable for Malta; (7) dependent variables are expressed in logs of %; PISA and PIAAC results are reported as log of value on a scale constructed using a generalised form of the Rasch model as described by Adams, Wilson and Wang (1997); for each domain (reading, mathematics and science), a scale is constructed with a mean score of 500 and standard deviation of 100 among OECD countries.

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