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Efficiency in Education. A review of literature and a way forward[1]

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Abstract

This paper provides an extensive and comprehensive overview of the literature on efficiency in education. It summarizes the earlier applied inputs, outputs and contextual variables, as well as the used data sources of papers in the field of efficiency in education. Moreover, it reviews the papers on education that applied methodologies as Data Envelopment Analysis, Malmquist index, Bootstrapping, robust frontiers, metafrontier, or Stochastic Frontier Analysis. Based on the insights of the literature review, a second part of the paper provides some ways forward. It attempts to establish a link between the parametric 'economics of education' literature and the (semi-parametric) 'efficiency in education literature'. We point to the similarities between matching and conditional efficiency; difference-in-differences and metafrontiers; and quantile regressions and partial frontiers. The paper concludes with some operative directions for prospective researchers in the field.

Keywords: Efficiency; Education; Review; Education Economics; Operational Research

JEL-classification: I21; I20; D61

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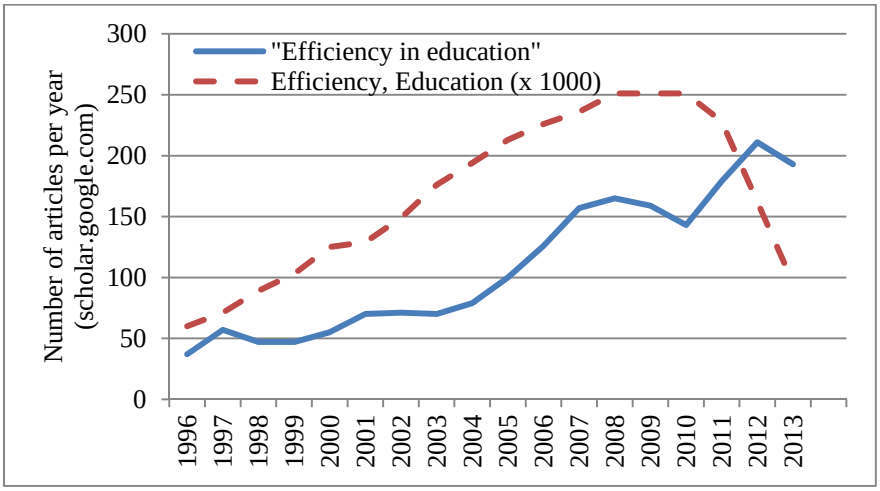
1. Introduction

The way public funding is spent receives an increased attention in times of austerity. Angel Gurria, OECD Secretary-General, states in the influential OECD 2013 report 'Education at a glance' that "*what matters more are the choices countries make in how to allocate that spending and the policies they design to improve the efficiency and relevance of the education they provide*" (OECD, 2013, p. 15). Ever since the pioneering work by Bessent and Bessent (1980), Charnes *et al.* (1978, 1981) and Bessent *et al.* (1982) efficiency in education is increasingly important. Education provision is considered as efficient if its producers make the best possible use of available inputs. In an inefficient system there are possibilities to increase the educational attainments for a given spending level, or to decrease the educational resources for given educational attainments (Bessent and Bessent, 1980).

Efficiency in education is a topic of intense debate among politicians, teachers, and other educational stakeholders. In addition to the increased awareness for public sector efficiency, the increasing cost for education might be a reason for the interest of efficiency in education. On average, education becomes more expensive than other commodities (Eurostat, 2014). For some countries, e.g., the Netherlands, the costs for education fall below the consumer price index. In other countries, e.g., the UK, education is increasingly expensive.

The increasing cost for education (at least relatively to the average inflation) is translated in a growing literature on the efficiency of education (e.g. recently Johnes, 2014b). Figure 1 presents the number of papers in a given year as referenced on Google.scholar.com. We observe for most years a larger number of papers on the themes efficiency and education (dashed line if the words are used separately in the paper), and 'efficiency of education' (full line if the words have been used in this exact phrase). Only for the most recent years, the number of papers on 'education' and 'efficiency' decreased.

Figure 1: Papers on efficiency in education (source: google.scholar.com)



Efficiency (meaning doing things right) in education should not been seen separately from effectiveness (meaning doing the right things) and value for money. Since the results of the education process are social constructs, there is always an effectiveness frontier, i.e. an acceptable level of the desired outcomes (e.g., quality, education attainments, equality of learning outcomes), which may be realized. Due to the social sensitivity of each education system, one should always

bear in mind not only the simple link between what is invested in the system and the results of education, but also take care of the balance between the dimensions of efficiency and effectiveness in creating education policy (OECD, 2006).

The education sector provides an excellent context for efficiency assessment as its institutions are non-profit, produce multiple outputs and there is an absence of output and input prices. Consequently, defining and estimating the production technology that students use to acquire knowledge is a complex task (Worthington, 2001; Johnes, 2014b). The toolbox to study efficiency in education comprises non-parametric methods based on mathematical optimization models (such as data envelopment analysis, DEA, or free disposal hull, FDH, e.g. Bradley *et al.*, 2010; Haelermans and De Witte, 2012), or parametric methods (such as stochastic frontier analysis – SFA, e.g. Gronberg *et al.*, 2012; Grosskopf *et al.*, 2009).[3] We come back to those procedures in Section 2. The toolbox of effectiveness research comprises experiments, difference-in-differences and instrumental variable estimations. Most of the effectiveness literature deals with the question 'what works in education'. In this respect, Teddlie and Reynolds (2000) provide a review of over 1,500 studies on educational effectiveness in over 80 countries[4]. As stated in their book, educational effectiveness research looks at all the variables within education institutions in particular, and the educational system in general, that might affect the learning outcomes of students in their academic and social development. The work of Teddlie and Reynolds (2000) follows a typical pedagogical point of view. Alternative reviews on effective educational strategies are the 'What works clearinghouse' (ies.ed.gov/ncee/wwc) or the Best evidence Encyclopedia (www.bestevidence.org, www.bestevidence.nl).

The efficiency and effectiveness literatures are currently rather distinct literatures. An exception is Powell *et al.* (2012), who assess the expenditures and institutional characteristics of U.S. institutions of higher education to determine how they relate to the efficiency and effectiveness of those institutions. Other studies have attempted to link institutional finances to organizational effectiveness, primarily using some measure of student retention and graduation rates (e.g. Titus, 2006). Finally, Cherchye, Perelman and De Witte (2015) provide a methodological framework and educational application on how efficiency with and without resource constraints can be interpreted in terms of the tradeoff between efficiency and effectiveness.

This paper contributes to the literature by discussing educational efficiency in a structured way and by providing methodological and practical steps forward. First, we review the existent literature on efficiency in education by covering all articles which have applied frontier efficiency measurement techniques up to the year 2015. We build further on the work of four previous papers that review this literature. The first one is the paper by Worthington (2001), who lists the papers that apply frontier techniques for measuring efficiency in education until 1998. Secondly, Johnes (2004) describes which techniques have been used for measuring efficiency and identifies the drawbacks and uses of applying different methods in the context of education. Then, Emrouznejad

[3] See Lovell (1993) or Coelli *et al.* (1998) for a detailed discussion on the methods for analyzing technical efficiency.

[4] There are a large number of publications which review the literature about educational effectiveness research (e.g. Mortimore, 1991; Reynolds, 2010; Reynolds *et al.*, 1994; Teddlie, 2010, among others).

et al. (2010) collect the first 30 years of scholarly literature in the non-parametric frontier technique 'Data Envelopment Analysis', and lastly, Johnes (2014b) discusses how operational research has been applied to education. The author provides an overview of the problems faced by government, managers and consumers of education, and the operational research techniques which have been applied to improve operations and provide solutions.

To the best of the authors' knowledge, the literature review presented in this paper appears to be the most complete source of references on frontiers methods and its applications in measuring the efficiency of education institutions. We list the applied inputs, outputs and contextual variables, as well as the levels of analysis and methodological approaches.

As a second contribution, we establish a link between the standard 'economics of education' literature and the non-parametric efficiency literature. We discuss what they could learn from each other, and how their methodological techniques resemble in various ways. We discuss the similarities between matching and conditional efficiency, difference-in-differences and metafrontiers, and quantile regressions and partial frontiers, and measuring value added. Insights in the similarities can foster further research on the efficiency in education.

It should be noted that this paper is not a starting point for novice scholars in the field of efficiency in education. On the contrary, it is a paper written for more advanced scholars who are familiar with the concepts and methodologies of the efficiency literature. Scholars who would like to familiarize with the methodologies are refereed to standard textbook by Fried et al. (2008). This paper aims to give experienced researchers an easy and quick overview of the literature, the selection of inputs, outputs and contextual variables, and some inspiration for their further work.

The remainder of the paper unfolds as follows. In section 2 we present an extensive literature review on measuring efficiency in education from the perspective of operational research literature, while section 3 provides the methodological steps forward. A final section concludes with some operative directions for prospective researchers in the field.

2. A systematic review on efficiency in education

2.1. Scope of review

For this review, we have used the search engines ERIC (Educational Resources Information Center) and ISI Web of Science (WOS). On the one hand, ERIC is an online digital library of education research and information and is sponsored by the Institute of Education Sciences of the United States Department of Education. It provides a comprehensive, searchable, Internet-based bibliographic and full-text database of education research and information for educators, researchers, and the general public. On the other hand, ISI WOS is the world's leading academic citation indexing database and search service, which is provided by Thomson Reuters. ISI WOS covers the sciences, social sciences, arts and humanities and it provides bibliographic content and tools to access, analyze, and manage research information. It has a multidisciplinary coverage of over 10,000 high impact journals in science, social sciences, as well as international proceedings for over 120,000 conferences.

As a criterion for inclusion, we have pragmatically restricted the literature search to English language literature. The data were retrieved from July to December 2014 and we included empirical papers starting from 1977 until 2015[5]. We decided to stablish 1977 as the starting point given that this is the year when Aigner *et al.* (1977) published their seminal paper on SFA. Nevertheless, we might note that in 1978 Charnes *et al.* wrote the paper "Measuring the efficiency of decision making units" which became the seminal paper on DEA. These two years represent an interesting starting point from the survey of frontier efficiency measurement techniques in education. The descriptors and keywords "efficiency", "education", "frontier", "school", "performance measurement", "primary education", "higher education", "academic achievement", "educational assessment", "DEA", "SFA" and "economic of education" have been used in search for abstracts. Using these keywords, ERIC and ISI WOS provided us with more than 250 papers. To limit the total number of hits, we also limited the search to those articles for which the full text was available. Finally, we obtained 221 papers.

The next subsections outline the main findings of this literature review from several angles. First, we discuss the different levels of analysis used to assess performance in education. Second, we discuss the main input/output variables specified in the education production literature at student, family, education institution and community level. Then, we revise another set of variables beyond internal control, namely non-discretionary (environmental) variables, which are determinants of educational achievement. Finally, we focus on which methodological approaches have been applied to study the efficiency of educational production. This extensive literature review might constitute an opportunity of deriving more detailed indicators about education institutions' resources, results and environmental variables for future research.

2.2. Levels of analysis

Efficiency in education has been widely studied at various teaching levels (see Table 1). Most studies focus either at the university level (88 studies in total), the school/high school level (57 studies in total), or the level of a district, county or city (44 in total). Only 9 studies were focused on the national level (country or multi-county). The latter is surprising as comparable national data sets (e.g. PISA, TIMSS, PIRLS) are increasingly available during the last few years. For future research, it seems very fruitfull to undertake more research about differences across countries and educational systems. Compared to the amount of papers at school/high school, university or district levels, there are few papers (i.e., only 23 papers) that focus on the student level. This is probably due to the lack of individual data in several countries. More research on this topic is needed. Finally, only two papers paid attention to the classroom level.

The majority of articles (143 in total) use national databases provided by the national Department of Education of each country (or similar agencies). Given the standardized way the databases are set up, this has the advantage that the data are less prone to measurement errors or diverging definitions (Table A1 in the Appendix[6] classifies the origin of the databases used in the papers reviewed).

[5] Papers from 2015 can be found online before the year starts.
[6] The Appendix is available from authors upon request.

2.3. Determinants of efficiency in education

This section reviews the main variables used to assess efficiency in education through frontier methods. Starting from a production function, it is assumed that the education institution transforms inputs into outputs through a production process (Worthington, 2001). The educational production function represents the maximum output that can be achieved given the available resources and serves as a reference to calculate the inefficiency of those who fail to achieve it. In addition, the production function can be influenced by various factors which are beyond the control of the evaluated observation.

Table 1: Level of analysis

Business School, College, Department, Research Program, Researchers/University teachers, University levels studies
Observed in: Taylor and Johnes (1989), Beasley (1990) (1995), Kao and Yang (1992), Johnes and Johnes (1993) (1995) (2009), Breu and Raab (1994), Sinuany *et al.* (1994), Johnes (1996), Mar-Molinero (1996), Athanassopoulos and Shale (1997), Madden *et al.* (1997), Haksever and Muriagishi (1998), McMillan and Datta (1998), Sarrico and Dyson (2000), Thursby (2000), Ying and Sung (2000), Avkiran (2001), Korhonen *et al.* (2001), Abbott and Doucouliagos (2002) (2003) (2009), Izadi *et al.* (2002), Moreno and Tadepali (2002), Flegg *et al.* (2004), Cherchye and Vanden Abeele (2005), Emrouznejad and Thanassoulis (2005), Joumady and Ris (2005), Stevens (2005), Agasisti and Dal Bianco (2006) (2009), Bonaccorsi *et al.* (2006), Bougnol and Dulá (2006), Casu and Thanassoulis (2006), Giménez and Martínez (2006), Johnes (2006a) (2006b) (2006c) (2008) (2014a), Koksal and Nalcaci (2006), McMillan and Chan (2006), Agasisti and Salerno (2007), Anderson *et al.* (2007), Fandel (2007), Tauer *et al.* (2007), Johnes *et al.* (2008), Johnes and Yu (2008), Kao and Hung (2008), Kuo and Ho (2008), Ray and Jeon (2008), Worthington and Lee (2008), Abramo and D'Angelo (2009), Agasisti and Johnes (2009) (2010), Cokgezen (2009), Colin-Glass *et al.* (2009), Tyagi *et al.* (2009), Agasisti and Pérez-Esparrells (2010), De Witte and Rogge (2010), Dehnokhalaji *et al.* (2010), Kantabutra and Tang (2010), Katharaki and Katharakis (2010), Kempkes and Pohl (2010), Rayeni and Saljooghi (2010), Agasisti *et al.* (2011) (2012), Johnes and Schwarzenberger (2011), Kounetas *et al.* (2011), Kuah and Wong (2011), Lee (2011), Thanassoulis *et al.* (2011), Wolszczak-Derlacz and Parteka (2011), Eff *et al.* (2012), Kong and Fu (2012), Sexton *et al.* (2012), Tochkov *et al.* (2012), Bayraktar *et al.* (2013), De Witte and Hudrlikova (2013), De Witte *et al.* (2013), Johnes (2013), Lu and Chen (2013), Zoghbi *et al.* (2013), Agasisti and Bonomi (2014), Duh *et al.* (2014), Mainardes *et al.* (2014), Nazarko and Saparauskas (2014).
Classroom, Course levels studies
Observed in: Cooper and Cohn (1997), De Witte and Rogge (2011).
Council, County, District, City levels (municipality, Local Education Authorities, Province) levels studies
Observed in: Butler and Monk (1985), Sengupta and Sfeir (1986) (1988), Jesson *et al.* (1987), Sengupta (1987), Smith and Mayston (1987), Mayston and Jesson (1988), Färe *et al.* (1989), Callan and Santerre (1990), Barrow (1991), Ganley and Cubbin (1992), McCarty and Yaisawarng (1993), Chalos and Cherian (1995), Ruggiero *et al.* (1995), Cubbin and Zamani (1996), Engert (1996), Ruggiero (1996a) (1996b) (2000) (2007), Bates (1997), Chalos (1997), Duncombe *et al.* (1997), Grosskopf *et al.* (1997) (1999) (2001) (2014), Heshmati and Kumbhakar (1997), Ray and Mukherjee (1998), Ruggiero and Bretschneider (1998), Ruggiero (1999), Ruggiero and Vitaliano (1999), Chakraborty *et al.* (2001), Grosskopf and Moutray (2001), Fukuyama and Weber (2002), Banker *et al.* (2004), Primont and Domazlicky (2006), Rassouli-Currier (2007), Denaux (2009), Davutyan *et al.* (2010), Houck *et al.* (2010), Naper (2010), Ouellette and Vierstraete (2010), Johnson and Ruggiero (2014).
School/high school levels studies
Observed in: Bessent and Bessent (1980), Charnes *et al.* (1981), Bessent *et al.* (1982), Diamond and Medewitz (1990), Ray (1991), Deller and Rudnicki (1993), Bonesrønning and Rattsø (1994), Thanassoulis and Dustan (1994), Jimenez and Paqueo (1996), Thanassoulis (1996), Kirjavainen and Loikkanen (1998), Mancebón and Bandres (1999), Mancebón and Mar-Molinero (2000), McEwan and Carnoy (2000), Bradley *et al.* (2001) (2010), Daneshvary and Clauretie (2001), Muñiz (2002), Wang (2003), Kiong *et al.* (2005), Oliveira and Santos (2005), Ouellette and Vierstraete (2005), Waldo (2007b), Conroy and Arguea (2008), Cordero-Ferrera *et al.* (2008) (2010), Mancebón and Muñiz (2008), Millimet and Collier (2008), Grosskopf *et al.* (2009), Hu *et al.* (2009), Kantabutra (2009), Sarrico and Rosa (2009), Alexander *et al.* (2010), Carpenter and Noller (2010), Essid *et al.* (2010) (2013) (2014), Khalili *et al.* (2010), Naper (2010), Sarrico *et al.* (2010), Agasisti (2011a) (2013), Mongan *et al.* (2011), Gronberg *et al.* (2012), Haelermans and Blank (2012), Haelermans and De Witte (2012), Haelermans *et al.* (2012), Johnes *et al.* (2012), Kirjavainen (2012), Mancebón *et al.* (2012), Misra *et al.* (2012), Portela *et al.* (2012), Burney *et al.* (2013), Haelermans and Ruggiero (2013), Aristovnik and Obadic (2014), Blackburn *et al.* (2014), Brennan *et al.* (2014).
Education system (country or multi-country) levels studies
Observed in: Geshberg and Schuermann (2001), Hanushek and Luque (2003), Afonso and Aubyn (2006), Kocher *et al.* (2006), Giménez *et al.* (2007), Agasisti (2011b) (2014), Thieme *et al.* (2012), Aristovnik (2013).
Student level studies
Observed in: Thanassoulis (1999), Colbert *et al.* (2000), Portela and Thanassoulis (2001), Robst (2001), Mizala *et al.* (2002), Thanassoulis and Portela (2002), Dolton *et al.* (2003), Johnes (2006b) (2006c), Waldo (2007a), Cherchye *et al.* (2010), De Witte *et al.* (2010), Portela and Camanho (2010), Cordero-Ferrera *et al.* (2011), Perelman and Santín (2011a) (2011b), Montoneri *et al.* (2012), De Witte and Kortelainen (2013), Deutsch *et al.* (2013), Portela *et al.* (2013), Thieme *et al.* (2013), Crespo-Cebada *et al.* (2014), Podinovski *et al.* (2014).

Source: The authors

2.3.1. Input variables

To start with, in this subsection we review the discretionary inputs specified in the education production function (or those factors that are amenable to managerial control). To facilitate the explanation, we divide them into four categories: inputs at students' level, family-related variables, education institution and community variables.

Table 2 collects the inputs at student-level. From the psychological and behavior variables, prior academic achievement has been broadly used (in 34 papers in total). It can be defined as exam success (Kuah and Wong, 2011), grade point average (Haksever and Muragishi, 1998; Kong and Fu, 2012) or test scores (De Witte *et al.*, 2010; Portela and Camanho, 2010) in the previous academic year. About 8 scholars (such as Crespo-Cebada *et al.*, 2014) have used the peer group effect as an input to control for the characteristics of students' classmates. Lastly, some authors have taken into account variables like motivation or predicted achievement in this category (e.g. Dolton *et al.*, 2003 or Grosskopf and Moutray, 2001). The main demographic variables include the race/ethnicity/minority, and the presence of educational limitations as disabilities or language deficits. Although over the past few years the achievement gap between native and non-native youths is lower, it is still an active variable in the literature. Finally, only few papers have taken into account issues related to the way of living (exceptions are Dolton *et al.*, 2003; Johnes, 2006b; Kong and Fu, 2012).

Table 2. Overview of inputs: student-related variables

Inputs	Examples
1. Psychological and behavior variables	
Motivation/aspirations	Dolton *et al.* (2003), Perelman and Santín (2011a), Mainardes *et al.* (2014).
Peer group	Deller and Rudnicki (1993), Waldo (2007a), Cordero-Ferrera *et al.* (2011), Mongan *et al.* (2011), Perelman and Santín (2011a) (2011b), Crespo-Cebada *et al.* (2014), Grosskopf *et al.* (2014).
Predicted achievement	Grosskopf *et al.* (1997), (1999), Grosskopf and Moutray (2001).
Prior academic achievement	Bessent and Bessent (1980), Bessent *et al.* (1982), Färe *et al.* (1989), Diamond and Medewitz (1990), Breu and Raab (1994), Thanassoulis and Dustan (1994), Johnes (1996) (2006a) (2006b) (2006c) (2014a), Thanassoulis (1996), Athanassopoulos and Shale (1997), Haksever and Muragishi (1998), Colbert *et al.* (2000), Sarrico and Dyson (2000), Portela and Thanassoulis (2001), Fukuyama and Weber (2002), Thanassoulis and Portela (2002), Oliveira and Santos (2005), Primont and Domazlicky (2006), Waldo (2007a), Ray and Jeon (2008), De Witte *et al.* (2010), Khalili *et al.* (2010), Portela and Camanho (2010), Sarrico *et al.* (2010), Kuah and Wong (2011), Perelman and Santín (2011a), Kong and Fu (2012), Portela *et al.* (2012) (2013), Johnes (2013), Podinovski *et al.* (2014).
2. Demographic variables	
Disabilities (additional educational needs)	Bessent *et al.* (1982), Barrow (1991), Conroy and Arguea (2008), Grosskopf *et al.* (2009).
Free lunch/pay full lunch	Bessent *et al.* (1982), Barrow (1991), Thanassoulis and Dustan (1994), Cooper and Cohn (1997), Mancebón and Mar-Molinero (2000), Bradley *et al.* (2001), Conroy and Arguea (2008).
Grants	Johnes and Johnes (1993) (1995), Thursby (2000), Ying and Sung (2000), Dolton *et al.* (2003), Conroy and Arguea (2008), Kuah and Wong (2011).
Age/Gender/Marital status	Diamond and Medewitz (1990), Cooper and Cohn (1997), Dolton *et al.* (2003), Jonhes (2006b) (2006b), Mongan *et al.* (2011), Perelman and Santín (2011a), Kong and Fu (2012), Thieme *et al.* (2013).
Language background (limited English proficiency)	Sengupta and Sfeir (1988), Ganley and Cubbin (1992), Conroy and Arguea (2008), Grosskopf *et al.* (2009), Kirjavainen (2012), Mancebón *et al.* (2012).
Race/ethnicity/ minority/nationality	Bessent and Bessent (1980), Bessent *et al.* (1982), Sengupta and Sfeir (1986), Jesson *et al.* (1987), Sengupta (1987), Diamond and Medewitz (1990), Ganley and Cubbin (1992), Cooper and Cohn (1997), Heshmati and Kumbhakar (1997), Dolton *et al.* (2003), Jonhes (2006b) (2006c), Conroy and Arguea (2008), Ray and Jeon (2008), Perelman and Santín (2011a), Mancebón *et al.* (2012).
Way of living	Johnes (1996) (2006b), Dolton *et al.* (2003), Hanushek and Luque (2003), Kong and Fu (2012).

Source: The authors

An overview of family-related variables is presented in Table 3. Socio-economic status (27 papers) and parental education (20 papers) are the most widely used variables. The former is usually measured by parents' employment status or family income (e.g. Mancebón and Bandres, 1999; Perelman and Santín, 2011a) and the latter is mentioned by many scholars as one of the key determinants of students' achievement (e.g. Hanushek and Luque, 2003; Kirjavainen, 2012). Some authors distinguish between mother and father education in order to detect who exerts the greatest influence (e.g. Kong and Fu, 2012). In addition, family structure and parental support or involvement is also known as predictors of students' success (e.g. Dolton *et al*, 2003; Thieme *et al.*, 2013). Finally, resources available at home, or the extent to which children have reading material, computers, their own room or a place to study at home, has been used as a solid determinant for educational outcomes (e.g. Mongan *et al.*, 2011, Deutsch *et al.*, 2013).

Table 3: Overview of inputs: family-related variables

Inputs	Examples
Economic needs	Bessent and Bessent (1980), Denaux (2009), Grosskopf *et al.* (2009), Sarrico and Rosa (2009), Sarrico *et al.* (2010), Mongan *et al.* (2011).
Family structure	Jesson *et al.* (1987), Smith and Mayston (1987), Bates (1997), Dolton *et al.* (2003), Perelman and Santín (2011a), Kirjavainen (2012).
Parental education	Charnes *et al.* (1981), Deller and Rudnicki (1993), Cooper and Cohn (1997), Heshmati and Kumbhakar (1997), Kirjavainen and Loikkanen (1998), McEwan and Carnoy (2000), Dolton *et al.* (2003), Hanushek and Luque (2003), Wang (2003), Conroy and Arguea (2008), Sarrico and Rosa (2009), Khalili *et al.* (2010), Sarrico *et al.* (2010), Cordero-Ferrera *et al.* (2011), Mongan *et al.* (2011), Perelman and Santín (2011a) (2011b), Kirjavainen (2012), Kong and Fu (2012), Mancebón *et al.* (2012).
Relationship with children	Thieme *et al.* (2013).
Resources available at home/internet use	Jesson *et al.* (1987), Ganley and Cubbin (1992), Cooper and Cohn (1997), Hanushek and Luque (2003), Mancebón and Muñiz (2008), Mongan *et al.* (2011), Perelman and Santín (2011a) (2011b), Mancebón *et al.* (2012), Aristovnik (2013), Deutsch *et al.* (2013), Thieme *et al.* (2013).
Socio-economic status (family income, employment)	Charnes *et al.* (1981), Smith and Mayston (1987), Sengupta and Sfeir (1988), Barrow (1991), Ganley and Cubbin (1992), Deller and Rudnicki (1993), Ruggiero (1996b), Thanassoulis (1996), Bates (1997), Cooper and Cohn (1997), Heshmati and Kumbhakar (1997), Mancebón and Bandres (1999), Fukuyama and Weber (2002), Mizala *et al.* (2002), Dolton *et al.* (2003), Mancebón and Muñiz (2008), Denaux (2009), Kantabutra (2009), Agasisti (2011a) (2013), Cordero-Ferrera *et al.* (2011), Perelman and Santín (2011a), Kirjavainen (2012), Mancebón *et al.* (2012), Thieme *et al.* (2013), Crespo-Cebada *et al.* (2014), Podinovski *et al.* (2014).

Source: The authors

With respect to education institutions variables (see Table 4) the literature has paid attention to study the relationship between traditional educational inputs and educational outcomes. Typical inputs in the education production function are the characteristics of teachers (expenditures – 110 papers, number of personnel – 68 papers, experience, methods and salary – 70 papers, etc.) and the learning environment (size – 36 papers, organization and resources – 53 papers, etc.).

However, there exists no strong empirical evidence to support the notion that educational inputs have a significant positive influence on outcomes (Worthington, 2001). One may wonder whether these variables are appropriate to include in efficiency studies. There is still debate about the importance of including educational input in the analysis, as Hanushek (2003, p. 91) shows that "*school resources are not closely related to student performance*". Moreover, some of the 'popular' variables like class size have been extensively shown in the economics of education literature as unproductive policy. What matters is teacher quality, but this variable is difficult to capture.

Table 4: Overview of inputs: education institution variables

Inputs	Examples
Acceptance rate (selectivity)	Haksever and Muragishi (1998), Kirjavainen and Loikkanen (1998), Ray and Jeon (2008), Agasisti (2011b), Thieme *et al.* (2013).
Attendance rate	Bessent and Bessent (1980), Bessent *et al.* (1982), Chalos and Cherian (1995).
Climate	Bessent and Bessent (1980), Mongan *et al.* (2011), Perelman and Santín (2011a).
Dropout rate	Conroy and Arguea (2008), Mancebón *et al.* (2012).
Educational resources (books, building, computers, class, bus, grants)	Ruggiero *et al.* (1995), Jimenez and Paqueo (1996), Ruggiero (1996a) (1996b), Athanassopoulos and Shale (1997), Cooper and Cohn (1997), Heshmati and Kumbhakar (1997), Ruggiero and Bretschneider (1998), Ruggiero (2000), Thursby (2000), Moreno and Tadepali (2002), Emrouznejad and Thanassoulis (2005), Kiong *et al.* (2005), Agasisti and Dal Bianco (2006) (2009), Bonaccorsi *et al.* (2006), Bougnol and Dulá (2006), Johnes (2006a) (2008), Primont and Domazlicky (2006), Giménez *et al.* (2007), Tauer *et al.* (2007), Johnes and Yu (2008), Ray and Jeon (2008), Agasisti and Johnes (2009), Hu *et al.* (2009), Agasisti and Pérez-Esparrells (2010), Essid *et al.* (2010), Agasisti (2011a) (2011b) (2013), Agasisti *et al.* (2011) (2012), Cordero-Ferrera *et al.* (2011), Lee (2011), Mongan *et al.* (2011), Perelman and Santín (2011a) (2011b), Haelermans and Blank (2012), Mancebón *et al.* (2012), Misra *et al.* (2012), Thieme *et al.* (2012) (2013), Haelermans and Ruggiero (2013), Zoghbi *et al.* (2013), Crespo-Cebada *et al.* (2014).
Enrollment	Johnes (1996), Ruggiero and Vitaliano (1999), Grosskopf *et al.* (2001), Cherchye and Vanden Abeele (2005), Kiong *et al.* (2005), Fandel (2007), Agasisti and Dal Bianco (2009), Grosskopf *et al.* (2009), Sarrico and Rosa (2009), Alexander *et al.* (2010), Davutyan *et al.* (2010), Khalili *et al.* (2010), Katharaki and Katharakis (2010), Rayeni and Saljooghi (2010), Gronberg *et al.* (2012), Johnes *et al.* (2012), Misra *et al.* (2012), Aristovnik and Obadic (2014), Johnes (2014a).
Expenditures (teaching, research, administrators, supporting staff)	Bessent and Bessent (1980), Bessent *et al.* (1982), Butler and Monk (1985), Sengupta and Sfeir (1986), Jesson *et al.* (1987), Sengupta (1987), Smith and Mayston (1987), Mayston and Jesson (1988), Färe *et al.* (1989), Beasley (1990), Callan and Santerre (1990), Diamond and Medewitz (1990), Barrow (1991), Ganley and Cubbin (1992), Deller and Rudnicki (1993), McCarty and Yaisawarng (1993), Breu and Raab (1994), Sinuany *et al.* (1994), Beasley (1995), Chalos and Cherian (1995), Ruggiero *et al.* (1995), Cubbin and Zamani (1996), Engert (1996), Jimenez and Paqueo (1996), Johnes (1996) (2006a) (2008) (2014a), Ruggiero (1996a) (1999) (2000), Athanassopoulos and Shale (1997), Bates (1997), Chalos (1997), Duncombe *et al.* (1997), Grosskopf *et al.* (1997) (1999) (2014), Heshmati and Kumbhakar (1997), McMillan and Datta (1998), Mancebón and Bandres (1999), Ruggiero and Vitaliano (1999), McEwan and Carnoy (2000), Daneshvary and Clauretie (2001), Geshberg and Schuermann (2001), Korhonen *et al.* (2001), Robst (2001), Abbott and Doucouliagos (2002) (2003), Fukuyama and Weber (2002), Izadi *et al.* (2002), Muñiz (2002), Banker *et al.* (2004), Flegg *et al.* (2004), Stevens (2005), Bonaccorsi *et al.* (2006), Casu and Thanassoulis (2006), Giménez and Martínez (2006), Kocher *et al.* (2006), McMillan and Chan (2006), Primont and Domazlicky (2006), Agasisti and Salerno, (2007), Anderson *et al.* (2007), Rassouli-Currier (2007), Conroy and Arguea (2008), Cordero-Ferrera *et al.* (2008) (2010), Johnes *et al.* (2008), Johnes and Yu (2008), Kao and Hung (2008), Kuo and Ho (2008), Millimet and Collier (2008), Worthington and Lee (2008), Agasisti and Johnes (2009) (2010), Denaux (2009), Hu *et al.* (2009), Johnes and Johnes (2009), Tyagi *et al.* (2009), Alexander *et al.* (2010), Carpenter and Noller (2010), Houck *et al.* (2010), Katharaki and Katharakis (2010), Kempkes and Pohl (2010), Ouellette and Vierstraete (2010), Johnes and Schwarzenberger (2011), Kounetas *et al.* (2011), Kuah and Wong (2011), Lee (2011), Mongan *et al.* (2011), Thanassoulis *et al.* (2011), Gronberg *et al.* (2012), Haelermans and Blank (2012), Haelermans and De Witte (2012), Haelermans *et al.* (2012), Kirjavainen (2012), Misra *et al.* (2012), Sexton *et al.* (2012), Aristovnik (2013), Essid *et al.* (2013) (2014), Haelermans and Ruggiero (2013), Johnes (2013), Lu and Chen (2013), Zoghbi *et al.* (2013), Agasisti (2014), Aristovnik and Obadic (2014), Blackburn *et al.* (2014), Brennan *et al.* (2014), Duh *et al.* (2014), Johnson and Ruggiero (2014).
Faculty to student ratio/number of faculties/faculties with doctorates	Breu and Raab (1994), McMillan and Datta (1998), Colbert *et al.* (2000), Kocher *et al.* (2006), Ray and Jeon (2008), Ouellette and Vierstraete (2010).
Job satisfaction	Bessent and Bessent (1980), Misra *et al.* (2012).
Mobility index	Bessent and Bessent (1980), Conroy and Arguea (2008).
Ownership (public, private, charter)	Diamond and Medewitz (1990), Johnes (1996) (2006b) (2006c), Cooper and Cohn (1997), Thursby (2000), Mizala *et al.* (2002), Dolton *et al.* (2003), Carpenter and Noller (2010), Kantabutra and Tang (2010), Perelman and Santín (2011a), Kirjavainen (2012), Thieme *et al.* (2013).
Parental visit index	Charnes *et al.* (1981), Jimenez and Paqueo (1996), Conroy and Arguea (2008).

Personnel (Teachers - academic staff-, other staff - administrators or support staff-) (FTE)	Bessent *et al.* (1982), Ray (1991), Johnes and Johnes (1993) (1995), Jimenez and Paqueo (1996), Mar-Molinero (1996), Ruggiero (1996b), Athanassopoulos and Shale (1997), Grosskopf *et al.* (1997) (1999) (2001) (2009), Madden *et al.* (1997), Ray and Mukherjee (1998), Ruggiero and Bretschneider (1998), Thursby (2000), Ying and Sung (2000), Avkiran (2001), Grosskopf and Moutray (2001), Abbott and Doucouliagos (2002) (2003) (2009), Fukuyama and Weber (2002), Moreno and Tadepali (2002), Muñiz (2002), Flegg *et al.* (2004), Agasisti and Dal Bianco (2006) (2009), Bonaccorsi *et al.* (2006), Bougnol and Dulá (2006), Johnes (2006a) (2008) (2014a), Fandel (2007), Kao and Hung (2008), Millimet and Collier (2008), Worthington and Lee (2008), Abramo and D'Angelo (2009), Agasisti and Johnes (2009), Cokgezen (2009), Colin-Glass *et al.* (2009), Tyagi *et al.* (2009), Agasisti and Pérez-Esparrells (2010), Alexander *et al.* (2010), Bradley *et al.* (2010), Davutyan *et al.* (2010), Essid *et al.* (2010) (2013) (2014), Katharaki and Katharakis (2010), Kempkes and Pohl (2010), Ouellette and Vierstraete (2010), Rayeni and Saljooghi (2010), Agasisti *et al.* (2011) (2012), Kounetas *et al.* (2011), Kuah and Wong (2011), Lee (2011), Wolszczak-Derlacz and Parteka (2011), Haelermans and Blank (2012), Haelermans *et al.* (2012), Johnes *et al.* (2012), Thieme *et al.* (2012), Burney *et al.* (2013), Deutsch *et al.* (2013), Haelermans and Ruggiero (2013), Brennan *et al.* (2014), Duh *et al.* (2014).
Research income/ Tuition fees/ outside funding	Beasley (1990), Breu and Raab (1994), Beasley (1995), Athanassopoulos and Shale (1997), Heshmati and Kumbhakar (1997), Haksever and Muragishi (1998), Ying and Sung (2000), Dolton *et al.* (2003), Koksal and Nalcaci (2006), Fandel (2007), Kempkes and Pohl (2010), Wolszczak-Derlacz and Parteka (2011).
Size (number of students, student per class, proportion of boys and girls)	Sengupta and Sfeir (1986) (1988), Sengupta (1987), Jimenez and Paqueo (1996), Johnes (1996), Athanassopoulos and Shale (1997), Heshmati and Kumbhakar (1997), Thursby (2000), Mizala *et al.* (2002), Hanushek and Luque (2003), Flegg *et al.* (2004), Agasisti and Dal Bianco (2006) (2009), Johnes (2006a) (2008), Koksal and Nalcaci (2006), Johnes and Yu (2008), Kao and Hung (2008), Ray and Jeon (2008), Worthington and Lee (2008), Agasisti and Johnes (2009), Agasisti and Pérez-Esparrells (2010), Bradley *et al.* (2010), Essid *et al.* (2010) (2013) (2014), Kounetas *et al.* (2011), Kuah and Wong (2011), Perelman and Santín (2011a), Wolszczak-Derlacz and Parteka (2011), Haelermans and Blank (2012), Kirjavainen (2012), Mancebón *et al.* (2012), Burney *et al.* (2013), Crespo-Cebada *et al.* (2014), Podinovski *et al.* (2014).
Student/teacher ratio (or vice versa)	Bessent and Bessent (1980), Charnes *et al.* (1981), Bessent *et al.* (1982), Ray (1991), McCarty and Yaisawarng (1993), Breu and Raab (1994), Chalos and Cherian (1995), Johnes (1996), Cooper and Cohn (1997), Heshmati and Kumbhakar (1997), Mancebón and Bandres (1999), Mancebón and Mar-Molinero (2000), Chakraborty *et al.* (2001), Mizala *et al.* (2002), Afonso and Aubyn (2006), Primont and Domazlicky (2006), Cordero-Ferrera *et al.* (2008) (2010), Johnes and Yu (2008), Denaux (2009), Hu *et al.* (2009), Kantabutra (2009), Cherchye *et al.* (2010), Naper (2010), Sarrico *et al.* (2010), Agasisti (2011a) (2011b) (2013) (2014), Perelman and Santín (2011b), Kirjavainen (2012), Misra *et al.* (2012), Johnes (2013), Zoghbi *et al.* (2013), Crespo-Cebada *et al.* (2014).
Teacher absences	Heshmati and Kumbhakar (1997).
Teacher age/gender/race	Johnes (1996), Sarrico and Rosa (2009), Misra *et al.* (2012).
Teacher experience/ education	Bessent *et al.* (1982), Sengupta and Sfeir (1986), Färe *et al.* (1989), Diamond and Medewitz (1990), McCarty and Yaisawarng (1993), Bonesrønning and Rattsø (1994), Chalos and Cherian (1995), Jimenez and Paqueo (1996), Johnes (1996), Ruggiero (1996b), Cooper and Cohn (1997), Heshmati and Kumbhakar (1997), Haksever and Muragishi (1998), Kirjavainen and Loikkanen (1998), Ruggiero and Bretschneider (1998), Chakraborty *et al.* (2001), Mizala *et al.* (2002), Hanushek and Luque (2003), Kiong *et al.* (2005), Stevens (2005), Primont and Domazlicky (2006), Rassouli-Currier (2007), Waldo (2007a), Denaux (2009), Hu *et al.* (2009), Bradley *et al.* (2010), Sarrico *et al.* (2010), Agasisti *et al.* (2011) (2012), Kuah and Wong (2011), Misra *et al.* (2012), Thieme *et al.* (2012).
Teacher methods/ organization and management/ quality/innovation	Bessent and Bessent (1980), Sengupta (1987), Kirjavainen and Loikkanen (1998), Mizala *et al.* (2002), Dolton *et al.* (2003), Oliveira and Santos (2005), Afonso and Aubyn (2006), Agasisti and Salerno, (2007), Giménez *et al.* (2007), Carpenter and Noller (2010), Cherchye *et al.* (2010), Dehnokhalaji *et al.* (2010), Sarrico *et al.* (2010), Haelermans and Blank (2012), Montoneri *et al.* (2012), Bayraktar *et al.* (2013), De Witte and Kortelainen (2013), Deutsch *et al.* (2013), Johnes (2013), Zoghbi *et al.* (2013), Nazarko and Saparauskas (2014).
Teacher salary	Butler and Monk (1985), Sengupta and Sfeir (1986) (1988), Sinuany *et al.* (1994), Ruggiero (1996a) (2000), Duncombe *et al.* (1997), Grosskopf *et al.* (1997) (1999) (2001), Ruggiero and Vitaliano (1999), Giménez and Martínez (2006), Koksal and Nalcaci (2006), Hu *et al.* (2009), Eff *et al.* (2012), Gronberg *et al.* (2012), Haelermans and Blank (2012), Johnson and Ruggiero (2014).

Source: The authors

A fourth category of inputs that should be noted refers to community-related variables. Student attributes, institution features and family background cannot be viewed apart from the context in which they are embedded and by which they are influenced (De Witte *et al.*, 2013).

While this category of variables has delivered by far fewer examples, it is very important to include them in the efficiency analysis. Inclusion can take the form of input variable, or as contextual variable. An overview of community variables included in papers as input variable is presented in Table 5. The geographical location (8 papers) and the number of education institutions in the area (4 papers) may have effects on students' performance, either directly or indirectly (McEwan and Carnoy, 2000). Neighborhood characteristics play also an important role. Youths living in disadvantaged environments may be more susceptible to fail (Grosskopf *et al.*, 2014). In addition, many other community variables like the proportion of household with school-aged children or how well educated the population in the neighborhood is, play a crucial role (Geshberg and Schuermann, 2001).

Table 5. Overview of inputs: community-related variables

Inputs	Examples
Competition (e.g. Herfindahl index, number of education institutions, location)	Grosskopf *et al.* (2001), Millimet and Collier (2008), Perelman and Santín (2011a), Nazarko and Saparauskas (2014).
Neighborhood characteristics (taxes, employment)	Ganley and Cubbin (1992), Grosskopf *et al.* (2001) (2014).
Percentage of households with school-aged children	Heshmati and Kumbhakar (1997).
Percentage of population with post-primary education	Geshberg and Schuermann (2001), Grosskopf *et al.* (2001), Wang (2003).
Urban/rural area (location)	Diamond and Medewitz (1990), Ganley and Cubbin (1992), Jimenez and Paqueo (1996), McEwan and Carnoy (2000), Grosskopf *et al.* (2001), Dolton *et al.* (2003), Kantabutra and Tang (2010), Kirjavainen (2012).

Source: The authors

2.3.2. Output variables

There is a generally greater agreement among educational efficiency studies regarding the specification of outputs. The numbers of graduates, passing rates and average test scores have all been used as output measures in educational efficiency analyses (see Table 6). However, none of these measures are ideal. For example, the number of graduates (included in 80 papers) captures the quantity of educational output, but it does not capture the quality. Quality is better reflected in test scores (in 126 papers).

Another set of frontier efficiency measurement studies that deserve particular attention is the literature concerned with universities and academic departments within universities. Table 6 indicates that their outputs are measured in categories of published work in journals or books (in 37 papers), number of citations (in 7 papers), number of research grants or incomes achieved (in 33 papers), patents, contracts and prized obtained (in 11 papers) and other measures about the quality of research (ranking or indices – 16 papers).

There are two major issues with the set of used outputs. First, the level of performance (like graduation rates, passing rates or average test scores) not only is the result of current level of educational inputs, but also the inputs provided in earlier academic years. Gronberg *et al.* (2012) argue persuasively that value-added analysis (which measures changes in student performance from one year to the next) yields better output measures for efficiency analysis than does relying on levels measures of performance.

Table 6. Overview of outputs

Outputs	Examples
1. Student achievement	
Number of graduates (percent passing)	Butler and Monk (1985), Jesson *et al.* (1987), Smith and Mayston (1987), Mayston and Jesson (1988), Beasley (1990), Callan and Santerre (1990), Barrow (1991), McCarty and Yaisawarng (1993), Bonesrønning and Rattsø (1994), Sinuany *et al.* (1994), Beasley (1995), Cubbin and Zamani (1996), Johnes (1996) (2006a) (2006c) (2008), Mar-Molinero (1996), Athanassopoulos and Shale (1997), Heshmati and Kumbhakar (1997), Madden *et al.* (1997), Haksever and Muragishi (1998), Kirjavainen and Loikkanen (1998), Ray and Mukherjee (1998), Mancebón and Bandres (1999), Ruggiero and Vitaliano (1999), Mancebón and Mar-Molinero (2000), Avkiran (2001), Grosskopf and Moutray (2001), Robst (2001), Abbott and Doucouliagos (2002) (2003) (2009), Izadi *et al.* (2002), Moreno and Tadepali (2002), Muñiz (2002), Flegg *et al.* (2004), Emrouznejad and Thanassoulis (2005), Stevens (2005), Agasisti and Dal Bianco (2006) (2009), Bonaccorsi *et al.* (2006), Kocher *et al.* (2006), Koksal and Nalcaci (2006), Anderson *et al.* (2007), Fandel (2007), Rassouli-Currier (2007), Cordero-Ferrera *et al.* (2008), Johnes *et al.* (2008), Kuo and Ho (2008), Mancebón and Muñiz (2008), Worthington and Lee (2008), Agasisti and Johnes (2009), Denaux (2009), Johnes and Johnes (2009), Kantabutra (2009), Sarrico and Rosa (2009), Agasisti and Pérez-Esparrells (2010), Alexander *et al.* (2010), Bradley *et al.* (2010), De Witte *et al.* (2010), Houck *et al.* (2010), Kantabutra and Tang (2010), Katharaki and Katharakis (2010), Kempkes and Pohl (2010), Khalili *et al.* (2010), Rayeni and Saljooghi (2010), Sarrico *et al.* (2010), Agasisti (2011b), Kuah and Wong (2011), Thanassoulis *et al.* (2011), Wolszczak-Derlacz and Parteka (2011), Misra *et al.* (2012), Burney *et al.* (2013), Haelermans and Ruggiero (2013), Johnes (2013), Lu and Chen (2013), Aristovnik and Obadic (2014), Duh *et al.* (2014), Grosskopf *et al.* (2014), Podinovski *et al.* (2014).
Students' test scores in different subjects (Reading, Languages, Math, Arts) / Students' performance	Bessent and Bessent (1980), Charnes *et al.* (1981), Bessent *et al.* (1982), Sengupta and Sfeir (1986) (1988), Jesson *et al.* (1987), Sengupta (1987), Smith and Mayston (1987), Mayston and Jesson (1988), Färe *et al.* (1989), Callan and Santerre (1990), Diamond and Medewitz (1990), Barrow (1991), Ray (1991), Ganley and Cubbin (1992), Deller and Rudnicki (1993), Breu and Raab (1994), Thanassoulis and Dustan (1994), Chalos and Cherian (1995), Ruggiero *et al.* (1995), Cubbin and Zamani (1996), Engert (1996), Jimenez and Paqueo (1996), Johnes (1996) (2006b) (2006c), Ruggiero (1996a) (1996b) (1999) (2000), Thanassoulis (1996), Athanassopoulos and Shale (1997), Bates (1997), Chalos (1997), Cooper and Cohn (1997), Duncombe *et al.* (1997), Grosskopf *et al.* (1997) (1999) (2001) (2009) (2014), Kirjavainen and Loikkanen (1998), Ray and Mukherjee (1998), Ruggiero and Bretschneider (1998), Mancebón and Bandres (1999), Ruggiero and Vitaliano (1999), Thanassoulis (1999), McEwan and Carnoy (2000), Bradley *et al.* (2001) (2010), Chakraborty *et al.* (2001), Daneshvary and Clauretie (2001), Grosskopf and Moutray (2001), Portela and Thanassoulis (2001), Fukuyama and Weber (2002), Mizala *et al.* (2002), Muñiz (2002), Thanassoulis and Portela (2002), Dolton *et al.* (2003), Hanushek and Luque (2003), Wang (2003), Kiong *et al.* (2005), Oliveira and Santos (2005), Afonso and Aubyn (2006), Bougnol and Dulá (2006), Primont and Domazlicky (2006), Giménez *et al.* (2007), Waldo (2007a), Conroy and Arguea (2008), Cordero-Ferrera *et al.* (2008) (2010) (2011), Johnes *et al.* (2008), Mancebón and Muñiz (2008), Millimet and Collier (2008), Denaux (2009), Hu *et al.* (2009), Kantabutra (2009), Sarrico and Rosa (2009), Alexander *et al.* (2010), Carpenter and Noller (2010), Cherchye *et al.* (2010), Davutyan *et al.* (2010), Essid *et al.* (2010) (2013), Houck *et al.* (2010), Khalili *et al.* (2010), Naper (2010), Portela and Camanho (2010), Sarrico *et al.* (2010), Agasisti (2011a) (2013) (2014), Kuah and Wong (2011), Mongan *et al.* (2011), Perelman and Santín (2011a) (2011b), Eff *et al.* (2012), Gronberg *et al.* (2012), Haelermans and Blank (2012), Haelermans and De Witte (2012), Haelermans *et al.* (2012), Johnes *et al.* (2012), Kirjavainen (2012), Mancebón *et al.* (2012), Misra *et al.* (2012), Montoneri *et al.* (2012), Portela *et al.* (2012) (2013), Sexton *et al.* (2012), Thieme *et al.* (2012) (2013), Aristovnik (2013), Bayraktar *et al.* (2013), De Witte and Kortelainen (2013), De Witte *et al.* (2013), Deutsch *et al.* (2013), Haelermans and Ruggiero (2013), Johnes (2013), Zoghbi *et al.* (2013), Blackburn *et al.* (2014), Brennan *et al.* (2014), Crespo-Cebada *et al.* (2014), Johnson and Ruggiero (2014), Podinovski *et al.* (2014).
2. Publications and research activity	
Citations (impact of research)	Thursby (2000), Korhonen *et al.* (2001), Bonaccorsi *et al.* (2006), Kocher *et al.* (2006), Abramo and D'Angelo (2009), Agasisti *et al.* (2012), De Witte and Hudrlikova (2013).
Contracts, patents and prizes / technology transfer	Ying and Sung (2000), Korhonen *et al.* (2001), Izadi *et al.* (2002), Moreno and Tadepali (2002), Flegg *et al.* (2004), Bougnol and Dulá (2006), Casu and Thanassoulis (2006), Johnes (2008), Agasisti and Johnes (2009), De Witte and Rogge (2010), Kuah and Wong (2011).
Credits given by the department	Sinuany *et al.* (1994), Tauer *et al.* (2007), Kao and Hung (2008).
Doctoral dissertations	Cherchye and Vanden Abeele (2005), Emrouznejad and Thanassoulis (2005), Bougnol and Dulá (2006), Johnes (2006a), McMillan and Chan (2006), Fandel (2007), Tyagi *et al.* (2009), Agasisti *et al.* (2011), Johnes and Schwarzenberger (2011), Kuah and Wong (2011).

Other research / teaching activities	Sarrico and Dyson (2000), Emrouznejad and Thanassoulis (2005), Koksal and Nalcaci (2006), Colin-Glass *et al.* (2009), De Witte and Rogge (2010), Dehnokhalaji *et al.* (2010), Kounetas *et al.* (2011).
Publications (paper published in international journals, books, chapters, research output)	Johnes and Johnes (1993) (1995), Sinuany *et al.* (1994), Johnes and Johnes (1995), Mar-Molinero (1996), Madden *et al.* (1997), Thursby (2000), Ying and Sung (2000), Cherchye and Vanden Abeele (2005), Stevens (2005), Bonaccorsi *et al.* (2006), Bougnol and Dulá (2006), Kocher *et al.* (2006), Koksal and Nalcaci (2006), Anderson *et al.* (2007), Tauer *et al.* (2007), Johnes and Yu (2008), Kao and Hung (2008), Worthington and Lee (2008), Abbott and Doucouliagos (2009), Abramo and D'Angelo (2009), Cokgezen (2009), Colin-Glass *et al.* (2009), Hu *et al.* (2009), De Witte and Rogge (2010), Kantabutra and Tang (2010), Rayeni and Saljooghi (2010), Agasisti *et al.* (2011) (2012), Kounetas *et al.* (2011), Kuah and Wong (2011), Lee (2011), Wolszczak-Derlacz and Parteka (2011), Bayraktar *et al.* (2013), Lu and Chen (2013), Duh *et al.* (2014), Nazarko and Saparauskas (2014).
Quality of the research (ranking /index/standard)	Beasley (1990), Beasley (1995), Johnes (1996), Haksever and Muragishi (1998), Avkiran (2001), Korhonen *et al.* (2001), Flegg *et al.* (2004), Giménez and Martínez (2006), Koksal and Nalcaci (2006), Johnes *et al.* (2008), Johnes and Yu (2008), Hu *et al.* (2009), Tyagi *et al.* (2009), Dehnokhalaji *et al.* (2010), Eff *et al.* (2012), De Witte and Hudrlikova (2013).
Research grants/ Research income	Beasley (1990) (1995), Sinuany *et al.* (1994), McMillan and Datta (1998), Sarrico and Dyson (2000), Izadi *et al.* (2002), Abbott and Doucouliagos (2003), Flegg *et al.* (2004), Emrouznejad and Thanassoulis (2005), Agasisti and Dal Bianco (2006), Bougnol and Dulá (2006), Johnes (2006a) (2008) (2014a), McMillan and Chan (2006), Agasisti and Salerno, (2007), Kao and Hung (2008), Ray and Jeon (2008), Worthington and Lee (2008), Agasisti and Johnes (2009) (2010), Hu *et al.* (2009), Johnes and Johnes (2009), Tyagi *et al.* (2009), Agasisti and Pérez-Esparrells (2010), Katharaki and Katharakis (2010), Kempkes and Pohl (2010), Agasisti *et al.* (2011) (2012), Lee (2011), Johnes and Schwarzenberger (2011), Thanassoulis *et al.* (2011), Duh *et al.* (2014).
3. Educational results	
Attendance rate	Bradley *et al.* (2001), Daneshvary and Clauretie (2001), Grosskopf and Moutray (2001).
Dropout rate	Ruggiero (1996a), Ruggiero and Vitaliano (1999), Alexander *et al.* (2010).
Enrollment	McMillan and Datta (1998), Ray and Mukherjee (1998), McEwan and Carnoy (2000), Sarrico and Dyson (2000), Avkiran (2001), Daneshvary and Clauretie (2001), Moreno and Tadepali (2002), Abbott and Doucouliagos (2003), Banker *et al.* (2004), McMillan and Chan (2006), Agasisti and Salerno, (2007), Kuo and Ho (2008), Ray and Jeon (2008), Cokgezen (2009), Tyagi *et al.* (2009), Agasisti and Johnes (2010), Davutyan *et al.* (2010), Essid *et al.* (2010) (2013) (2014), Ouellette and Vierstraete (2010), Johnes and Schwarzenberger (2011), Lee (2011), Eff *et al.* (2012), Aristovnik (2013), Bayraktar *et al.* (2013), Burney *et al.* (2013), Lu and Chen (2013), Aristovnik and Obadic (2014), Brennan *et al.* (2014), Johnes (2014a), Podinovski *et al.* (2014).
Meals served/ Number of beds	Essid *et al.* (2010) (2013) (2014).
Overseas staff/students	Sarrico and Dyson (2000), De Witte and Hudrlikova (2013).
Teachers' attitude	Montoneri *et al.* (2012).
Tuition revenues	Robst (2001), Casu and Thanassoulis (2006), Ray and Jeon (2008).
4. Job Market/Success	
Employability (Graduates with job, job destination)	Johnes (1996), Sarrico and Dyson (2000), Avkiran (2001), Tyagi *et al.* (2009), Agasisti (2011b), Kuah and Wong (2011), Kong and Fu (2012), Aristovnik (2013), Johnes (2013).
Starting salary of graduates	Haksever and Muragishi (1998), Agasisti (2011b), Kong and Fu (2012).
Student satisfaction (questionnaires)	Colbert *et al.* (2000), Giménez and Martínez (2006), Agasisti (2011b), De Witte and Rogge (2011), Kong and Fu (2012), De Witte and Hudrlikova (2013), Johnes (2013), Mainardes *et al.* (2014).

Source: The authors

In the context of DEA, Portela and Thanassoulis (2001) were the first to isolate the effects on pupil results that are due to different efforts of pupils (i.e. pupil efficiency), from the effects that are due to differences in the school attended (i.e. school efficiency).

Second, all these outputs concentrate on educational outcomes at short or middle-term. However, there is an increasing tendency to specify long-term educational benefits in more recent work (e.g. Tyagi *et al.*, 2009; Agasisti, 2011b; Kong and Fu, 2012). These studies focus on the number of graduates who achieve a job after finishing their studies or the starting salary of graduates.

2.3.3. Non-discretionary variables

Non-discretionary or environmental variables heavily account for differences in academic results. One of the main (and most controversial) conclusions of the Coleman Report (1966) was that educational resources explained only 10% of academic results, while the remainder percentage depends on other economic variables and the family environment of students. The principal analytical focus in the mainstream educational efficiency literature has been to study, through different methodological approaches, the influence of structural, institutional and socio-economic variables on efficiency scores (Worthington, 2001).

As in the case of discretionary inputs one can identify different categories of non-discretionary variables at student and family level, education institution, and community level. Table 7 summarizes the variables that have been used in each category and the observed effect on students' results. Comparing Table 7 with Tables 2-5 it is reveals that many scholars considered the same variables as both input and contextual variables.

Regarding student-related variables, the literature has focused on studying the effect of questions related to race, ethnicity, minorities or nationalities on students' results (15 papers). For example, Bradley *et al.* (2010) found that the percentage of students from non-white ethnic backgrounds increase the efficiency scores. On the contrary, Crespo-Cebada *et al.* (2014) conclude that those students who were born abroad or those whose parents were born abroad (at least one of them) obtain lower results than native students. Another substantial part of the literature (14 papers) has paid attention to the impact of the number of students with special educational needs on students' achievement and costs.

Regarding family variables, socio-economic status and educational level of parents (35 papers) represent key environmental variables in determining students' results. There is a global consensus about the impact of these variables as deemed predictive of educational achievement.
Most of the authors conclude by saying that the higher the status or level of education from parents, the better the results obtained by the children (e.g. Cherchye *et al.*, 2010; Blackburn *et al.*, 2014). Authors as De Witte and Kortelainen (2013) have focused on seeing if the maternal or paternal effect on the results is more important. They found that both are statistically significant.

With respect to education institutions variables, ownership (public, private, charter; 20 papers) provides mixed evidence on the efficiency scores. While this topic is very country-dependent, we observed some interesting findings. On the one hand, if students attend a private institution, their level of performance would tend to be higher, however, authors like Agasisti (2013) found that efficiency scores in private high schools are lower than in public institutions. This could be explained by the fact that the higher resources available in private schools are no longer translated to better students' results. On the other hand, Cordero-Ferrera *et al.* (2011) conclude that ownership is not significant. Overall, the mixed results in the literature review can be due to country specific heterogeneity, the economic situation of the family, the level of competition among schools, the class size and the admission policy, among other factors (Mancebón and Muñiz, 2008).

Closely related to the type of institution is size, most frequently defined by class size, number of students, or teacher-pupil ratio (29 papers). These variables also provide mixed results.

Table 7. Overview of non-discretionary variables

Non-discretionary variables	Examples	Observed effect
1. Student variables		
Disabilities (additional educational needs)	Barrow (1991), Cubbin and Zamani (1996), Duncombe *et al.* (1997), Mancebón and Mar-Molinero (2000), Chakraborty *et al.* (2001), Abbott and Doucouliagos (2002), Rassouli-Currier (2007), Bradley *et al.* (2010), Carpenter and Noller (2010), Houck *et al.* (2010), Naper (2010), Gronberg *et al.* (2012), Johnes *et al.* (2012), Grosskopf *et al.* (2014).	If higher, lower achievement (and higher costs)
Free lunch/pay full lunch	Barrow (1991), Thanassoulis (1999), Chakraborty *et al.* (2001), Rassouli-Currier (2007), Conroy and Arguea (2008), Carpenter and Noller (2010), Misra *et al.* (2012).	Mixed results
Gender	Thanassoulis (1999), Millimet and Collier (2008), Bradley *et al.* (2010), De Witte and Rogge (2010), Wolszczak-Derlacz and Parteka (2011), Johnes *et al.* (2012), Deutsch *et al.* (2013).	Mixed results
Grants	Ray (1991), Conroy and Arguea (2008), Lee (2011).	Mixed results
Language background (limited English)	Duncombe *et al.* (1997), Ruggiero (1999), Primont and Domazlicky (2006), Millimet and Collier (2008), Cherchye *et al.* (2010), Gronberg *et al.* (2012), De Witte and Kortelainen (2013), Grosskopf *et al.* (2014).	If it is not English, lower students' results
Prior achievement	Bonesrønning and Rattsø (1994), Thanassoulis (1999), Cherchye *et al.* (2010), De Witte and Rogge (2010) (2011).	The higher, the better for students' results
Race/ethnicity/minority/ nationality	Ray (1991), Chalos and Cherian (1995), Chalos (1997), Ruggiero (1999), Thanassoulis (1999), Primont and Domazlicky (2006), Millimet and Collier (2008), Bradley *et al.* (2010), Carpenter and Noller (2010), Houck *et al.* (2010), Cordero-Ferrera *et al.* (2011), Johnes *et al.* (2012), Misra *et al.* (2012), De Witte and Kortelainen (2013), Crespo-Cebada *et al.* (2014).	If immigrant, lower students' results
2. Family variables		
Family structure	Mayston and Jesson (1988), Ray (1991), Duncombe *et al.* (1997), Ruggiero and Vitaliano (1999), Muñiz (2002), De Witte and Kortelainen (2013).	Mixed results
Parental education	Duncombe *et al.* (1997), Chakraborty *et al.* (2001), Muñiz (2002), Kiong *et al.* (2005), Afonso and Aubyn (2006), Millimet and Collier (2008), Cherchye *et al.* (2010), De Witte and Kortelainen (2013), Deutsch *et al.* (2013), Zoghbi *et al.* (2013), Crespo-Cebada *et al.* (2014).	If lower, then lower students' results
Relationship with children	Mancebón and Mar-Molinero (2000), Muñiz (2002), Giménez *et al.* (2007), Cordero-Ferrera *et al.* (2008) (2010), Agasisti (2011a) (2013), Deutsch *et al.* (2013).	If better, then higher students' results
Resources available at home/intentet use	Giménez *et al.* (2007), De Witte and Kortelainen (2013), Agasisti (2014).	If lower, then lower students' results
Socio-economic status (family income, employment)	Mayston and Jesson (1988), Ray (1991), McCarty and Yaisawarng (1993), Chalos and Cherian (1995), Engert (1996), Chalos (1997), Duncombe *et al.* (1997), Ruggiero and Bretschneider (1998), Geshberg and Schuermann (2001), Muñiz (2002), Kiong *et al.* (2005), Ouellette and Vierstraete (2005), Primont and Domazlicky (2006), Giménez *et al.* (2007), Rassouli-Currier (2007), Cordero-Ferrera *et al.* (2008) (2010), Millimet and Collier (2008), Alexander *et al.* (2010), Carpenter and Noller (2010), Cherchye *et al.* (2010), Houck *et al.* (2010), Gronberg *et al.* (2012), Thieme *et al.* (2012), Deutsch *et al.* (2013), Zoghbi *et al.* (2013), Blackburn *et al.* (2014), Brennan *et al.* (2014), Grosskopf *et al.* (2014), Johnson and Ruggiero (2014).	If lower, then lower students' results
3. Education institution variables		
Attendance rate/drop out	Deller and Rudnicki (1993), Chalos (1997), Carpenter and Noller (2010), Zoghbi *et al.* (2013).	If lower, lower students' results
Hiring practices	Naper (2010).	Decentralized hiring practices is better
Local/External funding (revenues for tuition fees)	McMillan and Datta (1998), Abbott and Doucouliagos (2002), Cherchye and Vanden Abeele (2005), Denaux (2009), Houck *et al.* (2010), Naper (2010), Agasisti (2011b) (2014), Wolszczak-Derlacz and Parteka (2011), De Witte and Kortelainen (2013).	If higher, better efficiency scores
Ownership (public, private, charter). Type of institution	Johnes (1996), Duncombe *et al.* (1997), Bradley *et al.* (2001) (2010), Alexander *et al.* (2010), Kempkes and Pohl (2010), Agasisti (2011a) (2011b) (2013), Cordero-Ferrera *et al.* (2011), Kounetas *et al.* (2011), Wolszczak-Derlacz and Parteka (2011), Gronberg *et al.*	Mixed results

	(2012), Haelermans and Blank (2012), Haelermans and De Witte (2012), Haelermans *et al.* (2012), De Witte and Kortelainen (2013), Deutsch *et al.* (2013), Crespo-Cebada *et al.* (2014), Duh *et al.* (2014).	
Quality of teaching/ researching (innovation)	Mancebón and Mar-Molinero (2000), De Witte and Rogge (2011), Haelermans and Blank (2012), Haelermans and De Witte (2012).	If higher, better students' results
Rate of expulsion or suspension	Conroy and Arguea (2008), Cordero-Ferrera *et al.* (2011), Crespo-Cebada *et al.* (2014).	If higher, lower students' results
Organization/ climate/religious orientation	Mancebón and Mar-Molinero (2000), Abbott and Doucouliagos (2002), Kounetas *et al.* (2011), Gronberg *et al.* (2012), De Witte and Kortelainen (2013), De Witte *et al.* (2013), Duh *et al.* (2014).	Not always significant
Size (number of students/class size/students' teacher ratio)	Barrow (1991), Duncombe *et al.* (1997), McMillan and Datta (1998), Mancebón and Mar-Molinero (2000), Abbott and Doucouliagos (2002), Cherchye and Vanden Abeele (2005), Bonaccorsi *et al.* (2006), McMillan and Chan (2006), Rassouli-Currier (2007), Millimet and Collier (2008), Alexander *et al.* (2010), Bradley *et al.* (2010), Carpenter and Noller (2010), Houck *et al.* (2010), Naper (2010), Agasisti (2011a) (2011b) (2013), Cordero-Ferrera *et al.* (2011), De Witte and Rogge (2011), Gronberg *et al.* (2012), Haelermans and De Witte (2012), Haelermans *et al.* (2012), Johnes *et al.* (2012), Burney *et al.* (2013), De Witte and Hudrlikova (2013), De Witte and Kortelainen (2013), Crespo-Cebada *et al.* (2014), Duh *et al.* (2014).	Mixed results (large institutions can reduce costs, but results are worsen)
Structure (enrolment / proportion of boys and girls)	McMillan and Datta (1998), Mancebón and Mar-Molinero (2000), Bradley *et al.* (2001), Alexander *et al.* (2010), Agasisti (2011a) (2013), Johnes *et al.* (2012), Burney *et al.* (2013), De Witte and Kortelainen (2013), Zoghbi *et al.* (2013), Crespo-Cebada *et al.* (2014).	Mixed results
Teacher characteristics (age/ gender/education /experience/number/salary)	Cubbin and Zamani (1996), Chalos (1997), Abbott and Doucouliagos (2002), Rassouli-Currier (2007), Alexander *et al.* (2010), Bradley *et al.* (2010), Carpenter and Noller (2010), De Witte and Rogge (2010) (2011), Naper (2010), Haelermans and Blank (2012), Haelermans *et al.* (2012), Johnes *et al.* (2012), Burney *et al.* (2013), Agasisti (2014).	Mixed results, not always significant
4. Community variables		
Competition (Herfindahl index/ number of faculties within X km)	McMillan and Datta (1998), McMillan and Chan (2006), Naper (2010), Agasisti (2011a), Haelermans and Blank (2012), Haelermans *et al.* (2012), Misra *et al.* (2012).	Mixed results
GDP per capita	Ray (1991), Afonso and Aubyn (2006), Kempkes and Pohl (2010), Agasisti (2011b) (2014), Wolszczak-Derlacz and Parteka (2011), Zoghbi *et al.* (2013).	The higher, the better
Immigrants	Geshberg and Schuermann (2001), Denaux (2009), De Witte and Kortelainen (2013), Crespo-Cebada *et al.* (2014).	The higher the proportion, the worse
Mortality rate/crime-violence	Cubbin and Zamani (1996), Conroy and Arguea (2008)	Mixed results. Not always significant
Neighborhood characteristics (employment opportunities/ access to wealth/poverty rate)	Cubbin and Zamani (1996), Johnes (1996), Duncombe *et al.* (1997), Ruggiero and Vitaliano (1999), Bradley *et al.* (2001) (2010), Oliveira and Santos (2005), Primont and Domazlicky (2006), Anderson *et al.* (2007), Rassouli-Currier (2007), Millimet and Collier (2008), Houck *et al.* (2010), Agasisti (2011b) (2014), Haelermans and Blank (2012), Haelermans and De Witte (2012), Haelermans *et al.* (2012), Johnes *et al.* (2012), Haelermans and Ruggiero (2013), Grosskopf *et al.* (2014).	If detrimental, lower students' results If job scarcity, lower students' results
Percentage of households with school-aged children	Ruggiero *et al.* (1995), Duncombe *et al.* (1997), Ruggiero and Vitaliano (1999).	Mixed results
Percentage of population with/without higher education	Ray (1991), Ruggiero (1996a) (2000), Rassouli-Currier (2007), Denaux (2009), Bradley *et al.* (2010), Naper (2010), Agasisti (2011b), Johnes *et al.* (2012), Zoghbi *et al.* (2013).	The higher, the better for students' results
Population / district size	Chalos (1997), Duncombe *et al.* (1997), Bradley *et al.* (2001), Primont and Domazlicky (2006), Millimet and Collier (2008), Alexander *et al.* (2010), Agasisti (2013), Crespo-Cebada *et al.* (2014).	Mixed results
Urban/rural area (location)	Barrow (1991), Cubbin and Zamani (1996), Johnes (1996), Duncombe *et al.* (1997), Bradley *et al.* (2001), Millimet and Collier (2008), Naper (2010), Agasisti (2011a) (2013), Lee (2011), Haelermans and Blank (2012), Haelermans and De Witte (2012), Haelermans *et al.* (2012), Misra *et al.* (2012), Burney *et al.* (2013), Deutsch *et al.* (2013).	Urban educational institutions achieve better results and can reduce costs

Source: The authors

On the one hand, smaller class sizes and lower teacher-pupil ratios may have a positive effect on students' achievement due to better educational practices by teachers, or because they can be more focused on the students (e.g. in higher education De Witte and Hudrlikova, 2013). On the other hand, authors like Haelermans and De Witte (2012) or Haelermans *et al.* (2012) observe that student-teacher ratios in secondary education do not have significant influence on students' results.

Lastly, community variables include neighborhood characteristics (20 papers), location (16 papers), the level of competition (7 papers), as well as proxies for various demographic variables such as mortality rate, crime and violence or immigrants.

2.4. Methodological approaches

Although there are many empirical approaches to measure efficiency (see Johnes, 2014b and references therein), the efficiency in education literature has mainly used frontier methods in two forms: non-parametric (DEA, FDH, order-*m* frontiers) and parametric (SFA) methods[7] (see Table 8).

Frontier models have attracted significant attention of researchers. The reason is that the frontier concept faithfully illustrates the essential characteristics of measuring efficiency as it tries to assess how well an organization is achieving maximum output with minimum consumption of inputs. Despite being widely used there are advantages and disadvantages to each approach. First, non-parametric methods can handle multiple inputs and outputs in a simple manner, while most stochastic approaches require choosing a single explicative variable. Second, non-parametric approaches do not require any assumptions about the functional form or specification of the error term, while stochastic methods need these assumptions. In addition, non-parametric approaches assume that all deviations from the frontier are due to inefficiency. This means that bounds on estimates cannot easily be determined, and statistical significance is not available in the traditional models.

As can be seen from Table 8, education has been a popular area of application of DEA (in its different variants) and it is one of the top five areas of application of this methodological approach (Liu *et al.*, 2013). Another body of the literature has focused on the use of parametric methods such as SFA (introduced by Aigner *et al.* 1977; Battese and Corra, 1977; and Meeusen and van den Broeck, 1977).

At this point, some particularly novel aplications of frontier methods might be noted. These approaches have been proposed to deal with two issues that arise in this context. The first one is related to the problem of unobserved heterogeneity and the second one with the inclusion of environmental variables in the efficiency model. On the one hand, an inappropriate treatment of unobserved heterogeneity will distort estimates of inefficiency. Unobserved heterogeneity is related to environmental factors that are unobserved but constant for each unit (Greene, 2005). Research on efficiency has addressed this problem by using different approaches, such as the random parameters SFA (Tsionas, 2002). Unobserved heterogeneity enters into the stochastic frontier model in the form of ''effects'' and is usually viewed as an issue of panel data.

[7] A review of the advantages and shortcomings of different frontier analysis techniques can be found in Fried *et al.* (2008).

Table 8. Observed approaches, methods, and models

A. Non-Parametric approaches and semi-parametric approaches
1. Data Envelopment Analysis (DEA)
1.1. DEA (Descriptive statistics, Sensitivity analysis, slacks, significance tests, etc.)
Observed in: Bessent and Bessent (1980), Charnes *et al.* (1981), Bessent *et al.* (1982), Jesson *et al.* (1987), Smith and Mayston (1987), Sengupta and Sfeir (1988), Färe *et al.* (1989), Beasley (1990), Ganley and Cubbin (1992), Kao and Yang (1992), Johnes and Johnes (1993) (1995), Bonesrønning and Rattsø (1994), Breu and Raab (1994), Sinuany *et al.* (1994), Thanassoulis and Dustan (1994), Beasley (1995), Chalos and Cherian (1995), Ruggiero *et al.* (1995), Engert (1996), Mar-Molinero (1996), Ruggiero (1996a) (1999) (2007), Thanassoulis (1996), Athanassopoulos and Shale (1997), Chalos (1997), Madden *et al.* (1997), Haksever and Muragishi (1998), McMillan and Datta (1998), Ray and Mukherjee (1998), Mancebón and Bandres (1999), Thanassoulis (1999), Colbert *et al.* (2000), Sarrico and Dyson (2000), Thursby (2000), Ying and Sung (2000), Avkiran (2001), Korhonen *et al.* (2001), Portela and Thanassoulis (2001), Fukuyama and Weber (2002), Moreno and Tadepali (2002), Abbott and Doucouliagos (2003), Banker *et al.* (2004), Emrouznejad and Thanassoulis (2005), Joumady and Ris (2005), Kiong *et al.* (2005), Agasisti and Dal Bianco (2006), Bougnol and Dulá (2006), Casu and Thanassoulis (2006), Kocher *et al.* (2006), Giménez and Martínez (2006), Johnes (2006c), Fandel (2007), Giménez *et al.* (2007), Tauer *et al.* (2007), Mancebón and Muñiz (2008), Ray and Jeon (2008), Abramo and D'Angelo (2009), Cokgezen (2009), Colin-Glass *et al.* (2009), Kantabutra (2009), Sarrico and Rosa (2009), Tyagi *et al.* (2009), Dehnokhalaji *et al.* (2010), Kantabutra and Tang (2010), Katharaki and Katharakis (2010), Portela and Camanho (2010), Sarrico *et al.* (2010), Eff *et al.* (2012), Portela *et al.* (2012), Agasisti *et al.* (2012), Montoneri *et al.* (2012), Sexton *et al.*(2012), Aristovnik (2013), Aristovnik and Obadic (2014), Mainardes *et al.* (2014), Nazarko and Saparauskas (2014).
1.2. DEA (Assurance region)
Observed in: Koksal and Nalcaci (2006), Kao and Hung (2008), Khalili *et al.* (2010), Kong and Fu (2012).
1.3. Directional Distance Functions (cost direct, cost indirect, input, output distance functions)
Observed in: Grosskopf *et al.* (1997) (1999), Grosskopf and Moutray (2001), Waldo (2007a), Johnes (2008), Johnes and Yu (2008), Davutyan *et al.* (2010), Haelermans *et al.* (2012), Thieme *et al.* (2012), Portela *et al.* (2013), Brennan *et al.* (2014).
1.4. DEA + Bootstrapping procedure
Observed in: Johnes (2006a), Essid *et al.* (2010) (2013).
1.5. Multi-stage DEA (OLS, Canonical, HLM, Tobit, Truncated, with or without bootstrapping)
Observed in: Mayston and Jesson (1988), Ray (1991), McCarty and Yaisawarng (1993), Ruggiero (1996b), Duncombe *et al.* (1997), Kirjavainen and Loikkanen (1998), McMillan and Datta (1998), Ruggiero and Bretschneider (1998), Mancebón and Mar-Molinero (2000), Bradley *et al.* (2001) (2010), Abbott and Doucouliagos (2002), Muñiz (2002), Cherchye and Vanden Abeele (2005), Ouellette and Vierstraete (2005), Afonso and Aubyn (2006), Primont and Domazlicky (2006), Agasisti and Salerno (2007), Anderson *et al.* (2007), Rassouli-Currier (2007), Waldo (2007b), Cordero-Ferrera *et al.* (2008) (2010), Denaux (2009), Hu *et al.* (2009), Alexander *et al.* (2010), Houck *et al.* (2010), Naper (2010), Agasisti (2011a) (2011b) (2013) (2014), Kounetas *et al.* (2011), Lee (2011), Wolszczak-Derlacz and Parteka (2011), Johnes *et al.* (2012), Mancebón *et al.* (2012), Burney *et al.* (2013), Duh *et al.* (2014).
1.6. DEA + Malmquist Index
Observed in: Flegg *et al.* (2004), Worthington and Lee (2008), Agasisti and Dal Bianco (2009), Agasisti and Johnes (2009), Agasisti and Pérez-Esparrells (2010), Bradley *et al.* (2010), Ouellette and Vierstraete (2010), Rayeni and Saljooghi (2010), Agasisti *et al.* (2011), Thanassoulis *et al.* (2011), Agasisti (2014), Essid *et al.* (2014), Johnson and Ruggiero (2014).
2. Free Disposal Hull (FDH), Order-*m*, conditional efficiency (DEA, FDH, BoD, Order-*m*)
Observed in: Oliveira and Santos (2005), Bonaccorsi *et al.* (2006), Cherchye *et al.* (2010), De Witte *et al.* (2010) (2013), De Witte and Rogge (2010) (2011), Haelermans and De Witte (2012), De Witte and Hudrlikova (2013), De Witte and Kortelainen (2013), Haelermans and Ruggiero (2013), Thieme *et al.* (2013), Blackburn *et al.* (2014).
3. Metafrontier
Observed in: Ruggiero (2000), Thanassoulis and Portela (2002), Lu and Chen (2013), Thieme *et al.* (2013).
4. Other approaches (joint production, network, nested, hybrid returns to scale)
Observed in: Wang (2003), Johnes (2006a), Rayeni and Saljooghi (2010), Kuah and Wong (2011), Johnes (2013), Podinovski *et al.* (2014).
B. Parametric approaches
1. Stochastic Frontier Analysis (SFA)
1.1. SFA (Translog or Cobb-Douglas function, C-OLS, Stochastic Distance Functions, Stochastic Cost frontier)
Observed in: Butler and Monk (1985), Sengupta and Sfeir (1986), Deller and Rudnicki (1993), Jimenez and Paqueo (1996), Cooper and Cohn (1997), Heshmati and Kumbhakar (1997), McEwan and Carnoy (2000), Daneshvary and Clauretie (2001), Geshberg and Schuermann (2001), Grosskopf *et al* (2001), Izadi *et al.* (2002), Dolton *et al.* (2003), Hanushek and Luque (2003), Stevens (2005), Conroy and Arguea (2008), Johnes *et al.* (2008), Kuo and Ho (2008), Millimet and Collier (2008), Abbott and Doucouliagos (2009), Grosskopf *et al.* (2009), Carpenter and Noller (2010), Houck *et al.* (2010), Cordero-Ferrera *et al.* (2011), Mongan *et al.* (2011), Perelman and Santín (2011a) (2011b), Gronberg *et al.* (2012), Haelermans and Blank (2012), Kirjavainen (2012), Misra *et al.* (2012), Deutsch *et al.* (2013), Zoghbi *et al.* (2013), Crespo-Cebada *et al.* (2014).
1.2. Random Parameters Stochastic Frontier Model
Observed in: Johnes and Johnes (2009), Agasisti and Johnes (2010) (2015), Johnes and Schwarzenberger (2011).
C. Mixed approaches (DEA + SFA, DEA+MLM, performance indicators)
Observed in: Sengupta (1987), Taylor and Johnes (1989), Diamond and Medewitz (1990), Barrow (1991), Cubbin and Zamani (1996), Johnes (1996) (2006b), Bates (1997), Ruggiero and Vitaliano (1999), Chakraborty *et al.* (2001), Robst (2001), Mizala *et al.* (2002), McMillan and Chan (2006), Kempkes and Pohl (2010), Bayraktar *et al.* (2013), Grosskopf *et al.* (2014), Johnes (2014a).

Source: The authors

As can be seen from Table 8, some empirical studies on efficiency in education have used this method (e.g., Johnes and Johnes, 2009; Agasisti and Johnes, 2010, 2015; and Johnes and Schwarzenberger, 2011).

On the other hand, the literature provides several methodologies to incorporate environmental variables in the efficiency estimation. However, there is no consensus among researchers about which of the various methodological alternatives is the most appropriate. We do not aim to provide an answer to this intricate question, but rather summarize the earlier literature applying the methodologies. The so-called two-step method is popular and widely employed. In this approach the first stage includes only discretionary inputs, and in a second stage the nondiscretionary variables are regressed on the efficiency scores from the first stage. A drawback of this method is that not all important variables are necessarily identified and used in the regression. Simar and Wilson (2007) have recommended that if this approach is taken, truncated rather than Tobit regression is appropriate and a bootstrap of those results should be included to address serial correlation issues.

Daraio and Simar (2005) suggest using robust conditional estimators (such as order-*m* frontiers and alpha-quantile approaches) to introduce and analyze the effects of environmental variables. This type of approach has been employed by Haelermans and De Witte (2012), Thieme *et al.* (2012), among others. More recently, Badin, Daraio and Simar (2012) have proposed a two-stage procedure in the context of robust, conditional estimators with second stage nonparametric regression (e.g. De Witte and Kortelainen, 2013).

Lastly, some papers have applied a dynamic approach such as Malmquist index (introduced as a theoretical index by Caves *et al.,* 1982) in order to expand the findings obtained through DEA and to reveal the different changes in efficiency scores over the time (technical efficiency, scale efficiency and technological change) (e.g., Essid *et al.*, 2014; Johnson and Ruggiero, 2014). This method is particularly attractive for the education sector where multiple inputs and outputs are used and prices are unknown or difficult to estimate.

3. Methodological steps forward in non-parametric models

While the literature review of section 2 reveals the conceivable size of the OR literature studying education (see also Johnes, 2014b), it is remarkable that it is still a distinct literature from the ‘economics of education literature’. We denote by the latter the more standard (parametric) literature which is published in journals like ‘Journal of Human Resources’, ‘Economics of Education Review’, ‘Education Economics’ or ‘Journal of Public Economics’. While they focus on similar topics, in some way, the two strands of literature do not speak each others language.

It all starts from the difference in the research question. On the one hand, the economics of education literature studies the determinants of students’ results and the effects of specific policies and interventions in these results. On the other hand, the efficiency literature describes the ability of transforming inputs into outputs, and eventually tries to find correlation between efficiency and education institutions' characteristics or environment (Mace, 1984). However, education system is competing with other public expending areas (such as health or unemployment) in the resource allocation process. Therefore, once resources are devoted to education institutions, it is crucial to

know the level of efficiency in the use of these inputs in order to justify new allocations in the future (Psacharopoulos, 1996). In this context, there exists a link between these two streams. Mace (1984) argues that efficiency is one of the research areas inside the economics of education literature.

Another issue is the presumption that correlation does not equal causation. Far too often, the efficiency literature interprets its outcomes in terms of causality rather than correlational evidence. Acknowledging that efficiency models do not estimate causal relationships would be a good first step. Moreover, by carefully examining the applied methodology and data, some papers can improve their internal validity. The economics of education literature is highly concerned with the issue of endogeneity. This arises if there is a correlation between a variable and the error term. Perhaps because non-parametric DEA models do not have an error term, the issue is not picked up in the efficiency in education literature. Some notable exceptions are the (unpublished) work of Santín and Sicilia (2014), and Cordero-Ferrera, Santín and Sicilia (2013). The former exploits a natural experiment, while the latter tests whether DEA is robust for negative or positive endogeneity. Also Ruggiero noted already in 2004 that inputs and outputs are not exogenously determined such that endogeneity might arise. Endogeneity originates from various sources, which we discuss next.

3.1 Endogeneity and its sources.

3.1.1 Omitted variable bias.

First, omitted variable bias indicates that an uncontrolled confounding variable is correlated with the independent variable and the error term. This results in biased estimations (Ruggiero, 2005). A large majority of the efficiency literature is prone to omitted variable bias as non-parametric estimations with a large amount of confounding variables is infeasible due to (1) curse of dimensionality (i.e., there are too few observations given the amount of input and output variables – this is typically the case in studies which use the education institution as a unit of analysis); (2) computational issues as the non-parametric models ‘let the data speak for themselves’ (resulting in a computational burden); (3) the use of data sets that do not have sufficient control variables. The latter is typically the case in administrative and financial data at education institution level.

The literature review reveals that one major example of a similar omitted variable bias in efficiency of education studies is the absence of prior attainments of students. Particularly in international databases like PISA or TIMSS, prior attainment of students is lacking. Without this variable, one cannot estimate efficiency in an unbiased way. A notable exception about the lack of data regarding prior students’ grades is the evaluation program called AVES (Evaluation of Schools with Secondary Education) run by Fundação Manuel Leão in Portugal. This database includes data about tests scores on entry and exit of secondary education. Portela and Camanho (2010) and Portela *et al.* (2013) have used this data base to explore the changes in value added of a sample of high schools.

A related issue is the use of fixed effects regressions, which impose time independent effects for the units of observation. By using fixed effects, the economics of education literature accounts for time invariant observed and unobserved heterogeneity (Greene, 2005). While it would

be easy to include dummy variables, again the computational burden and the curse of dimensionality issue prevent us from doing so in deterministic models.

A solution for the omitted variables bias might involve non-parametric efficiency studies on more adequate datasets at pupil level, which include prior attainments of students. The increasing speed of computers will reduce the computational burden that a larger amount of observations and variables demands. By properly controlling for all observed heterogeneity, the efficiency literature will be closer to the economics of education literature.

3.1.2 Measurement error.

A second source of endogeneity, where particularly deterministic models are prone of, are measurement errors. Although measurement errors can shift the frontier, they are largely neglected. In the case of measurement errors, the efficiency scores will be biased due to the increased variability. Some suggested methodologies as order-*m* or order-alpha mitigate the influence of measurement errors by resampling the original sample. In the absence of prior information on measurement errors, the latter techniques should be favored on standard deterministic techniques. In addition, the efficiency literature should better discuss the presence of measurement errors and its effect on the efficiency scores. For example, the presence of measurement errors might result in an upper bound estimation of the efficiency scores. By discussing this, the policy relevance of the efficiency study increases.

3.1.3 Selection bias.

Another important source of endogeneity is selection bias. In the absence of random assignment (which is the case in most efficiency studies), observations can choose the degree to which they are exposed to a treatment or innovation. In education, the selection in education institutions, education programs or innovations is often strongly correlated to motivation and prior achievement. Examples are provided in Lara, Mizala, and Repetto (2011) or Mizala and Torche (2012).

A first, suboptimal, step to reduce selection bias is to include the motivation for the treatment as a confounding variable. The issue should also be rigorously discussed, and the results should be interpreted with sufficient caution. A second, more optimal, step to account for selection bias is to compare the efficiency scores of a treated and an untreated group. If those two groups are similar on the observed and unobserved characteristics, one can estimate the true efficiency of a treatment, innovation or education institution. In the next section, we discuss how one can proceed to do so.

Other alternatives to handle the selection bias are covered by Perelman and Santín (2011a). The authors address the endogeneity problem of school choice in Spain with instrumental variables. Furthermore, Crespo-Cebada *et al.* (2014) apply propensity score matching to the same scenario.

3.1.4 Simultaneous equation issues

The presence of simultaneous equations is a fourth source of endogeneity, and particularly of importance in education applications (Mayston, 2003). As stated in Mayston (2015) there is a growing literature on three key issues to deal with this source of endogeneity (that is, literature on simultaneous equation modelling within a panel data context, on dynamic panel data models and,

on SFA in a panel data context). However, there is a lack of literature that covers the three approaches together. In this paper, the author bridges this gap by applying the properties of multivariate skew-normal distributions for the further development of SFA in its application to a dynamic simultaneous equations panel data context.

3.2 Methodological similarities

While the language of the efficiency literature and the economics of education literature is different, the two strands have methodological similarities. By acknowledging the similarities the two literatatures can mutually learn. We focus on three important similarities, which have been overlooked before.

3.2.1 Matching versus Conditional efficiency.

While matching analysis focusses on the effect of a treatment and the conditional efficiency analysis focusses on the relative efficiency of observations, the techniques share similar ideas and aim to interpret the influence of confounding variables in a similar way.

The conditional efficiency framework uses non-parametric kernel estimations to attach weights to observations with similar observed characteristics. Observations which are similar to the evaluated observation are in the resampling (cfr. order-*m*) more frequently drawn than observations which are dissimilar. To obtain statistical inference, the conditional efficiency scores are compared to the unconditional efficiency scores.

As discussed in Van Klaveren and De Witte (2014), in many ways, this is closely similar to a '1:1 matching' strategy. This statistical technique searches for each treated (cfr. evaluated) observation a non-treated observation with similar observed characteristics. As the observed characteristics are the same for both groups, matching allows a researcher to assess the influence of a treatment without reduced bias from confounding variables. The assumption is that by selecting on the observed characteristics, also the unobserved characteristics will be similar. Also the 'kernel matching' is comparable to the weights that are assigned in conditional efficiency analysis.

Given that the matching methodology is generally more accepted in the economics of education literature, an interesting way forward is to combine the conditional efficiency approach with insights from matching.

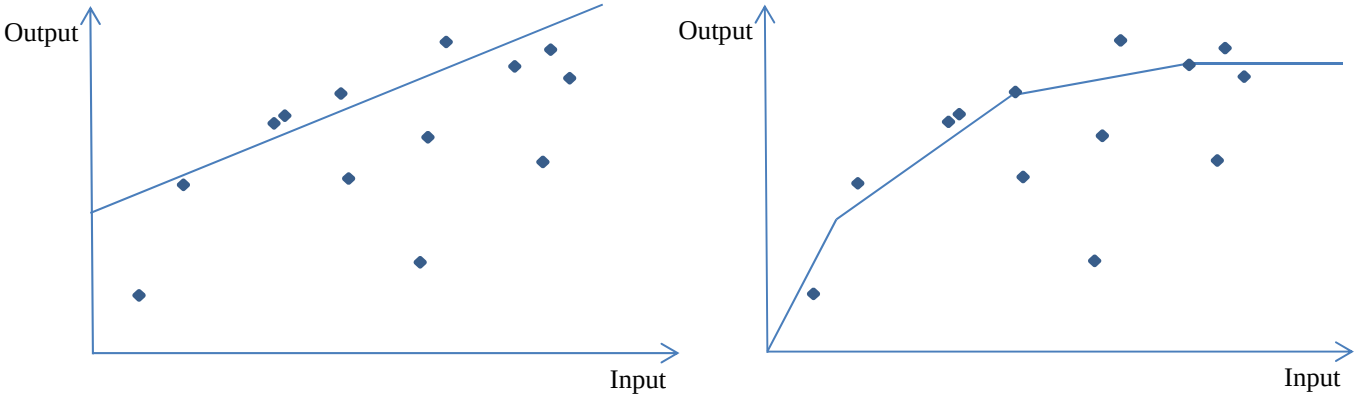
3.2.2 Quantile regressions versus Partial frontiers.

A second similarity between standard econometric procedures and efficiency models are the quantile regressions and partial frontiers. Deterministic frontier models use the outer boundary of a step-wise or convex hull as a starting point to examine relative efficiency. By drawing observations with replacement the 'best practice frontier' shifts inwards if partial frontier models (e.g. order-*m*, order-alpha) are applied.

The idea approaches quantile regressions that estimate the conditional quantile of response variables, compared to least squares techniques that focus on the mean of the response variable (see Figure 2). One way to stimulate methodological advances in partial frontiers is to use insights from quantile regressions.

Examples are the correlations between the confounding variables with the dependent variables for the different quantiles. This could be extended to partial frontier techniques in a straightforward way.

Figure 2: Graphical representation of quantile regression (left) and partial frontiers (right) in case of a two dimensional model

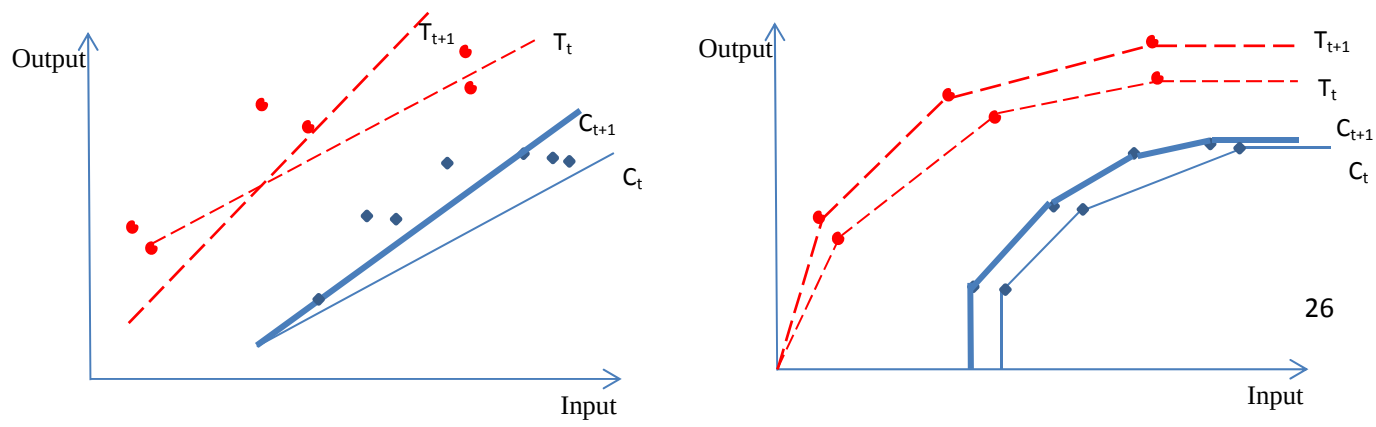


3.2.3 Difference-in-differences versus Metafrontier

One of the currently most popular identification strategies to obtain causal evidence is Difference-in-differences (DiD). A DiD framework compares the change over time of a treatment and a control group, before and after a treatment. To mimic a randomized experiment, it compares two groups and two time periods. In particular, it measures the progress in the control group relatively to the progress in the treatment group.

In some way, this intertemporal aspect is similar to ideas in a metafrontier framework (Battese *et al.*, 2004). In those efficiency models, one can measure the difference in efficiency between two groups. In a straightforward way, one can extend this to changes over time within a group. As revealed in Figure 3, this corresponds closely to the idea of DiD. Note that although Malmquist models also measure the intertemporal changes of observations and the best practice frontier, they are different from the idea of DiD as they do not compare the change between two groups of observations. Nevertheless, Malmquist indices are attractive as they might reveal a more detailed pattern of changes over time within a group. The decomposition in a Malmquist index can help to open the 'black box' of effect studies as it shows what exactly is driving the results. It provides, thus, an interesting way in how the economics of education literature can benefit from the efficiency in education literature.

Figure 3: Graphical representation of difference-in-differences (left) versus metafrontier (right) in a two dimensional model



3.2.4 Value added

In contrast to the relative sparse studies on student added value in the educational efficiency literature (with the exceptions of Portela and Thanassoulis, 2001; Portela and Camanho, 2010 and Portela *et al.,* 2013) one can find several papers about this topic in the literature about school effectiveness. For instance, the work of Ferrao and Couto (2014) focuses on the use of the value-added approach for promoting school improvement in the Portuguese system. In addition, Lenkeit (2013) also applies a value-added model to measure the impact of education on student learning net of the effect of student background variables. In this case, the author controls the estimations for prior achievement scores. The work of Timmermans *et al.* (2011) presents a conceptual framework of five different value-added measures and empirically provides estimates using data from Dutch secondary schools. They conclude by saying that the correlation between the different types of school effects estimated is rather high, but the models implicate different results for individual schools. Concluding, the literature on efficiency in education might find insights from school effectiveness research about how to measure value added compared to students' prior attainments.

4. Conclusion and Discussion

This paper reviewed in a comprehensive way the extensive literature on efficiency in education. The review summarized the input, output and contextual variables used in the literature, as well as the applied methodologies. As efficiency models heavily depend on the selection of the inputs and outputs, this paper can therefore be of use for anyone working in the field of efficiency analysis.

The literature review leads us to four main conclusions. First, it is necessary to properly quantify the influence of environmental variables on student outcomes. It will reveal the underlying mechanisms which drive the efficiency estimates, and make the efficiency estimates more accurate. Recent models such as the conditional efficiency model are suitable for this purpose, however, with the current technologies they are inappropriate for very large datasets due to the execution time required. Second, more research is necessary to the differences in educational outcomes and education system charactereristics between countries. We should be able to explain why some education systems are realizing higher education outcomes than others. The availability of international databases such as PISA and TIMSS allow researchers to conducting this research. Third, the literature review makes clear that researchers have to work with rather poor proxies to measure the abilities of students, finance of education institutions, or ICT investments. We should invest more in better and more detailed data on human resources, finance, ICT, procurement, estates, and student services. Nowadays, the variables are too generic and unspecific. We need, e.g., to develop indicators that can capture teacher quality, as this serves as a better proxy for school inputs than the commonly used school resources. Moreover, we need better output indicators to capture long-term educational benefits. Finally, more research about student added value is needed. It is interesting to investigate the evolution of the student in educational terms, whether the entry educational level has remained, improved or worsened within a particular educational period.

Using the insights from the literature review, we showed that the efficiency in education literature is currently distinct from the more standard economics of education literature. To start

with, they seem to have different research questions. While the economics of education literature studies the determinants of organizations' results (achievement) and/or the effects of specific policies and interventions, the efficiency literature describes the ability of transforming inputs into outputs, and eventually tries to find correlation between efficiency and organizations' characteristics or environment. Second, while the latter is concerned with endogeneity issues arising from measurement errors, selection bias or unobserved heterogeneity, these issues are barely mentioned in efficiency papers. This leads us to an operative direction for prospective researchers in the field. In particular, the efficiency literature pays currently a significant effort to optimize its own models. In doing so, it focusses on minor methodological details and neglects the current important issues in related fields. Therefore, we propose to focus more on the issue of causality, and on how endogeneity biases the efficiency outcomes.

Nevertheless, there are some clear similarities between efficiency models and some standard econometric techniques. First, the popular matching approach resembles in various ways to the conditional efficiency model. Further extensions to the latter approach can be inspired from the matching techniques. Second, partial frontier techniques remind us to the quantile analyses. Third, metafrontier techniques could drastically increase their popularity and relevance if they would mimic better the standard Difference-in-Differences ideas in which a control group is compared to a treatment group at two points in time. Finally, there are some clear similarities between the measurement of value added in the efficiency literature and the effectiveness literature. By paying attention to the differences and similarities, both literatures might benefit from each other.

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APPENDIX. DATA SETS USED IN THE LITERATURE ABOUT EFFICIENCY IN EDUCATION

Table A1: Data sets used in the literature

Data from another paper
Observed in: Bessent and Bessent (1980), Ray and Mukherjee (1998), Wang (2003), Millimet and Collier (2008).
Data from educational programs (Follow Through, Integrated Secondary Data System, SiBO-project)
Observed in: Charnes *et al.* (1981), Robst (2001), Cherchye *et al.* (2010).
GCSE Data (General Certificate of Education Advanced Level)
Observed in: Thanassoulis and Dustan (1994), Thanassoulis (1999), Portela and Thanassoulis (2001), Thanassoulis and Portela (2002), De Witte *et al.* (2010).
National Data Bases from the Department of Education/Employment or similar
Observed in: Bessent *et al.* (1982), Butler and Monk (1985), Sengupta and Sfeir (1986) (1988), Jesson *et al.* (1987), Sengupta (1987), Smith and Mayston (1987), Mayston and Jesson (1988), Färe *et al.* (1989), Taylor and Johnes (1989), Beasley (1990), Callan and Santerre (1990), Diamond and Medewitz (1990), Barrow (1991), Ray (1991), Ganley and Cubbin (1992), Kao and Yang (1992), Deller and Rudnicki (1993), Johnes and Johnes (1993) (1995) (2009), McCarty and Yaisawarng (1993), Bonesrønning and Rattsø (1994), Sinuany *et al.* (1994), Chalos and Cherian (1995), Ruggiero *et al.* (1995), Cubbin and Zamani (1996), Engert (1996), Jimenez and Paqueo (1996), Johnes (1996) (2006a) (2006b) (2006c) (2008) (2014a), Mar-Molinero (1996), Ruggiero (1996a) (1996b) (2000) (2007), Thanassoulis (1996), Athanassopoulos and Shale (1997), Bates (1997), Duncombe *et al.* (1997), Grosskopf *et al.* (1997) (1999) (2001) (2009) (2014), Heshmati and Kumbhakar (1997), McMillan and Datta (1998), Ruggiero and Bretschneider (1998), Ruggiero and Vitaliano (1999), Mancebón and Mar-Molinero (2000), McEwan and Carnoy (2000), Thursby (2000), Ying and Sung (2000), Avkiran (2001), Bradley *et al.* (2001) (2010), Chakraborty *et al.* (2001), Daneshvary and Clauretie (2001), Geshberg and Schuermann (2001), Grosskopf and Moutray (2001), Abbott and Doucouliagos (2002) (2003) (2009), Fukuyama and Weber (2002), Izadi *et al.* (2002), Mizala *et al.* (2002), Moreno and Tadepali (2002), Muñiz (2002), Emrouznejad and Thanassoulis (2005), Kiong *et al.* (2005), Oliveira and Santos (2005), Ouellette and Vierstraete (2005), Casu and Thanassoulis (2006), Koksal and Nalcaci (2006), Agasisti and Salerno (2007), Fandel (2007), Rassouli-Currier (2007), Waldo (2007a) (2007b), Conroy and Arguea (2008), Johnes *et al.* (2008), Kao and Hung (2008), Kuo and Ho (2008), Mancebón and Muñiz (2008), Millimet and Collier (2008), Worthington and Lee (2008), Agasisti and Dal Bianco (2009), Agasisti and Johnes (2009) (2010), Colin-Glass *et al.* (2009), Kantabutra (2009), Sarrico and Rosa (2009), Alexander *et al.* (2010), Carpenter and Noller (2010), Essid *et al.* (2010) (2013) (2014), Houck *et al.* (2010), Kempkes and Pohl (2010), Kantabutra and Tang (2010), Khalili *et al.* (2010), Katharaki and Katharakis (2010), Ouellette and Vierstraete (2010), Portela and Camanho (2010), Rayeni and Saljooghi (2010), Sarrico *et al.* (2010), Agasisti *et al.* (2011) (2012), Johnes and Schwarzenberger (2011), Kounetas *et al.* (2011), Lee (2011), Mongan *et al.* (2011), Thanassoulis *et al.* (2011), Eff *et al.* (2012), Gronberg *et al.* (2012), Haelermans and Blank (2012), Haelermans and De Witte (2012), Haelermans *et al.* (2012), Johnes *et al.* (2012), Kirjavainen (2012), Misra *et al.* (2012), Portela *et al.* (2012) (2013), Sexton *et al.* (2012), Tochkov *et al.* (2012), Burney *et al.* (2013), Haelermans and Ruggiero (2013), Johnes (2013), Lu and Chen (2013), Thieme *et al.* (2013), Zoghbi *et al.* (2013), Agasisti and Bonomi (2014), Blackburn *et al.* (2014), Brennan *et al.* (2014), Johnson and Ruggiero (2014), Mainardes *et al.* (2014), Nazarko and Saparauskas (2014), Podinovski *et al.* (2014).
Other OECD Data (than PISA and TIMSS)
Observed in: Kocher *et al.* (2006), Agasisti (2011b), Aristovnik and Obadic (2014).
Other Databases (Econlit, Eurostat, UNESCO, World Bank's World Depelopment database)
Sarrico and Dyson (2000), Cokgezen (2009), Aristovnik and Obadic (2014).
Own data (questionnaires, public data from web sites, registers, quality assessment reports, university rankings, etc.)
Observed in: Breu and Raab (1994), Beasley (1995), Chalos (1997), Cooper and Cohn (1997), Madden *et al.* (1997), Haksever and Muragishi (1998), Kirjavainen and Loikkanen (1998), Mancebón and Bandres (1999), Ruggiero (1999), Colbert *et al.* (2000), Korhonen *et al.* (2001), Abbott and Doucouliagos (2003), Dolton *et al.* (2003), Banker *et al.* (2004), Flegg *et al.* (2004), Cherchye and Vanden Abeele (2005), Joumady and Ris (2005), Stevens (2005), Bonaccorsi *et al.* (2006), Bougnol and Dulá (2006), Giménez and Martínez (2006), McMillan and Chan (2006), Primont and Domazlicky (2006), Anderson *et al.* (2007), Tauer *et al.* (2007), Cordero-Ferrera *et al.* (2008) (2010), Johnes and Yu (2008), Ray and Jeon (2008), Abramo and D'Angelo (2009), Denaux (2009), Hu *et al.* (2009), Tyagi *et al.* (2009), Agasisti and Pérez-Esparrells (2010), Davutyan *et al.* (2010), De Witte and Rogge (2010) (2011), Dehnokhalaji *et al.* (2010), Naper (2010), Wolszczak-Derlacz and Parteka (2011), Haelermans and Blank (2012), Haelermans and De Witte (2012), Haelermans *et al.* (2012), Kirjavainen (2012), Kong and Fu (2012), Montoneri *et al.* (2012), Bayraktar *et al.* (2013), De Witte and Hudrlikova (2013), De Witte *et al.* (2013), Duh *et al.* (2014).
PISA Data (Programme for International Student Assessment)
Observed in: Afonso and Aubyn (2006), Agasisti and Dal Bianco (2006), Agasisti (2011a), Cordero-Ferrera *et al.* (2011), Perelman and Santín (2011a) (2011b), Mancebón *et al.* (2012), Thieme *et al.* (2012), Agasisti (2013) (2014), Aristovnik (2013), De Witte and Kortelainen (2013), Deutsch *et al.* (2013), Crespo-Cebada *et al.* (2014).
TIMSS Data (Trends in International Mathematics and Science Study)
Observed in: Hanushek and Luque (2003), Giménez *et al.* (2007).

Source: The authors

Examples of national databases are the IGAP (Illinois Goal Assessment Program), ISBE (Illinois State Board of Education), HSMS (Household School Matching Survey Project, Philippines), CAR (Comprehensive Assessment Report) and PEP (Pupil Evaluation Program) from New York State, TEAMS (Texas Education Assessment of Minimum Skills), SIMCE (*Sistema Nacional de Evaluación de Calidad de la Educación*, Chile), NRC (National Research Council Survey, USA), ACT (American College Tests), The Annual Performance Assessment Scheme in Turkey, AVES (Evaluation of Schools with Secondary Education, Portugal), QuESTIO, survey developed by the Lombardy Regional Government, The National Operative of Educational Quality Evaluation of the Argentine Republic, NAPLAN Database developed by the Commonwealth Government in Australia, CAUBO (Canadian Association of University Business Officers), HESA (Higher Education Statistical Agency) in UK and SAT standardized test scores.