ABSTRACT
The measurement of efficiency in higher education has gained a growing interest in recent years, especially due to the expansion of the university system. This paper provides a review of the literature on efficiency in higher education institutions by covering empirical articles which applied frontier efficiency measurement techniques from 1997 to 2019. We review the methodological approaches used, both parametric and non-parametric techniques, such as Data Envelopment Analysis, Malmquist index and Stochastic Frontier Analysis. Second, we list the applied inputs, input prices, outputs, quality, and environment variables and based on the overview, we discuss the advantages and drawbacks of the different empirical proxy variables used. We address the importance of characterizing students and research funding as raw materials of both the teaching and research services, respectively, and we provide suggestions on how to deal with them empirically. We also discuss the difference between quality and environmental variables, and we give some practical indications to distinguish them in doubtful cases.

KEYWORDS
Data Envelopment Analysis, Efficiency Frontiers Review, Stochastic Frontier Analysis, university efficiency

HIGHER EDUCATION EFFICIENCY FRONTIER ANALYSIS: A REVIEW OF VARIABLES TO CONSIDER

INTRODUCTION
The measurement of efficiency in higher education has gained increasing interest in recent years, especially due to the expansion of the university system. With increasing enrolment rates all over the world, they are forced to employ increasing resources to achieve their goals. Arkeryd (2001), characterize the universities productive process as one with a ‘lack of profit motive’, goal diversity,..., diffuse decision making, and poorly understood production technology’. Productivity and efficiency improvements are then viewed as hard to define and are sometimes viewed with distrust or rejected by insiders. They are often conceived as quality-insensitive cost reductions or managerial practices which do not contribute to academic goals or that they relax academic requirements on students to improve achievement indicators (Gates and Stone, 1997).

TO CONSIDER

1. We do not consider for-profit universities although they do exist in some contexts. See Sav (2012).

2. Universities produce teaching, research, and extension (also called transfer or third mission), the latter services being added by each input, the simultaneous role of the consumer in improving achievement indicators (Gates and Stone, 1997).

3. In service sectors, productivity and efficiency are hard to measure. It is hard to identify and to measure outputs, the value added by each input, the simultaneous role of the consumer in the final outcome and as an input (e.g. personal effort devoted to study), and to account for environmental (contextual) and quality respects. Productivity measures are rank-free indicators of the rate at which inputs are transformed into outputs. Technical efficiency is defined as the ability to minimize input usage for a given output (or to maximize output for given quantities of inputs). That is not the only efficiency measure. Allocative or cost efficiency is defined as the ability to optimize the input mix, given their prices, while economic or overall efficiency considers both, technical and allocative efficiencies. Which variables are considered in empirical studies of efficiency depends on the type of efficiency assessed: technical efficiency studies require data of physical inputs and outputs, while cost efficiency studies employ information of costs, physical outputs and input-prices. Universities have multiple objectives and outcomes, some of them in a statistical and some in a non-statistical way. Some of them yield externalities or have public good features (that is, not rival consumption plus impossibility to exclude consumers, in issues such as social values building).

INTRODUCTION
The measurement of efficiency in higher education has gained a growing interest in recent years, especially due to the expansion of the university system. This paper provides a review of the literature by discussing in a structured way the empirical articles on efficiency in higher education institutions which apply frontier efficiency measurement techniques. We review 89 empirical studies and almost 40 methodological and conceptual articles written in English between 1997 to 2019 on higher education efficiency frontiers. We first review the used methodological approaches, both parametric and non-parametric techniques such as Data Envelopment Analysis, Malmquist index and Stochastic Frontier Analysis. Second, we list the applied inputs, input prices, outputs, quality, and environment variables. Based on the overview, we discuss the advantages and drawbacks of the different empirical proxy variables used. Some aspects of efficiency are studied in different periods, productivity change of each decision-making unit from the frontier is considered inefficiency; the method does not distinguish randomness, nor external noise affecting scores. In their standard variants, it is vulnerable to outliers and measurement errors. There are different DEA models’ extensions, including two-stage DEA, bootstrapping, and distance-function analysis (Durazo, Bonaccorsi and Simar, 2015). Besides, when efficiency is measured the distance to the frontier of each decision-making unit from the frontier is considered inefficiency; the method does not distinguish randomness, nor external noise affecting scores. In their standard variants, it is vulnerable to outliers and measurement errors.

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DEA provides a scalar measure of the efficiency of a collection of decision-making units (Charnes, Cooper, and Rhodes, 1978: 43). The efficiency measure is therefore total output divided by total input for each decision-making unit. DEA has been used in many applications, with different forms and error specifications, and with different types of quantitative data.2

Subject to:

\[ \sum_{j=1}^{m} y_{ij} \theta_j = \sum_{j=1}^{m} x_{ij} \theta_j = 1, \quad \text{for all } i, j = 1, \ldots, n \]

\[ u_i, v_i \geq 0; \quad \text{where } u_i \text{ and } v_i \text{ are infinitesimal constants} \]

The efficiency measure (score) for any decision-making unit is obtained as the maximum ratio of weighted outputs to weighted inputs, subject to similar ratios for every decision-making unit being less or equal to unity. Following the Charnes, Cooper, and Rhodes (1978) notation, for decision-making units \( j = 1, \ldots, n \), \( s \) outputs and \( t \) inputs the problem is:

\[ \text{Max } \theta = \frac{\sum_{j=1}^{m} y_{ij} \theta_j}{\sum_{j=1}^{m} x_{ij} \theta_j} \quad \text{subject to } \sum_{j=1}^{m} y_{ij} \theta_j = \sum_{j=1}^{m} x_{ij} \theta_j = 1, \quad \text{for all } i, j = 1, \ldots, n \]

2 Because individual inputs and outputs need to be suitably and meaningfully aggregated, in the absence of market prices, which are the natural weights, DEA endogenously generates “shadow prices” of inputs and outputs for aggregation. Thence, the estimated weights can be understood as “shadow prices” (Ray, 2004).
In this Section we review the main variables used to assess efficiency through the literature reviewed in a previous Section. We first analyze the output variables considered in the different articles. We then make an overview of the input variables, quality and the contextual environment variables.

### Outputs
University outputs can be classified in teaching (knowledge dissemination), research (basic or applied knowledge production), and extension (also known as transfer, public community or “third mission” activities) (See Table 2). The latter comprehends services which possess external effects and public goods aimed to valued audiences beyond campuses (Johnes and Johnes, 2009). There are complex synergies between the different areas. In the short run and research. On the one hand, there are potential scope economies among teaching and research; on the other hand, both consume resources and their rewards differ in the short- and long-run. Omitting research activities, implicitly, is such assuming no complementarities or substitutions exist among teaching and research (Horne and Hu, 2008).

### Inputs and input prices
The inputs can be classified in human and non-human resources (See Table 2). The former includes teaching and research effort of the university labor force and “raw materials”, measured through full-time equivalent students to be taught, and the latter are physical and financial resources.

Human resources are measured by the academic and non-academic staff as headcount or salaries paid to different categories of personnel. Faculty headcount, with some weights attached, such as one for professors, different one for associates and the third one for assistants, is the most frequently considered input variable. Because some academics work in both teaching and research activities, the ratio of researchers or research workload over full-time academics can be calculated to attribute inputs to outputs. Non-human resources include facilities and materials, which can be measured in physical or financial units, such as surface of laboratories or classrooms, classroom seats, computers, books in libraries, etcetera, in the former, and hardware money expenditure in the latter.

When costs frontiers are estimated, the unit prices of inputs result from some quotient between expenditure items and physical units employed: average labor cost of full-time academics of certain level, or an average cost for square meter of classroom, for instance.

### Quality
Quality variables are present in less than 20 percent of the examined studies (see Table 2). Quality can and ideally should be assessed either in outputs or inputs, for fair and meaningful comparisons, through different coefficients or dummy variables. To address teaching activities quality, researchers use indexes of completion, achievements and recognition, given length, structure and contents of the programs, time dedication, and qualification of the staff, while in research, quality is related to value and impact. If these elements are ignored, results can be incomplete and probably biased. Quality is costly, and it is in the hands of the universities to allocate resources for its improvement.

They can include drop-out rates as a proportion of the cohort, the faculty per student ratio, the staff expenditure on total expenditure ratio, the professorship or tenured academics ratio, the full-time researchers, teaching and/or management workload on total faculty. Impact factors and citation indexes account for quality in research.

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### Non-Parametric Estimates (* Two Stages DEA*)

**Production, Cross-Sectional (10 papers)**
- Abbott and Doucouliagos (2003), Agasisti and Pérez-Esparrell (2010), Agasisti et al. (2012), Akkvarn (2003), Costa, Ramos and de Souza (2011), Katharaki and Katharaki (2010), Johnes, Johnes (2006a, b), Kusul and Wong (2011), Marinho, Resende and Façanha (1997), Athanassioupolous and Shale (1997).
- Abbott and Doucouliagos (2003), Abrahao and D’Angelo (2009), Agasisti (2011, 2014), Agasisti and Bonomi (2014), Agasisti and Dal Bianco (2006), Agasisti and Johnes (2009), Agasisti and Welsack-Derlacz (2016), Anderson et al. (2016), Barra and Zott (2016b), Berbergal-Mirabet, Lafuente, and Soli (2013), Berbergal-Mirabet (2018), Cantele, Guerini and Campelledo. (2016), Cascino and Cabanda (2007), Costa, Ramos, and de Souza (2011), D’Elia and Ferro (2020), Flegg and Allen (2007), Flegg et al. (2004), Guccio, Martorana and Monaco (2016), Johnes and Yu (2008), Jones and Johnes (1993), Lee and Worthington (2016), Mikulović (2017), Sotomayor and Burtalioglu (2013).

**Cost, Cross-Sectional (1 paper)**
- Johnes and Tone (2016).

**Cost, Panel (3 papers)**
- Agasisti (2011), Johnes and Johnes (2009).

**Quality**

Various facts add complexity to measure research output: (1) Some research outcomes are not ex-ante observable or ex-post measurable (D’Elia and Ferro, 2019); (2) Unobserved research effort may well lead to no results, and conversely, given that “serendipity and luck may yield huge returns at little cost” (De Fraja and Valbonesi, 2012); (3) The research prestige is measurable (D’Elia and Ferro, 2019); (4) Some research outcomes, head-count of approved dissertations, patents and other intellectual property rights, measured by the number of registers, attached with some criteria to weigh them, awards, with similar problems than the former, grants, project money and/or partnership with business.

### Both Parametric and Non-Parametric Estimates

**Cost, Panel (5 papers)**
- Agasisti and Granja (2017), Agasisti and Granja and Zott (2016), Erkoc (2013), Guccio, Martorana and Monaco (2016), Johnes and Yu (2008), Jones and Johnes (1993), Lee and Worthington (2016), Mikulović (2017), Sotomayor and Burtalioglu (2013).

**Conceptual and Surveys**

**Surveys (5 papers)**
- De Witte and López Torres (2017), Granja (2018a), Riahiem (2017), Johnes (2004), Worthington (2001).

**Conceputal (11 papers)**
- Agasisti (2017), Baurer et al. (1998), De Fraja and Valbonesi (2012), Dyon et al. (2001), Eagan and Titus (2016), Gates and Stone (1997), Mensah and Werner (2003), Miller (2010), Sivonen (2003), Warning (2004), Wol, Baumol and Saini (2014).

**Table 1: Summary of the methods applied for estimating efficiency**

| RESULTS | In this Section we review the main variables used to assess efficiency through the literature reviewed in a previous Section. We first analyze the output variables considered in the different articles. We then make an overview of the input variables, quality and the contextual environment variables. |

| Outputs | University outputs can be classified in teaching (knowledge dissemination), research (basic or applied knowledge production), and extension (also known as transfer, public community or “third mission” activities) (See Table 2). The latter comprehends services which possess external effects and public goods aimed to valued audiences beyond campuses (Johnes and Johnes, 2009). There are complex synergies between the different areas. In the short run and long-run, omitting research activities, implicitly, is such assuming no complementarities or substitutions exist among teaching and research (Horne and Hu, 2008). Teaching output is proxied as the number of degrees completed, sometimes distinguishing between undergraduates and graduates, results in standardized tests, head-count of enrolled students standardized by full-time equivalent, courses/ hours/credits taught to proxy the added knowledge, job or remuneration attainments by degree to address students’ potential of employment, earnings, or rate-of-return, and/or graduate students admitted. Research output is commonly proxied by published documents. They are measured by some weighted sum of articles, books or chapters, conference papers, etcetera, where the problem is how to weight the different impact factor and age of the academic products, because practices and traditions differ among disciplines. It is also complex to compute externalities from co-authorship. Other measures for research outputs include citation indexes, which measure the impact of the published research outcomes, head-count of approved dissertations, patents and other intellectual property rights, measured by the number of registers, attached with some criteria to weigh them, awards, with similar problems than the former, grants, project money and/or partnership with business. |

| Quality | Quality variables are present in less than 20 percent of the examined studies (see Table 2). Quality can and ideally should be assessed either in outputs or inputs, for fair and meaningful comparisons, through different coefficients or dummy variables. To address teaching activities quality, researchers use indexes of completion, achievements and recognition, given length, structure and contents of the programs, time dedication, and qualification of the staff, while in research, quality is related to value and impact. If these elements are ignored, results can be incomplete and probably biased. Quality is costly, and it is in the hands of the universities to allocate resources for its improvement. They can include drop-out rates as a proportion of the cohort, the faculty per student ratio, the staff expenditure on total expenditure ratio, the professorship or tenured academics ratio, the full-time researchers, teaching and/or management workload on total faculty. Impact factors and citation indexes account for quality in research. In empirical studies, expected signs of quality variables are negative in productive efficiency estimates since they consume inputs, and positive in cost estimates since they are costly. Nevertheless, more complex relationships can appear in the empirical work, since quality yields prestige which systematically rewards professors and students, provided the system under analysis has a reasonable degree of mobility between universities. |
Environmental variables

Environmental variables are included in more than 70 percent of the analyzed studies (See Table 2). Those allow addressing for observable heterogeneity due to uncontrollable factors. The main difference between environmental and production or cost frontier modeling is that environmental variables reflect non-factor input influence or structure, while the latter influence the efficiency with which the drivers are converted into outputs (costs). It can be distinguished three groups of environmental variables in the former influence the structure, regional where the university is situated (poor or rich); and type of university (big or small, old or new, private or public). Environmental variables are included in 70 percent of the analyzed studies). Students’ socio-economic background is highly correlated with future performance of graduates thus it is a characteristic to be considered when data is available. At the same time, universities in some cases deliberately can select their students by socio-economic condition. Expected signs in inputs are positive in production studies, while in educational studies they are computed as a ratio between expenditure and some resources spent on them.

The delimitation criteria in our studies include: size; ownership and governance, contemplating public or private ownership; non-profit or for-profit; public or private, religious or non-religious, degree of specialization in capital intensive disciplines to denote the different hardware intensity, typically considering the share of natural sciences, engineering and/or medicine on total, and considered, whether it is old or new with respect to a local system, in the understanding that history could matter in efficiency. The latter are the most elusive, since they adopt mostly the form of good/wealthy students in good/wealthy universities. Of the lessons of this study. Below, we propose a criterion to deal practically with the issue. As a result, the concept of academic performance and research productivity or average cost measures. We propose as a possible solution to this ambiguity the following procedure: in DEA studies, correlating students with research, we included funding as the input measure. If correlations are positive, they are inputs; in SFA studies, analyzing the sign of the partial derivative of the estimated frontier with respect to students (research money), it is input. In fact, if the partial derivative of the estimated frontier with respect to inputs, it is not possible to do the same in SFA production frontiers (save, when “output” is a composite or a bundle of products or services), while it is possible to consider multiple measures of facilities or financial resources spent on them.

The determinacy of meaningful input prices is also an issue when parametric cost functions are estimated. Typically, they are computed as a ratio between expenditure and some physical input measure. Quality variables try to address observable characteristics or input/output ratios. However, while not in others; ethnic diversity can yield a very rich picture of the lessons of this study. Below, we propose a criterion to deal practically with the issue.

Results in standardized tests as an alternative measure of output do not consider economies of scale and scope studies in university systems by analyzing 89 specific studies published from 1997 to 2019. Most of the papers we review use non-parametric DEA models to estimate efficiency (54 percent of examined studies). Parametric studies are intended to address technical efficiency, while in the second stage the regression implicitly assumes that the scores are not identically distributed. The second category of variables are those referred to inputs. Results in standardized tests as an alternative measure of output instead, they are treated as outputs. Again, we propose below a criterion to deal with this fact in empirical work.

The literature discusses how to include environmental variables in efficiency estimates. In the past, a two-stage approach for including environmental variables was common, both in parametric and non-parametric approaches, however it was criticized by its limitations (Coelli et al., 2005; Simar and Wilson, 2007). In the parametric approach (including environmental variables as inputs or outputs) the estimated (ratio) sign of the partial derivative of the estimated frontier with respect to inputs is positive. Environmental variables are included in 70 percent of the examined studies. This fact is not always addressed in the same sense, and students are sometimes not considered as inputs, instead, they are treated as outputs. Again, we propose below a criterion to deal with this fact in empirical work. The purpose of this chapter is to provide a possible solution to this ambiguity the following procedure: in DEA studies, correlating students with research, we included funding as the input measure. If correlations are positive, they are inputs; in SFA studies, analyzing the sign of the partial derivative of the estimated frontier with respect to students (research money), it is input. In fact, if the partial derivative of the estimated frontier with respect to inputs, it is not possible to do the same in SFA production frontiers (save, when “output” is a composite or a bundle of products or services), while it is possible to consider multiple measures of facilities or financial resources spent on them.

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| Output variables                  | Empirical proxy | Authors                                                                 |
|----------------------------------|----------------|-------------------------------------------------------------------------|
| Degrees completed                | Head count     | D’Elia and Ferro (2020), Cantele, Guerini, and Campedelli (2016), Lauret, Secondi and Biggeri (2014), Kuah and Wong (2011), Katkarah and Katharakis (2010), Johns (2006 a), Salerno (2003), Avkiran (2001) |
| Results in standardized tests    | Standardized tests grades | Lauret, Secondi and Biggeri (2014), Zoghbi, Rocha and Mattos (2013), Kuah and Wong (2011), Worthington (2001) |
| Enrolled students                | Head count     | Cantele, Guerini and Campedelli (2016), Salerno (2003)                  |
| Knowledge added                  | Hours, courses, or credit taught | Kuah and Wong (2011), Cohn and Cooper (2004) |
| Student potential employment     | Job attainment once graduated | Zoghbi, Rocha and Mattos (2013), Kuah and Wong (2011), Worthington (2001) |
| Students’ potential earnings     | Salaries once graduated | Zoghbi, Rocha and Mattos (2013), Johns and Johns (2009), Worthington (2001) |
| Admission to graduate studies    | Head count     | Ferreyra et al. (2017)                                                   |
| Published products               | Weighted sum of articles, books, conference papers, etc. | Cantele, Guerini and Campedelli (2016), Kuah and Wong (2011), Worthington and Lee (2008), Salerno (2003) |
| Cited publications               | Count of citations | Kao and Hung (2008), Avkiran (2001) |
| Ph.D. awarded                    | Head count     | De Fraja and Valbonesi (2012), Kuah and Wong (2011), Worthington and Lee (2008) |
| Patents and other intellectual property rights | Number of registers | Kuah and Hong (2008), Kuah and Wong (2011) |
| Grant, project, business contract or research money | Money spent | Kao and Hung (2008), Kuah and Wong (2011), Salerno (2003), Katkarah and Katharakis (2010), Cantele, Guerini and Campedelli (2016) |
| Citizenship, behavioral changes, value transmission | None, hard to measure meaningfully | Ferreyra et al. (2017), Avkiran (2001) |
| Cultural, sport or recreational events | None, hard to measure meaningfully | Cohn and Cooper (2004), Avkiran (2001) |
| Informed opinion in media or community events | None, hard to measure meaningfully | Cohn and Cooper (2004), Avkiran (2001) |

| Input variables                  | Empirical proxy | Authors                                                                 |
|----------------------------------|----------------|-------------------------------------------------------------------------|
| Academic Staff                   | Full-time Equivalent Academic Head Count | D’Elia and Ferro (2020), Lauret, Secondi and Biggeri (2014), Kuah and Wong (2011), Johns and Yu (2008), Worthington and Lee (2008), Avkiran (2001) |
| Students to be taught            | Head count     | D’Elia and Ferro (2020), Lauret, Secondi and Biggeri (2014) |
| Non-academic staff               | Head count     | Worthington and Lee (2008), Avkiran (2001), Worthington (2001) |
| Non-human resources              | Classroom and labs surface, seats, computers, library items, materials | Cantele, Guerini and Campedelli (2016), Lauret, Secondi and Biggeri (2014) |
| Non-human inputs expenditure     | Money spent    | Kao and Hung (2008), Worthington and Lee (2008), Worthington (2001) |

| Quality variables                | Empirical proxy | Authors who proposed or discussed them                                                                 |
|----------------------------------|----------------|-------------------------------------------------------------------------|
| Drop-out rates                   | Proportion on cohort | Zoghbi, Rocha and Mattos (2013) |
| Student on Faculty               | Proportion on Faculty | Ferreyra et al. (2017) |
| Staff expenditure                | Proportion on total expenditures | Ferreyra et al. (2017) |
| Professorship or Tenured Academics | Proportion on Academics | Sav (2012a), Johns and Yu (2008), Kuo and Ho (2008) |
| Index of Full-Time Faculty       | Full-time Faculty on Total Faculty | Sav (2012a) |
| On-Line Students                 | On-line on total students | Wolff, Baumol and Salini (2014) |
| Research or Doctoral Students    | Ratio on total academics | Kao and Hung (2008), Johns and Yu (2008) |

| Environmental variables          | Empirical proxy | Authors who proposed or discussed them                                                                 |
|----------------------------------|----------------|-------------------------------------------------------------------------|
| Students’ intellectual background or potential | High school grades, access exams grades | Ferreyra et al. (2017), Lauret, Secondi and Biggeri (2014) |
| Individual effort and peer externalities | None, hard to measure meaningfully | Worthington (2001) |
| Parent economic condition        | Parents’ per capita GDP | Lauret, Secondi and Biggeri (2014) |
| Parental education level         | Parents’ years of schooling | Zoghbi, Rocha and Mattos (2013) |
| Full-time students               | Full time on total students | Zoghbi, Rocha and Mattos (2013) |
| Gender / age composition of students | Female on total students, average age of students | Lauret, Secondi and Biggeri (2014), Zoghbi, Rocha and Mattos (2013), Johns (2006b) |
| Ethnic composition of students   | Minority on total students | Worthington (2001) |
| International students           | Foreign to domestic students | Lauret, Secondi and Biggeri (2014) |
| Regional GDP                     | GDP of the region over national average | Cantele, Guerini and Campedelli (2016), Zoghbi, Rocha and Mattos (2013), Lauret, Secondi and Biggeri (2014), Costa, Ramos and de Souza (2011), Agathis and Johnston (2009) |
| Regional human capital           | Average years of schooling in the region on national average | Cantele, Guerini and Campedelli (2016), Zoghbi, Rocha and Mattos (2013) |
| Size of the university           | With respect to local context | Cantele, Guerini and Campedelli (2016), Daraio, Bonacorsi and Simar (2015) |
| Ownership or Governance          | Public or private, non-profit, or non-profit, Iac or religious | Milot (2003), Lauret, Secondi and Biggeri (2014) |
| Facilities intensiveness         | Share of medicine, engineering or science on total disciplines | Cantele, Guerini and Campedelli (2016), Daraio, Bonacorsi and Simar (2015), Lauret, Secondi and Biggeri (2014), Johns (2004), Johns and Johns (2009, 1993), Horne and Hu (2008), Cohn and Cooper (2004) |

Age of the university: Old or new in local context | Johns and Johns (2009, 1993) |

Table 2: Summarizing variables used in higher education efficiency frontier studies

References

Abbott, M., and Doucouliagos, C. (2009) ‘Competition and Efficiency: Overseas Students and Technical Efficiency in Australian and New Zealand Universities’, *Economics Education, Vol. 17*, No. 1pp. 31–37. https://doi.org/10.1080/09654529.2007.1773433

Abbott, M. and Doucouliagos, C. (2003) ‘The Efficiency of Australian Universities: A Data Envelopment Analysis’, *Economics of Education Review, Vol. 22*, No. 1, pp. 89-97. https://doi.org/10.1016/S0272-7757(02)00088-4

Abramo, G. and D’Angelo, C.A. (2009) ‘Assessing technical and cost efficiency of research activities: A case study of the Italian university system’, *Research Evaluation, Vol. 18*, No. 1, pp. 61–70. https://doi.org/10.1080/0958202080210378

Agasisti, T. (2017) ‘Management of Higher Education Institutions and the Evaluation of their Efficiency and Performance’, *International Review of Education, Vol. 23*, No. 3, pp. 187-190. https://doi.org/10.1007/s11187-017-93625-0

Agasisti, T. and Bonomi, F. (2014) ‘Benchmarking Universities’ Efficiency and Productivity Indices in the Presence of Internal Heterogeneity’, *Studies in Higher Education, Vol. 39*, No. 7, pp. 1237-1255. https://doi.org/10.1080/03075079.2013.801423

Agasisti, T., Barra, C. and Zott, P. (2016) ‘Evaluating the Efficiency of Italian Public Universities (2008-2011) in Presence of (Un)observed Heterogeneity’, *Socio-Economic Planning Sciences, Vol. 55*, pp. 47-58. https://doi.org/10.1016/j.seps.2016.06.002

Agasisti, T., Catalano G., Landoni, P. and Vegniati, R. (2012) ‘Evaluating the performance of academic departments: an analysis of research-related output efficiency’, *Research Evaluation, Vol. 21*, No. 1, pp. 2-14. https://doi.org/10.1177/096118611142407

Agasisti, T. and Dal Bianco, A. (2006) ‘Data Envelopment Analysis of the Italian University System: Theoretical and Policy Implications’, *International Journal of Business Performance Management, Vol. 8*, No. 4, pp. 344-367. https://doi.org/10.1584/jibpm.2006-099631

Agasisti, T. and Galli, S. (2017) ‘The Transient and Persistent Efficiency of Italian and German Universities: A Stochastic Frontier Analysis’, *CEPEJ Working Paper 14/17*. 

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