HOW EFFICIENT ARE UNIVERSITIES AT PUBLISHING RESEARCH? A DATA ENVELOPMENT ANALYSIS OF SPANISH STATE UNIVERSITIES

¿Cuán eficientes son las universidades en la publicación de investigación? Un análisis envolvente de datos de las universidades públicas españolas

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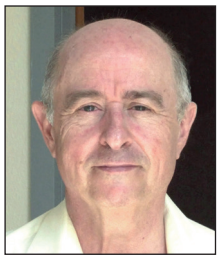

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Abstract

The level of efficiency regarding the production of published scientific research in 2015 for the 48 state universities of the Spanish education system is assessed. It is used a methodological approach based on output specifications of desirable outputs (total amount of published papers in Q1 journals) and undesirable outputs (non-cited publications). Relative measures are obtained under two efficiency schemes, natural and managerial. Results enable to identify certain management strategies to improve overall efficiency at publishing research of the Spanish university system. A higher allocation of budget resources among certain institutions would lead to efficiency gains for the system as a whole.

Keywords
Research publishing; Efficiency analysis; Benchmarking; Data envelopment analysis; State universities; Spain.

Resumen

Se evalúa el nivel de eficiencia en la publicación de trabajos de investigación en las 48 universidades públicas del sistema español de educación superior para el año 2015. El método utilizado se caracteriza por la diferenciación entre resultados deseados (total de trabajos publicados en revistas del primer cuartil) y resultados no deseados (trabajos no citados), obteniendo una medida de eficiencia relativa a partir de dos esquemas de eficiencia: natural y de gestión. Los resultados permiten identificar estrategias para mejorar la eficiencia en la publicación de trabajos de investigación del Sistema Universitario Español en su conjunto. Un aumento de recursos financieros en determinadas universidades generaría ganancias de eficiencia para el conjunto del sistema.

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Palabras clave

Publicación; Investigación; Análisis de eficiencia; Evaluación comparativa; Análisis envolvente de datos; Universidades públicas; España.

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1. Introduction

In the current global context, there is a growing interest in national and international comparisons of research and academic institutions in terms of scientific outputs (**Shin**; **Toutkouwshian**; **Teichler**, 2011). This increasing competition has placed the measurement of research performance at the centre of political concerns at a supranational level (**Hazelkorn**, 2013). In this same line, international rankings have prioritised the research dimension of universities in their calculations based on the use of objective ranking criteria from bibliometric sources on journal impact factors and citation metrics (**Abramo**; **Cicero**; **D'Angelo**, 2013). In order to advance in these rankings, authorities expect their academic staff to increase publishing in refereed journals (**McGrail**; **Rickard**; **Jones**, 2006), implicating a change in the university governance model with the application of the "*publish or perish*" approach for academic staff (**Zornic** *et al.*, 2015). International rankings do not analyse efficiency in the production of research outcomes nor offer information regarding resource allocation strategies to improve overall efficiency of a particular higher education system. Furthermore, rankings usually include multiple-output indexes regarding different dimensions of the university world (teaching, research, social impact, institutional reputation, etc.), which may result in unclear outcomes (**Pusser**; **Marginson**, 2013). This work aims to fill this gap through an alternative assessment method of the efficiency at publishing research by universities.

The application of methods based on Data Envelopment Analysis (DEA) techniques have helped to fill this gap (**Thanassoulis** *et al.*, 2016). While these types of studies are abundant in Anglo-Saxon countries such as the UK, USA and Australia (**Athanassopoulos**; **Shale**, 1997; **Avkiran**, 2001; **Abbott**; **Doucouliagos**, 2003; **Flegg** *et al.*, 2004; **Johnes**, 2006; **Worthington**; **Lee**, 2008; **Sexton**; **Comunale**; **Gara**, 2012), very little work has been carried out in the case of the Spanish high-education institutions (**Martí-Selva**; **Puertas-Medina**; **Calafat-Marzal**, 2014) or research groups (**Pino-Mejías** *et al.*, 2010).

In this regard, this work aims not to offer an additional university ranking in publishing research, but an efficiency "mapping" of Spanish state universities in producing a specific research outcome: published research in year 2015. Specifically, its objective is to answer the following research questions:

- How efficient are Spanish state universities at publishing research?
- How could the efficiency be improved of the Spanish system of state universities as a whole?

To the best of our knowledge, neither has the DEA approach applied in this paper yet been employed in the assessment of efficiency among higher education institutions, nor has it been used to measure relative efficiency in the production of published research by public universities with the aim of identifying resource allocation strategies that could improve efficiency of the system as a whole.

We are aware that university institutions play a much more important social role than simply being producers of research publications. Nevertheless, this paper focuses on the specific role of these institutions in publishing research as a specific outcome. The optimization problem and the selected output indicators have therefore been chosen following this aim. The rest of the paper is organised as follows:

Section 2 briefly introduces DEA methodology together with several related analytical concepts, and describes the input-output framework used in the study.

Data and output specifications are presented in Section 3.

Section 4 summarises the main results of the analysis for Spanish state universities.

Possible management strategies are discussed in Section 5.

Finally, Section 6 lays out the conclusions.

2. Methodology

In recent years DEA methods have become well-recognised techniques for measuring efficiency in public contexts due to their independence on particular assumptions regarding the distribution of efficiencies, and on the weighting of selected inputs and outputs. As a non-parametric methodology, DEA provides a relative efficiency assessment for a group of decision making units (DMUs) with a multiple number of inputs and outputs by obtaining a best-practice production frontier (or envelope). The method, proposed by **Farrell** (1957), has been subsequently extended under various schemes, such as an input-oriented scheme with constant returns to scale (**Charnes**; **Cooper**; **Rhodes**, 1978), output-oriented maximisation (**Charnes**; **Cooper**; **Rhodes**, 1981), variable returns to scale (**Banker**; **Charnes**; **Cooper**, 1984), and both radial and non-radial approaches (**Sueyoshi**; **Sekitani**, 2009). Recent DEA developments have revealed the importance of distinguishing between desirable and undesirable outputs (as common result of any productive activity) with the use of two efficiency specifications: natural and managerial (**Sueyoshi**; **Goto**, 2010, 2011).

Our approach follows a radial model to determine a relative efficiency indicator, as defined by **Sueyoshi** and **Goto** (2010, 2011, 2012a, 2012b). In this regard, an inefficient

DMU needs to project itself toward the efficiency frontier along the radial direction using two efficiency specifications.

The first specification implies that a DMU may decrease the directional vector of inputs to decrease undesirable outputs. Given a reduced vector of inputs, the unit increases the directional vector of desirable outputs as much as possible. This type of specification is referred to as "natural disposability" and it is commonly related to input allocation decisions since efficiency may be achieved through a relaxation of inputs in order to reduce undesirable outputs.

The second specification implies that a DMU increases the directional vector of inputs to decrease the directional vector of undesirable outputs. Given the increased input vector, the unit increases the directional vector of desirable outputs as much as possible. This specification is referred to as "managerial disposability" and it is commonly associated to a managerial innovation (e.g. as a result of new regulations designed to enhance research productivity) since it implies a decrease of undesirable outputs through an increase in production capacity (augmented inputs). Both specifications produce an autonomous efficiency indicator through the maximisation of the vector of desirable outputs given the disposability of undesirable outputs.

The applied DEA method also explores the associated returns to scale (RTS) under natural disposability, and damages to scale (DTS) under managerial disposability, in order to provide strategic guidance on how to enhance efficiency in the case of particular inefficient DMUs and the whole system (**Sueyoshi**; **Goto**, 2012a, 2012b). Although RTS and DTS have mathematical similarities, their economic implications differ greatly. Increasing RTS under natural disposability implies that a unit increase in inputs yields a greater proportion of increase of desirable outputs. This shows that if a DMU increases its size (by an increase of inputs), it would become more productive in terms of desirable outputs under natural disposability. In contrast, in the case of managerial disposability, increasing DTS implies the opposite result in the sense that a unit increase in inputs yields a greater proportion of undesirable outputs. This result suggests that the DMU should reduce its size in order to improve its performance efficiency. To summarise, RTS take into account production outcomes from the point of view of desirable outputs, whereas DTS focus on the undesirable outputs.

For our specific case study, we have built a radial DEA model to measure the unified efficiency in the production of published research of Spanish state universities under both natural and managerial disposability schemes, based upon the latest available data for 2015. Furthermore, we are interested in determining the type of RTS and DTS in each university, since these two measures can eventually provide strategic guidance and managerial orientation for university managers and public decision-makers in order to enhance efficiency of inefficient institutions individually and/or of the whole national system.

3. Data and models

The main aim of this study is to assess efficiency in research publishing based upon data regarding quantity and quality of inputs and outputs in the specific case of the Spanish state universities in year 2015. Therefore, to assess efficiency at producing published research, the following output measures have been considered in our specified models:

1) Total number of publications (per 100 academics) as the global desirable output indicator of research activities. Although there is a common consensus regarding the consideration of published work as a suitable measure of research outcomes, there are certain authors (**Salmi**, 2009; **Waltman** *et al.*, 2012) who suggest that only high-impact papers should be taken into account in the assessment of research performance among universities.

In this regard, an alternative output has been considered in our analysis:

2) High-impact research work published in Q1 journals (per 100 academics) as specified by the *Journal Citation Reports* (*JCR*) of *Clarivate Analytics*.

The authors acknowledge the limitations that the selected desirable outputs may imply, since the impact of scientific publications and the composition of the *JCR* categories may vary significantly between areas of knowledge. Although a majority of the analysed universities are of a generalist nature, a number specialise in certain fields of knowledge (as is the case of polytechnic universities), for which this fact may represent a disadvantage.

Direct citation remains a main indicator of the significance of a research study rather than alternative metrics (**Priem**, 2013) and it is commonly used as a proxy of effectiveness in the global scientific contribution (**Lukman**; **Krajnc**; **Glavic**, 2010; **Abramo**; **Cicero**; **D'Angelo**, 2013). In this regard, universities normally encourage their researchers to publish high-quality papers that can receive numerous citations and reach the widest possible audience. In order to account for this factor, the following undesirable output has been taken:

3) Non-cited publications, expressed as a percentage of total publications. This indicator enables the examination of the subsequent use of the research (citations) separately from quantity (total publications) and quality (Q1-tier papers) aspects (**Amabile**, 1988).

On the other hand, the following input indicators have been chosen:

4) Public expenditure per student as an input indicator of public capital investment in each university. This indicator has been selected since higher levels of allocated budget resources per student are associated with greater research outcomes (**Hazelkorn**, 2013), which is also confirmed by the results of the input-output correlation matrix (Table II) in our case study.

5) Public expenditure per academic. Although it is not possible to discriminate between spending on research and

spending on teaching in the Spanish higher education system due to the usual duality between these two activities, this input has been chosen as a proxy of the financial resources allocated per academic member. As argued by **Shin** and **Kehm** (2013), among other studies, and confirmed by the input-output correlation matrix (Table II), there exists a significant relationship between allocated budget resources per academic and research outcomes.

Table I. Specification of DEA models

	Inputs			Desirable output		Undesirable output
Model	Euro / student	Euro / academic	Research periods / academic	Publications / 100 academics	Q1 publications/ 100 academics	Non-cited publications (%)
1	✔	✔	✔	✔		✔
2	✔	✔	✔		✔	✔

Table II. Input-output correlation matrix

	Publications / 100 academics	Q1 publications / 100 academics	Non-cited publications (%)
Euro / student	0.221*	0.235*	-0.351*
Euro / academic	0.267*	0.565*	-0.174
Research periods / academic	0.513*	0.517*	-0.163

Note: *significance at 99% confidence interval

6) Mean number of recognised research periods per academic, as a measure of the quality dimension of human capital in each university. It is argued that research is a process that requires not only funds but also human capital. Again, estimated correlations confirm the suitability of incorporating this input in the model.

Output data regarding number of publications, articles published in Q1-tier journals and citation metrics have been obtained from *IUNE* data base of indicators on scientific activity by Spanish universities (*IUNE Observatory*, 2015), which uses scientometrics of the *Web of Science* platform as the main source of information. Input data has been obtained from the "University statistics" of the *Spanish Ministry of Education and Culture*. The selection of the output variables is also justified by the relevance given by the *Spanish Ministry of Education and Culture* to papers published in Q1-tier journals indexed in the *Web of Science* (over other alternative databases such as *Scopus*), as well as to citation rates and research periods of scholars, to evaluate both university institutions and scholars.

This work aims to test two models regarding the production of published research, as summarised in Table I. Our first model takes the total amount of published works per 100 academics as a desirable output and the percentage of non-cited publications as the undesirable output. The second model substitutes the total amount of published works with a more restrictive indicator given by the number of publications in journals with the highest impact factor (Q1-tier) per 100 academics, maintaining the undesirable output. Both models use the same inputs in their intrinsic production function.

As regards the potential problems that a high number of variables (inputs and outputs) may imply, the condition of the minimum number of observations per variable established by **Banker**, **Chang**, and **Cooper** (1996) is met, since 48 universities and 5 variables are included in our specified models. Moreover, the set of input and output variables, as defined above, allow these DEA models to fit the rule of thumb described by **Banker**, **Charnes** and **Cooper** (1984) and the expected sign in the input-output correlations, as shown in Table II.

In order to facilitate their understanding, Table III summarises abbreviations of our 48 assessed universities, since they are used in following sections.

Table III. Abbreviations and university names

EHU	*U. País Vasco*	*ULPGC*	*U. Las Palmas de Gran Canaria*
UA	*U. Alicante*	*UM*	*U. Murcia*
UAB	*U. Autònoma de Barcelona*	*UMA*	*U. Málaga*
UAH	*U. Alcalá de Henares*	*UMH*	*U. Miguel Hernández*
UAL	*U. Almería*	*UNAV*	*U. Navarra*
UAM	*U. Autónoma de Madrid*	*UNED*	*U. Nac. Educación a Distancia*
UB	*U. Barcelona*	*UNEX*	*U. Extremadura*
UBU	*U. Burgos*	*UOVI*	*U. Oviedo*
UC3M	*U. Carlos III*	*UPC*	*U. Politècnica de Catalunya*
UCA	*U. Cádiz*	*UPCT*	*U. Politécnica de Cartagena*
UCAN	*U. Cantabria*	*UPF*	*U. Pompeu Fabra*
UCLM	*U. Castilla-La Mancha*	*UPM*	*U. Politécnica de Madrid*
UCM	*U. Complutense*	*UPO*	*U. Pablo de Olavide*
UCO	*U. Córdoba*	*UPV*	*U. Politécnica de Valencia*
UDC	*U. Coruña*	*URIOJ*	*U. La Rioja*
UDG	*U. Girona*	*URJC*	*U. Rey Juan Carlos*
UDL	*U. Lleida*	*URV*	*U. Rovira i Virgili*
UGR	*U. Granada*	*US*	*U. Sevilla*
UHU	*U. Huelva*	*USAL*	*U. Salamanca*
UIB	*U. Illes Balears*	*USC*	*U. Santiago de Compostela*
UJAEN	*U. Jaén*	*UV*	*U. Valencia*
UJI	*U. Jaume I*	*UVA*	*U. Valladolid*
ULEON	*U. León*	*UVIGO*	*U. Vigo*
ULL	*U. La Laguna*	*UZAR*	*U. Zaragoza*

4. Results

The use of a radial DEA method with two types of output specifications (natural and managerial) gives two different (but related) efficiency measures:

1) Unified efficiency under natural disposability, where efficiency depends largely on the allocation of inputs and how they are used to produce desirable outputs. In this case, the imposition of minimising the undesirable output can be reached by a decrease of inputs and consequently, by a reduction of desirable outputs. This output specification leads to the estimation of "returns to scale" (RTS), which offers additional strategic information in relation to the operational size of DMUs.

2) Unified efficiency under managerial disposability, where efficiency relies heavily on an adequate resource management to reduce undesirable outputs. In this case, the imposition of minimising the undesirable output may be reached by an increase of inputs (through innovative management) and consequently, by an expansion of desirable outputs. This output specification leads to the estimation of the "damages to scale" (DTS) and helps towards the identification of additional managerial strategies for each DMU. Following **Sueyoshi** and **Goto** (2012a, b), although efficient DMUs under this managerial scheme would also be efficient in the natural disposability scheme, decision-makers should take both RTS and DTS estimates into account in order to correctly extract strategic information regarding resource allocation decisions for the improvement of the efficiency of the analysed system as a whole.

Table IV. Unified Efficiency (UEf) and RTS under natural scheme

	Model 1		Model 2			Model 1		Model 2	
DMU	**UEf**	**RTS**	**UEf**	**RTS**	**DMU**	**UEf**	**RTS**	**UEf**	**RTS**
UAB	1	↔	1	↔	*UZAR*	0.8157	↔	0.7862	↔
UAM	1	↑	1	↑	*UCA*	0.8032	↔	0.8032	↔
UB	1	↔	1	↔	*UJAEN*	0.8010	↔	0.8010	↔
UBU	1	↑	1	↑	*UAL*	0.7911	↔	0.7911	↔
UCM	1	↑	1	↑	*UPO*	0.7756	↔	0.7756	↔
UIB	1	↑	1	↑	*URIOJ*	0.7472	↔	0.7472	↔
ULL	1	↑	1	↑	*UCAN*	0.7468	↔	0.7469	↔
ULPGC	1	↑	1	↑	*UJI*	0.7440	↔	0.7424	↔
UNED	1	↑	1	↑	*UDL*	0.7374	↔	0.7374	↔
UOVI	1	↑	1	↑	*UCO*	0.7274	↔	0.7247	↔
UPC	1	↔	1	↔	*UNAV*	0.7229	↔	0.7229	↔
UPF	1	↔	1	↔	*UHU*	0.7031	↔	0.7031	↔
UPV	1	↑	1	↑	*UM*	0.6906	↔	0.6561	↔
URJC	1	↑	1	↑	*UA*	0.6858	↔	0.6736	↔
EHU	0.9906	↔	0.9801	↔	*UVA*	0.6647	↔	0.6576	↔
UPM	0.9700	↔	0.9409	↔	*UC3M*	0.6565	↔	0.6467	↔
URV	0.9268	↔	0.9258	↔	*UAH*	0.6546	↔	0.6444	↔
USC	0.9105	↔	0.8862	↔	*UMA*	0.6408	↔	0.6281	↔
UGR	0.8990	↔	0.8586	↔	*UMH*	0.6335	↔	0.6308	↔
UV	0.8862	↔	0.8538	↔	*UDC*	0.6275	↔	0.6008	↔
UCLM	0.8756	↔	0.8507	↔	*ULEON*	0.6269	↔	0.6269	↔
UVIGO	0.8754	↔	0.8713	↔	*UNEX*	0.6071	↔	0.6071	↔
US	0.8638	↔	0.8088	↔	*USAL*	0.5606	↔	0.5466	↔
UDG	0.8340	↔	0.8340	↔	Average	0.8336		0.8256	
UPCT	0.8198	↔	0.8198	↔	St. Dev.	0.1429		0.1449	

Note: ↑(increasing RTS), ↔ (constant RTS).

Table IV summarises the mapped efficiency results under a natural disposability scheme and also the type of RTS obtained for each DMU in our two tested models for year 2015. Under this scheme, our group of efficient universities (UEf=1) is composed of 14 universities, *Universidad Autònoma de Barcelona* (*UAB*), *Universidad Autónoma de Madrid* (*UAM*), *Universitat de Barcelona* (*UB*), *Universidad de Burgos* (*UBU*), *Universidad Complutense* (*UCM*), *Universitat de les Illes Balears* (*UIB*), *Universidad de La Laguna* (*ULL*), *Universidad de Las Palmas de Gran Canaria* (*ULPGC*), *Universidad Nacional de Educación a Distancia* (*UNED*), *Universidad de Oviedo* (*UOVI*), *Universitat Politècnica de Catalunya* (*UPC*), *Universitat Pompeu Fabra* (*UPF*), *Universidad Politécnica de Valencia* (*UPV*), and *Universidad Rey Juan Carlos* (*URJC*). As previously stated, optimisation restrictions under this output specification are more flexible since inputs may decrease in order to reduce the undesirable output (non-cited publications) and no possible managerial innovation regarding inputs is taken into account. These limitations usually lead to a greater group of efficient DMUs than expected. Nevertheless, it is significant that only 10 institutions show increasing RTS in both models, which shows that only these institutions would register a greater proportion of increase in desirable outputs due to an increase in inputs. Most of our DMUs show constant RTS, which would suggest that an increase in allocated resources would not increase efficiency in the production of scientific publications. Furthermore, the average unified efficiency is slightly reduced in Model 2 (Q1 publications) and the variability within the group is also increased, in comparison to Model 1, which is understandable since the output specification in Model 2 is of a more restrictive nature.

Under a managerial disposability scheme (Table V), our list of efficient universities has shrunk from 14 to only 6. In this case, *UAB*, *UAM*, *UB*, *UIB*, *UPC* and *UPF* turn out to be the most

Table V. Unified Efficiency (UEf) and DTS under managerial scheme

	Model 1		Model 2			Model 1		Model 2	
DMU	**UEf**	**DTS**	**UEf**	**DTS**	**DMU**	**UEf**	**DTS**	**UEf**	**DTS**
UAB	1	↔	1	↔	*UPCT*	0.7726	↓	0.7726	↓
UAM	1	↔	1	↔	*UC3M*	0.7704	↔	0.7704	↔
UB	1	↔	1	↔	*UJI*	0.7682	↓	0.7682	↓
UIB	1	↓	1	↓	*UDL*	0.7661	↓	0.7661	↓
UPC	1	↔	1	↔	*UNAV*	0.7580	↓	0.7580	↓
UPF	1	↔	1	↔	*UCA*	0.7561	↓	0.7561	↓
ULL	0.9801	↓	0.9908	↓	*URIOJ*	0.7559	↓	0.7559	↓
USC	0.9780	↓	0.9718	↓	*UJAEN*	0.7450	↓	0.7450	↓
URV	0.9742	↓	0.9742	↓	*UAL*	0.7439	↓	0.7439	↓
EHU	0.9217	↓	0.9132	↓	*UA*	0.6864	↓	0.6829	↓
UGR	0.9037	↓	0.8727	↓	*UMH*	0.6823	↓	0.6823	↓
UV	0.8948	↓	0.8762	↓	*UAH*	0.6734	↓	0.6727	↓
UBU	0.8600	↓	0.8600	↓	*UVA*	0.6536	↓	0.6437	↓
UVIGO	0.8575	↓	0.8450	↓	*UHU*	0.6425	↓	0.6425	↓
UCAN	0.8542	↔	0.8542	↔	*UMA*	0.6359	↓	0.6291	↓
UDG	0.8520	↓	0.8520	↓	*ULPGC*	0.6309	↓	0.6309	↓
UPV	0.8511	↓	0.8410	↓	*ULEON*	0.6176	↓	0.6176	↓
UOVI	0.8410	↓	0.8320	↓	*UM*	0.5974	↓	0.5850	↓
UPM	0.8410	↓	0.8198	↓	*UNEX*	0.5881	↓	0.5774	↓
UCLM	0.8315	↓	0.8214	↓	*URJC*	0.5867	↓	0.5852	↓
UCM	0.8247	↓	0.7990	↓	*USAL*	0.5595	↓	0.5559	↓
UZAR	0.8032	↓	0.7906	↓	*UDC*	0.5446	↓	0.5376	↓
UCO	0.7923	↓	0.7923	↓	*UNED*	0.4485	↓	0.4485	↓
UPO	0.7770	↓	0.7770	↓	Average	0.7874		0.7826	
US	0.7737	↓	0.7520	↓	St. Dev.	0.1425		0.1427	

Note: ↓ (decreasing DTS), ↔ (constant DTS)

efficient institutions in the way they manage their inputs to obtain outputs, both desirable and undesirable. Moreover, Table V shows that, for each of the two tested models, the majority of the Spanish state universities belong to decreasing DTS. This means that they may increase their inputs to produce more desirable outputs together with a greater proportion of increase in the citation rate. Among our efficient set of institutions, most of cases (with the exception of UIB) show constant DTS, which suggests that the introduction of managerial innovation in their production functions is highly recommended in order to further increase the proportion of cited papers on an increase in inputs.

5. Discussion

Educational decision-makers are developing policies to stimulate the strength of their state universities at producing research outcomes as a necessary step to successfully compete at global level (**Hazelkorn**, 2013). The most common options for governments to foster research efficiency include the concentration of resources on a few efficient higher education institutions, and/or the promotion of mergers and alliances between universities in order to develop research synergies (**Salmi**, 2009; **Albatch**; **Salmi**, 2011).

Our analysis has shown a high heterogeneity among Spanish state universities at producing research publications efficiently, not only under the more relaxed natural efficiency scheme, but also in the more restrictive specification under managerial disposability. In this last case, only six institutions have been revealed as being efficient and four more register a unified efficiency higher than 0.9 in both models. Far from being a problematic issue, this heterogeneity offers an opportunity to increase the average efficiency of the whole university system through alternative resource allocations. In this regard, findings show that the majority of institutions register decreasing DTS, which implies that these institutions should receive further support by decision-makers in terms of a higher allocation of budget resources since these universities have the potential to increase the number of publications together with a reduction of the non-citation rate if their inputs increase. Nevertheless, our two efficiency schemes (natural and managerial) must be considered together in order to obtain strategic information for the decision-making process. In our case, findings suggest that an increase in allocated resources would be extremely desirable in the case of institutions with increasing RTS and decreasing DTS (i.e. *UBU*, *ULL*, *ULPG*, *UOVI*, *UPV*, *URJC*, and *UIB*), thereby improving the efficiency of the whole system (current average around 0.78 under the managerial scheme), both at producing total and the highest impact publications (Q1-tier). Nevertheless, the existence of constant RTS and/or DTS would not necessarily mean that an increase of resources allocated in these institutions would be undesirable, but it would not lead to an improvement of the overall efficiency of the university system.

In most influential international high-education rankings (i.e. *ARWU*, *THE*, *Webometrics*, among others) two of our efficient institutions, *UPF* and *UAM* (as well as *UB*, *UAB*, and *UPC*) are usually placed in the Top 5 positions among Spanish state universities. Nevertheless, these rankings usually focus only on the outcomes of the education-research process (i.e. quantity of research studies published in high-impact journals), and fail to offer an efficiency measure in obtaining those outcomes, and therefore omit any consideration of the available inputs in these higher education institutions. At a national level, **Buela-Casal**, **Guillén-Riquelme**, **Ramiro-Sánchez** and **Quevedo-Blasco** (2017) have analysed research production and productivity of the Spanish higher education system in 2015 from an output assessment point

of view. With regards to publishing in high-impact journals (indexed by *JCR*), out of a total of 48 state universities, this study places *UAM* in the sixth position, *UPF* in the fifteenth, and *ULL* in the seventeenth, where big and well-established universities such as *UB*, *UAB*, *UCM*, *UV*, and *UGR*, occupy the Top 5 positions, respectively. In our opinion, the fact that *ULL*, and other highly efficient institutions, such as *URV*, *EHU* and *USC* (with efficiency scores above 0.9), do not appear well-positioned in those rankings may lead to misleading conclusions, despite their highly efficient use of their available resources. Further, institutions with a high efficiency potential, such as *UPV* and *UBU* (which register decreasing DTS and increasing RTS), would not attract decision-makers' attention, since they do not appear well-positioned in the aforementioned rankings.

6. Conclusions

This paper has assessed Spanish state universities under two different efficiency schemes (natural and managerial) resulting in a reduced but stable reference set of fully efficient universities together with a wide-ranging heterogeneous group of remaining institutions. Once efficiency mappings are obtained, the estimated RTS and DTS measures help in the decision-making process of resource allocation to improve the efficiency of the whole public higher education system, leading to a more efficient production of high-quality published research work and a more productive use of budget resources. Our two research questions, proposed at the beginning of this work, have therefore been answered.

Nevertheless, we believe that further research is needed to assess efficiency in the performance of higher education systems by taking into account that its various productive dimensions (i.e., teaching, research, social and labour dimensions) yield both desirable and undesirable outputs. Furthermore, the authors aim to carry out future research to analyse the significance of potential explanatory variables of the observed efficiency disparities between institutions, as well as their effect on efficiency changes over time. We hope that our study will also serve as a spearhead for further studies using the DEA methodology approach to university governance models, both in the specific case of the Spanish education system as well as in cross-country comparisons.

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