The interconnections of academic research and universities' "third mission": Evidence from the UK

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Abstract

A considerable body of work acknowledges the importance and benefits of the university–industry relationship for the economy and society, but also for increasing the revenue of universities themselves (known also as universities' "third mission"). However, questions have also been raised about the consequences of the university-industry relationship and its impact on their traditional role. This paper contributes to this debate by exploring whether and how being efficient in generating income from engagement activities impacts on universities' research performance. By using a sample of 119 UK higher educational institutions for period 2007–2014, and controlling for endogeneity issue, the results show that efficiency in terms of university-industry income and research performance exhibits a nonlinear relationship for both universities established before ("old universities"), and after ("new universities"), the Higher Education Act 1992 (HEA). However, for high level of efficiency, "old universities" do not appear able to improve their research performance further. Finally, positive synergies between the third mission and research mission decline in a more teaching-oriented environment. We conclude that policy makers should account for organisational heterogeneity and teaching orientation to promote research excellence effectively by stimulating engagement.

Keywords: Efficiency; Higher education institutions; Industry Engagement; REF

1. Introduction

In recent years, UK universities have adopted an entrepreneurial university model to stimulate knowledge transfer through external collaborations with industry and commerce and to bring in further resources for the accomplishment of academic goals (e.g. Clark 1998; Schulte, 2004; Kitagawa, 2005; Shattock, 2005; Kitagawa et al., 2016). Even though the commercialisation of academic research and various forms of engagement with non-academic communities are encouraged from both policy and management perspectives, it is still debated in the literature whether these can be successfully integrated with the traditional areas of teaching and research (among others, D'Este and Patel, 2007; Larsen, 2011; Hewitt-Dundas, 2012; Perkmann et al., 2013; Sánchez Barrioluengo et al., 2016).

Crucial to this debate is the fact that universities exhibit heterogeneous backgrounds, strengths, and resources, and encompass many institutional differences, leading them to respond differently to external opportunities and challenges (Huggins et al., 2012; Hewitt-Dundas, 2012; Charles et al., 2014; Chang et al., 2016; Sánchez-Barrioluengo et al., forthcoming).

As argued by Martin (2012), the promotion of the interaction between university and industry is not new to the university system. In fact, it is based on the idea of a "social contract", which is closer to the one in place before the second half of the twentieth century. At that time, the so-called "third mission" was pursued by some types of universities, such as "polytechnics" and "grant" universities in the US and Europe[1]. Even though these types of institutions disappeared in several countries, universities still employ differing capabilities and strategies in terms of knowledge transfer activities in response to policy requirements (Kitagawa et al., 2016). For example, Sánchez Barrioluengo (2016) shows that more research-oriented universities tend to focus on "harder" forms of engagement, such as collaborative research, contract research, and the generation of intellectual property (IP), while newer universities, or more teaching-oriented universities, focus more on "softer" forms of engagement, such as training and consultancy activities.

Arguably, universities try to differentiate themselves within an increasingly competitive sector by searching their own synergies and balance between all three missions' activities

[1] Nowadays, technical universities remain strongly rooted in some countries (i.e. the Netherlands), instead others, such as the UK, have eliminated that type altogether (i.e. the polytechnics).

(Molas-Gallart et al., 2002).[2] However, in contrast to this specialization trend, there is a tendency from both policy and management perspectives to impose on all institutions the need to be simultaneously centres of excellence in education, research, and in terms of interactions with the socioeconomic environment (Sánchez Barrioluengo, 2014). Policy initiatives have required a homogenising process of higher education policy frameworks through research evaluation and resource allocation mechanisms at various levels (see Hicks, 2012; Aagaard, 2015). All these policy interventions have been associated with the idea of a "one-size-fits-all" model, which considers HEIs as organisations with homogeneous and uniform capacities to achieve similar accomplishments in terms of social engagement (Kitagawa et al., 2016). However, as argued by Sánchez Barrioluengo (2014), this model can be unrealistic and contrasts with the heterogeneous pathways that HEIs appear to adopt in practice.

Following on from these discussions, we formulate our research questions as to whether, and how, the relationship between missions can change according to a different organisational context. In particular, this paper attempts to uncover the mechanisms between universities' missions by addressing the following questions: (1) Which universities are most efficient in generating income from "third mission" activities? (2) Are the most efficient universities in terms of "third mission" also able to excel in research performance? (3) Does the diversity of institutions affect the synergies between missions? (4) How does the teaching orientation of universities moderate the relationship between the third mission and research mission in different organisational contexts? The purpose is to assess the efficiency of HEIs by modelling their capabilities to generate higher income from engagement activities given the human resources and infrastructure available on a comparative basis. This measure takes into consideration the variety of resources available at the university level that could adversely affect the achievement of higher income from engagement activities compared to other similar institutions. Next, we present nuanced evidence on the capabilities of efficient universities in underpinning various forms of engagement with industry to produce excellent research.

To address these research questions, we employ a detailed dataset of 119 UK HEIs, collected over the period from 2007 to 2014. The focus on the UK is motivated by several reasons. First, the UK educational system has profoundly changed its business practices and policies to effectively value and promote a deep engagement with business and government. As pointed outby Martin (2016), in the UK more than anywhere else, there has been a greater

[2] The first mission relates to the teaching activities, the second to the research activities, whereas the third mission refers to their ability to interact with the socioeconomic environment (Sánchez Barrioluengo, 2014).

formalisation and more burdensome bureaucracy has been implemented by promoting policies based on mass production and standardisation. This has led to the pursuit of policies based on accountability and performance targets designated on standardized metrics (Burrows, 2012). Specifically, all the HEIs in the UK are subject to the same system of research, namely the Research Excellence Framework (REF), which ranks and assesses universities based on their overall research indicators (Martin, 2011)[3]. Despite this metric of evaluation allows for a comparison of the research performance of universities, its adoption is not free from criticisms as it may favour certain departments over others. As extensively argued by Martin (2016), the research performance metric seems to value more traditional disciplines and is therefore more likely to benefit departments focusing on the disciplinary mainstream rather than devoting themselves to interdisciplinary research. This could also discourage industrial engagement that requires the adoption of interdisciplinary research.

Furthermore, the "third mission" of the university in the UK is increasingly seen as a crucial aim of universities' activities and has become progressively institutionalised and incentivised via a range of policies, funding streams (such as the Higher Education Innovation Funding (HEIF)) and infrastructure investment (Kitagawa and Lightowler, 2013). Furthermore, the UK REF now considers the assessment of the 'impact' research has on wider society in addition to the existing assessment of research excellence.

Finally, it must be emphasised that the UK education system encompasses different organisations in terms of research intensity and third mission portfolio of activities (Goddard et al., 2014). Consistent with previous studies focusing on the UK (Guerrero et al., 2015; Hewitt- Hewitt-Dundas, 2012; Kitagawa et al.,2016; Sánchez Barrioluengo et al., 2016) there are two main group of universities in the UK: the so-called "old universities", which are typically more research focused; and "new universities", which were granted university status after 1992 as a result of the Further and Higher Education Act (HEA). Before the HEA, the polytechnics offered higher diplomas, undergraduate degrees and postgraduate education (masters degrees and doctorates) under the Council for National Academic Awards (CNAA) at the national level. As pointed out by Guerrero et al. (2015), although all the universities are devoted to research and teaching, the balance of these activities varies and tends to differ in terms of the mix of knowledge exchange activities carried out (Hewitt-Dundas, 2012). For example, "new universities" tend to be locally oriented, given their traditional focus on vocational education and training, and their relatively low engagement in basic research

[3] Student feedback is collected through the national student survey, which is active in the UK since 2005.

(Charles et al., 2014; Goddard et al., 2014). They are more involved in consultancy activities, especially with SMEs and local communities, while "old universities" are active in various third mission activities such as contracts of research with SMEs and large companies, consultancy contracts, and IP (including patents, copyright, design, registration, and trade marks) (Sánchez Barrioluengo et al., 2016).

Based on the previous discussion, our paper contributes to the relevant literature in different ways. To the best of our knowledge, this is the first study that investigates universities' performance (efficiency) in generating income from their engagement in third mission activities (Avkiran, 2001; Bonaccorsi and Daraio, 2007; Bonaccorsi et al., 2014; Daraio et al., 2011, 2015a, b; Gimenez and Martinez, 2006; Johnes and Johnes, 2009; Wolszczak-Derlacz and Parteka, 2011; Wolszczak-Derlacz, 2017). Specifically, we introduce a new measure of performance for engagement activities at the institutional level that allows us to explore how the heterogeneity of resources and different managerial skills can allow institutions to better accomplish their third mission functions. From a methodological viewpoint we employ a robust frontier technique (Cazals et al., 2002) as an analytic tool to quantify the efficiency of institutions in generating income from engagement activities on a comparative basis. Other studies make use of the perceived performance of individuals, which makes the validity and comparability of results across studies difficult. The applied estimator overcomes this issue as it assesses the relative efficiency of a sample of HEIs in improving income from industrial engagement through the construction of a production frontier in the multi-input/multi-output. By only using the frequency or amount of engagement, as other studies, we could draw biased conclusions. This is because universities can differ in the resources invested or employed for the accomplishment of their third mission activities.

Second, we explore whether the co-existence of a hybrid role identity that comprises a more traditional academic format (with teaching and research mission) and a commercial format is optimal for all institutions or whether it depends on specific organisational characteristics. Specifically, we investigate the impact of the efficiency of generating income from the third mission on the research excellence of "old universities" and "new universities". These two groups of universities exhibit a diverse third mission portfolio that reflects different strategies that they have pursued by nurturing their strengths over time and for historical reasons (Kitagawa et al., 2016). In this context, more entrepreneurial universities could be better off by setting academic goals to transmit academic knowledge to society. For example, "technical" higher education institutions such as "polytechnics" and "land grant" universities have historically shown a stronger emphasis on the third mission (Martin, 2012). This could be

translated into a reduction of possible frictions between third missions and other traditional missions.

Finally, from a methodological point of view we tackle possible endogeneity issues between the third mission and research performance. Endogeneity related problems can arise since universities could set the sources and goals of their third mission activities based on the expected and desirable research performance levels. Furthermore, thee literature also highlights that former research outputs, which are related to future outcomes, can impact positively on universities' knowledge transfer activities (Sengupta and Ray, 2017).

Therefore, this paper contributes to the recent debate by providing nuanced evidence on the existence of possible synergies and frictions between different missions (Kitagawa et al., 2016, Sánchez Barrioluengo, 2014; Sánchez Barrioluengo et al., 2016 among others). Our findings suggest that the pursuit of the third mission activities may not be detrimental to a university's goal of achieving research excellence. Specifically, we provide evidence that "old" and "new" universities that are efficient in generating income from engagement activities, can attain research excellence at the same time. However, our findings also indicate that "old universities" experience synergies in terms of the third mission and the research mission up to a certain threshold. After this threshold, the efficiency in terms of income from third mission activities does not lead to the improvement of research excellence. In the case of "new universities", efficiency in terms of third mission seems to be positively associated with better research quality without any specific threshold. Finally, we find that a relatively low student-staff ratio can help to amplify the impact of the income generated by engagement activities on research quality.

The paper is structured as follows. Section 2 provides a review of the literature on the studies that have examined the measurement on the efficiency in the university context. Section 3 discusses the robust frontier technique (Cazals et al., 2002) that we have employed to quantify the efficiency of institutions in generating income from engagement activities on a comparative basis. We further describe the measure of research performance employed in the analysis. Section 3 discusses the data and the inputs and outputs used for the efficiency analysis. Section 4 presents the main results and sensitivity analysis by taking into consideration the student-staff ratio and mission or disciplinary affiliations of each university. Section 5 concludes the paper by discussing the trade-off between the third mission and research mission and policy implications.

2. Literature review

2.1 An overview of the studies on efficiency of HEIs in the UK

The UK higher education sector has seen a steady and consistent process of transformation, with increased competition and subsequent reduction of public resources. Since the 1980s, the British government has recommended the introduction of performance indicators (Casu and Thanassoulis, 2006) with the scope of identifying and reducing the inefficient allocation of public resources, and to recognise and support national excellence. Consequently, the UK Higher Education Institutions (HEIs) engage in the Research Assessment Exercise (RAE) for the evaluation of universities' performance and Teaching Quality Assessment (TQA) based on performance indicators. In the UK, the government started to provide support to the university-industry technology transfer back to the 1970s. However, the first interventions were rather fragmented and restricted to certain disciplines, such as science and engineering. Only since the 1990s have policymakers promoted initiatives such as the Knowledge Exploitation Programme to support universities' third mission engagement in a more comprehensive way (Rosli and Rossi, 2016). Performance-based funding system for the third mission was established later in 2007.[4]

Among the studies focusing specifically on the UK education system, most have assessed the efficiency of HEIs by focusing on their teaching and research missions. For example, Athanassopoulos and Shale (2006) investigate whether UK universities generate sufficient outcome in terms of research (weighted research rating) and teaching (e.g. the number of higher degrees awarded) given their resources and student availability. Johnes and Johnes (2009) assess the cost function of 121 English institutions of higher education over a three-year period from 2000–2001 through to 2002–2003 by focusing on the traditional roles of teaching and research.

Nevertheless, recent studies do not focus solely on the UK, but instead employ an international dataset for a comparative analysis. This makes it even more difficult to collect data on third mission activities. Specifically, Wolszczak-Derlacz (2017) examines HEIs' efficiency by focusing on the dual mission and using Data Envelopment Analysis (DEA) on 348 universities in 10 European countries (Austria, Finland, Germany, Italy, the Netherlands, Poland, Spain, Sweden, Switzerland and the UK) for the years 2000–2012 and 152 universities in the US for the years 2000–2010. The author finds a positive association between both

[4]Nowadays, technical universities remain strongly rooted in some countries (i.e. the Netherlands).

regional GDP per capita and the institutions' efficiency (for both the European and US samples), while the effect of government funding is mixed. Similarly, Bolli et al. (2016) analyse the impact of the introduction of competitive funding on university efficiency by using a panel dataset across eight European countries from 1994–2006. Using a European dataset, Daraio et al. (2015a) conduct an analysis of teaching and research efficiency of 400 HEIs from 16 European countries for the 2008/09 academic year. They find that both size (economy of scale) and specialisation (economy of scope) have a statistically significant impact on efficiency. Likewise, Daraio et al. (2015b) propose a new technique to rank universities according to their research and teaching missions. Differently from these studies, Casu and Thanassoulis (2006) instead examine the cost-efficient central administrative services in the UK by focusing on the allocation of resources between academic and administrative activities.

While there is a relatively large number of studies focusing on research and teaching missions, here is a scarcity of studies on the third mission efficiency, in part, maybe due to the lack of data and difficulty in identifying third mission activities. So far, only a few studies have investigated the efficiency of infrastructure and ad hoc offices such as technology transfer offices (TTOs), science parks and incubators related to third mission activities. Chapple et al. (2005) is the first study to have investigated the relative performance of university technology transfer offices (TTOs) in the UK.

As pointed out by Resli and Rossi (2016), it is problematic to measure the "success" of HEIs with respect to third mission activities. In this context, the impact generated by these activities represents an important driver for success. However, it is also difficult to set the criteria and identify the impacts to be measured (Resli and Rossi, 2016). For this reason, the general orientation is to focus on engagement measures (Robichau and Lynn, 2009). Consistent with this view, the allocation of funds in the UK mainly relies on indicators of engagement, most recently including only income (Resli and Rossi, 2016). By drawing on these considerations, we therefore focus on external engagement activities to assess the performance of universities with respect to the third mission. Specifically, in line with the relevant literature on this topic (Fontana et al., 2006; D'Este and Patel, 2007; Martinelli et al., 2008; D'Este and Perkmann, 2011, Soh and Subramanian, 2014; Sánchez Barrioluengo et al., 2016) we consider as outputs the total income coming from: (1) contract research (£000s); (2) consultancy contracts (£000s); and (3) intellectual property (IP) (including patents, copyright, design, registration and trademarks). Differently from previous studies we assess the efficiency of UK HEIs by modelling their capabilities to generate higher income from engagement activities given the human resources and infrastructure available on a comparative basis. This measure

takes into consideration the variety of resources available at the university level that could adversely affect the achievement of higher income from engagement activities compared to other similar institutions.

2.2 Methodological strategy

In our analysis we estimate universities' performance levels in generating income by applying a fully nonparametric framework. This framework gives greater flexibility, derived mainly by the fewer assumptions imposed on universities' estimated production function. However, one of the main drawbacks of the nonparametric approaches (i.e. DEA) is the determinist nature that can make them very sensitive to sample characteristics (Assaf and Tsionas, 2018). To overcome this concern, we employ a different nonparametric estimator (Order-m) proposed by Cazals et al. (2002). This estimator is more robust to extreme values and sample characteristics compared to the relative DEA measures. Daraio and Simar (2007) show that these estimators are $\sqrt{n}$ consistent and are less exposed to the potential bias that is related to the "curse of dimensionality".

In particular, we consider a production function where y is the output and x is the input level. Then, for a fixed integer value of $m \geq 1$ the Order-m expected frontier can be defined by the following estimator as:

$$\hat{\Delta}_{m,n}(y) = \hat{E}[\min(x^1, \dots x^m) | y \geq y] = \int_0^\infty \left(1 - \left[\hat{F}_{x|y,n}(x|y)\right]^m\right) d_x. \quad (1)$$

For any y we can define:

$$\tilde{\mu}_m(x,y) = \inf\{\mu | (\mu x, y) \in \Delta_m\} = \left\{\frac{x_i^j}{x^j}\right\}. \quad (2)$$

The nonparametric estimator of Order-m efficiency measure can be defined as:

$$\hat{\mu}_{m,n}(x,y) = \int_0^\infty \left(1 - \hat{F}_{x|y,n}(ux|y)\right)^m d_u = \hat{\mu}_n(x,y) + \int_{\hat{\mu}_n(x,y)}^\infty \left(1 - \hat{F}_{x|y,n}(ux|y)\right)^m d_u. \quad (3)$$

According to Daraio and Simar (2007, p.71), the applied Order-m frontiers are robust to outliers that are asymptotically unbiased and asymptotically normally distributed. The efficiency scores calculated from Order-m frontiers are not bound by 1 (in contrast to the data envelopment analysis-DEA estimators). Specifically, the estimated Order-m efficiency score indicates universities' third mission performance levels and represents the minimal input efficiency score of a university *i* compared to *m* universities (peers) randomly drawn from the population of the universities producing more outputs than the outputs produced by the university *i*. For instance, a university with an Order-m efficiency score equal to 0.7 uses 30% more inputs than the expected value of the minimum input levels of *m* other universities

producing a level of output$\geq y$. In addition, if a university's efficiency score is equal to 1.8 this means that it uses 80% less inputs than the expected value of the minimum input levels of m other universities producing a level of output$\geq y$. Finally, if the Order-m efficiency score equals 1 then the university under evaluation uses the same levels of inputs as the expected value of the minimum input levels of m other universities producing a level of output$\geq y$. In our analysis, we construct two frontiers based on universities' third mission performance levels: one for the old polytechnics ("new universities"); and another one for the universities ("old universities") established before the Higher Education Act 1992 (HEA).

Following this, we further explore the impact of efficiency (i.e. third mission performance) on the research quality of UK HEIs. From a methodological viewpoint, we apply a nonparametric instrumental variable regression (Horowitz, 2011) that tackles endogeneity-related problems by incorporating instrumental variables directly into the estimation. This enables us to address endogeneity issues without imposing any functional form on, and linearity between, the variables and therefore provides us with the ability to reveal nonlinear phenomena among the variables under examination. The general look of the nonparametric regression takes the form:

$$GPA_i = f(EFF_i) + \varepsilon_i, i = 1, \dots i, n. \quad (4)$$

The term $f(.)$ is the unknown smooth function, whereas the term ε_i represents the disturbances. The main independent variable is the efficiency score5 for third mission income for each HEI. Instead, the dependent variable is the research performance of each HEI measured referring to the REF2014. Section 2.3 discusses the research performance indicator we have used for this analysis more extensively.

Furthermore, we tackle the possible endogeneity issues between the third mission and research performance. These could be driven by the fact that universities could either set the resources to be dedicated to the third's mission activities in advance and/or they can set the target to be achieved based on the expected and desirable research performance. In addition, as pointed out by Szücs (2018), the benefit to the industry of collaborating with universities is positively associated with the quality of the institutions concerned. Generally, universities with a high reputation and prestige that can produce high-quality research could attract more external industrial collaborations and raise more funds from the private sector. In turn, such prospects can raise possible endogeneity concerns. In order to treat endogeneity we utilize a

[5] Since GPA is a single measure (grade point average) and covers the entire period, the EFFi is the only control variable we use and represents the mean efficiency score over the period from 2007–2014.

nonparametric instrumental variable regression. As reported previously, we apply the nonparametric instrumental variable (IV) regression analysis introduced by Horowitz (2011). For the choice of appropriate instrument variables we first apply a nonparametric regression framework. Specifically, we regress the potential instruments on efficiency score by employing a local linear least square regression (Li and Racine, 2007). We then select only the variables that are not related to the dependent variable. A further step of our analysis is to examine the correlation of the selected instruments with the endogenous regressors and use them as instrumental variables in the nonparametric IV regression. After applying the described procedure, we consider as instruments[6] the gross domestic product (GDP) at current market prices and the population density by NUTS 3 regions. The literature suggests that different stages of economic development and environmental factors can generate different patterns of university-industry relations (Siegel et al., 2003; Perkmann et al., 2013). Furthermore, we include the amount of research training, support grants, tuition fees[7], and education contracts[8] for the academic years 2005–2007 (in £000s) as instruments (finance return 2005–2007). This is motivated by the fact that the industry/business-university collaboration is also related to the ability of firms to get access to trained students (Feller, 2005; Perkmann al., 2011). Therefore, a high number of students and training activities in the years 2005–2007 could favour an increase of engagement activities from 2007 to 2014. In addition, this factor is not directly correlated to the REF evaluation of 2014 and thus is a valid instrument for efficiency scoring.

2.3. Research performance

The REF2014 has been conducted jointly by the Higher Education Funding Council for England (HEFCE), the Scottish Funding Council (SFC), the Higher Education Funding Council for Wales (HEFCW) and the Department for Employment and Learning, Northern Ireland (DEL) rank UK HEIs based on their performance in order to allocate blocks of research grants. The assessment mechanism is based primarily on a peer-review system. In particular, the evaluation process is managed by expert review which is carried out in 36 subject-based units of assessment. Sixty-five percent of the overall results come from the outputs of any form of research, including publications (such as journal articles, monographs, and chapters in

[6] The variables presented below are instruments for the estimated efficiency score.

[7] It refers to income for general research studentships (not awarded as part of a research grant or contract).

[8] They include all fee income, including short courses, self-financing full-cost courses funded by private/non-private sources, and support grants in respect of all and only those students on courses for which fees are charged.

books), as well as outputs disseminated in other ways such as designs, performances, and exhibitions published between January 2008 and December 2013. The quality of the output is evaluated based on its "originality" and "significance and rigour" by the reviewers. Finally, 25 percent of the overall results comes from the "impact" of the research, while the remaining 10 percent comes from the "environment". To be precise, *Impacts* refers to "any effect on, change or benefit to the economy, society, culture, public policy or services, health, the environment or quality of life, beyond academia[9]". For the purposes of the REF, *Impacts* do not include any advancement of academic knowledge within the higher education sector (whether in the UK or internationally). *Environment* refers to the strategy, resources, and infrastructure that support research.

For our analysis we make use of the grade point average (GPA) provided by the REF2014. GPA can take any value from 0 to 4 and reflects the average quality of the research reached by each HEI during the period 2007–2014 for all the disciplines. Particularly, there are five categories: 4* (world- leading), 3* (internationally excellent), 2* (internationally recognised), 1* (nationally recognised), and unclassified. For impact, there are instead four categories that include 4* (outstanding), 3* (very considerable), 2* (considerable), 1* (recognised but modest), and unclassified. The *Times Higher Education* aggregates all these scores into a single institutional quality profile by considering both the number of full-time equivalent staff and the number of units of assessment.[10] The idea is that a larger department will count more for the calculation of an institutions' overall quality. Then: "each institution's quality profile [is] converted into a grade point average by multiplying its percentage of 4* research by 4, its percentage of 3* research by 3, its percentage of 2* research by 2 and its percentage of 1* research by 1; the results are added together and divided by 100 to give a score between 0 and 4" .[11] The advantages of using the GPA are various. First, it summarises the overall quality of research at the institutional level and it is not disciplinary oriented. Second, it embeds both an objective and subjective component of evaluation: publications in journals and events are assessed by a team of experts. More details on the procedure of evaluation of research and impact are provided in the next Section.

3. Data and definition of inputs and outputs to measure the HEIs' efficiency

[9]For details see: https://re.ukri.org/research/ref-impact/.

[10] See https://www.timeshighereducation.com/sites/default/files/Attachments/2014/12/17/k/a/s/over-14-01.pdf for more details.

[11] Text retrieved from https://www.timeshighereducation.com/news/ref-2014-results-table-of-excellence/2017590.article, accessed 27/04/2018.

3.1. Selection of inputs and outputs

Similarly to previous studies (Casu and Thanassoulis, 2006; Daraio et al., 2015a,b, 2016; Wolszczak-Derlacz, 2017), we select as inputs: (1) full-person equivalent academic staff (teaching & research & manager roles); (2) full-person equivalent non-academic staff; and (3) total expenditure that includes consolidated income and expenditure account expenditure (other than staff costs) (£000s) and total capital expenditure (£000s). Choosing the appropriate outputs is crucial for the assessment of the performance of the university-industry income. Many empirical studies argue that the process of knowledge transfer between university and industry occurs through multiple channels, such as personnel mobility, informal contacts, consulting relationships, and joint research projects (D'Este and Patel, 2007). In line with the relevant literature on this topic (Fontana et al., 2006; D'Este and Patel, 2007; Martinelli et al., 2008; D'este and Perkmann, 2011, Soh and Subramanian, 2014; Sánchez Barrioluengo et al., 2016) we consider as outputs the total income coming from: (1) contract research (£000); (2) consultancy contracts (£000s); and (3) intellectual property (IP) (including patents, copyright, design, registration and trade marks). As recently pointed out by Wilson (2018), the convergence rates of nonparametric efficiency estimators become slower when the numbers of input and output quantities increase (i.e., dimensionality). Wilson (2018) also highlights that while dimension reduction is widely used in nonparametric density and regression where similar problems occur, it is more unpopular in the context of efficiency estimation. We tackle the dimensionality problem by employing a factorial analysis. In particular, following Bădin et al. (2012) we identify a unique factor for inputs and outputs. Details relative to the factor analysis procedure are reported in Appendix B.

3.2. Data sources

In this section we describe the source of data employed for this study. Specifically, we employ the higher education information database for institutions (HEIDI) provided by the Higher Education Statistics Agency (HESA) that comprises detailed data on each UK HEI. The dataset provides data for 206 institutions. To guarantee a relative homogeneity, specialised colleges or institutions such as music, art and theatre entities and entities that exhibit a unique unit of assessment are excluded from the dataset. In addition, the final sample also reflects the feasibility of collecting complete data for inputs and outputs and it consists of 119 HEIs (the list of universities is reported in Appendix A). Furthermore, compared to other studies focusing

on the UK education system (Casu and Thanassoulis, 2006; Daraio et al., 2015a,b; Wolszczak-Derlacz, 2017), we include a higher number of HEIs. Data on GDP and population at the NUTS3 level has been retrieved from Eurostat. As regards the variables of our model, there is no consensus on the inputs/outputs selection in the assessment of university efficiency.

Table 1 shows the descriptive statistics for inputs, outputs, instruments and environmental variables used in our analysis.

Insert Table 1 about here

Specifically, Table 1.a shows the descriptive statistics for "new universities" while Table 1.b focuses on "old universities". Of course, it should be emphasised that the average values and the variation in the GPA is different between the two groups and is much higher in the case of "old universities". As can be seen from Table 1, the mean and standard deviation of the outputs and inputs vary greatly between the two groups of universities. This further supports the use of an ad hoc frontier for "new universities" and "old universities". We denote instead more similarities in terms of the factors for both inputs and outputs. Factor analysis and the dimensionality reduction allows us to reduce outliers and at the same time make the size of the variables included in the model more homogeneous.

4 Empirical results

The results relative to the Order-m efficiency frontier for "new universities" and "old universities" are presented in Figure 1. Figure 1 shows the kernel distribution of the mean efficiency scores (i.e. universities' third mission performance levels) over the period 2007–2014 for the two university groups. Both groups are characterised by a leptokurtic and skewed distribution with a concentration of mass in the lower tail in the direction of less efficient units. This suggests that UK HEIs have a relatively large margin to improve the use of human and infrastructure resources to enhance the income coming from engagement activities. Figure 2 also shows that the mean efficiency scores vary slightly between the two groups. The mean score of "old universities" is 0.435 while it rises to 0.588 for the "new universities". This means that "old universities" use 56.5% more inputs compared to the best practice universities. Similarly, "new universities" use 41.2% more inputs compared to the benchmarked

universities. Finally, it is also evident that the "old universities" have a lower standard deviation equal to 0.375 compared to the "new universities", which have a standard deviation value equal to 0.512.

Insert Figure 1 about here

Table 2 presents the top-ten HEIs based on their mean efficiency scores over the years 2007–2014.[12] Two separate lists are presented: one for "old universities" and one for "new universities". The results suggest that the University of Cambridge and the University of Oxford are in the top three of universities, together with the Imperial College of Science, Technology and Medicine in terms of the estimated third-mission performance levels. Both the University of Cambridge and the University of Oxford offer residential colleges, tutorial-based teaching, and centuries of tradition. Instead, the Imperial College of Science, Technology and Medicine benefits from the focus and excellence achieved in a discipline that tends to attract high income from industrial and public engagement. By shifting our attention to the "new universities", we notice that Cranfield University is the top institution on the list. This is the only exclusively postgraduate university in the UK, with strong industry partnerships and with a strong research culture.

Insert Table 2 about here

Figure 2 addresses our main research question, which is whether the development of university third mission performance can harm or benefit the research quality of HEIs. Two separate regressions are run: one for "old universities" and one for "new universities". Figure 2.a shows the results for the nonparametric regression (Li and Racine, 2007) (red dash-dotted line) where the dependent variable is the GPA and the main independent variable is the mean efficiency score for "old universities" (over the period from 2007–2014). To take into account the possible endogeneity issue between GPA and efficiency score, we also run a nonparametric instrumental variable regression (Horowitz, 2011) (blue dashed-line). Our findings suggest that an increase of the efficiency score has a positive effect in terms of GPA, as indicated by the increasing nonparametric line. The nonparametric regression strongly supports the fact that

[12] The analytical efficiency scores for all the universities are available upon request.

maximising the income generated from a university-industry link can also contribute to an increase in the quality of research. However, this relationship appears to follow a nonlinear pattern especially when we focus on the nonparametric instrumental variable regression (blue dashed line). Figure 2.b shows the existence of a positive nonlinear trend until a threshold point after which the line between efficiency score and GPA is rather flat. This suggest that universities with high efficiency in terms of income from engagement activities do not improve their research performance

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Insert Figure 2 about here

Figure 2.b shows noteworthy differences in terms of impact of efficiency on the quality of research (GPA) for the "new universities". Overall, the results reveal a significant and positive relationship between the efficiency in terms of university-industry income and the quality of the research of "new universities". However, such a relationship displays a highly nonlinear pattern with an increasing trend for efficient institutions (when the efficiency score is above 1). In addition, the relationship between the efficiency in terms of university-industry income and the quality of research appears to be negative in the range of efficiency scores between 0.5 - 1. Instead, for the most efficient units (over 1.5) the line is less steep (blue-dashed line). Differently from "old universities", the trend for "new universities" is overall positive but highly nonlinear. Overall, our findings suggest that the engagement with industrial and external partners can spur the quality of research of "new universities" especially for institutions with a high efficiency score.

Figure 2.c combines the "new universities" with "old universities" and provides an overall picture of the relationship between the efficiency and quality of research. The overall picture shows an increasing trend for the institutions that are efficient up to a specific threshold (1.6), after which the generation of additional income from engagement with the industry harms the quality of research. Again, we find a nonlinear relationship between the efficiency and quality of research.

Controlling for student-staff ratio

In this section, we explore how the student-staff ratio (teaching mission) can drive our results. Although our focus is not the teaching mission, we however consider in our analysis a variable that may provide an indication of how much academic scientists are actively involved in educating and advising/mentoring students. High engagement in educating and advising/mentoring students may in fact prevent research-active academics from being productive in terms of research. Specifically, we consider the student-staff ratio for this additional analysis. The reason is that a low student-staff ratio is associated with institutional quality, research productivity, and the wellbeing of academic staff (McDonald, 2013). Therefore, this dimension of analysis could affect the way efficiency impacts on research performance as it provides an indication of staff commitment with the first mission (teaching).

Research and teaching are in fact seen to be very loosely coupled (Hattie and Marsh, 1996). For this analysis, we use the student-staff ratio provided by the HESA dataset, which is calculated using the student and staff full-time equivalent (FTE). Then, we split the sample of "new universities" and "old universities" based on the median value of the student-staff ratio for each group.[13] We again apply the nonparametric regression for "old universities" and "new universities". The results for "old universities" are reported in Figure 3.a-b, while those for the "new universities" can be found in Figure 3.c-d.

Insert Figure 3 about here

Similarly, to Figure 2, Figure 3 shows the results for the nonparametric regression (Li and Racine, 2007) (red dash-dotted line) and for a nonparametric instrumental variable regression (Horowitz, 2011) (blue dashed-line) where the dependent variable is the GPA and the main independent variable is the efficiency score.

As regards the group of "old universities", Figure 3.a reports the findings for universities with a student-staff ratio above the median value, while Figure 3.b shows the results for the student-staff ratio below the median value. By comparing Figure 3.a and Figure 3.b, it is clearly visible that the pattern between efficiency and GPA is steeper for the case with a student-staff ratio below the median value (blue dashed-line). This suggests that efficiency in terms of

[13] The median for "old universities" is 14.829, while for "new universities" it is 19.793. Bootstrapped based sub-sampling techniques for efficiency and productivity estimators can be found in the studies by Kneip et al. (2008, 2011).

university-industry income can be faster and more effectively transferred to the research quality when the ratio of students to staff is relatively low. However, consistently with Figure 2.a, universities with a high efficiency score exhibit a negative relationship between efficiency and GPA (blue dashed-line). This supports the need to set the improvement of the nexus between research, teaching, and third mission activities as a goal.

By shifting our attention to "new universities", we find consistent results (Figure 3.c and Figure 3.d) with Figure 2. Figure 3.c reports the findings for universities with a student-staff ratio above the median value, while Figure 3.d shows the results for those universities with a student-staff ratio below the median value. The results suggest that in both cases the efficient universities (i.e. efficiency scores ≥ 1) realise a positive effect of income efficiency generation on their quality of research. Similarly, for inefficient universities (i.e. efficiency scores < 1) the effect is highly nonlinear. Overall, the relationship between efficiency and GPA is positive but still nonlinear (blue dashed-line).

Additional analysis for efficiency score

We run additional analysis to compare the efficiency distributions of institutions depending on their mission or disciplinary affiliation. In particular, we first examine the mean efficiency distributions for the university-industry income between universities that belong to the Russell Group and other universities (all the universities in the sample were established prior to the HEA) over the entire period. The Russell Group consists of 24 leading UK universities that "are committed to maintaining the very best research, an outstanding teaching and learning experience and unrivalled links with business and the public sector". Compared to other universities, these "elite" research-intensive universities tend to show a concentration of knowledge exchange income (Sánchez Barrioluengo et al., 2018). In the next Section, we specifically infer whether the distribution of efficiency scores of Russell Group universities differs from the rest of the UK universities. Second, we compare the efficiency distribution of universities with a medical and engineering school with those of universities without such schools. The reason is that disciplinary affiliation is an important driver for engagement with industry and commercialisation (Bekkers et al., 2008; Martinelli et al., 2008). Biomedical and chemical engineering patents and licensing, together with contract research, represent two important channels of engagement with the industry (Perkmann et al., 2013). For other disciplines, such as computer science and social science, for example, these represent a less important channel. In addition, medical schools and engineering schools benefit from dedicated

grant scheme applications, such as Medical Research Council (MRC) grants, and the Engineering and Physical Sciences Research Council (EPSRC).

From a methodological viewpoint, we compare the distributions of universities' mean efficiency levels (from 2007–2014) for different university groups. We apply both Kernel density plots alongside the adapted version of Li-test (Li 1996, 1999) in order to examine the equality of the efficiency distributions of the different groups. We utilise the bootstrapped-based adapted version of Li-test statistic to the DEA context as has been introduced by Simar and Zelenyuk (2006). Figure 4.a shows that Russell Group universities perform better than the other universities in terms of university-industry income efficiency. In addition, it is clearly visible that the distribution of the two groups is very different, in this way denoting a net overtaking of the other institutions as a whole. Figure 4.b compares the efficiency distribution for the universities with medical and engineering schools with the rest. The results suggest that the efficiency distributions between the two groups are more similar compared to the previous case. Surprisingly, both subgroups exhibit similar performance levels.

Table 3 reports the bootstrapped p-values of the adapted Li-test. The null-hypothesis of the test signifies that the two distributions are equal. The test confirms that the Russell Group universities do not have an equal efficiency distribution to the other universities. The null hypothesis is rejected (p-value = 0.0000). Instead, consistently with Figure 4.b, we cannot reject the null-hypothesis that the two distributions are equal.

Insert Figure 4 about here

Insert Table 3 about here

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5. Conclusions

Public opinion and practitioners largely acknowledge the importance of universities as a vehicle for the creation and diffusion of knowledge. Policy makers have put forward several initiatives to support the so-called third mission, especially by facilitating the commercialisation of academic knowledge, such as patenting and licensing of inventions (D'Este and Perkmann, 201; Geuna and Nesta, 2006). Concomitantly, scholars as well as practitioners have stressed the importance of academic engagement with non-academic organisations to create direct benefits for the economy and society. However, recent studies

(Sánchez-Barrioluengo, 2014; Sánchez-Barrioluengo et al., 2016) have raised concerns on the compatibility of the third mission with the research and teaching missions.

This study attempts to contribute to this debate by providing a further understanding of the relationship between efficiency in terms of university-industry income (i.e. third mission) and research performance. This study focuses on a sample of 119 UK universities over the period from 2007 to 2014 and employs robust efficiency estimators (Order-m) to evaluate the relative efficiency in terms of university third mission performance. This is the most comprehensive analysis at the level of individual institutions that models the efficiency of university-industry income.

Overall, the results show that all the universities have room for improvement in terms of income generated by industrial engagement activities. Among the "old universities", those belonging to the Russell Group significantly perform better than the rest as they tend to dedicate more resources to research and impact. Russell Group universities are in fact strongly committed to high quality research and engagement with local and national business and the public sector. In a second step of the analysis, we explore whether universities that are efficient in generating income from engagement activities experience an increase in performance in terms of research quality. For this analysis, we tackle possible endogeneity issues between efficiency and research quality by running a nonparametric instrumental regression. In general, the findings show that the increase of efficiency in terms of university-industry engagement can positively enhance the research quality of "new universities" and "old universities". However, the results also show that this relationship is highly nonlinear and not always positive for "new institutions" with a relative low efficiency. Instead, we find that "old universities" that are mostly efficient do not gain any benefits in terms of research quality by generating additional income from engagement activities. For both types of university, a low student-staff ratio enhances the effect of efficiency on the quality of research.

Some key limitations should be considered when interpreting these results. The choice of inputs and outputs is consistent with the existing literature and conditioned by the availability of data for all UK HEIs. Furthermore, data relative to spin-off is either not reliable or missing. For example, turnover or external investment figures available for the various categories of spin-offs and start-ups as data is not fully reliable. Moreover, data on estimated external investment received from spin-offs with some HEP ownership (£000s) is available for only some HEIs included in the sample. In addition, the assessment of the research's quality through the REF system has been the object of criticism. Although the REF represents one of the most institutionalised forms of research evaluation in the OECD economies that both

encourages a traditional research approach and socio-economic impact (Barker, 2007), it still presents some shortcomings and might not be the optimum way of funding university research (Martin, 2011). As pointed out by Smith et al. (2011), there is some controversy related to the REF, for example with regards to the definition of expert review, the delimitation of reviewers, and the mechanisms for evaluating impact case studies.

Nevertheless, our findings contribute to the debate of the effect of the third mission on research and provide relevant policy considerations. Public policies aimed at fostering the income from engagement activities with the industry through the development of performance indicators should consider the capability of universities to make an efficient use of the heterogeneity of resources available at the institutional level to accomplish their third mission and research mission roles. Differently from recent studies (Kitagawa et al., 2016, Sánchez Barrioluengo, 2014; Sánchez Barrioluengo et al., 2016 among others) that have mainly criticised the existence of possible synergies between different missions, we found that efficient "old" and "new" university in terms of income generated from engagement activities are also capable of achieving higher performance in terms of research.

In the case of "old universities", the results instead show that being efficient is not always beneficial for the improvement of research performance. The efficiency beyond a certain threshold does not help universities to improve their research excellence. These institutions have made concerted efforts in terms of human and capital structure to increase revenue generated by academic engagement. However, they are not able to accomplish excellent targets for both engagement and research equally after a certain threshold. Instead, in the case of "new universities", the universities' management and the UK government can promote better research by incentivising engagement with the industry. However, this still requires taking into consideration the availability of resources at the university level to accomplish both targets. For example, a relatively low student-staff ratio can help to amplify the impact of efficiency in terms of the income generated by engagement activities on research quality. This finding highlights the need for policy makers to design policies and procedures to enable universities to better integrate research, teaching, and their third mission activities based on their unique characteristics. Instead, the 'one-size-fits-all' university model which treats universities as homogeneous and isomorphic entities applying a simultaneous excellence framework on all three missions (Philpott et al. 2011; Sánchez Barrioluengo, 2014) is now an "utopic" accomplishment at least for the vast majority of universities. However, it sets the future policy agenda alongside the additional challenges for which the universities' stake- and shareholders need to find plausible solutions.

As pointed out by Martin (2016), universities are today subject to more burdensome bureaucracy without consideration for the load imposed on staff, for example, to engage in teaching and supervising activities. Therefore, it is becoming more challenging for staff to achieve excellent outcomes over all three missions. There could be a need to establish rules and procedures to integrate the accomplishment of goals in terms of research, teaching, and third mission activities. This implies also that institutional goals and priorities are accordingly needed for resource allocation decisions and the vocational role of the institution, and also for individuals in the academic scene. This could help to effectively strengthen the scope of the current university ecosystem, which is characterised by heterogeneous universities that do not share the same resources and capabilities.

Despite the fact that universities are changing their third mission strategies in response to the implementation of a performance-based funding system, universities still set different objectives and follow various approaches. In general, the current funding system appears to not fully take into consideration the heterogeneous ecosystem of universities that consists of different resources, levels of bureaucracy, varieties of research, and third mission activities (Martin, 2013; Rosli and Rossi, 2016). As hypothesized by Rosli and Rossi (2016), success in terms of the third mission could be evaluated on the basis of the outcomes achieved instead of imposing homogenous metrics and indicators that do not reflect the different capabilities and resources available at the university level.

The paper can be further extended in several directions. One of these might be by focusing on the mechanisms through which university-society interactions can improve research quality. Moreover, future research could also consider a wider range of knowledge transfer mechanisms (for example joint R&D and sitting on advisory boards as suggested by Abreu and Grinevich, 2013). In addition, limited to the availability of the data, future studies could introduce performance indicators based on impact. Alternatively, an additional extension of our study might explore the determinants of efficiency in terms of income generated through engagement activities.

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Appendix A. List of universities included in the sample (in alphabetical order)

'Old' Universities	**'New' Universities**
Aberystwyth University	Anglia Ruskin University
Aston University	Bath Spa University
Bangor University	Birmingham City University
Birkbeck College	Bishop Grosseteste University

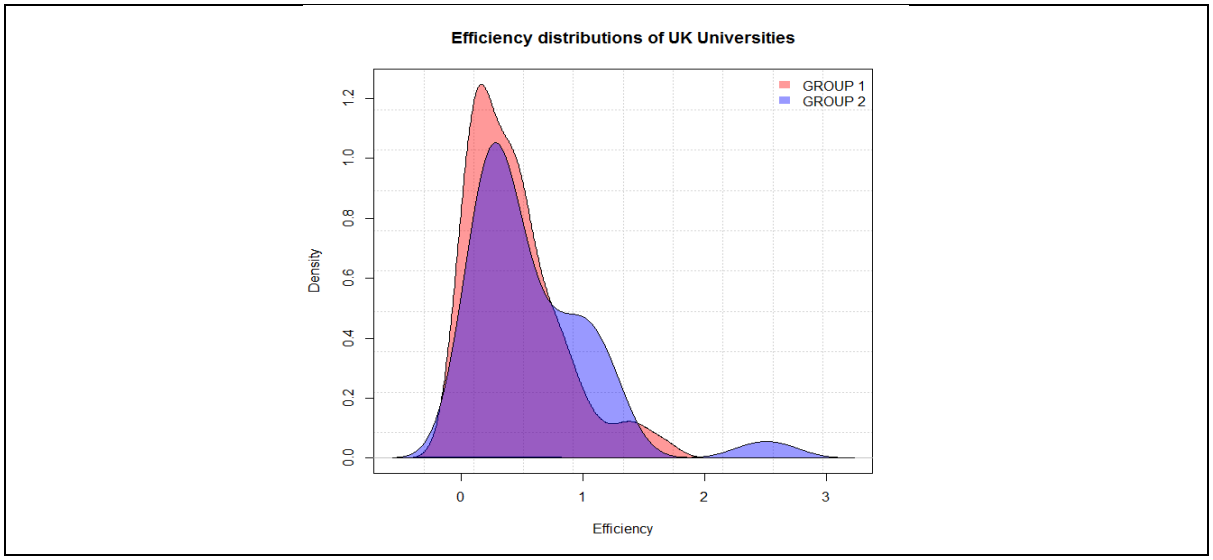
Cardiff University
Goldsmiths College
Heriot-Watt University
Imperial College of Science, Technology and Medicine
King's College London
London School of Economics and Political Science
London School of Hygiene and Tropical Medicine
Loughborough University
Queen Mary University of London
Royal Holloway and Bedford New College
St George's Hospital Medical School
Swansea University
The City University
The Institute of Cancer Research
The Open University
The Robert Gordon University
The School of Oriental and African Studies
The University of Aberdeen
The University of Bath
The University of Birmingham
The University of Bradford
The University of Bristol
The University of Cambridge
The University of Dundee
The University of East Anglia
The University of Edinburgh
The University of Essex
The University of Exeter
The University of Glasgow
The University of Hull
The University of Keele
The University of Kent
The University of Lancaster
The University of Leeds
The University of Leicester
The University of Lincoln
The University of Liverpool
The University of Manchester
The University of Oxford
The University of Reading
The University of Salford
The University of Sheffield
The University of Southampton
The University of St Andrews
The University of Stirling
Bournemouth University
Brunel University London
Buckinghamshire New University
Canterbury Christ Church University
Coventry University
Cranfield University
Edge Hill University
Edinburgh Napier University
Glasgow Caledonian University
Glyndŵr University
Kingston University
Leeds Beckett University
Leeds Trinity University
Liverpool Hope University
Liverpool John Moores University
London Metropolitan University
London South Bank University
Middlesex University
Newman University
Oxford Brookes University
Queen Margaret University, Edinburgh
Roehampton University
Sheffield Hallam University
Southampton Solent University
St Mary's University, Twickenham
Staffordshire University
Teesside University
The Manchester Metropolitan University
The Nottingham Trent University
The University of Bolton
The University of Brighton
The University of Chichester
The University of East London
The University of Greenwich
The University of Huddersfield
The University of Northampton
The University of Portsmouth
The University of Sunderland
The University of the West of Scotland
The University of West London
The University of Westminster
The University of Winchester
The University of Wolverhampton
University of Abertay Dundee
University of Chester

The University of Strathclyde	University of Cumbria
The University of Surrey	University of Derby
The University of Sussex	University of Gloucestershire
The University of Warwick	University of Hertfordshire
The University of York	University of Northumbria at Newcastle
University College London	University of Plymouth
University of Durham	University of the Highlands and Islands
University of Newcastle-upon-Tyne	University of the West of England, Bristol
University of Nottingham	University of Worcester
University of Ulster	Writtle University College
	York St John University

Appendix B: Factor analysis for inputs and outputs

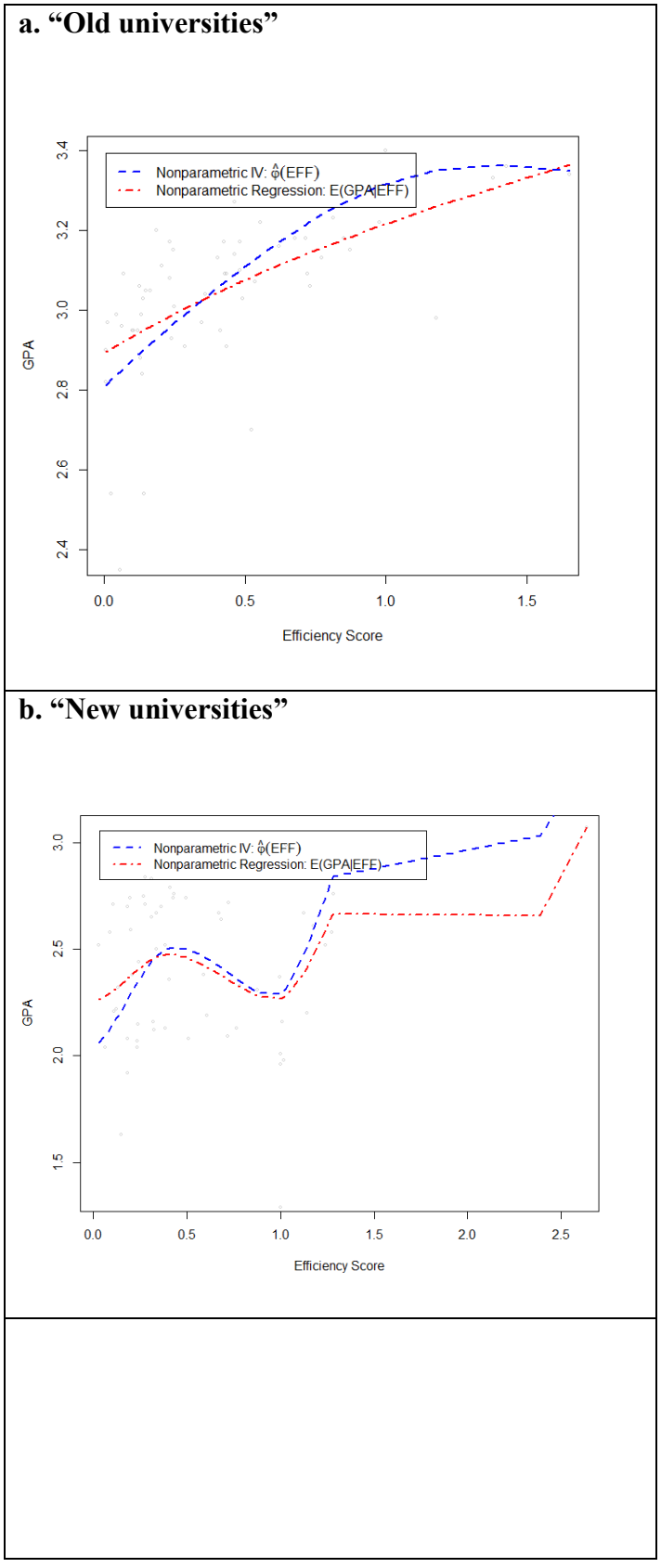
As described in Section 3, for the empirical analysis we have employed a factor analysis to reduce the number of inputs and outputs in order to get accurate estimation of efficiency, In particular, consistently with Bădin et al. (2012) and Wilson (2018), we replace the three scaled inputs by their best (non-centered) linear combination that is a unique factor. The same has been done for the three outputs. We apply this procedure for both "new universities" and "old universities". We first scale the inputs and outputs by dividing each variable for its mean value. By aggregating the variables for both "new universities" and "old universities" we lose less than 15% of the information. In particular, for both "new universities" and "old universities" the factor relative to the inputs and outputs explains around 90 percent of total inertia of the original data. Finally, the factors are highly correlated with the original variables (more than 90 percent).

Figure 1. The distribution of the mean efficiency scores for "old" and "new" universities over the period 2007-2014.

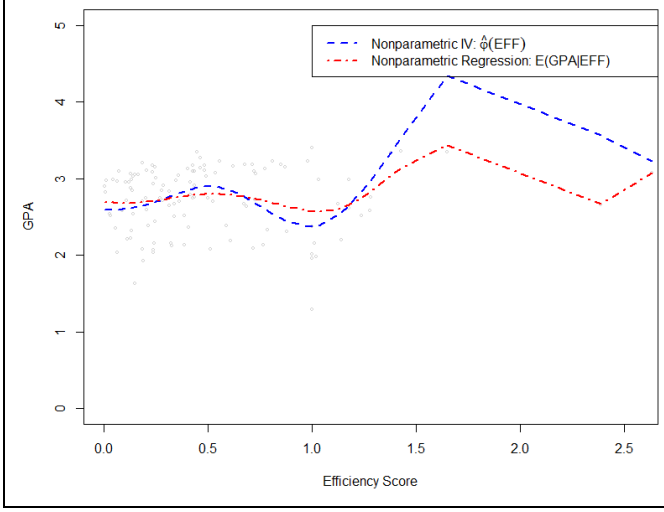


Note: Group 1 encompasses the "old universities", while Group 2 includes the "new universities.

Figure 2. The mean efficiency score and quality of research: Nonparametric instrumental kernel regression

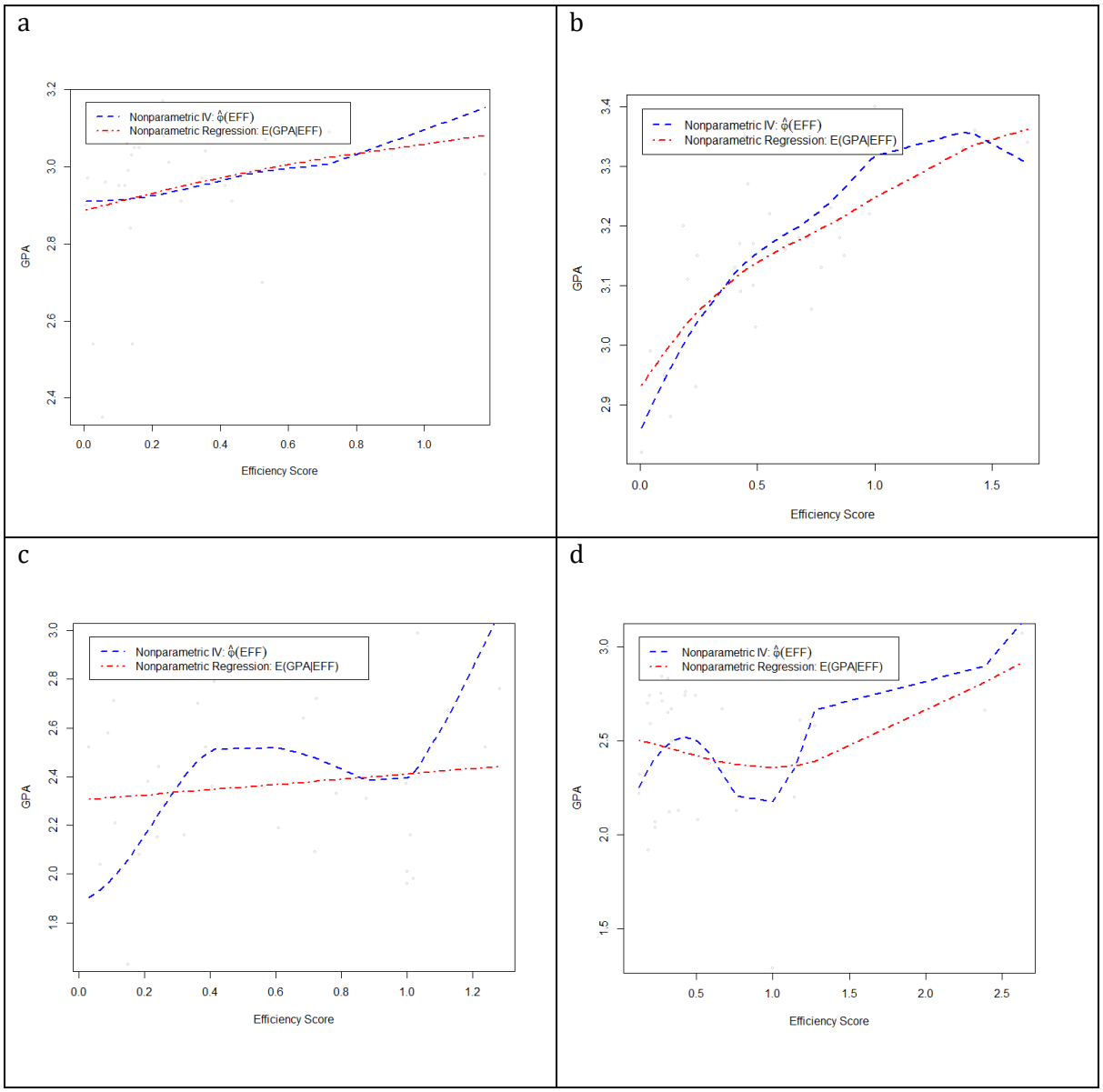


c. "Entire sample"



Note: All the results are statistical significance at the conventional 5% level. For the description of the variables and instruments refer to Section 4.

Figure 3. Efficiency score, quality of research and student to staff ratio: Nonparametric instrumental kernel regression



Note: All the results are statistical significance at the conventional 5% level. Figure 3.a reports the findings for "old universities" with a student-staff ratio above the median value, while Figure 3.b shows the results for the student-staff ratio below the median value. Figure 3.a reports the findings for "new universities" with a student-staff ratio above the median value, while Figure 3.b shows the results for the student-staff ratio below the median value.

Figure 4: The distribution of the mean efficiency scores for HEIs in the Russell Group and HEIs with Medical & Engineering Schools over the period 2007-2014.

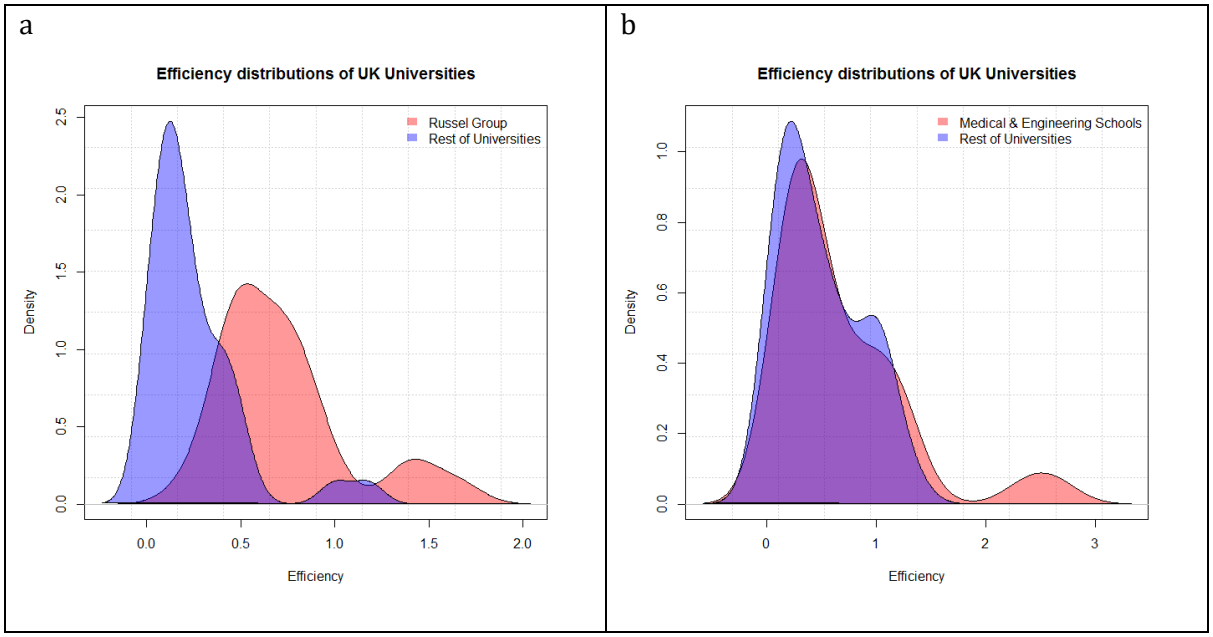


Table 1. Descriptive statistics of the variables over the period 2007-2014

Variable	Mean	Std. Dev.	Min	Max
a. "New universities" (60)				
Factor Input	1.732	0.950	0.243	3.716
Factor Output	1.712	2.328	0.032	12.764
GPA (0-4)	2.411	0.343	1.290	3.070
Contract Research (£000)	2150.250	2874.696	0.000	18509.000
Consultancy contracts (£000)	1538.092	2344.507	6.170	13320.170
Intellectual property (IP) (including patents,copyright, design, registration and trade marks): Revenues (£000s)	72.602	239.986	0.000	1746.286
Academic staff	601.238	388.059	10.700	1478.600
Non-academic staff	964.933	550.111	164.000	2365.000
Total expenditure (£000s)	61876.750	32696.340	8134.000	127305.000
Finance return 2005-2007	31635.470	19764.780	2506.670	71548.330
GDP	14965.700	8810.854	5308.250	43926.750
Population	874.917	1374.219	56.000	7960.000
b. "Old universities" (59)				
Factor Input	1.732	1.094	0.297	5.172
Factor Output	1.700	1.919	0.036	8.934
GPA (0-4)	3.048	0.195	2.350	3.400
Contract Research ((£000)	21052.470	23630.460	325.000	118054.000
Consultancy contracts (£000)	4102.427	4636.476	83.000	20961.500
Intellectual property (IP) (including patents, copyright, design, registration and trade marks): Revenues (£000s)	1601.037	3261.409	0.000	15719.500
Academic staff	838.663	457.635	72.900	1985.000
Non-academic staff	2098.424	1231.298	337.000	5237.000
Total expenditure (£000s)	163403.400	142097.200	30255.000	819825.000
Finance return 2005-2007	52457.840	31721.650	1129.670	145690.300
GDP	17858.760	9634.215	2802.875	43926.750
Population	1372.729	1896.034	56.000	7649.000

Notes: Descriptive statistics are reported for the pooled sample. I brackets is reported the number of universities of each category.

Table 2: Ranking of the most efficient institutions over the 2007-2014

Rank	"Old Universities"	"New universities"
1	The University of Oxford	Cranfield University
2	Imperial College of Science, Technology and Medicine	Oxford Brookes University
3	The University of Cambridge	University of the Highlands and Islands
4	The University of Surrey	Teesside University
5	The Institute of Cancer Research	Edinburgh Napier University
6	University College London	University of Hertfordshire
7	The University of Southampton	Staffordshire University
8	Queen Mary University of London	Glasgow Caledonian University
9	King's College London	Queen Margaret University, Edinburgh
10	The University of Leeds	St Mary's University, Twickenham

Table 3: Adapted Li-test for equality across efficiencies

Null hypothesis (H0)	p-value	Decision on H0
pdf(Russel Group)=*pdf*(Rest of Universities)	0.00000	Reject
pdf(Medical & Engineering School)=*pdf*(Rest of Universities)	0.16162	Do not reject