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Regional development, quality of government, and the performance of universities

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Abstract

We empirically evaluate how the efficiency of Spanish public universities impacts regional economic performance in Spain during the period 2010–2019. Efficiency is measured using activity analysis methods that attempt to capture reflect how universities perform in their respective missions—namely, teaching, research, and knowledge transfer. We analyse the geography of higher education by examining efficiency at the provincial (NUTS3) and regional (NUTS2) levels, as well as for groups of regions (NUTS1). Our results offer several key insights. First, we find that geography plays a differential role primarily when knowledge transfer activities are considered, while geographical patterns are similar for teaching and research activities. Second, the impact of universities' efficiency on regional economic activity varies across different outcome measures. While provinces with more efficient public university systems show higher labor productivity and capital intensity levels, there is no significant relationship with per capita income. The spatial analysis indicates that efficiency gains generate indirect and positive spillovers, particularly for capital intensity, suggesting that improvements in university performance can benefit broader regional areas. Additionally, institutional quality, measured through regional government performance indicators, reinforces these effects. Our findings suggest that policies aimed at enhancing university efficiency should prioritise the research mission. Among the three university missions, research has the greatest impact on improving productive processes and is the most effective in fostering regional economic development.

Keywords: bias-corrected efficiency; capital intensity; higher education institutions; regional growth; productivity

JEL classification: C61; J24; R11

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1. Introduction

Scholars have extensively investigated the correlation between economic growth and higher education, approaching the subject from both theoretical and empirical perspectives (Goddard and Vallance, 2010; Atta-Owusu and Fitjar, 2022). Although multiple factors contribute to this intricate relationship, universities make a substantial contribution to building human capital. By establishing conducive learning environments, cultivating essential skills and amassing resources, universities play a fundamental role in fostering economic development at both national and regional scales. Consequential outcomes include enhanced social cohesion and heightened competitiveness (Duch Brown et al., 2011; Boucher et al., 2003). Higher education is therefore pivotal in facilitating economic welfare and advancement in contemporary societies. Furthermore, it is widely acknowledged as an indispensable prerequisite for countries to engage effectively in competition in a globalised world.

Despite the acknowledged significance of higher education institutions in fostering growth at both national and regional levels, the existing literature primarily concentrates on the role of human capital (Castelló-Climent, 2010) with the result that knowledge about the direct economic impact of universities is scarce, particularly at the country level. However, a limited number of scholarly contributions have explored this subject. For instance, Aghion et al. (2009) investigate the link between research activities of universities and economic outcomes in various US states, while Hausman (2012) examines the innovation stimulated by universities at the county level in the USA. In a historical context, Cantoni and Yuchtman (2014) explore the causal role played by medieval universities in 14th-century Germany in driving the commercial revolution. More explicit quantification of this direct impact has been undertaken by Valero and Van Reenen (2019), who establish a robust association between the growth of universities and subsequent per capita GDP growth at sub-national levels across 1,500 regions in 78 countries. Notably, their findings reveal that a 10% increase in the number of universities within a particular region corresponds to a 0.4% increase in GDP per capita.

However, if we consider both direct and indirect effects and focus more closely on the impact at the regional and other sub-national (e.g., local) levels, we observe a rapid growth in the literature since the beginning of the 2000s (see, for instance Huggins and Johnston, 2009; Stephens et al., 2013; Goddard et al., 2014; Brekke, 2021). The mechanisms here are multiple and different authors specify different classifications. In this regard, and following Duch Brown et al. (2011), we can consider that there are four main groups of studies, which analyse: (i) the role of higher education institutions (HEIs) as attractors, educators and retainers of students (Boucher et al., 2003; Bramwell and Wolfe, 2008); (ii) the links between HEIs and firm formation (Woodward et al., 2006; Kirchhoff et al., 2007); (iii) the generation of spillovers by HEIs activity (Goldstein and Drucker, 2006; Kantor and Whalley, 2014, 2019); and (iv) the effects of R&D activities on (regional) productivity and economic growth (Sterlacchini, 2008;

Andersson et al., 2009). The mechanisms underlying each of these impacts differ, although they are ultimately related since they all model how the presence of a university in a given region affects its economic outcome.

An alternative, but not mutually exclusive, classification of the channels through which HEIs impact economic growth and development (at both national and sub-national levels) has been proposed more recently by Valero and Van Reenen (2019). These authors identify four categories: (i) the role of HEIs as producers of human capital and skilled workers, a mechanism that operates at both the country (Card, 2001) and regional levels (Gennaioli et al., 2013, 2014); (ii) greater innovation, a mechanism which could operate both directly or indirectly, with several contributions finding that universities increase local innovative capacity (e.g. Toivanen and Väänänen, 2016); (iii) increasing quality of institutions, which universities may strengthen it via their role as human capital producers (Acemoglu et al., 2005, 2019; Rodríguez-Pose and Di Cataldo, 2015); and (iv) demand effects, which can be direct via the increase in local consumption by students, staff and the universities themselves.

Therefore, the mechanisms underlying how the presence of a university and the spillovers they generate for economic development are now well known. However, few studies have focused explicitly on how the *performance* of HEIs themselves—which can be understood as a measure of their quality—impacts the economic development and economic growth of their home regions. In this regard, by conceptualising university performance in terms of efficiency, we may argue that regions with more efficient HEIs (i.e., those which can produce more outputs with similar levels of inputs to the most inefficient ones) will, *cæteris paribus*, benefit in terms of higher regional economic development. Multiple mechanisms may be at play, but we put forward the following possible classification: (i) reputational issues (e.g., inefficient universities might find it more difficult to establish partnerships with local firms and institutions); (ii) generation of efficiency spillovers (local institutions that interact with universities might be implicitly driven to operate efficiently); and (iii) adverse interactions with the labour market (e.g., inefficient universities might employ graduates whose contribution to the region's GDP would be higher if they worked in industry).

These powerful engines justify why universities' performance should be included in the analysis when evaluating their contribution to regional development. In this line, recent studies have considered similar issues in a variety of geographical contexts, from both national and sub-national perspectives (see, among others, Barra and Zotti, 2017; Agasisti et al., 2019, 2021; Crespo et al., 2022; Bertoletti et al., 2022; Agasisti and Bertoletti, 2022). We extend these contributions by explicitly accounting for the fact that universities perform different functions, but they might not perform them equally (Atta-Owusu et al., 2021). For instance, whereas some universities perform better at educating qualified graduates for the job market, others may excel in producing and transferring scientific research (Kempton, 2019; Sánchez-

Barrioluengo, 2014), which might ultimately have varying impacts on their home regions' level of development. Indeed, not only is there a scarce number of studies analysing the impact of universities' research intensity on local development (Minguillo and Thelwall, 2015) but also some of them have found an inverse link between universities' research output and their links with their surrounding business ecosystem (Atta-Owusu et al., 2021).

In this study, we therefore examine the mechanisms governing the performance of universities in a range of dimensions and whether they have an impact on levels of economic development in their home regions. Thus, with respect to previous contributions to this literature, we consider different measures for universities' efficiency by adopting a cost specification. We explicitly account for the fact that universities perform different missions and, accordingly, consider models focusing on different sets of outputs, which reflect different university functions, as they may have a varying impact on levels of development in their home regions. From a methodological point of view, we consider a bias-corrected counterpart of data envelopment analysis (one of the most popular choices when evaluating HEI efficiency) that to date has not been applied in studies of university efficiency. The analysis in the first stage yields indicators of efficiency not only at the university level but also for geographical units, as universities' impacts might extend across varying geographical scales. In the second stage of the analysis, we plug these regional-based indicators of efficiency into models to evaluate how the regional university systems affect their home regions economic indicators, not only in terms of GDP per capita but also for labour productivity and capital intensity. In this regard, regions with a focus on capital intensity are more likely to adopt and invest in cutting-edge technologies, thus contributing to innovation and competitiveness. Indeed, capital-intensive industries often create jobs that demand a more skilled workforce, which ultimately results in higher long-term economic development.

Our empirical context is Spain, whose university system has grown remarkably over the last thirty-five years in both size and number of universities as well as in geographical coverage. Evaluation of Spanish universities is a more recent phenomenon, with several studies measuring different aspects of their performance (Berbegal-Mirabent et al., 2013; De La Torre et al., 2017; García-Aracil, 2013; Salas-Velasco, 2020), and others analysing their contributions to the regional economy (Pastor and Peraita, 2016). The fact that the policy of university expansion was partly a policy pursued by different levels of government, rather than simply a response to local sub-national conditions and needs, has certain advantages in terms of measuring the contributions to regional development, since not only all regions (*comunidades autónomas*, corresponding to NUTS2 in European terminology) have a university, but also most provinces (*provincias*, corresponding to NUTS3 in European terminology).

Our analysis explicitly accounts for the variations in institutional quality across Spanish regions. The relevance of this issue has been examined recently for European regions by Ganau and Rodríguez-Pose (2019), who found that productivity growth is both directly and indirectly associated with regional institutional quality. Although related research has focused on its impact on other dimensions, such as economic growth, innovation or entrepreneurship (Nistotskaya et al., 2015; Rodríguez-Pose and Ketterer, 2020), the joint analysis of the impact on per capita income together with variables that are more directly related to the productive structures of each region (not only labour productivity but also capital intensity) has attracted less academic attention (with a few exceptions such as Tortosa-Ausina et al., 2005, who focused on provincial convergence in Spain). We consider that the combination of regional institutional quality variables with those related to the efficiency of universities is also particularly relevant, as they might be partly reflecting similar issues. As Balaguer-Coll et al. (2022) point out, government efficiency is a particular dimension of quality of government and, although public universities do not correspond to any level of government, they are relevant public institutions in their home provinces that also reflect institutional quality at the provincial level.

Our results can be explored from several perspectives. First, our models reveal remarkable differences in performance across universities and show that these differences do not diminish over time. For some specific universities, performance is particularly poor, regardless of the model under consideration. The territorialisation of Spanish higher education enables a geographical evaluation of university performance (as the majority of provinces, NUTS3, have at least one public university, and most universities do not have campuses beyond the boundaries of their home province), with results indicating that efficiency differentials across regions are indeed significant. In the second stage analysis, we find that HEIs' efficiency does have an economic impact in their home regions but the impact cannot be generalised as it impacts the production processes positively and significantly (via capital intensity and labour productivity), but it is more intricate in the case of GDP per capita. Furthermore, our analysis of the role of government quality variables shows interesting patterns that differ across our set of dependent variables. We find a mixed effect of institutional quality on per capita income, with the impartiality component of quality of government having a strongly significant effect, but the overall European Quality Indicator (EQI) showing a negative—albeit barely significant—impact. The results are more conclusive for both labour productivity and capital intensity, where the EQI effect is positive, although with varying magnitudes. For labour productivity the effect is modest, but for capital intensity the magnitude is much stronger both in terms of the magnitude of the coefficient and its significance. These findings are consistent with recent evidence on how institutional quality affects regional development in Europe, particularly regarding the productivity challenge faced by European regions (Rodríguez-Pose and Ganau, 2022), and complement studies that focus on the varying impacts of different dimensions of government quality on economic performance (Balaguer-Coll et al., 2022). Interestingly, since part of the efficiency of universities might be capturing this institutional effect, our findings may be suggesting that university performance could be partly reflecting the quality of regional institutions, which would be consistent with some hypotheses in the literature (Valero and Van Reenen, 2019).

The rest of the paper is organised as follows. After this introduction, Section 2 outlines the context of the Spanish university system and Section 3 describes the different efficiency models based on what universities do. Section 4 explains how university efficiency is computed and presents the model specifications used for the regressions. The data used for the analysis are described in Section 5. Results are presented and discussed in Section 6, and concluding remarks are made in Section 7.

2. Key facts of the Spanish university system

As in many European countries, the first universities in Spain were established several centuries ago. However, by the early 20th century, Spain still had only ten public universities. The significant transformation of the system, both in terms of quantity and quality, began in the 1970s. This evolution was particularly noteworthy following two key events: first, the democratic transition leading to the creation of a decentralised state in 1978, and second, the enactment of the University Reform Law (LRU, or *Ley de Reforma Universitaria*) in 1983, which aimed to modernise Spanish universities.

Concerning the quantitative aspect, while the number of public universities began to increase in the final years of the dictatorship, the advent of the democratic system further strengthened this upward trajectory. Regional governments, acting as the primary authorities in the funding and administration of universities and guided by an informal principle of one university (or at least one university campus) in each province, played a significant role in the prolific growth of new universities and campuses. This approach justifies our decision to examine the impacts of universities at the provincial level (NUTS3), even though decisions are made at the regional level (NUTS2), and minimal authority has been delegated to provinces (see Balaguer-Coll et al., 2010).

We examine 47 universities that exhibit a diverse spatial distribution.[1] Each region has at least one public university, with Madrid and Barcelona having six and four, respectively. No province is without a public university campus and universities do not extend beyond their home regions. However, universities are structured within the provinces of a region in various ways. In some regions with multiple provinces, a single university has campuses in each province (e.g., Basque Country or Castilla-La Mancha). In other multi-province regions,

[1] We omitted the public universities Universidad Nacional de Educación a Distancia (UNED), Universidad Internacional Menéndez y Pelayo (UIMP) and Universidad Internacional de Andalucía (UNIA) due to their distinctive characteristics, either functioning solely for distance learning or lacking a permanent staff.

each province has at least one university, but they are confined to their respective provinces (e.g., Catalonia). In regions with a single province, some have a single university (e.g., Asturias or Cantabria) while others have several (e.g., Madrid or Murcia). This information is reported in Tables 1 and 2.

As regards the qualitative dimension, the LRU has laid down the foundations of the university system in terms of autonomy, the structure of its functioning based on departments and its governance. Subsequent legislative reforms in 2001 (LOU) and 2007 (LOMOU) did not alter the essence of this system but brought in substantial operational changes, in order to align Spanish universities with the Bologna Declaration of 1999, scheduled for completion by 2010, and to enhance internationalisation, research significance, and knowledge transfer activities. To achieve these objectives, university degrees were redefined to align with the three-cycle system (undergraduate, master, doctoral studies), the National Agency for Quality Evaluation (ANECA) was established, and the career development system for academic staff was overhauled to more closely reflect their research performance.

Some of these changes were introduced during the years of the Great Recession, a crisis that affected university activities in different ways and which is partly covered by our study period (2010–2019). On the one hand, the economic crisis turned into a debt crisis, forcing regional governments to make budget cuts. On average, there was a reduction in public funding of around 25% in the period 2009–2014, but this was not applied uniformly across the regions, as there were differences in the deterioration of their financial situation, as well as in the areas that each region defined as priorities to apply cuts. For example, according to the Spanish Ministry of Education, the reduction in public funding between 2009 and 2013 was less than 19% in some regions, such as Aragon, La Rioja or Navarre, while it was more than 33% in others, such as Madrid, the Valencian Community or Castile-La Mancha. Since 2012, these cuts have been partially offset by a gradual increase in tuition fees, the final amount of which has also been set by the regional authorities. As a result, the figures show an increase in the number of students enrolled in public universities between 2008 and 2011, followed by a decrease. This is probably explained by the combination of two effects: the increase in unemployment in the first years of the crisis reduced the opportunity cost of higher education, but the increase in fees in a context of economic difficulties may have limited access to university.

With regard to the second and third missions of universities, research and knowledge transfer activities, public universities are now expected to meet higher standards. The proliferation of global university rankings has made competition between universities more visible and has pushed them to excel, especially in research activities. Moreover, the necessary transition to a knowledge-intensive and innovative economy, in which universities must play a central role, is becoming a common political language and has been recognised as such in frameworks such as the triple helix model or regional innovation systems. Therefore, as mentioned above, the LOU and LOMOU reforms have linked the career progression of academic staff to their performance in research and knowledge transfer activities.

However, the changes in student numbers, the redefinition of university degrees and the increase in expected outcomes in terms of research knowledge standards converged in a context that was far from favourable. The public administration budget cuts constrained by the debt crisis, led to the aforementioned reduction in funding for universities. In this context, it was essential for universities to become efficient institutions.

3. Modelling HEIs' missions

In order to estimate the efficiency of universities we must first define what they actually do. The literature on the performance of educational institutions and, in particular, the efficiency of universities, has grown rapidly over the last two decades. Although there is a broad consensus on the main "missions" of universities, i.e., teaching, research and knowledge transfer, it is challenging to measure them precisely for a number of reasons. First, it is problematic *per se* to measure these activities, not only because of the different dimensions they comprise but also because they weigh differently depending on the field of knowledge. Second, data availability can differ remarkably across countries, and the measures considered are different as well. Finally, there is disagreement over whether several items should be classified as inputs or outputs, which ultimately affects the scores obtained. An additional difficulty is related to the quality of the outputs produced, which can frequently make the difference between an outstanding or an average institution (Berbegal-Mirabent and Ribeiro-Soriano, 2015).

In this context, following Berbegal Mirabent and Solé Parellada (2012), universities' outputs should reflect their teaching, research and knowledge transfer activities, whereas inputs should reflect the resources, either monetary or physical, used to obtain the outputs. Although there is relatively broad agreement on the concepts that both inputs and outputs are expected to reflect, a cursory look at the empirical literature on HEI efficiency reveals a wide variation in definitions used across studies, even when the same country is examined. Therefore, results can differ not only because different contexts or periods are analysed, or different methodologies are used, but also because the concepts being measured vary as well.

We partly deal with this issue by specifying several definitions of inputs and outputs, which is not a common approach in this literature. Specifically, in order to measure universities' output more precisely and, as indicated in the introduction, to better understand how the different activities performed by universities contribute to regional development, we consider three models of HEI production. These models attempt to capture the three missions more accurately and, therefore, will also allow us to uncover the differential hypothesis as to the differential contribution to local and regional economic growth depending on the activities considered.

All three models consider a single input, namely total operating costs (TC), net of residence and catering costs, analogously to Thanassoulis et al. (2011). Considering a single input has the additional advantage of avoiding the problems related to the dual nature of some variables, i.e., those that can be classified as inputs and outputs. Considering total costs as a single input is also popular in other public sector efficiency studies (Balaguer-Coll et al., 2007).

The main differences across the different models considered are confined to the definition of outputs. The first of these three models is the research-teaching model (R-T), in which only research- and teaching-related variables are included and, therefore, the scores obtained provide a painstaking characterisation of how universities perform in their research-related activities. To model these research activities, we consider as outputs the competitive research grants obtained (yR_1), at both country and EU levels (projects funded by the Spanish National R&D Programme and the EU) (see Johnes et al., 2008; Thanassoulis et al., 2011). We also consider the number of publications (yR_2) (Duh et al., 2014; Lee, 2011; Wolszczak-Derlacz and Parteka, 2011; Martínez-Campillo and Fernández-Santos, 2020) and, as a measure of their quality, the number of citations (yR_3). This is particularly important nowadays, when initiatives such as the Declaration of Research Assessment (DORA) are recognising the need to improve how research output is measured.

Our second model is the knowledge transfer-teaching model (KT-T), aimed to provide a better characterisation of this type of activity. We therefore, we consider three outputs linked to these activities, namely R&D contracts, patents and spin-offs. Unfortunately, the information for these variables is usually poor or unavailable and, in some cases, we only have partial data. This is the case of R&D contracts (yKT_1), for which the only available information is the number of contracts, but not the total amount corresponding to each university. This can be problematic, as the total amount corresponding to contracts might vary considerably from one field to another. We also consider the number of patents (yKT_2) and spin-offs (yKT_3), which are essential for transferring new knowledge and research results from universities to both the private and public sectors, thereby increasing the competitiveness of firms, creating new business opportunities, providing new solutions to societal challenges, and renewing industrial structures (Crespo et al., 2022; Bathelt et al., 2010; Berbegal-Mirabent et al., 2013; Caldera and Debande, 2010; Laredo, 2007; Berbegal-Mirabent, 2018; Iacobucci and Micozzi, 2015; Agasisti et al., 2019; Calcagnini et al., 2016).

Both models (research-teaching and knowledge transfer-teaching) include teaching activities as output. We consider this output to be essential because, whereas public universities' involvement in research and knowledge transfer activities can vary a great deal from one university to another, differences in teaching are much less marked. Students usually study at universities in their home regions, a trend exacerbated by the relative absence of grants that would facilitate their mobility (Pastor Monsálvez et al., 2019). In addition, universities have only limited means with which to attract foreign students. The outputs considered to measure the teaching mission are the number of graduates with a bachelor degree (yT_1), and number of postgraduates with a master's degree (yT_2) or a PhD (yT_3) (see Agasisti and Pérez-Esparrells, 2010; Duh et al., 2014; Berbegal-Mirabent et al., 2013; Barra and Zotti, 2017; Agasisti et al., 2016; Martínez-Campillo and Fernández-Santos, 2020). These outputs have an indirect but essential impact on regional and local development, as society demands well-educated and highly-skilled workforces—i.e., there is a human capital effect (Agasisti et al., 2019).

We consider a third model, labelled the global restricted model, which considers all three HEI missions. This model is therefore a combination of models R-T and KT-T, but excludes some variables in order to have three balanced models in terms of the total number of variables. As we will discuss in the following subsections, our efficiency measurement models are based on nonparametric frontier methods that are sensitive to the total number of variables included and, therefore, a relatively homogeneous number of outputs across models is recommended to avoid any result obtained as a statistical artefact. Therefore, our global restricted model excludes the teaching, research and knowledge transfer variables for which there is less academic consensus, namely, the number of students completing their PhD studies (yT_3), number of citations (yR_3), and number of spin-offs (yTR_3).[2]

4. Methods

4.1. Measuring the efficiency of universities: methodological aspects

The methodological alternatives for measuring efficiency has evolved significantly, offering a rich array of approaches beyond the traditional parametric and nonparametric dichotomy. Historically, stochastic frontier analysis (SFA) emerged as the dominant parametric technique following Aigner et al. (1977)'s foundational work, while data envelopment analysis (DEA), introduced by Charnes et al. (1978), established itself as the preeminent nonparametric method. Despite the continued prevalence of these approaches, the field has expanded considerably, with Bayesian methods gaining prominence in parametric analysis (Koop and Steel, 2001) and partial frontier estimators like order-m and order-α advancing nonparametric measurement capabilities (Cazals et al., 2002; Aragon et al., 2005).

A significant methodological contribution came from Badunenko et al. (2012)'s comparative analysis, which evaluated two relatively sophisticated estimators in cross-sectional set-

[2]We refer to this model as "restricted" because some output variables are dropped.

tings: the nonparametric kernel SFA estimator developed by Fan et al. (1996) (FLW) and Kneip et al.'s (2008) bias-corrected DEA estimator (KSW). For the current study of university efficiency, the KSW estimator was selected exclusively, as it offers distinct advantages when analysing complex decision-making units with multiple inputs and outputs, such as higher education institutions. The FLW estimator, while valuable, presents greater challenges in such multidimensional contexts. This methodological choice also maintains analytical focus and reasonable scope, recognising that a comprehensive comparative application of both estimators to higher education would merit a specific investigation.

We consider the KSW estimator is particularly well-suited for this analysis as it preserves the flexibility of traditional DEA while addressing its inherent bias issues, resulting in improved performance with finite samples (Kneip et al., 2008). Unlike standard DEA, which can overestimate efficiency in small samples, the KSW approach implements a consistent bootstrap procedure that yields more reliable efficiency scores by correcting for this estimation bias. This correction is especially valuable when examining the relatively limited sample of Spanish universities across multiple years, where precision in efficiency measurement is crucial for drawing meaningful conclusions about performance variations across regions and time periods.

Frontier estimators such as DEA or its nonconvex variant, free disposal hull (see Tulkens, 1993; Tulkens and Vanden Eeckaut, 1995; Kerstens and Zhao, 2025), do not need to specify the production process—in our case, HEIs' production processes. Instead, for a given technology, which we will denote by $\mathcal{T}$ decision-making units (universities) use a set of p inputs, x, to produce y set of q outputs such that

$$\mathcal{T} = \{(x, y) | x \text{ can produce } y\} \tag{1}$$

This flexibility is particularly advantageous when analyzing universities, as their production processes are multifaceted and complex, involving multiple inputs and outputs that vary across different institutional missions. For each (x_i, y_i) inputs-outputs combination, a DEA measure of (technical) efficiency can be obtained via linear programming techniques, as proposed in Charnes et al.'s (1978) seminal paper, following the early proposals by Farrell (1957). Since we will be assuming that universities attempt to maximise outputs, for given input mixes, the output-oriented efficiency measure for university i, θ_i, will be yielded by

$$F_j^o(x_i, y_i) = \sup\{\theta_i | (x_i, y_i/\theta_i) \in \mathcal{T}\}. \tag{2}$$

We consider output maximisation to be a reasonable assumption in the Spanish higher education context, since public universities receive a relatively fixed quantity of resources through regional government funding mechanisms. With these predetermined inputs, they are required to produce as much output as possible across their three missions—teaching, research, and knowledge transfer. This assumption aligns particularly well with the Spanish university system's governance structure, where resource allocation is primarily determined externally. Thus, although input-minimisation could also be assumed, we consider that output-orientation more accurately reflects the operational reality and institutional incentives facing these universities.

For a consistent bootstrap estimator, $\widehat{F^o}^*$, if the estimator $\widehat{F^o}$ is yielded by a known data generating process $\widehat{\mathcal{P}}(x,y)$, and the true score F^o_j results from an unknown data generating process $\mathcal{P}$, then:

$$\left(\widehat{F^o}^*/\widehat{F^o}-1\right)|\widehat{\mathcal{P}}(x,y) \overset{approximately}{\sim} (\widehat{F^o}/F^o-1)|\mathcal{P}. \tag{3}$$

This bootstrap method to perform statistical inference for the estimator in Equation (2) is proposed by Kneip et al. (2008) after deriving the asymptotic distribution of the DEA estimator, taking into account that both $F^o_i(x_i,y_i)$ and $\mathcal{T}$ are unknown (in practice). Then, after designing a two-step consistent bootstrap (subsample) procedure, the bias-corrected DEA efficiency score is given by

$$\widehat{\widehat{F^o}} = \widehat{F^o} - \widehat{\text{bias}}_B, \tag{4}$$

and the bias

$$\widehat{\text{bias}}_B = \left(\frac{m}{n}\right)^{2/(p+q+1)} \left[\frac{1}{B}\sum_{b=1}^{B}\widehat{F^o}^*_b - \widehat{F^o}\right]. \tag{5}$$

where B is the number of repetitions and m is the size of the subsample to adjust the bias.

As indicated by Kneip et al. (2008), this estimator offers several advantages that are particularly relevant for our analysis of the Spanish university system. First, it enables more rigorous classical statistical inference, critically important when examining efficiency differences across Spain's diverse regions. Second, it improves upon the standard DEA estimator by reducing bias, which is essential when comparing universities with varying scales and regional characteristics. Third, it demonstrates superior performance in finite samples, a significant benefit given our limited sample of Spanish public universities. This methodological refinement is especially valuable when analyzing provincial university systems with relatively few observations per geographical unit, allowing for more reliable efficiency comparisons across Spain's heterogeneous regional landscape. While the approach does require careful selection of subsample size to optimize estimator precision (see Kneip et al., 2008, for details), this minor limitation is far outweighed by the substantial improvements in statistical reliability for our institutional performance assessment.

4.2. Impact of universities' performance on regional economic development

In this section, we illustrate the long-run production relationship model used to assess the relationship of the performance of Spanish universities on the economic development of the Spanish provinces. Our dataset consists of a panel model comprised of 50 Spanish provinces, covering the period from 2009 to 2019. The baseline model is as follows:

$$Y_{it} = \alpha_i + \beta_1 EFF_{it} + \beta_2 QGOV_{it} + \beta_3 X_{it} + \varepsilon_{it} + \mu_i + \xi_{it} \tag{6}$$

where Y_{it} represents a metric for economic development, EFF_{it} denotes the efficiency of universities, $QGOV_{it}$ represents the indicator of the quality of government, and X_{it} stands for the control variables associated with provinces; ν indicates the unobserved area-specific effect, ξ_{it} are the year dummies controlling for time-specific effect and ε are the disturbance errors. The subscripts i and t refer to the units of analysis (the Spanish provinces) and the time periods (years).

To better adjust the model for spread of backwash effects, Equation (6) is been extended by incorporating spatial lag variables in both the error term and the dependent variable (Anselin, 1988). This extension allows for a more comprehensive consideration of spatial autocorrelation, which might be relevant as we are dealing with provincial data. Spatial models make it possible to examine spatial interaction effects and, related to this, to assess spatial spillover effects. Hence, by considering these spatial phenomena, we can more precisely capture the impact of economic development on neighbouring regions. Hence, our baseline model becomes:

$$Y_{it} = \alpha_i + \rho W Y_{it} + \beta_1 EFF_{it} + \beta_2 QGOV_{i,t-1} + \beta_3 X_{it} + \varepsilon_{it} \tag{7}$$

$$Y_{it} = \alpha_i + \beta_1 EFF_{it} + \beta_2 QGOV_{i,t-1} + \beta_3 X_{it} + \lambda W \nu_{it} + \nu_{it} \tag{8}$$

$$\varepsilon_{it} = \lambda W \nu_{it} + \nu_{it} \tag{9}$$

where W represents the spatial weight matrix, which describes the pattern of spatial interdependence among units, specifically provinces,[3] and WY_{it} represent the endogenous interaction effect of the dependent variable, accounting for possible spillover effects deriving from neighbouring regions. The scalar parameters ρ and λ measure the strength of dependency among spatial units.

As explained in the related literature (Anselin, 1988; Elhorst, 2014; LeSage and Pace, 2009), the parameters of a spatial autoregressive model (SAR), corresponding to Equation (7), do

[3] First-order contiguity.

not reflect the direct marginal effects of changing the explanatory variables. Introducing the spatial lag of the endogenous variable generates both direct and indirect effects on the dependent variable, which require an accurate interpretation of the results. In contrast to the SAR model, the spatial error model (SEM) specified in Equation (8) captures spatial dependence through the error process rather than through the dependent variable.

In this context, Equation (10) represents the matrix of partial derivatives of Y_{it} with respect to the k^{th} explanatory variable of unit X_{it}, spanning from province 1 to unit N. These derivatives are obtained from the SAR model specified in Equation (7). The diagonal elements of this matrix represent direct effects, which capture the immediate impact of a change in the explanatory variable on the dependent variable for the same unit (or province). The off-diagonal elements represent indirect effects or spatial spillovers, which capture the influence of changes in the explanatory variable in one unit on neighboring units. These effects are independent of time (t) (Elhorst, 2017).

$$\left[\frac{\delta E(Y_t)}{\delta x_{1kt}}, \quad \ldots, \frac{\delta E(Y_t)}{\delta x_{Nkt}}\right] = (I - \rho W)^{-1} (\beta_k + W\theta_k) \tag{10}$$

Where

- I is the identity matrix,
- ρ is the spatial autoregressive parameter,
- W is the spatial weight matrix, which represents the spatial relationships between units,
- β_k represents the coefficients of the explanatory variables,
- θ_k is the vector of spatially lagged effects.

5. Data and provincial aggregation

5.1. University variables

Data related to universities are gathered from two primary sources. The first source is the Integrated University Information System (SIIU) through which the Spanish Ministry of Education provides data on the budget of HEIs in euros, along with the number of students enrolled and those who have graduated (with both bachelor's and master's degrees). The second source is the IUNE Observatory, which provides information on research activities (including the number of publications and research grants received) and knowledge transfer activities (such as the number of patents and spin-offs). This observatory collects data from the Web of Science and various Spanish administrative sources such as, for instance, RedOTRI. The summary statistics are presented in Table 3.

5.2. Provincial variables

The variables used to estimate the effect of universities on provincial development are reported in Table 4, with their descriptive statistics presented in Table 5. The economic development of Spanish provinces is measured not only through GDP per capita (GDP/N) but also through indicators more closely related to the provinces' economic structure, namely labour productivity (measured as gross value added per worker, GVA/L) and capital intensity (K/L) (see Tortosa-Ausina et al., 2005).

The set of independent variables consists, first, of the three efficiency models explained in the previous sections. Second, for the reasons given in previous sections, our models also include regional quality of government variables. These are based on the information provided by the Quality of Government Institute (University of Gothenburg).[4] They capture average citizens' perceptions and experiences of corruption, quality and impartiality of three essential public services—health, education and policing—in their home regions. Interestingly, to date this is the only measure available at sub-national levels of government and for large territorial areas (NUTS1 and NUTS2 European regions). Although some other measures exist, they cover more limited geographical areas.[5] Full details were provided by the designers of the database in a series of documents and research articles.[6] Conceptually, quality of government is understood as impartiality in the exercise of public power, which is the standard definition in the literature (Rothstein and Teorell, 2008). The measure is constructed by evaluating citizens' experiences and perceptions of three domains: (i) quality, related to whether or not public services are perceived as high-quality; (ii) impartiality, which refers to the perception of whether governments (national or sub-national) treat their citizens equally, regardless of their connections or personal characteristics; and (iii) corruption, which refers to the absence of abuse of public office for private gain. The European Quality Index has already had a relevant impact on scientific research of territorial differences in several disciplines, and many researchers use it as the main indicator of institutional quality across regions of Europe.[7] Third, we also include a set of control variables, which contains some of the most commonly used variables in the empirical literature on economic growth, such as levels of education attainment, physical capital and infrastructure quality, labour force participation rates, technology adoption or government policies related to economic development (Sala-i-Martin, 1997). Due to data limitations in our study, when human capital data

[4] See `https://www.gu.se/en/quality-government/qog-data/data-downloads/european-quality-of-government-index`.

[5] See, for instance, the study by Barra and Papaccio (2024) for the case of Italy.

[6] See, for instance, Charron et al. (2014), Charron et al. (2019), Charron et al. (2021), Dinesen and Sønderskov (2021) and, more recently, Charron et al. (2022). Relevant applications of these indices by other authors include Crescenzi et al. (2016), Ezcurra and Rodríguez-Pose (2013), Ketterer and Rodríguez-Pose (2016) and Muringani et al. (2019), among others.

[7] The data have also been a key feature in the Economic, Social and Territorial Cohesion Reports published by the European Commission to monitor cohesion levels across European sub-national units (basically NUTS2).

were unavailable at the provincial level, we used data on the working-age population and the economic value of human capital at the provincial level (Serrano et al., 2022). The provincial sectoral diversification is proxied by the distribution of employment across industrial and agricultural sectors, while the stock of capital (which is only present as a control in those models whose dependent variable is not capital intensity) is proxied by capital density (per square kilometre). Additionally, the labour force is represented by the working-age population. Also, in regressions where capital intensity is the dependent variable, gross investment in R&D has been incorporated.

5.3. Provincial aggregation

As discussed in Section 2, Spain does not have a one university per province structure, which complicates the assessment of efficiency for provincial university systems. This complexity arises from two factors: university performance must be attributed across all provinces where the institution maintains campuses, while a province's university system performance should reflect a weighted combination of all universities within its boundaries. To address this, we evaluate provincial university system performance using a weighted measure based on student enrollment proportions, calculated as:

$$PERFCH_i = \sum_{j=1}^{J} PERFCH_j \times \frac{STUD_{ij}}{\sum_{j=1}^{J} STUD_{ij}} \tag{11}$$

where i denotes the province, j represents the university, J indicates the total number of universities in each province, and $STUD_{ij}$ represents the enrollment count for university j in province i. See also Crespo et al. (2022).[8]

6. Results

6.1. Results for efficiency

We report results for each input and output specification considered in Section 3, as well as the methodologies presented in Subsection 4.1. Specifically, we report descriptive statistics in the three panels of Table 6 for the global restricted cost efficiency model (M1, upper panel), the research-teaching cost efficiency model (M2, central panel) and the transfer-teaching model (M3, lower panel).

These three tables present results for selected sample years (2010, 2015 and 2019) and summary statistics. The periods of analysis cover crisis and post-crisis years—2010 and

[8] To ensure robustness, we also computed all results using the proportion of degrees and the proportion of graduates as alternative weighting criteria instead of student proportions. Both alternative approaches yielded consistent results, which are available upon request.

2019 respectively. The year in between (2015) cannot be fully considered as a post-crisis year, as most universities were still under financial pressure, being prevented from hiring staff other than those strictly necessary to replace retiring employees.[9] Interestingly, Table 6 also reports information on the geography of university performance, since results are given for each of the Spanish NUTS1 regions (ES1 to ES7 in Table 6). These are major socio-economic regions, formed by groups of NUTS2 regions. Therefore, although they have formal devolved powers and are eligible for support from cohesion policy, the NUTS2 regions are more clearly identified with geographical patterns. Specifically, ES1 corresponds to the regions in the Northwest (*Noroeste*), ES2 to the Northeast (*Noreste*), ES4 to the Centre (*Centro*), ES5 to the East (*East*), ES6 to the South (*Sur*), and ES7 to the Canary Islands (*Canarias*)—which, geographically, are part of Africa. The remaining NUTS1 region is Madrid (ES3). Therefore, the universities in each of these groups of regions are part of different territories.

In the results reported in Table 6, given that universities attempt to maximise their objective function (output orientation), values closer to unity indicate higher efficiency, with efficient universities (on the frontier) having a value of one, whereas the most inefficient universities are those with higher values. Therefore, a value of 1.5 would indicate that this HEI (which is off the frontier) could be producing 1.5 more outputs when compared with its efficient peers—i.e., those on the efficient frontier.

Several patterns emerge from the results in the three panels of Table 6. First, we observe large discrepancies according to geographical regions (NUTS1), which not only persist over time but actually grow in most instances. As an example, for the global restricted model (Table 6), whereas most regions had efficiencies below 1.25 in 2010, by 2019 the tendency had reversed. Second, these eroded efficiencies over time are a consistent result across models, since the averages for the two restricted cost efficiency models (M2 and M3) also increased for many regions—particularly for the teaching-knowledge transfer model (M3, lower panel in Table 6). Given that the number of inputs and outputs is relatively balanced across models, efficiencies are comparable because our models are not affected by the fact that the higher the number of outputs, the higher number of dimensions in which a particular university can excel and, *cæteris paribus*, become more efficient. However, at the same time the table indicates that when fewer university activities are considered—particularly when those related to research and knowledge transfer are limited—some notable discrepancies emerge across universities (as shown by, for instance, particularly high values in 2019 for M3, lower panel in Table 6), pointing to a specialisation effect. This has been previously suggested by Aldás et al. (2016), who identified several strategic groups in the Spanish university system.

The median and standard deviation, also reported in Table 6, reveal additional trends. In

[9]This is the so-called *tasa de reposición* or "replacement rate", which was part of the package of austerity measures set up by the Spanish government following the European Union's mandates (Méndez et al., 2016; Sánchez-Moral et al., 2018).

some cases (for instance, the Northeast region, ES2, for model M3 in 2019), the gap between the mean and the median reveals the presence of very inefficient universities in those territories when the focus is on knowledge transfer activities. Therefore, some regions might not be benefiting from the spillovers of being physically closer, which is particularly relevant for some types of knowledge transfer activities (Hewitt-Dundas, 2013; Trippl, 2013; Calcagnini et al., 2016).

The results reported in Table 6 are complemented by Figures 1, 2 and 3, which report densities (estimated nonparametrically via kernel smoothing) for the efficiency scores for different subperiods and models, and considering conditioning schemes by geography. Specifically, the first of these three figures (Figure 1) displays densities for the three output specifications, with solid and dashed lines in each subfigure corresponding to the crisis and post-crisis subperiods, respectively. Although these subperiods are not exactly coincidental with the financial crisis that started in 2007/08, the first one (2010–2014) corresponds to the years when Spanish universities were most affected by the austerity policies, whereas in the second one (2015–2019) the tendencies reversed. Figure 2 reports analogous information, but presented from a different perspective, as the results for each model are compared directly, and for each subperiod separately—in Figures 2.a and 2.b for 2010–2014 and 2015–2019, respectively. Finally, Figure 3 differs from the previous ones, since we directly evaluate the effect of conditioning on geography—i.e., controlling for the effect of being located in a given NUTS1 or NUTS2 region.

According to Figure 1, the performance of universities has improved, on average, only slightly. The vertical lines, which represent the average, are closer to the unity (recall that higher values indicate more inefficiency) for all three models. However, although this trend is consistent across models, it is modest, particularly for the knowledge transfer-teaching model (M3, Figure 1.c). Nonetheless, regardless of the model considered, there are pockets of inefficient behaviour represented by the densities stretching to the upper tails. These bumps in the vicinity of 2-2.5 represent very inefficient universities, whose output could be as much as twice (or about 2.5) when compared to those universities on the efficient frontier, which can produce much more, with similar budgets (costs). While this is an admittedly crude conclusion that could probably be tempered if the models of university performance could be specified more accurately, the trend is robust across output specifications. When results for the three models are compared directly (Figure 2) we perceive some additional trends, as the most comprehensive model (global restricted model) is characterised by tighter densities (solid lines in both Figures 2.a and 2.b). This would indicate that universities are slightly more efficient when all their missions are included in the same model, as there are more dimensions in which they can excel; therefore, excelling in one particular dimension can offset lower competence in another one. This idea had already been anticipated when strategic groups were identified in the Spanish university system (Aldás et al., 2016), although not formally tested.

Finally, we initially control for the role of geography in Figure 3 by dividing each university efficiency score by its home region's (either NUTS1 or NUTS2) average. Therefore, a relative efficiency index of 1.5, for instance, would be indicating that the university is 50% more efficient than its home region (either NUTS1 or NUTS2) peers, whereas an index of 0.5% would indicate the opposite. For this reason, the solid lines in Figure 3, corresponding to the mean, are centred at the unity. Results show that for the three models considered there are some differences, with geography-conditioned densities leaning slightly to the unity, although in the case of the research-teaching model (Figure 3.b) the differences are more modest.

We can formally test whether these differences are significant by using nonparametric tests such as those proposed by Li (1996, 1999) and Li and Racine (2007). These tests are also based on kernel smoothing, and explicitly test for the differences between two given densities; the results are therefore not simply a comparison of only one or two moments of the distribution, such as the mean or the median. The outcome from the test provided in the upper panel of Table 7 shows that the differences when comparing efficiencies over time (2010–2014 vs 2015–2019) are not significant, regardless of the model considered. However, as indicated by the p-values in the lower panel of the table, which corresponds to NUTS2-conditioning, the results anticipated in Figure 3 are confirmed. In this case, the geography-conditioned scenario, the differences are significant for Models 1 and 3, i.e., for the models which include knowledge transfer activities, but not for Model 2, which excludes them.

Comparisons with previous findings in the literature are complex for many reasons. The most obvious one could be the choice of methods, to which sometimes results can be sensitive, although, as indicated by Ferrier and Lovell (1990), this is closely related to the assumptions made.[10] In this regard, none of the previous contributions to the literature (either for the the Spanish university system or for other contexts) has used the KSW estimator. The differences are actually even more substantive, since we also focus on different concepts of efficiency (cost efficiency), and stretch the sample period to cover some years that have barely been examined previously. We also consider that combining measures of cost efficiency (based on universities' budgets) in times of crisis is particularly informative.

Although our aim was not to explicitly evaluate what determined the efficiency of Spanish universities during the examined period, we can provide some insights on this issue by comparing with related literature such as Salas-Velasco (2020) or Martínez-Campillo and Fernández-Santos (2020), both of which consider a two-stage approach based on Simar and Wilson (2007). Despite the very different choices (methods, periods, efficiency measure,

[10]For a more recent comparison of methods, see Narbón-Perpiñá et al. (2020).

etc.), some results coincide. For instance, Salas-Velasco's (2020) study, which focused on 2008/2009, finds that the universities in the Canary Islands show high inefficiency levels; in our study, extending the analysis to other periods and models, this finding holds is preserved. They also find that the Catalonian universities perform "relatively well", a result that is partly upheld in our Table 6—depending on the year and model considered. However, these findings are not directly comparable, as we report results for the East (*Este*) region, which encompasses Catalonia, the region of Valencia and the Balearic Islands. This would confirm the importance of the regional effect reported in Table 7.

We also find relatively comparable results to those by Martínez-Campillo and Fernández-Santos (2020).[11] Although they focus on an earlier period (ending in 2013) and find that the average efficiency is remarkably high (Spanish public HEIs generated 41.62% fewer outputs than if they had operated on the efficient frontier), they also reveal that public HEIs' inefficiencies decreased during the crisis years, in spite of budgetary restrictions and reductions in university resources. Although our formal tests show that the differences in efficiency levels between the periods 2010–14 and 2015–19 are not significant, this is probably because during 2016 and 2017 most universities were still affected by budget cuts.

6.2. Performance of the provincial university system and its impact

The results of the impact of universities' efficiency on regional economic development are reported in Tables 8 to 12. Compared to previous studies focusing on similar issues, and as indicated in previous sections, we consider that different concepts of efficiency may have disparate effects on different variables related to regional economic activity. Thus, while Table 8 reports estimations for the impact on regional (in our specific case, provincial) GDP per capita, Tables 9 and 10 extend the analysis to variables more closely related to economic activity, namely labour productivity (measured via gross value added per worker) and capital intensity, for the reasons discussed above.

Each table reports the results for the impact of the different types of variables considered in the study. These have been grouped into three main categories, namely those that directly measure the performance of universities through different models ($effglob$, $effres$ and $effkt$), those related to different indicators of government quality (eqi, $qualityp$, $impartialityp$ and $corruptionp$), and a set of controls chosen according to the relevant literature ($ldens$, $shagr$, $shind$, $shbet1664$, $stock\_k\_const\_mkm$ and $lchpc$).

To avoid overlap, the impact of some of these variables is reported in different columns. This is the case for the models of university performance (all of which include teaching) and

[11]We compare our results with some of the most recent studies on the efficiency of Spanish universities, although the topic has been well documented. For other relevant studies, see Berbegal-Mirabent (2018), Berbegal-Mirabent et al. (2013), Agasisti and Pérez-Esparrells (2010), De La Torre et al. (2017), García-Aracil (2013), Giménez and Martínez (2006) and Salas-Velasco (2019), among others.

for the quality of government variables. In the case of the latter, the global effect (European Quality Indicator, *eqi*) is presented separately from its three components, namely, the quality of government pillar (*qualityp*), the impartiality pillar (*impartialityp*), and the corruption pillar (*corruptionp*).

6.2.1. Baseline models

Results confirm that it is indeed important to expand the range of variables that might be influenced by the performance of universities. Specifically, as reported in Table 8, corresponding to the estimation of Equation (7), regardless of how we model what universities do, the impact on GDP per capita (GDP/N) is positive, albeit not significant at the usual levels. This result is robust not only for the different measures of HEI efficiency, but also for the quality of government variables considered—i.e., regardless of whether we include the European Quality Indicator (*eqi*) or its components separately (Charron et al., 2019, 2021). In this case the effects are mixed, since the impartiality component (*impartiality*) of quality of government has a strongly significant effect, but the overall effect (*eqi*) is negative—albeit barely significant (10%). This could indicate not only that the effects of the quality of government on provincial economic performance are intricate, as suggested by Rodríguez-Pose (2013), but also that other indicators could be analysed as well. In addition, we should factor in that quality of government variables are only available at the NUTS2 level (Spanish regions), whereas the rest of the variables are available at the NUTS3 level (Spanish provinces)—on which we focus.

When we extend the analysis to the variables that are more strongly related to regional production processes (GVA/L, K/L), results differ substantially (see Tables 9 and 10). Similarly to Tortosa-Ausina et al. (2005)—who find that convergence across Spanish provinces between 1965 and 1995 was particularly strong for labour productivity, total factor productivity and capital intensity, but considerably less for GDP per capita—we also find dissimilar effects for our set of dependent variables. Specifically, as reported in Table 9 the effect of the performance of universities on productivity is positive and significant, regardless of how we define what universities do. This might be corroborating that the three missions are strongly related, and that performing with more quality in the different dimensions has a pay-off in terms of enhanced regional development (Agasisti et al., 2019, 2020). Only for the efficiency corresponding to the knowledge transfer-teaching model ($effkt$) do we find a slightly less significant impact (5% instead of 1%), and of less magnitude, but it is also positive. Thus, being more efficient at managing knowledge transfer activities does not seem to necessarily translate into higher economic gains for the production processes of the environment—at least compared to the rest of the models. This might be reinforcing some previous findings that question whether there is a trade-off between academic excellence and commercial engagement, suggesting instead that high-quality research can complement industry collaboration (Perkmann et al., 2011; Scandura and Iammarino, 2022).

The results are very similar for capital intensity. As reported in Table 10, the magnitude of the coefficients is similar and the significance holds, regardless of the model considered. Indeed, for the global efficiency model ($effglob$), the magnitude of the coefficients is even slightly higher. This would further corroborate previous findings in the literature, summarised by Perkmann et al. (2013), according to which university-industry relations can enhance academic research and teaching.

The main differences between labour productivity (GVA/L) and capital intensity (K/L), though, are related to the quality of government variables. The effects are also notably different when compared to per capita income (GDP/N), since for both labour productivity and capital intensity we find that the European Quality Indicator (eqi) has a positive effect. However, while for labour productivity it is barely significant (10%), the magnitude is much stronger for capital intensity, both in terms of the magnitude of the coefficient and its significance (1%). In addition, regardless of whether we focus on labour productivity or capital intensity, the impact is positive and significant across models. This varying impact of quality of government on different regional economic activity variables has received less consideration in the literature. Only a few studies such as, for instance, Rodríguez-Pose and Ganau (2022), have explicitly examined how labour productivity and institutional quality are intertwined, finding that skill, innovation and institutional deficiencies in Europe thwarted its regional productivity growth.

Some reasons might be explaining the different impact on per capita income *vis-à-vis* the provincial productive characteristics—as measured by GVA/L and K/L. They could be partly associated with explanations related to the lack of convergence in GDP/N since the end of the 1970s as pointed out by Tortosa-Ausina et al. (2005), including differences in the percentage of dependent population between provinces (due to uneven unemployment and activity rates) that contributed to slowing convergence in per capita income. This slowing down of regional convergence, however, did not affect labour productivity (Tortosa-Ausina et al., 2005), whose converging trend was actually boosted by capital intensity through structural change from agriculture to industry and service sectors, the reduction of the disparities in human capital and public infrastructures, or the opening to trade (De la Fuente, 2002; Martínez-Galarraga et al., 2015; Díez-Minguela et al., 2018).

6.2.2. Spatial effects

Given that our data are province-based, incorporating spatial effects can provide important insights beyond those offered by the baseline (non-spatial) models considered in the preceding sections. Hence, we extend our models to also include spatial effects, considering the spatial autoregressive (SAR) and spatial error (SEM) models—corresponding to Equations (7) and (8), respectively—discussed in Section 4.2. Table 11 extends the baseline results from Tables 9 and 10 by incorporating spatial effects, providing a more precise estimation of the models, since the effects of productivity and capital intensity could generate spillover effects beyond provincial borders, influencing neighbouring provinces.

The results reported in Table 11 present a nuanced picture. For productivity, spatial effects are not statistically significant, suggesting that productivity gains remain largely contained within provincial boundaries. In contrast, capital intensity demonstrates significant spatial effects, indicating that investments in capital generate meaningful spillover effects that extend beyond provincial borders and influence economic outcomes in surrounding areas.

For the spatial autoregressive model (SAR), as noted by (Anselin, 1988; Elhorst, 2014; LeSage and Pace, 2009), the estimated parametres, presented in Table 11 cannot be directly interpreted due to the presence of spatial dependencies. Given these overlapping effects, it is essential to decompose the impact into direct, indirect, and total effects to properly capture the transmission of capital intensity across space. This distinction allows for a more precise assessment of how capital intensity affects not only its own region but also neighbouring provinces through spatial interactions.

These stronger spatial effects for capital intensity could be indicating that policies aimed at improving university performance might be particularly effective at attracting investment at a regional level—not just in each university's home province—thereby contributing to reinforce the country's regional cohesion (Di Caro and Fratesi, 2022). Thus, the results could be supporting the Spanish model of having strong provincial university systems while acknowledging their broader regional impact.

The results reported in Table 12 for the decomposition into direct, indirect and total effects can also be particularly valuable for regional and university policy planning. On the one hand, direct effects show the immediate impact within a province whereas, on the other hand, indirect effects, also known as spillover effects, measures how a change in a variable in one region impacts neighbouring regions through spatial interactions. Hence, if a change occurs in one region, the indirect effect quantifies how this change affects nearby regions. This is due to the spatial dependence embedded in the model, where the value of the dependent variable in one region depends not only on its own characteristics but also on the values in neighbouring regions. The total effects combine both, providing a complete picture of how university efficiency improvements spread through the Spanish provincial system (Golgher and Voss, 2016).

The positive and significant indirect effects of efficiency of universities variables ($effglobp$, $effresp$ and $effktp$) indicate that university efficiency influences capital intensity not only within its own region, but also through spatial spillovers driven by interregional dependencies in capital intensity itself. This result is a direct consequence of the spatial autoregressive structure of the dependent variable, meaning that an increase in efficiency university variables initially affects the capital intensity within the same province and, due to spatial interactions in capital intensity, this effect propagates to neighbouring provinces. This result underscores the importance of considering spatial effects in economic policy, as the benefits of improving university efficiency extend beyond administrative boundaries, influencing capital accumulation across an entire region.

These findings are especially relevant given Spain's quasi-federal structure and the importance of both provincial and regional (autonomous community) governance levels. They could be suggesting that while university performance has its strongest effects locally, there are important inter-provincial linkages that should be considered in educational and economic development planning. These results also highlight the need for coordination between provinces, especially within the same autonomous community, as the benefits of the most efficient universities extend beyond provincial boundaries, regardless of the model considered to measure efficiency. This is particularly relevant for regions with multiple provinces and multiple universities, such as Catalonia, Andalusia or Castilla y León.

6.2.3. Control variables

Regarding the control variables, several patterns emerge consistently across model specifications. These patterns, in general, are in line with the related literature. Population density (*ldens*) shows a negative and significant relationship with both GDP per capita and labour productivity, suggesting that Spanish provinces with higher population concentrations do not necessarily benefit from agglomeration economies. The magnitude of this effect is particularly strong for labour productivity, where a 1% increase in population density is associated with approximately a 0.2% decrease in productivity.

The sectoral composition variables display varying effects across different dependent variables. The share of agricultural employment (*shagr*) has a positive and significant effect on GDP per capita but no significant impact on labour productivity or capital intensity. In contrast, the industrial share (*shind*) does not show a consistently significant effect across specifications, although its coefficient is predominantly negative for labour productivity. The share of working-age population ($shbet1664$) exhibits a strong and consistently negative relationship with all three dependent variables, with particularly large coefficients. This somewhat counterintuitive result might reflect the challenges faced by provinces with larger working-age populations during our sample period (2010–2019), which partly coincides with the end and the aftermath of the Great Recession as, in the case of Spain, it continued until almost 2015. Finally, capital stock per square kilometre (*stock_k_const_mkm*) shows a modest but consistently positive effect across all specifications, while the human capital indicator (*lchpc*) also displays positive and significant coefficients, particularly for GDP per capita models, highlighting the importance of human capital accumulation for regional development.

7. Conclusions

The links between universities and growth have been explored in the literature for some time now. Although it is not on the same scale as research on human capital and growth, several contributions have attempted to shed light on how higher education institutions might affect the economic development of their home regions. This association between university growth and regional growth can derive from various sources, including a greater supply of education (human capital effect), the creation of knowledge (innovation effect), an enhanced support for democratic values (institutional quality effect), and even a demand effect via increased consumption from staff and students at universities. These mechanisms have been explored by, among others Valero and Van Reenen (2019), who provide evidence for a large sample of countries, concluding that there is a sizeable association between university growth and GDP per capita growth, particularly at the regional level.

This and related literature have been also exploring the association between university presence and economic performance, implicitly adopting *the more the better* principle, and from a myriad of perspectives—which include both direct and indirect channels. Whereas the direct approach evaluates how different HEI activities such as, for instance, innovation in the broad sense (Hausman, 2022) or local agglomeration spillovers (Kantor and Whalley, 2014, 2019) affect regional economic development, the indirect channels are more typical of studies evaluating the impact of universities on the performance of the economic actors in their surroundings, which might not only be private firms (Perkmann et al., 2013; Kempton, 2019; Atta-Owusu et al., 2021).

Adopting *the more the better* principle implicitly assumes that HEIs are efficient, i.e., they can all produce the same with comparable levels of inputs. However, this might not necessarily be the case, particularly if we consider that in many countries they are public institutions funded by either national or sub-national levels of government and, therefore, their efficiency and its measurement is an essential issue from a public finance perspective. But inefficiency can also be relevant as a proxy for reputational issues (with inefficient universities facing difficulties in establishing partnerships with local firms and institutions), or because more efficient universities contribute to enhance the performance of their partner firms by generating efficiency spillovers. Accordingly, some studies evaluating the link between universities and economic performance have proposed a two-stage procedure, examining whether the quality of HEIs (measured via efficiency) has an impact on regional economic development.

We argue that this impact might vary depending on how intensively universities perform their three missions. For instance, some policies have encouraged universities to play more active roles in the commercialisation of academic knowledge (Perkmann et al., 2011; Siegel et al., 2003; Bercovitz and Feldman, 2006), implicitly suggesting that the local economic impact might be greater. However, some research also finds that more research-focused institutions, with academics that generate high numbers of publications in peer-reviewed journals also excelling at patenting and academic entrepreneurship (Perkmann et al., 2011). We therefore defined different models to measure universities' efficiency in order to consider their varying intensities in the missions. Our approach is also more comprehensive, since we consider not only the impact on regional GDP, but also on other variables related to the productive structure such as labour productivity and capital intensity, in light of some recent studies (Bellocchi et al., 2023).

We evaluate these issues in the context of the Spanish university system, which is particularly relevant to our analysis for several issues such as the possibility of being *provincialised*, as most public limit their presence to a province only. This implies that it is possible to measure with certain degree of precision the regional and local impact of each university or, at least, what we refer to as the provincial university system.

The results can be explored from multiple perspectives. In the first stage, we measure the efficiency of universities considering different models of what they produce, and providing regional summaries by NUTS1 regions. The universities of some regions are particularly inefficient (other universities can produce more with similar amounts of inputs), and there seems to be an overall trend towards more inefficiency, that could partially be attributed to an easing of the budget constraints faced by universities (Martínez-Campillo and Fernández-Santos, 2020). However, the nonparametric tests reveal that efficiency differences are not significant when the results before and after 2015 are compared. Interestingly the differences were statistically significant when knowledge transfer activities were included in the model. The differences were found at NUTS2 level, implying that universities in some Spanish regions are more dynamic in this particular mission, which has a payoff in terms of efficiency.

The relevance of knowledge transfer-related activities, however, is diluted in the second stage analysis, in which we evaluate the impact of the provincial university systems' efficiency on relevant economic development variables. In this case, regardless of the HEIs' production model considered (global restricted model, research-teaching model, or knowledge transfer-teaching model), the impact is positive. Significance, though, is restricted to the variables that are more strongly related to the province's productive structure, however, namely labour productivity and capital intensity, whereas per capita income is not significant for any of the different models specified. As part of the set of covariates, we also include those which directly reflect the regional institutional quality since part of the efficiency of universities might be capturing this effect. Again, the effect is only positive and significant for labour productivity (Ganau and Rodríguez-Pose, 2019) and capital intensity, but not for per capita income.

These extensive results imply that, although universities play a complex and multifaceted role in regional development via teaching, research and knowledge transfer (also referred to as community services), not all of them perform them efficiently and, in addition, there are also relevant differences depending on which activity we focus on. However, regardless of the activity examined, more efficient universities have a positive and significant impact on their regional and local communities. Although some universities' performance was penalised when knowledge transfer activities were included, the positive effect of universities' performance is robust across models. This might suggest that even in the cases where in which national/international research engagement could be prioritised over a regional focus (Goddard and Chatterton, 1999; Goddard et al., 2012; Chatterton and Goddard, 2000), being more efficient has a strong economic impact in their home regions.

This complementarity between different university missions suggests that policies aimed at improving overall institutional efficiency, rather than focusing exclusively on knowledge transfer activities, may be more effective at fostering regional economic development. The robustness of our results across different efficiency models indicates that universities' contributions to their regions' productive processes operate through multiple channels simultaneously. This has important implications for both university governance and regional development policies, as it suggests that maintaining balanced excellence across teaching, research and knowledge transfer activities may be more beneficial than excessive specialisation in any single mission.

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Table 1: Descriptive statistics, Spanish university system. Number of public universities present in each province

Region (*comunidad autónoma*) (NUTS2)	Province (NUTS3)	Number of public universities present in the province
Andalusia	Almería	1
	Cádiz	1
	Córdoba	1
	Granada	1
	Huelva	1
	Jaén	1
	Málaga	1
	Sevilla	2
Aragon	Huesca	1
	Teruel	1
	Zaragoza	1
Asturias	Asturias	1
Balearic Islands	Illes Balears (Les)	1
Canary Islands	Las Palmas	2
	Santa Cruz de Tenerife	1
Castilla - La Mancha	Albacete	1
	Ciudad Real	1
	Cuenca	1
	Guadalajara	1
	Toledo	1
Castilla y León	Ávila	1
	Burgos	1
	León	1
	Palencia	1
	Salamanca	1
	Segovia	1
	Soria	1
	Valladolid	1
	Zamora	1
Cantabria	Cantabria	1
Catalonia	Barcelona	4
	Girona	1
	Lleida	1
	Tarragona	1
Comunitat Valenciana	Alacant	3
	Castelló	2
	València	2
Extremadura	Badajoz	1
	Cáceres	1
Galicia	A Coruña	2
	Lugo	1
	Ourense	1
	Pontevedra	1
Madrid	Madrid	6
Murcia	Murcia	2
Navarra	Navarra	1
Basque Country	Álava	1
	Guipúzcoa	1
	Vizcaya	1
La Rioja	La Rioja	1
TOTAL		
17	50	47

Table 2: Descriptive statistics, Spanish university system. Number of provinces in which a given public university is present

Region (*comunidad autónoma*) (NUTS2)	Public university	Number of provinces in which the university is present
Galicia	A Coruña (Universidade da Coruña, UDC)	1
Castilla-La Mancha	Alcalá (Universidad de Alcalá, UAH)	2
Comunitat Valenciana	Alacant (Universitat d'Alacant, UA)	1
Andalucía	Almería (Universidad de Almería, UAL)	1
Catalonia	Autònoma de Barcelona (Universitat Autònoma de Barcelona, UAB)	1
Madrid	Autonòma de Madrid (Universidad Autónoma de Madrid, UAM)	1
Catalonia	Barcelona (Universitat de Barcelona, UB)	1
Castilla y León	Burgos (Universidad de Burgos, UBU)	1
Andalusia	Cádiz (Universidad de Cádiz, UCA)	1
Cantabria	Cantabria (Universidad de Cantabria, UNICAN)	1
Madrid	Carlos III de Madrid (Universidad Carlos III, UC3M)	1
Castilla-La Mancha	Castilla-La Mancha (Universidad de Castilla-La Mancha, UCLM)	4
Madrid	Complutense de Madrid (Universidad Complutense de Madrid, UCM)	1
Andalusia	Córdoba (Universidad de Córdoba, UCO)	1
Extremadura	Extremadura (Universidad de Extremadura, UNEX)	2
Catalonia	Girona (Universitat de Girona, UDG)	1
Ceuta	Granada (Universidad de Granada, UGR)	3
Andalusia	Huelva (Universidad de Huelva, UHU)	1
Balears (Illes)	Illes Balears (Universitat de les Illes Balears, UIB)	1
Andalusia	Jaén (Universidad de Jaén, UJAEN)	1
Comunitat Valenciana	Jaume I de Castelló (Universitat Jaume I, UJI)	1
Canary Islands	La Laguna (Universidad de La Laguna, ULL)	2
La Rioja	La Rioja (Universidad de la Rioja, UNIRIOJA)	1
Canary Islands	Las Palmas de Gran Canaria (Universidad de Las Palmas de Gran Canarias, ULPGC)	1
Castilla y León	León (Universidad de León, UDL)	1
Catalonia	Lleida (Universitat de Lleida, UDL)	1
Andalusia	Málaga (Universidad de Málaga, UMA)	1
Comunitat Valenciana	Miguel Hernández de Elche (Universidad Miguel Hernández, UMH)	1
Murcia	Murcia (Universidad de Murcia, UM)	1
Asturias	Oviedo (Universidad de Oviedo, UNIOVI)	1
Andalusia	Pablo de Olavide (Universidad Pablo de Olavide, UPO)	1
Basque Country	País Vasco (Euskal Herriko Unibertsitatea, EHU)	3
Murcia	Politécnica de Cartagena (Universidad Politécnica de Cartagena, UPCT)	1
Catalonia	Politécnica de Catalunya (Universitat Politécnica de Catalunya, UPC)	1
Madrid	Politécnica de Madrid (Universidad Politécnica de Madrid, UPM)	1
Comunitat Valenciana	Politécnica de Valencia (Universitat Politécnica de València, UPV)	2
Catalonia	Pompeu Fabra (Universitat Pompeu Fabra, UPF)	1
Navarre	Pública de Navarra (Universidad Pública de Navarra, UPNA)	1
Madrid	Rey Juan Carlos (Universidad Rey Juan Carlos, URJC)	1
Catalonia	Rovira i Virgili (Universitat Rovira i Virgili, URV)	1
Castilla y León	Salamanca (Universidad de Salamanca, USAL)	3
Galicia	Santiago de Compostela (Universidade de Santiago de Compostela, USC)	2
Andalusia	Sevilla (Universidad de Sevilla, US)	1
Comunitat Valenciana	València (Universitat de València, UV)	2
Castilla y León	Valladolid (Universidad de Valladolid, UVA)	4
Galicia	Vigo (Universidade de Vigo, UVIGO)	2
Aragon	Zaragoza (Universidad de Zaragoza, UNIZAR)	3

Table 3: Descriptive statistics, universities inputs and outputs (2010 and 2019)

	Variable name	Variable	Mean		Median		Std.dev.	
			2010	2019	2010	2019	2010	2019
INPUTS								
	TC	Total costs (budget)[a]	206,934,122.57	200,929,420.60	157,264,172	164,739,270.39	131,770,550.24	120,448,311.29
OUTPUTS								
Research	yR_1	# of competitive grants (projects)	59.60	54.38	46	39	42.74	40.19
	yR_2	# of publications	989.62	1,685	711	1,257	811.42	1,306.08
	yR_3	# of citations	29,122.40	7,289.43	19,560	5,394	27,291.26	6,550.11
	yR_4	# research scholarships	29.87	26.30	22	18	27.78	23.53
Knowledge transfer	yKT_1	# R&D contracts	42,969.09	111,689.70	5,775	3,625	164,909.55	251,021.21
	yKT_2	# patents	16.49	11.51	11	9	16.79	10.09
	yKT_3	# spin-offs	2.60	1.62	1	1	3.21	2.18
Teaching	yT_1	# graduates (bachelor)	3,211.34	3,027.70	2,713	2,544	1,992.14	1,861.22
	yT_2	# postgraduates (master)	726.47	1,331.30	654	1,050	507.06	889.64
	yT_3	# postgraduates (PhD)	170.17	187.66	126	138	147.70	164.26

[a] Euros.

Table 4: Description of the variables

Typology	Variable	Definition	Units
Dependent variables	GDP per capita (GDP/N)	GDP per capita in constant terms (in logs)	Euros (2015)
	Labour productivity (GVA/L)	Gross Value Added (GVA) per worker (in logs)	Euros (2015)
	Capital intensity (K/L)	Net capital stock per worker (in logs)	Euros (2015)
Efficiency variables	$effglob$	Global restricted model	
	$effres$	Research-teaching model	
	$effkt$	Knowledge transfer-teaching model	
Quality of government	eqi	European Quality of Government Index (EQI index)	
	$qualityp$	European Quality of Government Index - Quality pillar	
	$impartialityp$	European Quality of Government Index - Impartiality pillar	
	$corruptionp$	European Quality of Government Index - Corruption pillar	
Control variables	$shagr$	(Employment in the agricultural sector)/(Total employment)	Share
	$shind$	(Employment in industrial sector)/(Total employment)	Share
	$shpob1664$	(Population between 16 and 64 years)/(Total population)	Share
	$ldens$	Population density (in logs)	(Total population)/km^2
	ID_const	Gross Investment in Research and Development (R+D) (in logs)	Thousands of euros (2015)

Table 5: Summary statistics

Variable	# of obs.	Mean	Std. dev.	Min	Max
GDP/N	500	21,917.930	4,632.215	14,688.960	37,581.310
GVA/L	500	52,195.160	7,227.911	36,472.320	82,407.280
K/L	500	217,831.900	30,436.550	134,314.600	323,824.700
$effglob$	500	1.138	0.141	1.000	1.895
$effresp$	500	1.173	0.153	1.000	1.861
$effktp$	500	1.168	0.190	1.000	1.957
eqi	500	−0.034	0.324	−0.650	0.860
$qualityp$	500	0.030	0.391	−0.800	1.155
$impartialityp$	500	−0.215	0.456	−0.730	0.990
$corruptionp$	500	−0.103	0.312	−0.735	0.610
$ldens$	500	4.232	1.124	2.151	6.721
$shagr$	500	0.070	0.051	0.001	0.292
$shind$	500	0.150	0.057	0.038	0.311
$shbet1664$	500	0.649	0.023	0.580	0.714
$stock\_k\_const\_mkm$	500	10.792	15.308	0.834	87.440
$lchpc$	500	12.555	0.152	12.354	13.057
ID_const	500	285,068.900	596,976.100	6,623.269	3,987,180.000

Table 6: Performance of universities, KSW estimator, selected years

Global restricted model (M1)													
NUTS1 region		NUTS2 regions [a]	Number of public universities	2010			2015			2019			
Name	Code			Mean	Median	Std.dev.	Mean	Median	Std.dev.	Mean	Median	Std.dev.	
Northwest	ES1	ES11, ES12, ES13	5	1.1974	1.1645	0.0574	1.3081	1.1701	0.2229	1.3615	1.3911	0.1497	
Northeast	ES2	ES21, ES22, ES23, ES24	4	1.2340	1.2333	0.1168	1.3025	1.4022	0.2017	1.2915	1.2685	0.1452	
Madrid	ES3	ES30	6	1.2622	1.2576	0.0757	1.1635	1.1667	0.0542	1.2342	1.1841	0.0975	
Centre	ES4	ES41, ES42, ES43	6	1.1214	1.1034	0.0460	1.3540	1.3290	0.2137	1.3810	1.3714	0.1304	
East	ES5	ES51, ES52, ES53	13	1.2122	1.2009	0.0976	1.1636	1.1458	0.0524	1.2183	1.2029	0.0819	
South	ES6	ES61, ES62	10	1.1674	1.1487	0.1127	1.2729	1.3134	0.1275	1.3401	1.2988	0.1829	
Canary Islands	ES7	ES70	2	1.6125	1.6125	0.4280	1.7624	1.7624	0.4272	1.5781	1.5781	0.1961	

Research-teaching model (M2)												
NUTS1 region		NUTS2 regions[a]	Number of public universities	2010			2015			2019		
Name	Code			Mean	Median	Std.dev.	Mean	Median	Std.dev.	Mean	Median	Std.dev.
Northwest	ES1	ES11, ES12, ES13	5	1.1692	1.1621	0.0570	1.3295	1.2557	0.1352	1.4160	1.4375	0.1783
Northeast	ES2	ES21, ES22, ES23, ES24	4	1.3224	1.2261	0.1107	1.3005	1.3825	0.2023	1.3927	1.2785	0.1707
Madrid	ES3	ES30	6	1.3640	1.2670	0.2256	1.2830	1.2189	0.1385	1.2541	1.2531	0.0704
Centre	ES4	ES41, ES42, ES43	6	1.1142	1.1033	0.0345	1.3246	1.2115	0.2823	1.3816	1.3823	0.2229
East	ES5	ES51, ES52, ES53	13	1.2768	1.2148	0.1885	1.2493	1.2171	0.1622	1.2960	1.2104	0.1977
South	ES6	ES61, ES62	10	1.1850	1.1573	0.0706	1.3163	1.1859	0.2638	1.2879	1.2318	0.1638
Canary Islands	ES7	ES70	2	1.6100	1.6100	0.4918	1.6711	1.6711	0.3943	1.5496	1.5496	0.2410

Knowledge transfer-teaching model (M3)												
NUTS1 region		NUTS2 regions [a]	Number of public universities	2010			2015			2019		
Name	Code			Mean	Median	Std.dev.	Mean	Median	Std.dev.	Mean	Median	Std.dev.
Northwest	ES1	ES11, ES12, ES13	5	1.2705	1.2581	0.0594	1.3351	1.2687	0.1892	1.5529	1.5794	0.2116
Northeast	ES2	ES21, ES22, ES23, ES24	4	1.4461	1.2672	0.1428	1.2705	1.3356	0.1846	1.6155	1.3446	0.2299
Madrid	ES3	ES30	6	1.3445	1.3172	0.1447	1.2460	1.2143	0.1001	1.2681	1.2699	0.0757
Centre	ES4	ES41, ES42, ES43	6	1.1407	1.1380	0.0412	1.3694	1.3271	0.2074	1.3111	1.2911	0.0862
East	ES5	ES51, ES52, ES53	13	1.4066	1.3791	0.1591	1.4546	1.2738	0.3240	1.2744	1.2594	0.1330
South	ES6	ES61, ES62	10	1.1854	1.1684	0.0558	1.3711	1.2958	0.2606	1.4366	1.2934	0.4246
Canary Islands	ES7	ES70	2	1.6694	1.6694	0.3530	1.6932	1.6932	0.2743	1.8055	1.8055	0.0888

[a] ES1: Galicia (ES11), Asturias (ES12), Cantabria (ES13); ES2: Basque Country (ES21), Navarre (ES22), La Rioja (ES23), Aragon (ES24); ES3: Comunidad de Madrid (ES30); ES4: Castilla-León (ES41), Castilla-La Mancha (ES42), Extremadura (ES43); ES5: Catalonia (ES51), Comunitat Valenciana (ES52), Balearic Islands (ES53); ES6: Andalusia (ES61), Murcia (ES62); ES7: Canary Islands (ES70).

Table 7: Distribution hypothesis tests for the performance of universities over time (2010/14 vs 2015/19) and across space (unconditioned vs geographically conditioned, NUTS2)[a]

Hypothesis tests: 2010/14 vs 2015/19		
Hypothesis:	T-statistic	p-value
$f(\text{Global restricted model}_{2010-2014}) = g(\text{Global restricted model}_{2015-2019})$	0.8011	0.2115
$f(\text{Research-teaching model}_{2010-2014}) = g(\text{Research-teaching model}_{2015-2019})$	0.7893	0.2150
$f(\text{Knowledge transfer-teaching model}_{2010-2014}) = g(\text{Knowledge transfer-teaching model}_{2015-2019})$	0.4422	0.3292
Hypothesis tests: unconditioned vs geographically conditioned (NUTS2)		
Hypothesis tests:	T-statistic	p-value
$f(\text{Global restricted model}_{\text{unconditioned}}) = g(\text{Global restricted model}_{\text{NUTS2 conditioned}})$	8.3377	0.0000
$f(\text{Research-teaching model}_{\text{unconditioned}}) = g(\text{Research-teaching model}_{\text{NUTS2 conditioned}})$	–0.1448	0.5576
$f(\text{Knowledge transfer-teaching model}_{\text{unconditioned}}) = g(\text{Knowledge transfer-teaching model}_{\text{NUTS2 conditioned}})$	3.5717	0.0002

[a] Notes: the functions f and g are (kernel) distribution functions for the efficiency scores in each respective university performance model. For time tests, scores are compared between periods 2010–14 and 2015–19. For geographical comparisons, scores with NUTS2 conditioning (divided by the average efficiency of the university's home region) are compared against unconditioned scores. The null hypothesis is that both compared distributions are equal. A statistically significant p-value indicates the distributions are different, with the T-statistic showing the direction and magnitude of the difference.

Table 8: Impact of university performance on regional economic development, baseline model, GDP per capita (GDP/N)[a]

Type of variable	Variable	Dependent variable: GDP/N					
		MODEL 1A	MODEL 1B	MODEL 2A	MODEL 2B	MODEL 3A	MODEL 3B
Efficiency of universities variables	$effglob$	0.00979	0.00973				
		(0.01174)	(0.01157)				
	$effres$			0.01432	0.01152		
				(0.01073)	(0.01065)		
	$effkt$					0.00335	0.00518
						(0.00865)	(0.00851)
Quality of government variables	eqi	−0.01291*		−0.01283*		−0.01280*	
		(0.00732)		(0.00731)		(0.00733)	
	$qualityp$		−0.00954		−0.00981		−0.00906
			(0.00742)		(0.00743)		(0.00740)
	$impartialityp$		0.07323***		0.07183***		0.07417***
			(0.01823)		(0.01829)		(0.01826)
	$corruptionp$		−0.01382		−0.01312		-0.01424
			(0.01035)		(0.01039)		(0.01033)
Controls	$ldens$	−0.21482**	−0.19810**	−0.20021**	−0.18988**	-0.22093**	−0.20041**
		(0.09169)	(0.09368)	(0.09265)	(0.09433)	(0.09143)	(0.09368)
	$shagr$	0.21037**	0.20988**	0.20663**	0.20533**	0.20674**	0.20724**
		(0.09462)	(0.09385)	(0.09437)	(0.09371)	(0.09456)	(0.09381)
	$shind$	−0.09727	−0.1087	−0.1018	−0.11195	−0.09305	−0.10347
		(0.10213)	(0.10061)	(0.10209)	(0.10065)	(0.10231)	(0.10073)
	$shbet1664$	−0.67816***	−0.73486***	−0.66450***	−0.72260***	−0.67607***	−0.73305***
		(0.21781)	(0.21463)	(0.21765)	(0.21461)	(0.21794)	(0.21469)
	$stock\_k\_const\_mkm$	0.00304	0.00333*	0.00304	0.00338*	0.00309	0.00334*
		(0.00188)	(0.00201)	(0.00188)	(0.00201)	(0.00188)	(0.00201)
	$lchpc$	0.05445	0.07239**	0.05598*	0.07271**	0.05271	0.07169**
		(0.03346)	(0.03311)	(0.03339)	(0.03304)	(0.03348)	(0.03316)
	$Constant$	10.66308***	10.40814***	10.56869***	10.35944***	10.71589***	10.43005***
		(0.59046)	(0.59551)	(0.59612)	(0.59947)	(0.58844)	(0.59574)
# Observations		500	500	500	500	500	500
R^2		0.82482	0.83171	0.82526	0.83189	0.8246	0.83158

[a] This table presents regression results examining the impact of university efficiency on provincial GDP per capita (GDP/N) in Spain during the period 2010–2019. The models reflect different specifications of university efficiency and quality of government measures. Models 1A and 1B use the global restricted efficiency measure, Models 2A and 2B use the research-teaching efficiency measure, and Models 3A and 3B use the knowledge transfer-teaching efficiency measure. For each pair, the 'A' variant includes the aggregate European Quality of Government Index (EQI), while the 'B' variant decomposes it into its three components (quality, impartiality, and corruption). All continuous variables are in logarithms. Standard errors are reported in parentheses below the coefficients. Statistical significance is indicated by asterisks: $***p < 0.01$, $**p < 0.05$, $*p < 0.10$.

Table 9: Impact of university performance on regional economic development, labour productivity (GVA/L)[a]

Type of variable	Variable	Dependent variable: GVA/L					
		MODEL 1A	MODEL 1B	MODEL 2A	MODEL 2B	MODEL 3A	MODEL 3B
Efficiency of universities variables	$effglobp$	0.03632**	0.03555**				
		(0.01553)	(0.01560)				
	$effresp$			0.05187***	0.05054***		
				(0.01409)	(0.01424)		
	$effktp$					0.02384**	0.02486**
						(0.01145)	(0.01147)
Quality of government variables	eqi	0.01635*		0.01665*		0.01701*	
		(0.00968)		(0.00960)		(0.00970)	
	$qualityp$		0.00898		0.00746		0.01074
			(0.01000)		(0.00993)		(0.00998)
	$impartialityp$		0.03616		0.02975		0.04029
			(0.02458)		(0.02447)		(0.02462)
	$corruptionp$		0.00225		0.00574		0.00089
			(0.01395)		(0.01389)		(0.01393)
Controls	$ldens$	-0.0019	0.04581	0.0502	0.08717	−0.01427	0.04304
		(0.12133)	(0.12630)	(0.12163)	(0.12617)	(0.12106)	(0.12631)
	$shagr$	0.16282	0.16436	0.14891	0.14692	0.15159	0.15563
		(0.12520)	(0.12652)	(0.12388)	(0.12535)	(0.12520)	(0.12648)
	$shind$	−0.07939	−0.1036	−0.09561	−0.11953	−0.05646	−0.08113
		(0.13513)	(0.13564)	(0.13402)	(0.13463)	(0.13547)	(0.13582)
	$shbet1664$	−2.28326***	−2.30995***	−2.23350***	−2.25895***	−2.27919***	−2.30559***
		(0.28821)	(0.28935)	(0.28573)	(0.28705)	(0.28856)	(0.28948)
	$stock\_k\_const\_mkm$	0.00488*	0.00451*	0.00490**	0.00475*	0.00511**	0.00457*
		(0.00249)	(0.00271)	(0.00247)	(0.00269)	(0.00249)	(0.00271)
	$lchpc$	0.12052***	0.12675***	0.12579***	0.13048***	0.11924***	0.12703***
		(0.04428)	(0.04464)	(0.04383)	(0.04419)	(0.04434)	(0.04471)
	$Constant$	10.75154***	10.49999***	10.41727***	10.22834***	10.82653***	10.51424***
		(0.78129)	(0.80282)	(0.78258)	(0.80181)	(0.77913)	(0.80328)
# Observations		500	500	500	500	500	500
R^2		0.40644	0.40809	0.41718	0.41795	0.4049	0.40741

[a] This table reports regression results examining the impact of university efficiency on provincial labor productivity (GVA/L) in Spain during the period 2010–2019. Models labeled 1A through 3B represent different specifications of university performance measures. Models 1A–1B use the global restricted efficiency measure, Models 2A–2B use the research-teaching efficiency measure, and Models 3A–3B use the knowledge transfer-teaching efficiency measure. For each pair, the 'A' specification includes the composite European Quality of Government Index (EQI), while the 'B' specification breaks it down into its three constituent pillars (quality, impartiality, and corruption). All continuous variables are expressed in logarithms except for share variables. Standard errors are reported in parentheses below the coefficients. Statistical significance is denoted as: $***p < 0.01$, $**p < 0.05$, $*p < 0.10$.

Table 10: Impact of university performance on regional economic development, capital intensity (K/L)[a]

Type of variable	Variable	Dependent variable: K/L MODEL 1A	MODEL 1B	MODEL 2A	MODEL 2B	MODEL 3A	MODEL 3B
Efficiency of universities variables	$effglobp$	0.05146***	0.05013***				
		(0.01675)	(0.01683)				
	$effresp$			0.05505***	0.05659***		
				(0.01530)	(0.01542)		
	$effktp$					0.03163**	0.03084**
						(0.01239)	(0.012429
Quality of government variables	eqi	0.05158***		0.05197***		0.05252***	
		(0.01044)		(0.01039)		(0.01047)	
	$qualityp$		0.03076***		0.03003***		0.03326***
			(0.01005)		(0.01000)		(0.01005)
	$impartialityp$		-0.04539*		-0.05175*		-0.04031
			(0.02664)		(0.02659)		(0.02675)
	$corruptionp$		0.02866**		0.03144**		0.02664*
			(0.01440)		(0.01438)		(0.01442)
Controls	$ldens$	−0.34776***	−0.30622**	−0.30529**	−0.26375**	−0.35861***	−0.31121**
		(0.12111)	(0.12216)	(0.12216)	(0.12285)	(0.12135)	(0.12260)
	$shagr$	−0.31877**	−0.31433**	−0.33972**	−0.33783**	−0.33639**	−0.32746**
		(0.13459)	(0.13646)	(0.13384)	(0.13563)	(0.13484)	(0.13676)
	$shind$	0.10911	0.0819	0.09332	0.06523	0.14046	0.1119
		(0.14584)	(0.14651)	(0.14541)	(0.14590)	(0.14651)	(0.14708)
	$shbet1664$	−2.30760***	−2.24466***	−2.26605***	−2.19858***	−2.29404***	−2.22824***
		(0.32073)	(0.32326)	(0.31953)	(0.32159)	(0.32177)	(0.32419)
	$lIDconst$	0.05089***	0.05120***	0.04943***	0.05003***	0.05241***	0.05228***
		(0.01051)	(0.01061)	(0.01048)	(0.01056)	(0.01055)	(0.01065)
	$lchpc$	0.07527	0.05944	0.07668	0.06039	0.07232	0.05766
		(0.04779)	(0.04819)	(0.04756)	(0.04786)	(0.04795)	(0.04839)
	$Constant$	13.25917***	13.23750***	13.06127***	13.03406***	13.32469***	13.26899***
		(0.88960)	(0.89737)	(0.89234)	(0.89786)	(0.89309)	(0.90254)
# Observations		500	500	500	500	500	500
R^2		0.61132	0.61246	0.61438	0.61647	0.60874	0.61006

[a] This table presents regression results examining the impact of university efficiency on provincial capital intensity (K/L) in Spain during the period 2010–2019. The models follow an identical structure to examine how different aspects of university performance affect capital-labour ratios. Models 1A–1B employ the global restricted efficiency measure, Models 2A–2B use the research-teaching efficiency measure, and Models 3A–3B use the knowledge transfer-teaching efficiency measure. For each pair, specification 'A' includes the aggregate European Quality of Government Index (EQI), while specification 'B' decomposes it into its three components (quality, impartiality and corruption). The model differs from Tables 8 and 9 by including R&D investment as an additional control, given its particular relevance for capital accumulation. All continuous variables are in logarithms except for share variables. Standard errors are reported in parentheses below the coefficients. Statistical significance is indicated as: $***p < 0.01$, $**p < 0.05$, $*p < 0.10$.

Table 11: Impact of university performance on regional economic development, spatial effects[a]

Type of variable	Variable	MODEL 1A SAR	MODEL 1A SEM	MODEL 1B SAR	MODEL 1B SEM	MODEL 2A SAR	MODEL 2A SEM	MODEL 2B SAR	MODEL 2B SEM	MODEL 3A SAR	MODEL 3A SEM	MODEL 3B SAR	MODEL 3B SEM
Dependent variable: GVA/L													
Spatial effects	*lvab_ocup*	0.06801		0.07258		0.05229		0.05719		0.06737		0.07126	
		(0.06767)		(0.06746)		(0.06775)		(0.06758)		(0.06776)		(0.06754)	
	e.lvab_ocup		0.0438		0.04012		0.01652		0.01365		0.04191		0.03837
			(0.07606)		(0.07644)		(0.07732)		(0.07789)		(0.07616)		(0.07645)
Efficiency of universities variables	*effglobp*	0.03563**	0.03589**	0.03483**	0.03513**								
		(0.01522)	(0.01532)	(0.01525)	(0.01534)								
	effresp					0.05086***	0.05155***	0.04941***	0.05026***				
						(0.01387)	(0.01393)	(0.01399)	(0.01405)				
	effktp									0.02323**	0.02339**	0.02421**	0.02448**
										(0.01123)	(0.01130)	(0.01123)	(0.01130)
Quality of government variables	*eqi*	0.01521	0.01683*			0.01576*	0.01682*			0.01586*	0.01748*		
		(0.00955)	(0.00975)			(0.00947)	(0.00953)			(0.00957)	(0.00976)		
	qualityp			0.00838	0.00941			0.00704	0.00765			0.01012	0.01115
				(0.00979)	(0.00997)			(0.00972)	(0.00983)			(0.00977)	(0.00994)
	impartialityp			0.03638	0.03576			0.03007	0.02964			0.04041*	0.03998
				(0.02401)	(0.02428)			(0.02392)	(0.02403)			(0.02406)	(0.02432)
	corruptionp			0.00156	0.0023			0.00511	0.0057			0.00024	0.00095
				(0.01364)	(0.01390)			(0.01360)	(0.01368)			(0.01363)	(0.01387)
Dependent variable: K/L													
Spatial effects	*lstock_k_const_L*	0.24622***		0.24049***		0.23313***		0.22579***		0.25028***		0.24359***	
		(0.05820)		(0.05870)		(0.05849)		(0.05899)		(0.05824)		(0.05876)	
	e.lstock_k_const_L		0.28514***		0.30970***		0.27285***		0.29849***		0.29434***		0.31593***
			(0.06930)		(0.06947)		(0.07001)		(0.07034)		(0.06920)		(0.06923)
Efficiency of universities variables	*effglobp*	0.05080***	0.04687***	0.04984***	0.04482***								
		(0.01602)	(0.01648)	(0.01608)	(0.01646)								
	effresp					0.05059***	0.04826***	0.05219***	0.04903***				
						(0.01472)	(0.01521)	(0.01482)	(0.01519)				
	effktp									0.03249***	0.02994**	0.03169***	0.02823**
										(0.01184)	(0.01211)	(0.01186)	(0.01209)
Quality of government variables	*eqi*	0.04163***	0.05101***			0.04254***	0.05155***			0.04243***	0.05210***		
		(0.01025)	(0.01164)			(0.01024)	(0.01154)			(0.01028)	(0.01171)		
	qualityp			0.02410**	0.03588***			0.02401**	0.03592***			0.02650***	0.03814***
				(0.00974)	(0.01076)			(0.00971)	(0.01070)			(0.00973)	(0.01076)
	impartialityp			-0.04118	-0.05514**			-0.04717*	-0.06027**			-0.03596	-0.04946*
				(0.02548)	(0.02723)			(0.02551)	(0.02716)			(0.02557)	(0.02736)
	corruptionp			0.02293*	0.02131			0.02564*	0.02312			0.02087	0.01967
				(0.01383)	(0.01573)			(0.01386)	(0.01567)			(0.01384)	(0.01577)
Observations		500											
Number of groups		50											

[a] This table reports spatial regression results examining how university efficiency affects both labor productivity (GVA/L) and capital intensity (K/L) in Spanish provinces during the period 2010–2019, explicitly accounting for geographical spillover effects. For each dependent variable, results are presented for both Spatial Autoregressive (SAR) and Spatial Error Model (SEM) specifications. Models 1A–1B use the global restricted efficiency measure, Models 2A–2B use the research-teaching efficiency measure, and Models 3A–3B use the knowledge transfer-teaching efficiency measure. For each pair, specification 'A' includes the aggregate European Quality of Government Index (EQI), while specification 'B' uses its three components (quality, impartiality, corruption). The spatial parameters ρ (in SAR models) and λ (in SEM models) measure the strength of spatial dependence. For GVA/L models, *lvab_ocup* and *e.lvab_ocup* represent the spatially lagged dependent variable and its error term, respectively. For K/L models, *lstock_k_const_L* and *e.lstock_k_const_L* serve the same purpose. Control variables are identical to those in Tables 9 and 10. All continuous variables are in logarithms except for share variables. Standard errors are reported in parentheses. Statistical significance is indicated as: $***p < 0.01$, $**p < 0.05$, $*p < 0.10$.

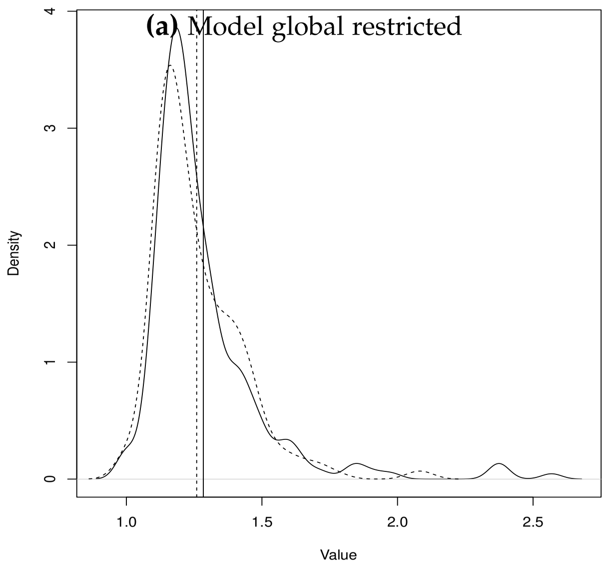
Table 12: Impact of university performance on regional economic development, capital intensity (K/L), direct, indirect, and total spatial effects[a]

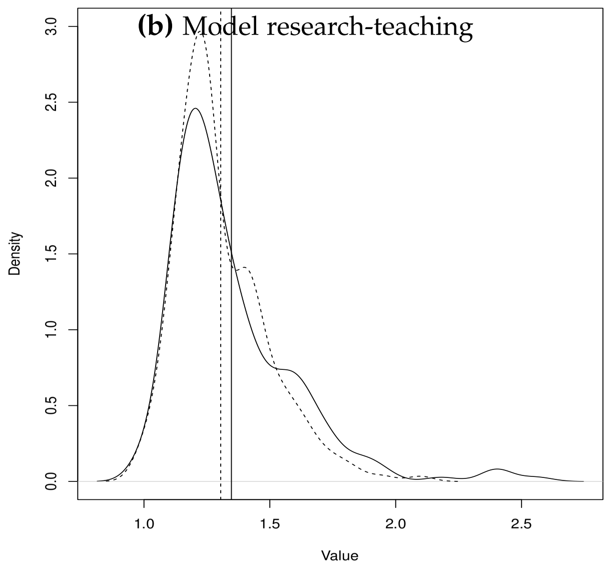
		MODEL 1A	MODEL 1B	MODEL 2A	MODEL 2B	MODEL 3A	MODEL 3B
				Direct			
Efficiency of universities variables	$effglob$	0.0515***	0.0505***				
	$effres$			0.0512***	0.0528***		
	$effkt$					0.0329***	0.0321***
Quality of government variables	eqi	0.0422***		0.0430***		0.0430***	
	$qualityp$		0.0244**		0.0242**		0.0268***
	$impartialityp$		−0.0417		−0.0477*		−0.0364
	$corruptionp$		0.0232*		0.0259*		0.0211
				Indirect			
Efficiency of universities variables	$effglobp$	0.0149**	0.0142**				
	$effresp$			0.0138**	0.0137**		
	$effktp$					0.0097**	0.0091**
Quality of government variables	eqi	0.0122***		0.0116***		0.0127***	
	$qualityp$		0.0068**		0.0063**		0.0077**
	$impartialityp$		−0.0117		−0.0124*		−0.0104
	$corruptionp$		0.0065		0.0067*		0.0060
				Total			
Efficiency of universities variables	$effglobp$	0.0664***	0.0647***				
	$effresp$			0.0650***	0.0665***		
	$effktp$					0.0427***	0.0413***
Quality of government variables	eqi	0.0544***		0.0547***		0.0557***	
	$qualityp$		0.0313**		0.0306**		0.0345***
	$impartialityp$		−0.0534*		−0.0601*		-0.0468
	$corruptionp$		0.0297*		0.0327*		0.0272

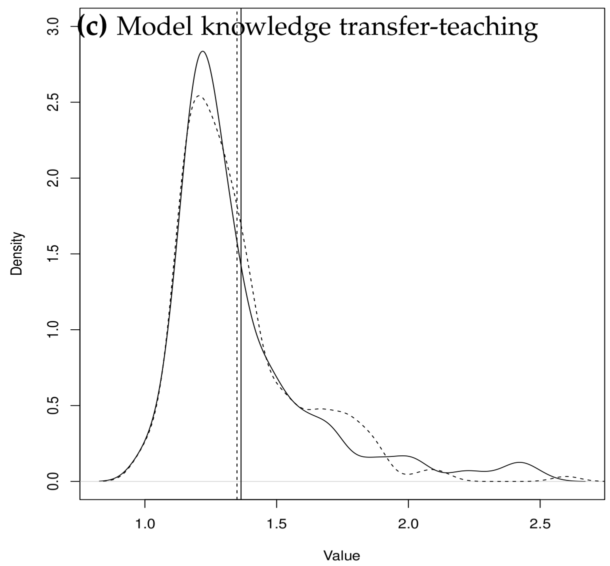
[a] This table reports the spatial decomposition of the effects of university efficiency and other variables on capital intensity (K/L) across Spanish provinces during the period 2010–2019. The models (1A through 3B) correspond to different specifications of university efficiency: global restricted model, research-teaching model and knowledge transfer-teaching model. For each model, the effects are decomposed into three components: (i) Direct effects measure the impact of changes in variables within a province on that same province's capital intensity; (ii) Indirect effects (spatial spillovers) capture how changes in one province affect capital intensity in neighbouring provinces; and (iii) Total effects combine both direct and indirect impacts. All models include controls for local characteristics (population density, sectoral composition, human capital) and quality of government indicators. Standard errors are not reported for brevity but significance levels are indicated by asterisks: *** p<0.01, ** p<0.05, * p<0.10. The spatial effects are calculated using a first-order contiguity weight matrix that defines neighbouring provinces based on shared borders. All continuous variables are in logarithms to facilitate elasticity interpretation.

Figure 1: Performance of universities, densities, 2010–14 vs 2015–19

These figures contain densities estimated using kernel smoothing methods for all three models (global restricted, research-teaching and knowledge transfer-teaching). All densities were estimated using Gaussian kernel, and plug-in methods were chosen to select the bandwidth (see Li and Racine, 2007).



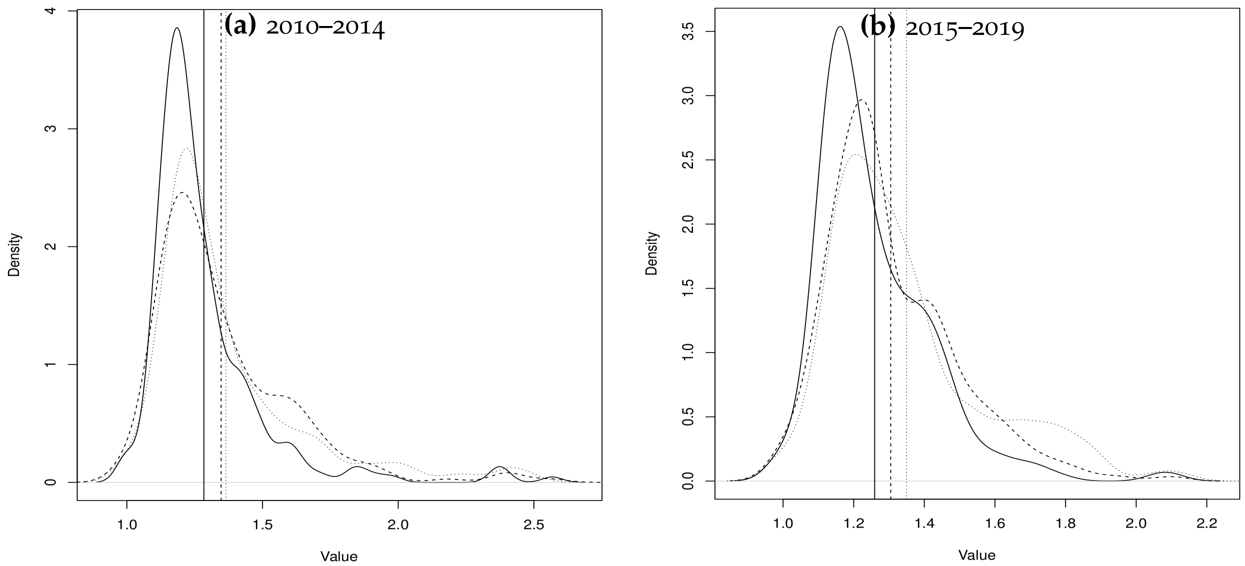




2010–2014 ——— 2015–2019 ------

Figure 2: Performance of universities, densities, global restricted vs research-teaching vs knowledge transfer-teaching models, 2010–14 and 2015–19

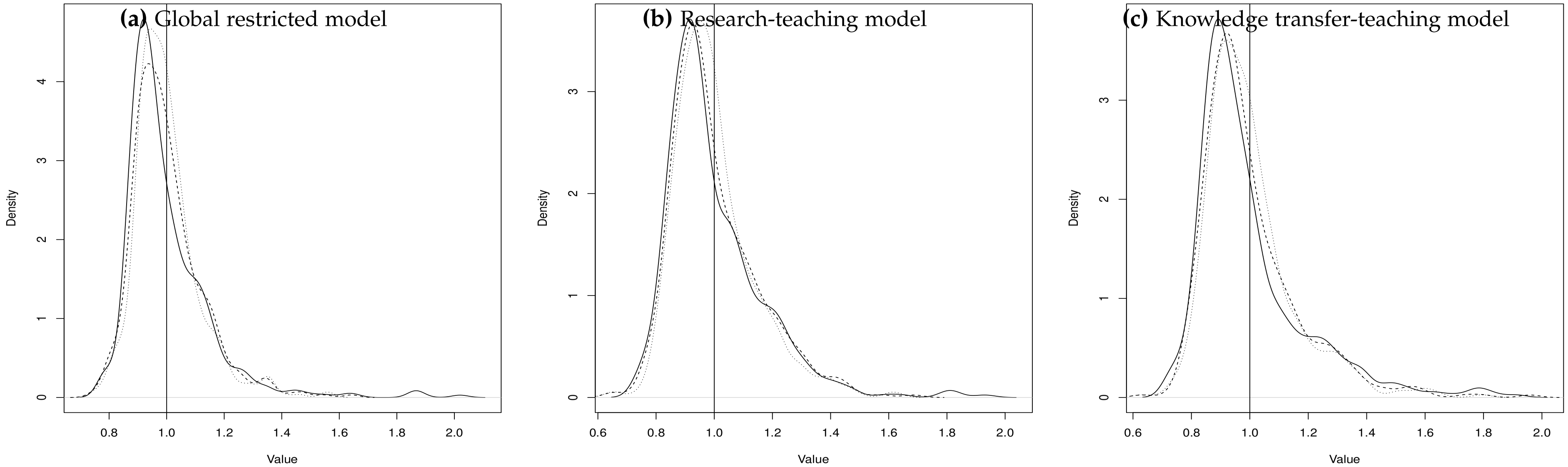
These figures contain densities estimated using kernel smoothing methods for all three models (global restricted, research-teaching and knowledge transfer-teaching). All densities were estimated using Gaussian kernel, and plug-in methods were chosen to select the bandwidth (see Li and Racine, 2007).



Global-restricted model —— Research-teaching model ------ Knowledge transfer-teaching model · · · · · ·

Figure 3: Relative performance of universities, home region effect (NUTS1 and NUTS2), densities, 2010–2019

These figures contain densities estimated using kernel smoothing methods for all three models (global restricted, research-teaching and knowledge transfer-teaching). All densities were estimated using Gaussian kernel, and plug-in methods were chosen to select the bandwidth (see Li and Racine, 2007).



Unconditioned relative performance —— Home region (NUTS1) relative performance ------ Home region (NUTS2) relative performance · · · · · ·