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Postal Address:
Institut d'Economia de Barcelona
Facultat d'Economia i Empresa
Universitat de Barcelona
C/ Tinent Coronel Valenzuela, 1-11
(08034) Barcelona, Spain
Tel.: + 34 93 403 46 46
Fax: + 34 93 403 98 32
ieb@ub.edu
http://www.ieb.ub.edu

ECONOMIES OF SCALE AND SCOPE OF UNIVERSITY RESEARCH AND TECHNOLOGY TRANSFER: A FLEXIBLE MULTI-PRODUCT APPROACH *

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ABSTRACT: This paper empirically analyzes economies of scale and of scope in the production of research and technology transfer outputs in the Spanish public university system. We employ the flexible fixed cost quadratic function which relates total university R&D expenditure and the budget of the technology transfer offices with different outputs of research and technology transfer, from which we then compute the ray economies of scale, the specific economies of scale and the economies of scope. Our results indicate that ray economies of scale and research specific economies of scale hold up to 100% of current mean expenditure. The technology transfer product specific economies of scale hold up to 150% of current mean of the R&D expenditure. Our results also show that cost subadditivity acts a positive constraint, from which we infer the presence of economies of scope.

JEL Codes: I21, I23

Keywords: Multi-product cost function, economies of scale and scope, research and technology transfer.

Néstor Duch-Brown
University of Barcelona & IEB
Faculty of Economics and Business
Dpt. of Public Finance
Avda. Diagonal, 690, T4, 2ª
08034 Barcelona, Spain
E-mail: nduch@ub.edu

Martí Parellada-Sabata
University of Barcelona & IEB
Faculty of Economics and Business
Dpt. of Public Finance
Avda. Diagonal, 690, T4, 2ª
08034 Barcelona, Spain
E-mail: mparellada@ub.edu

Jose Polo-Otero
University of Barcelona & IEB & CYD foundation
Faculty of Economics and Business
Dpt. of Public Finance
Avda. Diagonal, 690, T4, 2ª
08034 Barcelona, Spain
E-mail: josepolo@ub.edu

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1. Introduction

Traditionally, Higher Education Institutions (hereafter HEIs) have focused their efforts on teaching and research. However, over the last two decades, above all in industrialized countries, universities and governments alike have increased their investment in innovation and research commercialization, fostering more effective and have been encouraging more effective linkages between universities, governments and firms (Etzkowitz and Leydesdorff 1997 and 2000; Etzkowitz 1998). This investment has been driven by the perceived need to smooth Technology Transfer (TT), ensuring university innovations promote the required economic and social development (Geiger 2004; Mowery 2007). At the same time, the motivation for HEIs to commercialize their research has grown for a variety of reasons, including the opportunity it affords to generate new sources of income and to strengthen links with public and private firms.

Since the early 80s, studies examining the economics of higher education have recognized the possible presence of economies of scale in the output of the universities (Brinkman and Leslie 1986) and many papers (James 1978; Jimenez 1986; Cohn et al. 1989; Cohn and Geske 1990; de Groot et al. 1991; Lloyd et al. 1993; Koshal and Koshal 1995 and 1999; Hashimoto and Cohn 1997; Johnes 1997; Longlong et al. 2009; among others) have analyzed both economies of scale and of scope within HEIs, by focusing their attention on the relationship between total university expenditure and teaching and research outputs.

Cohn et al. (1989) was one of the first studies to analyze the system of HEIs in the United States by adopting a multi-product cost function approach. They computed economies of scale and scope for a sample of 1,887 HEIs, covering virtually all institutions awarding four-year degrees in America. This study was later extended by de Groot *et al*., (1991). First, they examined a subsample of 147 doctorate-granting universities, from which they drew specific conclusions regarding the economies of scale and scope for universities with a marked research specialization. Second, they conducted a sensitivity analysis of their cost function estimates for various measures of research output, and finally, they tested the impact of the state regulation of personnel and financial administrative practices on production efficiency in HEIs.

In a subsequent study, Koshal and Koshal (1995) introduced the relationship between cost and quality, stressing that earlier studies had ignored this feature when explaining the cost variations between HEIs. They argued the importance of assuming that average university costs vary according to the quantity and quality of their outputs. Moreover, in a later paper (Koshal and Koshal 1999) they noted the importance of differentiating HEIs according to their specific goals, claiming it was inappropriate to perform the same analysis for small teaching colleges and large research-focused universities.

The main conclusions drawn from these preceding studies are the existence of ray economies of scale, product-specific economies of scale and economies of scope in the production of teaching and research outputs. However, the marginal cost coefficients associated with these outputs vary significantly across the different studies.

Discussions regarding the complementarity or substitutability of research and teaching outputs have tended to stress different features. The research findings conclude that HEIs behave as multi-product firms, in which the presence of economies of scale and scope is relevant. However, in recent years, the goals of universities have extended well beyond their two primary functions of research and teaching, and gradually, TT has acquired more and more importance for universities, governments and the private sector. However, to date, little has been said about the presence of economies of scale and scope in the production and transmission of knowledge in universities, when approached from the perspective of research and TT outputs.

This paper empirically analyzes the presence of economies of scale and economies of scope in the simultaneous production of research and TT outputs in the Spanish public university system. We employ a flexible fixed cost quadratic (FFCQ) function, relating total university R&D expenditure and the cost of transferring technology to different outputs of research and TT. Once the cost function is estimated, we calculate the ray economies of scale, the product-specific economies of scale and the economies of scope.

The paper is structured as follows: In section 2 we analyze the HEIs' research and TT cost function, describing the total cost of the production of research and the transfer of technology. Section 3 describes the methodology used in this study. Section 4 explains the data employed, the estimation results and the calculation of the ray economies of scale and economies of scope. Finally, section 5 concludes.

2. The HEIs research and technology transfer cost function.

The objective of this paper is to estimate a multi-output cost function for HEIs, and to calculate the degree of scale and scope economies in their production of research and technology transfer. To do this, we first need to identify the total costs associated with their production of knowledge, and then establish the different outputs of this production function.

Total costs of research and technology transfer

The total costs of the HEI production of research and technology transfer are approximated by university expenditure on R&D activities plus the cost of transferring technology. R&D expenditure in Spain is calculated following the international standards in their definition of R&D expenditure, in this definition, the R&D espenditure comprises two elements: (i) salaries, including wages, remunerations and complementary expenditure on R&D personnel and; (ii) other current expenditure, including the purchase of materials, supplies and support equipment, etc. Moreover, we include the cost of transferring technology based on the total budget of the university's technology transfer office (TTO). This variable measures the capacity of the TTO and proxies the quantity of technology transferred.

We consider university expenditure on R&D to be a good measure for approximating the total costs of production of research and TT, since it represents the share of the budget specifically devoted to these activities, thereby allowing us to avoid analyzing teaching outputs, which are not the focus of this paper.

Research and technology transfer outputs

HEIs are extremely complex organizations that seek the simultaneous achievement of multiple goals (Cohn et al. 1989) and, as such, the identification of their inputs and outputs is equally complex. University outputs should present two primary characteristics: first, they need to be clearly separable from among all the university's distinct objectives, and second, they should be homogeneous and comparable across different HEIs. The absence of any consensus as to what might constitute appropriate outputs for research and TT should be stressed.

Research outputs

Research outputs should, ideally, consist of a range of items, including publications, patents, research reports, etc. However, such outputs are not always homogeneous among HEIs and, for this reason, these institutions are not always comparable. In the various analyses undertaken of the economies of scale and scope of HEIs, research outputs have been approximated in a variety of ways, for example, Cohn et al. (1989) used the total sum of research grants received by an HEI. Elsewhere, the level of research expenditure of each HEI has been adopted (Koshal & Koshal 1999, and Longlong et al. 2009). By contrast, de Groot et al. (1991) used an HEI's total number of publications as their proxy of research output.

Here, we propose using the total number of scientific articles published in journals indexed in the Journal of Citation Reports (JCR) as our indicator. We believe this measure approximates research output better than research grants received and an HEI's level of research expenditure as in some instances the latter are used for purposes other than research. Furthermore, by taking into consideration JCR scientific articles we not only control for the heterogeneity of scientific production, but we are also able to control for quality, as the JCR is the standard in scientific research.

Technology transfer outputs

According to Landry et al. (2006), the TT indicators should represent the conversion of technology into products that are easily amenable to commercial transactions. As such, TT indicators should represent the instrumentality of knowledge. In the literature, a large number of variables have been used to approximate TT from universities to the private and public sector. These variables can be classified into four groups: the first group is associated with intellectual property, and includes indicators such as communications of inventions, patent applications and non-disclosure agreements that protect university know-how. The second group comprises licenses and options, such as firm licenses to use and exploit technologies developed by universities. The third group consists of R&D contracts and collaboration agreements between businesses and universities. Finally, the fourth group refers to the creation of firms within HEIs, whether based on the knowledge generated by universities (spin-off) or entrepreneurial companies formed by university students or teachers, albeit not based on specific knowledge created by universities (start-ups). The most common indicators of technology transfer are the number of patents or their associated royalties (Siegel et al. 2008; Spyros et al. 2008; Thursby and Thursby 2007, among others) and the number and value of R&D contracts (Link et al. 2007; Link and Siegel 2005; Spyros et al. 2008 and Brouwer 2005, among others).

The technology transfer variable used in this paper consists of 3 measures: (i) the total value of private R&D sub contracted to universities; (ii) the total income generated by the private use of university licenses; and (iii) the total income from technical support offered by universities This measure is a good approximation of the technology generated in HEIs and transferred to society, and at the same time, it gives us an idea of the quality of this technology, since the total value is not only a proxy of the capacity to transfer technology, but also of the quality of the technology transferred.

Faculty salary

The literature analyzing economies of scale and scope in the HEIs has examined the benefits of introducing input prices in the multi-product cost function. Thus, according to Cohn et al. (1989) and Koshal and Koshal (1999), HEIs are labor-intensive firms and, as such, the faculty is the most important input price, being capable of altering the output mix. Therefore, they claim faculty salaries must be included in the multi-product cost function. By contrast, de Groot et al. (1991) argue that the academic market is a competitive market and a variation in faculty salaries will only reflect a variation in productivity; therefore, they claim that there is no point in calculating returns to scale at a given salary level.

In our case, faculty salaries capture a number of specific university characteristics, including the academic staff structure and the age of the staff, as well as regional differences, given that Spain's university wages are subject to components that may vary from one region to another. These characteristics should, therefore, be taken into account when calculating the total cost function. Nonetheless, the faculty salary coefficients are used here only as a control variable, and not as a factor that explains variations in the cost function.

3. Methodology: the multi-product cost functions

In the specification of the cost function we follow the work of Baumol, Panzar and Willig (1982) (hereafter BPW). The chosen functional form model is a flexible fixed cost quadratic function (FFCQ). The FFCQ function becomes

$$C = \alpha + \sum_{i=1}^{N} \beta_i Y_i + \frac{1}{2}\sum_{i=1}^{N}\sum_{j=1}^{N} \lambda_{ij} Y_i Y_j + \varepsilon \qquad (1)$$

Where C is the university cost, in our case, the R&D expenditure, α, a constant term, the β_i's and the δ_{ij}'s are scalars, and ε is an error term, and the Y's represent the various outputs.

We also include both linear and quadratic terms for input prices, as well as the interaction terms associated with the different outputs. In principle this specification sacrifices the linear homogeneity property of the function with respect to factor prices, but according to Cohn *et al.* (1989) when analyzing the characterization of HEIs, the linear homogeneity property is not relevant to the analysis of institutions of this kind. However, HEIs are labor-intensive organizations; therefore the faculty salary is the most important input price and it may well alter the output mix. On the other hand, the faculty salary is a way to control for unobservable heterogeneity across different universities since it can capture regional and institutional differences. Finally, in the case of HEIs, it is reasonable to expect a positive bidirectional relationship between the quantity of output produced and faculty remuneration.

Economies of scale and scope

Following the BPW model, we are able to distinguish, on the one hand, the ray economies of scale by measuring the overall scale economies and the product-specific economies of scale and, on the other, the economies of scope, by measuring the degree of complementarity between outputs.

The ray economies of scale: let C(Y) be the total cost of producing the "N" outputs (Y_i), and let $C_i = \delta C(Y) / \delta Y_i$ be the marginal cost of producing the i[th] output. Then the ray economy of scale coefficient, $S_n(Y)$, is defined by:

$$S_n(Y) = \frac{C(Y)}{\sum_{i=1}^{N} Y_i C_i(Y)} \tag{2}$$

Ray economies of scale exist if $S_n(Y)$ is greater than unity, and diseconomies of scale are present when $S_n(Y)$ is lower than one.

The degree of product-specific economies of scale with respect to product "i" at Y, $S_i(Y_i)$ is defined as:

$$S_i(Y_i) = \frac{C(Y) - C(Y_{n-i})}{Y_i C_i(Y)} \tag{3}$$

Where $C(Y_{n-i})$ is the cost of producing all the outputs except the i[th]. If $S_i(Y_i)$ is greater (lower) than one, we say there exist economies (diseconomies) of scale of producing the Y_i. This measure is interpretable as the specific return to scale in increasing the production of the analyzed output.

Economies of scope exist when it is cheaper to produce Y_i in conjunction with Y_j, as opposed to producing these outputs separately. The degree of economies of scope, $SC_t(Y)$, for a product set "t" is defined as:

$$SC_t(Y) = \frac{[C(Y_t) + C(Y_{n-t}) - C(Y)]}{C(Y)} \tag{4}$$

Where $C(Y_t)$ is the cost of producing only the outputs in the product set "t", and $C(Y_{n-t})$ is the total cost of producing all the outputs except those in the subset "t". Economies of scope exist when $SC_t(Y) > 0$. If $SC_t(Y)$ is positive at Y, then the fragmentation of production to "t" and its complement would increase the total cost.

4. Economies of Scale and Scope

Data and estimation of the multi-product cost function

For the empirical analysis we have created a dataset of 45 public universities in Spain for the period 2004-2008. Our information is drawn from three databases: (i) the annual survey conducted by the TTO network in Spain provides information concerning total university R&D expenditure and the value of their R&D contracts; (ii) the Institute of Documentary Studies on Science and Technology (IDSST) provides the number of scientific articles published in JCR journals; and (iii) the biannual publication of the Rector's Conference of Spanish Universities is the source for the basic characteristics of each university. Our descriptive statistics are presented in Table 1 and the evolution in the main variables considered in this analysis is presented in Table 2.

Table 1. Descriptive statistics

	Obs	*Mean*	*Std. Dev*	*Min*	*Max*
R&D expenditure (thousands)	202	57,441.39	44,635.64	4,934.00	205,574.00
Value of R&D contracts (thousands)	213	8,030.12	10,464.78	38.00	82,998.08
JCR Publications	228	658.24	538.01	79.00	2,529.00
Faculty salary (thousands)	228	61.41	11.37	27.85	86.23

Table 2. Evolution in the multi-product cost function

	*R&D expenditure**	*Value of R&D contracts**	*JCR Publications*	*Faculty salary**
2004	47,304.52	5,273.98	553.51	57.51
2005	54,185.19	7,196.04	623.54	59.74
2006	56,578.21	8,507.26	679.86	61.52
2007	60,803.08	9,536.93	727.97	62.82
2008	65,543.12	9,713.39	708.15	65.57

*thousands. Constant prices of 2002. Geometric mean of values for each year.

As discussed in section 2 above, the variables used to calculate the economies of scale and the economies of scope are: (i) total university expenditure on R&D (C(R&D)); (ii) total value of R&D contracts (TT); (iii) number of JCR articles (R); and (iv) the average faculty salary (FS).

For the empirical analysis we first used OLS estimation, and following Koshal and Koshal (1999) we tested the residuals for heteroscedasticity. The Breusch-Pagan test revealed the presence of heteroscedasticity, and suggested a different estimation procedure. In a second step, we estimated a fixed effects panel data approach but the estimation results still showed heteroscedasticity problems. Finally we estimate a cross-sectional, times-series, generalized least squares controlling for heteroscedasticity. We also estimate the model without the faculty salary, and the results hold almost constant. From equation (1) presented in section 3, the FFQC function becomes:

$$C_{it}(R\,\&\,D) = \alpha + \beta_1 R_{it} + \beta_1 TT_{it} + \frac{1}{2}\left[\lambda_{11} R_{it}^2 + \lambda_{12} R_{it} TT_{it} + \lambda_{22} TT_{it}^2\right] + \gamma_t + \varepsilon_{it} \qquad (5)$$

Where C_{it}(R&D) represents the total R&D expenditure plus the budget of the TTO "i" in the period "t"; β and λ are the parameters to be estimated; R and TT are the research and technology transfer outputs, respectively; α is the fixed cost, γ_t is a time dummy and ε is the error term

According to the results presented in table 3, the coefficients of the variables analyzed are statistically significant and present the expected sign. The output coefficients are positive and significant, implying that an increase in the level of each output will augment the total university expenditure on R&D. The interaction coefficient between the TT and research outputs is significant and negative, suggesting complementarity between these outputs. This result holds even when we analyze the multi-product cost function without the faculty salary as a proxy of the input price. Furthermore, from the estimated parameters (column 3 and 4) we have calculated the total cost, the average cost and the marginal cost and we observe that our cost function is well behaved and the global and local concavity conditions are met. This result implies that there exists a single level of output that ensures the maximum efficiency; this level is reached when the marginal cost equals the average cost, i.e., the scale economy is equal to one.

Table 3. Estimation results of the multi-product cost function

	(1)	**(2)**	**(3)**	**(4)**
Value of R&D contracts	3.325 (0.544)***	3.163 (0.596)***	3.325 (0.636)***	3.380 (0.652)***
Value of R&D contracts^2	$1.02\cdot10^{-04}$ ($6.02\cdot10^{-06}$)*	$1.15\cdot10^{-04}$ ($6.33\cdot10^{-06}$)*	$-1.28\cdot10^{-04}$ ($6.64\cdot10^{-06}$)*	$-1.52\cdot10^{-04}$ ($6.62\cdot10^{-06}$)**
Research	72.041 (7.199)***	73.313 (6.606)***	85.663 (15.136)***	90.282 (15.481)***
Research^2	0.007 (0.004)*	0.005 (0.003)	0.010 (0.004)**	0.011 (0.004)**
*Value of R&D contracts*Research*	-0.003 (0.001)***	-0.003 (0.001)***	-0.001 (0.001)***	-0.001 (0.001)***
Faculty Salary	-.-	-.-	-2168.727 (406.249)***	-1848.967 (378.830)***
Faculty Salary^2	-.-	-.-	60.084 (7.966)***	54.458 (7.657)***
*Faculty Salary*Value of R&D contracts*	-.-	-.-	-0.065 (0.016)***	-0.069 (0.016)***
*Faculty Salary*Publications*	-.-	-.-	-1.183 (0.515)**	-1.389 (0.528)***
Constant	2145.225 (1546.595)	-1581.463 (2097.551)	21316.91 (6587.338)***	12381.58 (7152.882)*
Time effects	No	Yes	No	Yes
Log likelihood	-2138.979	-2133.018	-2119.454	-2116.498
Chi^2(4) (time effects)	-.-	57.474***	-.-	61.201***

Note: Standard errors are in parenthesis. *,**, *** denotes the significance at 90%, 95% and 99%, respectively. Estimation based on Generalized Least Squares, controlling for heteroscedasticity. Number of observations: 191. Dependent variable is the R&D expenditure.

The faculty salary coefficient is negative and significant (column 3 and 4). This result is apparently contradictory, since one would expect the total cost to increase as the faculty salary rises and *vice versa*. However, given that the faculty salary we use here does not correspond directly to the wage paid to academics to do research and TT, this bidirectional relationship between the cost and the faculty salary does not apply. Nevertheless, the interaction coefficients between the faculty salary and the research and TT outputs are negative and significant. Moreover, the coefficient of the interaction of faculty salary with research is significantly higher than the coefficient of the interaction between the faculty salary and the TT output. This result could be explained by the fact that the faculty salary depends directly on faculty members' research skills. Similarly, a portion of the income from R&D contracts entered into by HEIs and private institutions comes to form part of the faculty salary. It is therefore reasonable to expect a relationship of complementarity between the faculty salary and the different outputs analyzed.

Calculation of the economies of scale and the economies of scope

The calculation of the economies of scale and scope is based on the estimated results of the multi-product cost function including the faculty salary (fourth column of Table 3). From these results we can calculate the ray economies of scale, the product-specific economies of scale, and the economies of scope, using the set of equations 2-4 presented in section 3 above.

Table 4. Marginal cost of research and TT for different levels of output

	MgC_{TT}	MgC_R	MgC_R/MgC_{TT}
Min - 50%	2.198	69.933	31.817
50% - 100%	2.203	71.711	32.522
100% - 200%	1.372	71.523	52.130
200% - Max	1.331	75.147	56.450

According to our findings (Table 4), the correlation coefficient between total TT output and the marginal cost of TT is negative and equal to -0.402, which implies that the marginal cost of TT decreases as TT output increases. By contrast, the correlation coefficient between research output and the marginal cost of research is positive and equal to 0.178, which means that an increase in output leads to an increment in the marginal cost of this output. Moreover, the marginal cost ratio increases with the level of outputs. Thus, for HEIs with high levels of research and TT outputs, this result implies that increasing their research output is more expensive than increasing their TT output.

Table 5. Degree of scale and scope economies for alternative proportions of R&D expenditure and TTO budget

% of mean R&D expenditure	$S_n(Y)$	$S_{tt}(Y_{tt})$	$S_r(Y_r)$	$SC(Y)$
Min - 50%	1.196	1.827	2.122	1.441
50% - 100%	1.073	1.850	1.506	0.617
100% - 150%	0.862	1.073	0.733	-0.355
150% - Max	0.809	0.691	0.782	-0.348

Note: The average (100%) R&D expenditure is set at 55.13 millions

The ray economies of scale, the product-specific economies of scale and the economies of scope based on a fixed level of R&D expenditure are presented in Table 5. The results show that ray economies of scale disappear when the level of expenditure on R&D exceeds the threshold of 100% of the expenditure on R&D. Likewise, the research specific economies of scale disappear at this level of R&D expenditure, while the TT specific economies of scale remain greater than one until the level of R&D expenditure exceeds the 150% threshold. The economies of scope also disappear when the level of R&D expenditure is higher than 100%.

Table 6. Degree of scale and scope economies for alternative proportions of TT output

% of mean TT output	$S_n(Y)$	$S_{tt}(Y_{tt})$	$S_r(Y_r)$	$SC(Y)$
Min - 25%	1.231	1.488	2.371	1.811
25% - 50%	1.109	1.463	1.621	0.755
50% - 100%	1.036	1.801	1.268	0.307
100% - 200%	0.921	1.244	1.040	0.081
200% - Max	0.788	0.969	0.693	-0.543

Note: The average (100%) TT output is set at 7.78 millions

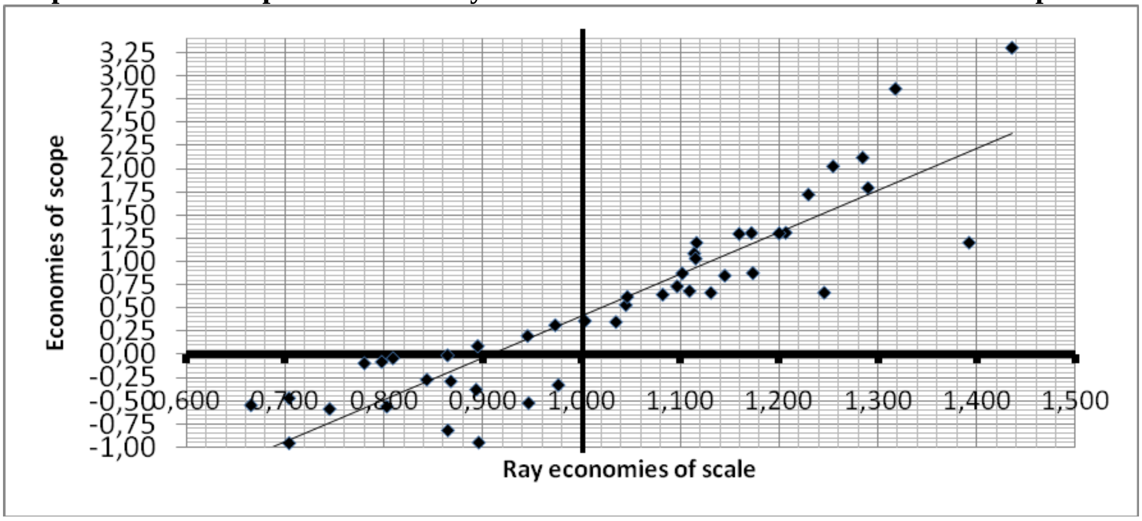
Table 7. Degree of scale and scope economies for alternative proportions of research output

% of mean R output	$S_n(Y)$	$S_{tt}(Y_{tt})$	$S_r(Y_r)$	$SC(Y)$
Min - 25%	1.334	1.414	2.932	2.531
25% - 50%	1.153	1.791	1.912	1.038
50% - 100%	1.058	1.698	1.365	0.476
100% - 200%	0.862	0.981	0.778	-0.305
200% - Max	0.760	0.756	0.721	-0.253

Note: The average (100%) research output is set at 657 JCR publications

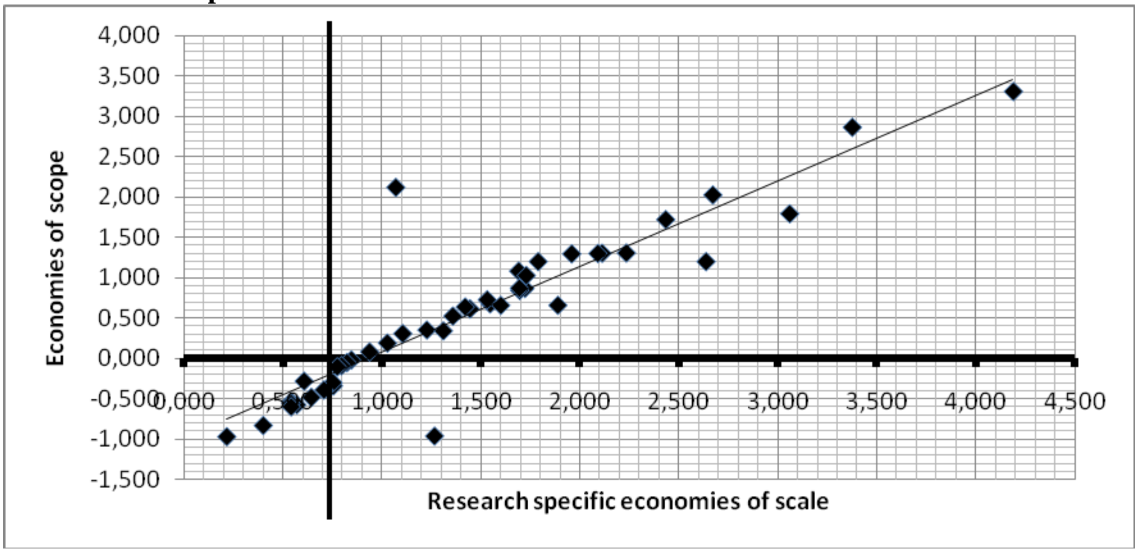
The ray economies of scale remain greater than one until the level of TT output (Table 6) falls below its average, while the specific economies of scale of both research and TT outputs are greater than one even when the level of TT output exceeds 200%. Likewise, the economies of scope remain positive until the level of TT output is greater than 200%. By contrast, when analyzing economies of scale and scope in terms of the level of research output (Table 7), we found that the ray economies of scale, the product-specific economies of scale and the economies of scope disappear when research output is greater than 100%, indicating that HEIs with a large amount of research outputs undergo diseconomies of scale and that cost subadditivity becomes a negative constraint, which implies that the production of research and TT outputs separately will lead to lower costs.

Graph 1. Relationship between the ray economies of scale and the economies of scope

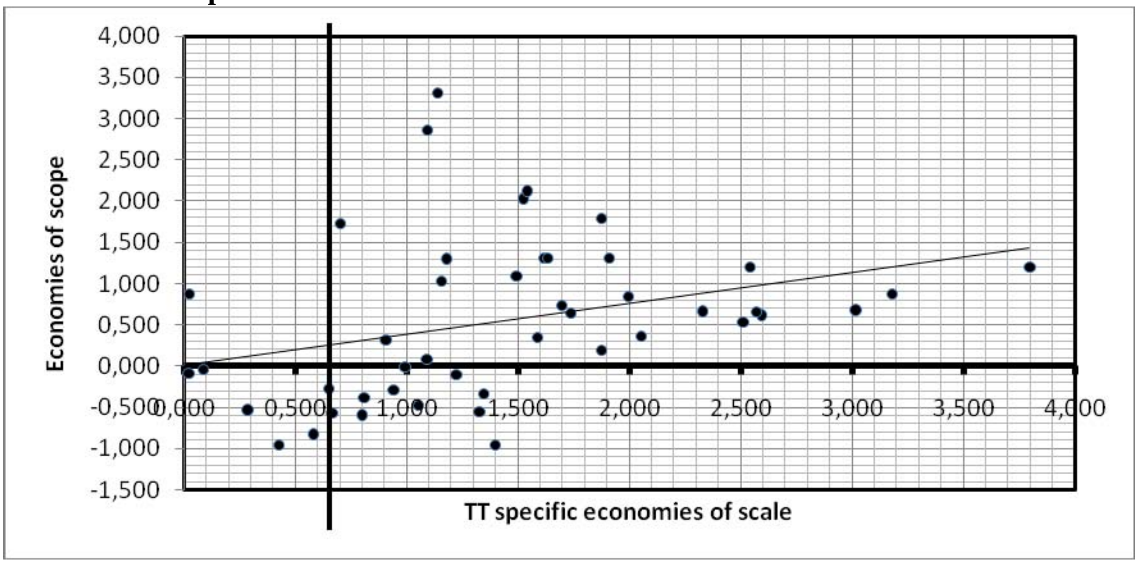


From Graph 1, we are able to identify two distinct groups of institutions. One is composed of HEIs that present neither ray economies of scale nor economies of scope. The HEIs belonging to this group are, with few exceptions, the oldest and the largest HEIs in terms of the number of academic staff and students. By contrast, the second group consists of 26 HEIs that do present economies of scale and scope. The institutions in this group tend to be the newest and smallest HEIs. One of the main reasons underlying this result is the fact that the oldest HEIs were created with the sole aim of providing teaching outputs; consequently, these HEIs today have an organizational structure that was not designed to make research and TT their chief goals. Therefore, these universities present diseconomies of scale in the production of research outputs and the transfer of technology and cost subadditivity is a negative constraint. Moreover, the newest and smallest HEIs are more flexible, enabling them to adopt more efficient production structures.

Graph 2. Relationship between the research product specific economies of scale and the economies of scope



Graph 3. Relationship between the TT product specific economies of scale and the economies of scope



There is a positive bidirectional relationship between the economies of scale (global and specific) and the economies of scope. This relationship is basically explained by the high correlation between the economies of scope and the research-specific economies of scale (see Graph 2), while the degree of adjustment between the scope economies and the TT-specific economies of scale, although positive, is lower than in the case of the research economies of scale (see Graph 3).

5. Conclusions

The objective of this paper has been to calculate and then analyze the economies of scale and scope in the production of research and TT outputs. We have used a dataset composed of 45 public Spanish universities for the period 2004-2008, in which are recorded their respective outputs of research and TT, as well as the total cost of producing these outputs. We have used faculty prices to control for a number of characteristics specific to each HEI.

Our main findings show that there exist ray economies of scale and economies of scope below the mean threshold of 100% of R&D expenditure. TT-specific economies of scale remained higher than one until mean R&D expenditure exceeded 150%, while research-specific economies of scale disappeared when mean R&D expenditure rose above 100%.

When analyzing the degree of economies of scale and scope for alternative levels of outputs we found that the ray economies of scale, in addition to the product-specific economies of scale and the economies of scope, disappeared when the level of research output exceeded 100%. By contrast the specific economies of scale and the economies of scope remained until the level of TT output reached 200%.

Finally, we were able to identify two clearly differentiated types of HEI. The first includes the group of the oldest HEIs, which have neither economies of scale nor economies of scope; the second comprises the newest HEIs, which have both economies of scale and scope. One of the main reasons underpinning this result is that the newest and smallest HEIs are more flexible, enabling them to adopt more efficient production structures.

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