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Specialization vs. diversification of university technological knowledge across European regions

First Draft

(This is a preliminary version. It is incomplete, please do not quote)

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Abstract: This paper explores the regional patterns of university technological diversification/specialization in Europe and its effects on the production of new university technologies measured as patents counts. Several econometric specifications reveal that both regional diversification of technology and specialization in high technology have positive and significant effects on the production of subsequent new technological outcomes.

Key words: university technological knowledge, university patents, technological specialization, technological diversification.

1. Introduction

This paper is framed in the new entrepreneurial roles that according to Etzkowitz (1998) universities have proven themselves critical to regional economic development. The term ‘entrepreneurial university’ is a broad concept supported in the recent literature for a long list of theoretical and empirical analysis (see, for instance, the recent survey by Yusof and Kishore, 2007). As claimed by Etzkowitz and Zhou (2006), the entrepreneurial role of universities includes five main activities: technology patents and licensing, consultation for industry, new firm formation (spin-offs), entrepreneurial education (training top-level workforce) and providing rare facilities for R&D. In this paper we focus on the first entrepreneurial function: the role of innovation in universities, claimed as one of the main basic elements of an entrepreneurial university (Etzkowitz et al. 2008). Particularly, our objective is to explore the relationship between the regional specialization of the university technological knowledge (UTK) and the production of university technological outcomes across European regions. We know remarkably little about this issue, despite from a policy view many national and regional governments have the capacity to call attention (through financing or other incentives) on industrial strategic sectors in which universities should focus. Therefore, promoting a technological specialization or a diversification strategy (or doing nothing) of UTK in regions can lead to different outcomes. We particularly address the following research questions:

- What are the patterns of the regional specialization/diversification of UTK in Europe?
- What is the role of the regional specialization/diversification of UTK to encourage the production of new technology outcomes in the future?

The methodology relies on patents as measured of UTK in European regions. Our results are based on a new panel dataset of 4,580 European university patents classified by European regions and covering the period 1998–2004. The empirical methodology involves two parts. In the first part, we undertake a descriptive analysis of regionalized data to identify the patterns of regional diversification/specialization of UTK in Europe. In the second part, we put forward an econometric framework to test how regional diversification/specialization can affect the quantity of technological university outputs (new university patents). Note that in contrast to other empirical studies that took universities as focus, in this paper regions are our centre of attention. Regions are suitable units of analysis because a profound understanding of how UTK is spatially distributed and its characteristics make easier the implementation of regional strategies that contributes to a better integration of universities in the regional innovation system (Fritch and Slavtchev, 2007) or in a regional organizational model based in triple helix (Etzkowitz and Klofsten, 2005). Besides, from an empirical perspective, the regional analysis of the technological knowledge produced in universities is relevant for several reasons. First, technology generated in universities may be potentially transferred to the regional productive system through patents and licensing, improving the whole innovation capacities in an area (); second, interaction between researchers who produce technology in universities and private sector generate spillovers with effects on firms' innovative outputs (Jaffe, 1989; Feldman and Florida, 1994; Anselin et al., 1997, 2000; Varga, 1998; Fischer and Varga, 2003), new firm formation across geographical areas (Zucker et al., 1998; Di Gregorio and Shane, 2003; Audretsch and Lehman., 2005; Woodward et al., 2006), or regional economic growth; third, university technology might be used for academic researchers to exploit these technological outputs for themselves creating new firms (spin-off) that will increase the high technological potential of the region (). As all this literature reveals, we know a lot about the positive effects of universities on a series of key relevant variables for regional development; by contrast, we know considerably less about the factors leading to strengthen the innovation entrepreneurial activities in universities.

The remainder of the paper is organized as follows. Section 2 summarizes the relevant literature for this paper. Section 3 describes the data and maps the regional patterns of technological university diversification and specialization of UTK in Europe. Section 4 presents several models explaining the effects of diversification and specialization in the production of UTK using regions as unit of analysis. Section 5 provides the results. We briefly summarize the conclusions and discuss future research in Section 6.

2. Literature review

This literature review is organized around two questions: (i) what are the main viewpoints about the regional technological diversification/specialization; (ii) what factors are relevant in explaining the production of technology in universities.

Regarding the first question, despite the arguments in favour of one or other strategy have a long tradition in urban economics, this discussion has not reached the knowledge produced in universities yet. While a full review of the literature on this topic is beyond the scope of this paper, we summarize the main points following several key papers (Feldman and Audretsch, 1999, Glaeser et al., 1992; Acs et al. 2002, Carlino et al. 2007). On the one hand, the Marshall-Arrow-Romer (MAR) externality concerns

knowledge spillovers among firms in an industry. This view says that the concentration of an industry in a city helps knowledge spillovers between firms and, therefore, the growth of that industry and of that city; specialization in geographically concentrated industries would stimulate growth. On the other hand, the position by Jacobs (1969) sustains that diversity of geographically proximate industries rather than geographical specialization promotes innovation and growth. To bring these ideas to the production of university technological knowledge (UTK) in regions, we would have two strategies to follow in order to foster the production of UTK in regions: first MAR externalities would support a specialization view in the sense that researchers working in the same topics in the same region can learn from each other much better than isolated, because of the flow of knowledge in the same technological field; second, the diversification position underlying by the Jacobian theory would suggest that following different lines of work is the best way to increase the production and stock of UTK; the flow of knowledge among university researchers in the regions working in different fields of technological knowledge would foster new inventions.

With regard to the second questions, we distinguish two groups of studies that pursue similar research questions to those in this paper a) studies investigating the production of UTK measured as patents; b) studies dealing with the regional aspects of the production of UTK.

a) Most studies on the production of UTK have used universities as unit of analysis and United States (US) as context. The analysis of the European case began more recently than the analysis of the US situation, and the empirical evidence for Europe is not as extensive. For instance, Henderson et al., 1998, explored the US universities' patents for the period 1965–1988; they emphasized three essential aspects that determine the evolution of university patents: the legal framework, or changes in the federal laws that facilitate patent applications by universities; increases in industrial funds destined to support university research; and the growth in the numbers of interface centres and institutions. Coupé, 2003, estimated a production function for university patents by means of empirical count models, in which the principal explanatory factors were academic expenditures on R&D, and the institutional factors considered previously by Henderson et al., 1998. The results of this study confirmed the evidence on the institutional effects and the significant influence of R&D expenditure on the output of university patents. Payne and Siow, 2003, discussed the effect of federal funding on university patents. After analysing the data under different specifications, they suggested that when universities receive more funding, they produce more patents at the margin. As possible explanatory causes of the mechanisms by which universities develop patents, these authors suggested know-how (the accumulation of previous patents or experience in the particular field), the personnel dedicated to technology transfer, and contractual links with companies that patent. In two similar papers, Foltz et al., 2000, 2003, examined the production of patents in agricultural-biotech sectors for US universities. They found strong evidence of a correlated dynamic effect in which patenting experience helps to produce more patents and that patent production is enhanced by the overall university propensity to patent (patenting culture effects), a strong land grant effect, and a biological science research funding effect. They did not find convincing evidence that university reliance on industry financing increases patent production (there were no industry effects present). In Europe, the review by Geuna and Nesta (2006) concluded, first that the broadly defined research area of biotechnology and pharmaceuticals tends to be an area of extremely high university patenting activity

across (European) countries; second, historical developments in Italy and Germany seem to support the view that university patenting is not a new phenomenon. The authors also suggested that the rapid rise of academic patenting was driven more by the growing technological opportunities in the biomedical sciences than by policy changes affecting the universities' rights to own patents arising from publicly funded research. Baldini et al., 2006, showed that, in the last 10 years, the number of Italian university patent applications, in Italy and/or abroad, rose substantially; patenting activities almost tripled in universities with an internal Intellectual Property Right regulation, after controlling for several universities' characteristics, previous patenting activity, and time trends. Each time a university creates its own patent regulation, there is a 9% increase in the likelihood that universities without any internal patent regulation will adopt one. Furthermore, consistent with previous studies on academic patenting, Baldini et al., 2006, found greater patenting activity in the north of Italy, where there is a higher level of industrial development. In a broad paper, in which the authors considered a patent as an input and an output, Azagra-Caro et al., 2003, estimated a patent production function using data on patent applications from 43 departments of the Polytechnic University of Valencia (Spain). Their results showed that the aggregate R&D expenditure has a positive effect on patents, but they found decreasing returns to scale. When they used R&D split by source of funding, they found that government and industry funding has a significant and positive effect, and that the public funding is more important for patenting than private funding. The internal characteristics of departments are relevant in patent generation.

b) The regional analyses addressing the causes of the production of UTK -measured as patents- are practically absent from the empirical literature. We have briefly reviewed some of the key papers on the determinants of university patents, but none of these studies focused on the regional level. To our knowledge, only Azagra-Caro et al. (2006) for the Spanish case, and Acosta et al. (2009) for European regions, discussed this question from a regional perspective. In the first study the authors built a university patent production function to identify the factors determining the generation of patents in 17 Spanish autonomous regions (NUTS-II) over a time span of 14 years. As in previous research, they found a significant positive relationship between the number of university patents and academic R&D in all estimations (they found that academic R&D was the only significant determinant of international university patents), but their elasticities were extremely high compared with previous papers applied in other contexts. The authors explained this as being the result of using different units of observation (regions instead of universities) and the inclusion of all the funds (not only public funding). Other relevant variables to explain the production of national patents were control variables (trend), and an index of technological distance between university patenting and other institutions. They did not find evidence of the effects of variables such as the number of university researchers, university structure, or the joint research structure. The second study by Acosta et al. (2009) explored a panel data set of European university patents regionalized by European NUTS II regions. Their findings suggested that variations in regional R&D funding do affect patenting activities in regions, with elasticities showing constant returns to scale, but no evidence was found regarding the industrial potential of the region encouraging the production of new UTK. To our knowledge the role of university specialization/diversification to promote the university production of technological knowledge have not been considered in empirical analysis so far.

3. The data

3.1 Description of the data

Our dataset contains 4,580 European university patents (obtained from the Derwent Innovation Index) related to 202 European regions (15 Members) and 378 universities for the period from 1998 to 2004. As regions for our analysis, we chose the territorial units from Eurostat in each country at the NUTS II level of aggregation. As it is well known, a NUTS II is a territorial unit with some degree of administrative and policy authority. A patent was assigned to a university (and in consequence to a region) when the name of the university appeared in the list of applicants of the patent, so the name of the university was the criterion for detecting a university patent. In order to avoid the national distortions arising from the different patent application requirements in different countries, we included only European patents in our sample. Furthermore, the higher costs for a national patent compared to a European patent suggest that we are dealing with valuable technological knowledge with real potential applications. We have considered that a patent belongs to a university when the university's name appears in the list of applicants (note that we are considering university-owned patents in this paper); therefore, this spatial distribution does not necessarily coincide with other criteria; for example, it excludes patents that are invented by academic researchers but where the university does not appear on the patent's applicant list. To avoid problems with the university name, we examined those institutions included in the European Indicators, Cyberspace, and the Science–Technology-Economy –System (EICSTES) Project and in the Worldwide Web of Universities (www.univ.cc, web site with links to 7,884 universities in 190 countries). Of the 202 regions, 54 have no university-owned patents; 42 regions have between one and five patents; 45 have between six and 15; 35 have 16 to 50; 16 have 51 to 100; and 10 regions have more than 100 university-owned patents. Other relevant information included in our models was European regional data of higher education R&D (HERD) expenditures in millions of PPS -purchasing power standard- at 2000 prices, taken from Eurostat. This sector is composed by all universities, colleges of technology, institutions of post-secondary education, and research institutes associated with high education institutions. The total data includes general university funds and a variety of external sources related to HERD (see Frascati Manual for details).

3.2 Specialization/diversification of UTK across European Regions 1998-2004

In order to obtain the specialization/diversification patterns of UTK across European regions, we classified university patents according to an economic concordance table developed by Schmoch et al. (2003) between the four-digit of the International Patent Classification (IPC) codes and the 44 industrial sectors. Using this equivalence table, we assigned the original IPC data (at the four-digit level) to the Classification of Economic Activities in the European Community (NACE) at the two-digit level based on the industrial sector where the patent originated. For generating the correspondence between IPC classes and the 44 industrial sectors only the first IPC code of the patent was taken into account. In our analysis we understand technological specialization as the extent in which a region has concentrated their efforts to produce patents mostly in specific sectors. Our measure of regional specialisation for UTK takes the form of the revealed technological advantage (RTA). For three levels of specialization (high

technology, medium technology and low technology) the RTA of a region is calculated according to the Balassa (1965) traditional indicator of revealed comparative advantage:

$$RTA_{ir} = \frac{P_{rj} / \sum_j P_{rj}}{\sum_r P_{rj} / \sum_{ir} P_{rj}}$$

Where P_{rj} is the number of patents of region r in sector j ; $\sum_j P_{rj}$ is the number of patents of region r in all sectors. $\sum_r P_{rj}$ is the number of patents of all regions in sector j . $\sum_{ir} P_{rj}$ is the number of patents of all regions in all sectors. As it is well known, the RTA index varies around unity; values greater than one indicate that a region is comparatively advantaged in that sector in relation to other regions, whilst values less than one are interpreted as implying a comparative disadvantage. Note that this index has a skewed distribution; therefore, to include it in our regression analysis we took a normalised RTA index: $NRTA = (RTA^2 - 1) / (RTA^2 + 1)$ (see details in Grupp, 1994). This method has the advantage of symmetry (it takes values between -1 and 1). As the value of RTA, it can be interpreted as the degree of regional specialization in a sector j when for that sector $NRTA > 0$. The distribution of patents in three levels of technology (high, medium, low) was made from the OECD classification taken as input the 44 sectors developed by Schmoch et al. (2003).

We capture the degree of technological diversification of university technology in a region with the entropy index. This index measures the degree of unrelated or total technological diversification considering the spread of patents across 44 different sectors in a region:

$$EI = \sum_{i=1}^N T_i \ln(1/T_i)$$

Where T_i is the share of the sector i in the overall university patents in region r . This measure takes into consideration two elements of technological diversification: the number of technological fields in which a region has patents and the relative importance of these fields compared to the total number of patents in the region. The index takes value 0 for the minimum entropy: only one sector in the region concentrates the production of university patents. The entropy is maximum when all sectors have equal share of patents in the regions, then the value would be equal to $\ln(n^o \text{ sectors})$; as we are considering 44 industrial sectors, the value of the maximum entropy is 3.78. Note that the specialization index focuses on only one sector, while the diversity index takes into account the sectors of the entire regional technological knowledge produced in universities; therefore they are not necessarily mutually exclusive concepts. For all European regions we have calculate both indexes in order to include them in our models.

3.3 Production, diversification and specialization of UTK

Table 1 summarizes the main descriptive data so far. Previous Maps together with this Table reveal several preliminary relevant facts: first, patent activity is highly concentrated in space (only 5% of regions account for 40% of patents); second, entropy seems to decrease when the average patent per regions decreases. Observe that 10 regions with the highest number of university patents show an entropy index exceeding two points, that is, a diversified production of UTK considering that the maximum entropy index is 3.78; third, average specialization in high, medium or low technology is not clearly related to the number of university patents in subsequent periods.

A closer look at the correlation coefficients and graphic relationships between the production of UTK and diversification/specialization offers a preliminary view of how diversification (entropy) and specialization (NRTA) may be related to the production of university technological knowledge (patents). From now on, to calculate correlations and scatter graphs we consider regions with five or more patents in a year (111 regions instead of 202), because it does not make sense to analyse diversification or specialization with an extremely few number of patents.

Table 2 presents the correlation coefficients. This data shows that the production of patents is significantly correlated with the level of entropy: the higher the level of diversification the more the number of patents (in logarithms). Looking at the figures, one or two years lags seem to be the lapse of time in which these two variables present the higher correlations. Significant correlation coefficients also appear between the number of patents in each region and the level of specialization in both high and low technology.

Table 1
University patents production across European regions 1998-2004

	N° regions	N° patents	%	N° patent/ N° regions	Average specialization			Average Entropy
					NRTAht	NRTAmht	NRTAlt	
More than 100 pat.	10	1,831	39.98	183.10	0.06	-0.24	-0.17	2.20
51-100 patents	16	1,093	23.86	68.31	-0.05	-0.04	-0.09	1.96
26-50 patents	27	985	21.51	36.48	-0.10	0.08	-0.04	1.96
11-25 patents	21	339	7.40	16.14	-0.11	0.00	0.03	1.67
5-10 patents	37	262	5.72	7.08	-0.05	-0.18	-0.30	1.27
Total (5 o more patents)	111	4510	98.47	40.63	0.96	1.09	1.15	1.70
Others (Less than 5 pat.)	91	70	1.53	0.76
All European regions	202	4,580	100	22.67

NRTAht: Normalised specialization index in high technology sectors (according to the OCDE criterium)

NRTAmht: Normalised specialization index in medium technology sectors.

NRTAlt: Normalised specialization index in low technology sectors.

Table 2

Correlation coefficients between the production of patents and variables capturing diversification/specialization in high, medium and low technology (Regions with five or more patents)

Variables capturing divers/specialis. (1)	Patents (in ln)	
	Coeff. Corr.	N° Obs
entrolag	0.5694*	260
entrolag2	0.5461*	226
entrolag3	0.4719*	188
nrtahlag	0.1447*	260
nrtahlag2	0.1465*	226
nrtahlag3	0.1197	188
nrtamlag	-0.0311	260
nrtamlag2	-0.0551	226
nrtamlag3	-0.0411	188
nrtalag	0.1550*	260
nrtalag2	0.1771*	226
nrtalag3	0.1109	188

* Significant coefficient at 5% level.

(1) Variables:

- entrolag, entrolag2, entrolag3: Regional entropy index with 1, 2 and 3 lags with respect to the production of patents.

- nrtahlag, nrtahlag2, nrtahlag3: Regional coeff. of specialisation in high technology with 1, 2 and 3 lags with respect to the production of patents.

- nrtamlag, nrtamlag2, nrtamlag3: Regional coeff. Specialisation in medium technology with 1, 2 and 3 lags with respect to the production of patents.

- nrtalag, nrtalag2, nrtalag3: Regional coeff. of specialisation in low technology with 1, 2 and 3 lags with respect to the production of patents.

4. Model and variables

This section aims to establish an econometric framework to test the importance of the specialization/diversification patterns (along with other control variables) on the production of UTK.

2.1 Theoretical model

To analyse the relationship between the production of UTK and specialization/diversification, we regress this variable on RTA and HI. As RTA and HI are not the only determining factors, we control for other standard elements that according to the literature influence production of UTK, particularly R&D university funding:

$$P_{it} = f(EI_{it-\mu}, NRTA_{it-\mu}, HERD_{it-\mu}, year_t, u_{it})$$

Where P is the technological new knowledge produced in universities in a region i; EI is the entropy index for each region with μ years lag; NRTA in the normalized revealed technological advantage index for each region. EI and NRTA capture the potential spillovers effects from the specialization/diversification technological university activities on the production of patents. The model controls for a main important variable to determine P: the regional amount higher education R&D expenditures (HERD). We included HERD as a control variable because the focus of attention is the diversification and specialization of UTK. Several dummy variables were also considered to capture for temporal effects. Finally, “u” is the usual independent and identically distributed error term. All explanatory variables were lagged μ years because, as it is well known, it takes time before explanatory variables yields an output in the form of a patent. Note that the standard departure of model is a “knowledge production function” (Griliches, 1979), but modified to consider the possible knowledge spillovers of a technological diversification or specialization strategy in the production of new inventions.

2.2 Empirical model and variables

The empirical function to estimate the previous model would take the lineal form:

$$\ln(patents)_{it} = \alpha + \beta EI_{it-2} + \sum_{j=1}^{j=3} \nu_j NRTA_{jit-2} + \phi \ln(HERD_{it-2}) + \sum_{t=2001}^{t=2004} \lambda_t year_{it} + u_{it}$$

Where the dependent variable $\ln(patents)$ is the logarithm of the number of patents in each region.

The independent variables with a two years lags are as follows:

- EI is the entropy index calculated for a maximum of 44 sectors in each region;
- NRTA is the normalization of the RTA calculated for a maximum of 44 sectors in each regions and three level of technology (high, medium, low).
- HERD is the variable capturing the regional R&D expenditures for the Higher Education Sector;
- $year_{it}$ include five dummy variables to consider temporal effects.

This regression may be estimated using a standard panel data procedure with fixed or random effects. However, two problems arise when we try to estimate with our sample. First, the variable HERD is not available for all regions or for all years; missing data

results in a strongly unbalance panel that makes unfeasible the application of panel techniques; the solution was pooling the data considering dummy variables to capture temporal effects.

Second, the inclusion of NRTA and HI is a novel aspect in the knowledge production function that requires changes in the empirical function for the estimation of this model. As we pointed out before, it does not make sense to obtain specialization of university technological knowledge (NRTA calculated with university patents) when there are only a small number of patents in the region. In order to calculate NRTA and EI with a reasonable number of patents and include these indexes as regressors, we are forced to introduce a process of sample selection that is the cause of a truncated dependent variable (n° of university patents in log.). If we consider that a reasonable NRTA is calculated when the number of the patents in a region exceeds a number “c” (for instance five or more patents) the observed dependent variable is left truncated; we only would take into account data in our model when a region has at least “five” patents. For this case, OLS provide us good results for inference of the effects of the variables EI and NRTA because our population of interest is the European regions with a number of patents equal to five or higher. Note that in this case we do not have the exigency of specification a typical left truncated model; therefore it would not be necessary to go further (nevertheless, we also consider the estimation of truncated models in our robustness analysis in order to obtain an improve coefficient for the variable HERD). Table 3 includes the definition of all variables in our models.

Table 3
Variables included in the empirical equations explaining the production of University Technological Knowledge (UTK)

Variables (1)	Definition
ln(patents)	Logarithm of the number of patents in each region.
LHERD	Logarithm of higher education R&D (HERD) expenditures in each region (in millions of PPS -purchasing power standard- at 2000 prices).
EI	Entropy index calculated for a maximum of 44 sectors in each region.
NRTAH, NRTAM, NRTAL	Normalized revealed technological advantage index calculate for a three technological level (High, Medium, Low) in each region.
year01, year02, year03, year04	Dummy variables to capture for temporal effects (base year: 2000).
(1) All variables for regions with five patents or more. All explanatory variables with two years lag.	

5. Results

Following the empirical specifications and the procedure to estimate the models put forward previously, three models were estimated to test the relevance of the variables capturing the diversification/specialization on the production of UTK. We include a second subsection to consider a final robustness study with several more models to determine how feasible our results are.

5.1 Effects of diversification/specialization on the production of the UTK

Table 4 presents the main descriptive statistics for all the variables in the main models. Table 5 presents the OLS estimation for three Models explaining the effects of diversification/specialization on the production of patents. Given the heterokedastic structure of the variance of several regressors (see the graphics presented above), we applied in all models the Eicker-White correction to obtain robust values of the standard errors. We have included the variables capturing specialization (in high, medium and

low technology) in separate models because a region is usually specialised in one type of technology and occasionally in two; besides, when we include both variables (e.g. specialization in high and medium technology, or in high and low technology) we have multicollinearity problems for a strong negative correlation between these pairs of variables. These results show that the variable EI with two years lag (EIlag2) is positive and highly significant in all models, supporting the hypothesis that the diversification of UTK is a cause of the production of university patents in subsequent periods; the higher the diversification of the university technology generated in regions the more the number of patents produced in the future.

The three variables capturing specialization are also significant but with very different meaning. The coefficient of the variable NRTAHLag2 (specialization high technology with two years lag) is positive and significant at 5% level, therefore increasing the specialization in high technology sectors would result in more patents in subsequent periods, while increasing specialization in medium or low technology would produce the opposite effect.

Table 4
Descriptive statistics

Variable	Mean	Std.Dev.	Min	Max
lpatent	2.3930	0.6646	1.6094	4.3695
LHERDlag2	5.5895	0.7668	3.9502	7.6171
EIlag2	1.1453	0.5759	0.0000	2.3026
NRTAHLag2	-0.0860	0.3719	-1.0000	0.3615
NRTAMtlag2	-0.1467	0.6648	-1.0000	0.9272
NRTALtlag2	-0.4017	0.7837	-1.0000	0.9926
N° obs	121			

Table 5
The production of UTK. Pooled OLS regression for regions with five or more patents

Dep Var: lpatent									
	(1)			(2)			(3)		
	Coef.		Std. Err.	Coef.		Std. Err.	Coef.		Std. Err.
LHERDlag2	0.2827	***	0.0668	0.2887	***	0.0667	0.3099	***	0.0682
EIlag2	0.4929	***	0.0772	0.5304	***	0.0785	0.5285	***	0.0822
NRTAHLag2	0.3108	**	0.1309						
NRTAMtlag2				-0.1511	**	0.0688			
NRTALtlag2							-0.1114	*	0.0613
Year ₂₀₀₁	-0.0029		0.1718	-0.0179		0.1703	-0.0200		0.1501
Year ₂₀₀₂	0.1266		0.1574	0.1064		0.1580	0.1594		0.1466
Year ₂₀₀₃	0.3293	**	0.1620	0.3043	*	0.1602	0.3477	**	0.1479
Year ₂₀₀₄	0.3616	**	0.1702	0.3372	**	0.1695	0.3598	**	0.1603
Cons	0.0851		0.4049	-0.0216		0.4030	-0.1924		0.4108
N° obs	121			121			121		
F(7, 113)	13.09	***		14.33	***		14.10	***	
Prob > F	0.0000			0.0000			0.0000		
R-squared	0.4812			0.4730			0.4667		
Root MSE	0.4933			0.4972			0.5002		
(***) Significant at 1% (**) Significant at 5% (*) Significant at 10%									

These base models show that a diversification strategy in the production of UTK favours the generation of new UTK in the future and at the same time the specialization is a good strategy but only specialization in high technology sectors. Other variables in

models are LHEDlag2 (logarithm of the higher education R&D expenditures) and dummy capturing year effects. With regard to LHEDlag2, we obtain significant coefficients for elasticities of around 0.3, but note that these elasticities are only justifiable for regions that produce a number of patents of five or higher.

5.2 Robustness

We have reached conclusions about the effects of diversification/specialization on the production of UTK when the regions in the sample have five or more patents, but do the conclusions hold if we estimate the models with new samples regarding regions with more patents? To evaluate how robust our results are, we have analysed the possible changes when we increase the number of patents for each region. We have reproduced the previous models considering six or more patents in the region, seven or more... and so on (obviously, as we consider regions with a higher number of patents, the number of observations decreased). The results of the estimation of these new models do not greatly differ from Models (1) to (3) in Table 5. The same coefficients remain significant.

Up to now we have been interested in the effects of specialization (NRTA) and diversification (EI) on the production of university patents, but our models include other relevant variable: the higher education R&D expenditures (lnHERDlag2). According to our estimations this variable is highly significant to explain the production of university patents when the region has five or more patents (six, seven..., or ten or more in latest models) with elasticities around 0.30. However, higher education R&D expenditures are supposed to explain the production of all university patents in all regions and not only of those which number of university patents are greater than “c”. This means that if we focus on this variable (elasticities for the whole population) the specification needs to be treated as left truncated, because OLS procedure does not provides correct estimates for this coefficient; it is biased and inconsistent when the objective is the whole population, and the same holds for the estimation of the error variance.¹ A QML (pseudo-likelihood) estimator is usually applied to estimate this model.² In the new models the elasticities fall between 0.43 and 0.50, higher than in previous models.

6. Conclusions

Our econometric results based in a modified knowledge production function for the European regions can be summarized as follows:

- The coefficient of the entropy index with two years lag is positive and highly significant. This means that diversification of UTK in a period would result in more quantity of technology outcomes in subsequent periods.
- The coefficient for the regional specialization in high technology (with two years lag) is positive and significantly related with the production of university patents, while a regional specialization in medium and low technology have a

¹ OLS estimator is biased and inconsistent because $E(u|X)$ in the truncated model is a function of X (regressors' matrix) and not equal to zero. The distribution of our dependent variable when it is greater than the truncation point “c” yields to a non lineal conditional mean.

² The importance of considering truncation is illustrated with examples, for instance, in Hausman and Wise's (1977), and details of the general specification and of the truncated regression models can be found in Greene (2008, pp. 863-905) and Davision and Mackinnon (1993, pp. 537-545).

- negative effect in the number of patent in subsequent periods.
- The coefficient of higher education R&D expenditures (included as control variable) was significant in all models, with elasticities around 0.2-0.3 (on average for regions with five patents or more) and 0.5 (on average for the whole population). Similar results were obtained in previous literature in other contexts (e.g. Payne and Siow, 2003); however, this result should be cautiously taken, given the problems in measuring this variable.

From a political viewpoint (regional or national), these results give some clues about the strategies to think about in order to promote the production of technology in universities. Several ideas arise: first, encourage the diversification of technology supporting projects with outcomes in multiple different sectors; second, stimulate the production of university technological knowledge in just high technology sectors.

In terms of the direction for future research, we first intend to go a step further addressing the role of collaboration to encourage the production of UTK in European regions; second, the determining factors of the quality of technological knowledge should be treated closely, with a model that may explain why there are European regions that generate patents of a better quality than others.

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