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Fuzzy cluster analysis on Spanish public universities

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**Abstract**

The present study tries to provide an alternative approach to the analysis of universities, by grouping Spanish public universities for the academic year 2006, into clusters that are statistically similar across all criteria, without making assumptions about the relative importance of each criterion. In (non fuzzy) clustering techniques, universities grouped according to particular performance. However, the same university could be important from more than one perspective at the same time, and to different degrees. Thus, in our view, a fuzzy clustering approach is more applicable. The results of the present analysis provide information on the situations of each Spanish public university within a national context.

**1. Introduction**

Higher Education Institutions (HEIs) around the world are undergoing important changes. Experts in the field of higher education (HE) affirm that the 21st century will be see the highest growth in HE in the history of education, and will be subject to qualitative changes that will force HEIs to make major readjustments to bring them into line with public sector financial management systems (Rodriguez Vargas, 2005; Leydesdorff, 2006; Bonaccorsi and Daraio, 2007).

According to the OECD (1999), universities are developing new roles and missions that are having serious implications for their structures. At the same time, universities are involved in cost rationalizations based on the decrease in public R&D funding and the increase in private funding among other factors. For example, between 1997 and 2005, public R&D funding in Germany, Spain and Portugal decreased by 1.0%, 0.5% and 10.6% respectively, while private financing of their universities respectively increased by 2.4%, 5.6% and 13.7% (Eurostat, 2007; INE, 2007).

To cope with these changes, governments and HE agencies are implementing strategies to improve HE efficiency and ensure optimal utilization of resources. Spanish universities have undergone complete legal and structural transformations over the last few decades, which have resulted in major reforms to their systems. Governments are establishing new management forms for public institutions, the most important being greater autonomy, which demands greater efficiency, efficacy and responsibility from these organizations (LOU, 2001, 2007). In this context, many theoreticians think it is vital for universities to be evaluated (Keller, 1999; Villarreal, 1999; Pla and Villarreal, 2001; García-Aracil et al., 2006).

Evaluation of universities is a relatively recent phenomenon in Spain compared to other western countries; North America can be taken as the reference case (Blank, 1993; De Miguel, 2007). HE assessment is a complex process that requires previously agreed, reliable and appropriate standards (Miguel Díaz, 1999). Rather surprisingly, in a world where information plays an important role in the creation of new knowledge, we have no information on how to develop such indicators (Bonaccorsi and Daraio, 2007). This has provoked an upsurge in work on university evaluation and the use of different indicators systems (Douglas Williams, 1995; García-Aracil et al., 2006; Aghion et al., 2007; García-Aracil and Villarreal, 2009), which has resulted in a multiplicity of

indicators addressed to teaching, research, transfer of research results and the evaluation of some or all of these factors combined. There is also a lack of adequate disaggregated data. Therefore, it is necessary to systematize existing indicators to facilitate the establishment of criteria for decision making and classification of the factors related to evaluation (Oakes, 1989; Consejo de Universidades, 1999; Westerheijden, 1999; García-Aracil, 2007; MEC, 2007).

In this paper we present some indicators of different aspects of university performance according to the three main missions of teaching, research and knowledge transfer. In Section 2 we present them as academic rankings of the university missions and derive a global ranking. Section 3 describes the fuzzy cluster methodology. Section 4 presents the results, and Section 5 offers some concluding remarks.

## **2. Descriptive data**

Data for the academic year 2006/07 for public universities in Spain were collected from various government and institutional sources. In 2006, there were 48 public institutions; this study considers 47 of them (the National Open University (UNED) is excluded due to its different structure).

It is clear that ranking systems and league tables are becoming more prominent in HE systems. In this study, we select three indicators for each university mission. To measure teaching, we considered successful performance defined as the ratio between number of credits achieved with respect to the number of credits enrolled; student-teacher ratio; and, the total spending per student. For research, we classify universities based on the indicators of : thesis awarded respect to the numbers of academic staff holding a PhD degree; the ratio of articles published in ISI peer-reviewed journals to total tenured academic staff; and ratio of *sexenios* to tenured academic staff (every six years, a tenured professor can present his/her most relevant scientific contribution to a

national committee of experts in his/her particular discipline; a positive assessment of research activity is awarded a *sexenio*, which carries a salary increase). Finally, knowledge transfer is measured by: percentage of patent applications from academic staff; per-teacher university income from contracts (private income); and per-teacher university income from grants (public income).

Some of the indicators proposed are included in more than one of the international rankings, but a number are unique and specific to the characteristics of the Spanish HE System (e.g. number of *sexenios* per tenured academic staff).

Scores are ranked from highest to lowest; universities are classified from 1 (the highest ranking) to 47 (the lowest ranking).

Table 1 presents the classification of Spanish public universities according to these indicators. For performance, the University Pompeu Fabra is rated highest, followed by the Autònoma of Barcelona, Carlos III of Madrid, Public University of Navarra and University of Lleida. For student-teacher ratio, values range from fewer than 11 students per teacher at the Public University of Navarra (10.44) and the Basque Country University (10.75), to more than 16 students per teacher for the University of Malaga (17.63). For expenditure per student, the top ranked is the Public University of Navarra with more than 8,000 euros per student, followed by the Technical University of Madrid (7,000-8,000 euros). The last two columns in Table 1 show the classification of Spanish public universities calculated on an index incorporating these three teaching-indicators - the global ranking. The top five public universities in Spain are the Public University of Navarra, University of Lleida, Pompeu Fabra, Carlos III of Madrid and the Basque Country University.

Table 2 presents the classification of Spanish public universities according to the research indicators. The highest ranked universities for number of theses awarded by

those academic staff holding a PhD degree are the University of Miguel Hernandez, Autonomia of Barcelona, Complutense of Madrid and Autonomia of Madrid, with more than 18 successful PhD supervisions per 100 professors. Regarding the number of ISI publications per tenured academic staff, the top ranked university in 2006/2007 is the University of Burgos. For ratio of *sexenios* per tenured academic staff Autonomia of Madrid is first (2.31) followed by Pompeu Fabra (1.95) and the Autonomia of Barcelona (1.94). The last two columns in Table 2 show the ranking of universities based on an index calculated from the three research indicators, the global ranking. The five highest ranked public universities are Autonomia of Madrid, Pompeu Fabra, Cordoba, Santiago of Compostela and Rovira Virgili.

Table 3 presents the classification of Spanish public universities based on knowledge transfer. For number of patents per full-time teacher, the Technical University of Catalunya is ranked highest. The universities that received the most income from R&D contracts are Technical University of Valencia, Cantabria, Technical University of Catalunya and Autonomia of Madrid with more than 10,000 euros per full-time teacher. The universities that received the most money from R&D grants are the Rovira Virgili, Santiago of Compostela and Technical University of Catalunya with more than 17,000 euros per full-time teacher. The last two columns in Table 3 present the global ranking based on these three knowledge transfer scores. The five best public universities are: Technical University of Catalunya, Cantabria, Technical University of Valencia, Technical University of Madrid and Autonomia of Madrid.

Table 1. Teaching performance rankings for Spanish public universities. Academic year 2006/2007.

R	University	Successful Performance Rate	R	University	Students/Teacher Staff (FTE)	R	University	Running expenses / Students (€)	Global R	University
1	pompeu_fabra	81.70	1	publica_navarra	10.44	1	publica_navarra	8,323.53	1	publica_navarra
2	autonoma_barcelona	70.38	2	pais_vasco	10.75	2	poli_madrid	7,122.61	2	lleida
3	carlosIII_madrid	69.36	3	lleida	11.05	3	poli_catalunya	6,795.56	3	pompeu_fabra
4	publica_navarra	69.36	4	zaragoza	11.24	4	lleida	6,713.32	4	carlosIII_madrid
5	lleida	69.02	5	poli_madrid	11.80	5	pais_vasco	6,595.75	5	pais_vasco
6	girona	68.85	6	cantabria	11.90	6	cantabria	6,521.25	6	poli_catalunya
7	roviraivirg	68.21	7	pompeu_fabra	11.90	7	pompeu_fabra	6,406.07	7	barcelona
8	poli_catalunya	67.70	8	carlosIII_madrid	11.95	8	carlosIII_madrid	6,303.43	8	cantabria
9	autonoma_madrid	66.98	9	valladolid	12.20	9	alcala	6,247.02	9	zaragoza
10	barcelona	66.71	10	poli_cartagena	12.38	10	barcelona	6,202.16	10	autonoma_barcelona
11	pablo_olavide	65.95	11	salamanca	12.90	11	roviraivirg	6,075.02	11	salamanca
12	huelva	65.36	12	barcelona	12.98	12	zaragoza	6,013.66	12	autonoma_madrid
13	castilla_mancha	65.36	13	huelva	13.11	13	autonoma_barcelona	5,964.58	13	huelva
14	salamanca	65.14	14	alcala	13.16	14	poli_valencia	5,816.52	14	roviraivirg
15	pais_vasco	64.98	15	poli_valencia	13.20	15	complutense_madrid	5,814.44	15	alcala
16	zaragoza	64.70	16	poli_catalunya	13.22	16	jaume	5,727.62	16	girona
17	complutense_madrid	64.03	17	autonoma_madrid	13.27	17	salamanca	5,702.48	17	poli_madrid
18	santiago_compostela	63.34	18	burgos	13.31	18	castilla_mancha	5,673.45	18	poli_valencia
19	leon	63.22	19	la_laguna	13.50	19	autonoma_madrid	5,639.38	19	valladolid
20	cantabria	62.87	20	girona	13.69	20	poli_cartagena	5,579.59	20	castilla_mancha
21	valencia	62.69	21	jaume	13.83	21	la_laguna	5,565.51	21	complutense_madrid
22	valladolid	62.66	22	miguel_hernandez	14.18	22	santiago_compostela	5,541.42	22	santiago_compostela
23	cadiz	61.72	23	santiago_compostela	14.25	23	miguel_hernandez	5,452.93	23	miguel_hernandez
24	cordoba	60.77	24	autonoma_barcelona	14.29	24	huelva	5,410.31	24	jaume
25	poli_valencia	60.12	25	extremadura	14.40	25	valencia	5,263.30	25	pablo_olavide
26	malaga	59.96	26	alicante	14.43	26	valladolid	5,235.92	26	poli_cartagena
27	oviedo	59.90	27	oviedo	14.51	27	girona	5,199.26	27	valencia
28	alcala	59.67	28	castilla_mancha	14.62	28	cordoba	5,174.40	28	la_laguna
29	is_balears	59.65	29	complutense_madrid	14.65	29	oviedo	5,122.66	29	oviedo
30	miguel_hernandez	59.58	30	pablo_olavide	14.67	30	la_rioja	4,989.41	30	leon

31	la_rioja	59.55	31	cadiz	14.69	31	las_palmas_gran_canaria	4,982.85	31	burgos
32	granada	59.43	32	roviraivirg	14.73	32	burgos	4,937.57	32	cadiz
33	jaen	59.33	33	valencia	14.83	33	leon	4,906.13	33	cordoba
34	sevilla	58.48	34	murcia	14.89	34	almeria	4,855.43	34	alicante
35	rey_jc	58.34	35	leon	14.94	35	pablo_olavide	4,854.67	35	la_rioja
36	almeria	57.51	36	is_baleares	15.03	36	alicante	4,810.37	36	almeria
37	vigo	57.19	37	almeria	15.23	37	cadiz	4,793.49	37	sevilla
38	burgos	57.17	38	sevilla	15.38	38	sevilla	4,651.48	38	is_baleares
39	jaume	56.76	39	las_palmas_gran_canaria	15.44	39	granada	4,596.67	39	extremadura
40	la_laguna	55.42	40	vigo	15.61	40	murcia	4,594.07	40	las_palmas_gran_canaria
41	alicante	54.88	41	jaen	16.00	41	malaga	4,485.53	41	malaga
42	murcia	54.66	42	a_corunya	16.08	42	vigo	4,407.93	42	granada
43	a_corunya	54.52	43	la_rioja	16.09	43	jaen	4,299.41	43	murcia
44	las_palmas_gran_canaria	54.10	44	granada	16.34	44	extremadura	4,177.62	44	jaen
45	extremadura	53.60	45	rey_jc	16.67	45	a_corunya	4,176.07	45	vigo
46	poli_madrid	52.03	46	cordoba	16.89	46	rey_jc	4,171.95	46	rey_jc
47	poli_cartagena	51.25	47	malaga	17.63	47	is_baleares	4,168.86	47	a_corunya

Table 2. Research performance rankings for Spanish public universities. Academic year 2006/2007.

R	University	Thesis awarded/ 100 Professor holding PhD	R	University	ISI publications/ Total tenured professor	R	University	Sexenios/ Total tenured professor	Global R	University
1	miguel_hernandez	61.9	1	burgos	3.89	1	autonoma_madrid	2.31	1	autonoma_madrid
2	autonoma_barcelona	20.2	2	roviraivirg	0.96	2	pompeu_fabra	1.95	2	pompeu_fabra
3	complutense_madrid	19.0	3	alicante	0.91	3	autonoma_barcelona	1.94	3	cordoba
4	autonoma_madrid	18.3	4	castilla_mancha	0.79	4	carlosIII_madrid	1.78	4	santiago_compostela
5	barcelona	16.0	5	lleida	0.71	5	complutense_madrid	1.70	5	roviraivirg
6	poli_catalunya	15.5	6	autonoma_madrid	0.63	6	barcelona	1.66	6	alicante
7	valencia	14.7	7	girona	0.56	7	santiago_compostela	1.65	7	complutense_madrid
8	pompeu_fabra	14.6	8	santiago_compostela	0.55	8	valencia	1.62	8	granada
9	cordoba	14.2	9	cantabria	0.45	9	cantabria	1.59	9	cantabria
10	alcala	14.1	10	cordoba	0.44	10	pablo_olavide	1.56	10	alcala
11	alicante	13.9	11	valladolid	0.44	11	granada	1.54	11	autonoma_barcelona
12	rey_jc	13.4	12	vigo	0.43	12	cordoba	1.53	12	miguel_hernandez
13	roviraivirg	13.0	13	oviedo	0.41	13	murcia	1.46	13	oviedo
14	salamanca	12.8	14	granada	0.37	14	salamanca	1.45	14	barcelona
15	leon	12.7	15	jaen	0.34	15	alcala	1.44	15	valencia
16	granada	11.9	16	pompeu_fabra	0.33	16	oviedo	1.36	16	leon
17	jaume	11.9	17	almeria	0.32	17	sevilla	1.35	17	murcia
18	santiago_compostela	11.7	18	zaragoza	0.32	18	zaragoza	1.34	18	zaragoza
19	almeria	11.5	19	leon	0.32	19	miguel_hernandez	1.27	19	carlosIII_madrid
20	oviedo	11.4	20	carlosIII_madrid	0.32	20	is_baleares	1.24	20	sevilla
21	poli_valencia	11.0	21	murcia	0.32	21	roviraivirg	1.19	21	almeria
22	sevilla	10.7	22	alcala	0.31	22	publica_navarra	1.19	22	lleida
23	vigo	10.7	23	is_baleares	0.29	23	poli_catalunya	1.16	23	is_baleares
24	poli_cartagena	10.6	24	la_laguna	0.29	24	alicante	1.14	24	poli_catalunya
25	zaragoza	9.5	25	malaga	0.28	25	leon	1.13	25	vigo
26	murcia	9.4	26	publica_navarra	0.28	26	valladolid	1.11	26	salamanca
27	cantabria	9.3	27	sevilla	0.27	27	jaume	1.09	27	publica_navarra
28	publica_navarra	9.3	28	poli_cartagena	0.27	28	malaga	1.08	28	girona

29	is_baleares	8.8	29	miguel_hernandez	0.26	29	extremadura	1.07	29	castilla_mancha
30	extremadura	8.7	30	poli_valencia	0.26	30	lleida	1.03	30	valladolid
31	a_corunya	8.7	31	extremadura	0.26	31	la_laguna	1.01	31	pablo_olavide
32	pais_vasco	8.5	32	complutense_madrid	0.25	32	pais_vasco	0.99	32	malaga
33	malaga	8.2	33	a_corunya	0.23	33	girona	0.95	33	rey_jc
34	poli_madrid	8.1	34	poli_madrid	0.23	34	almeria	0.89	34	burgos
35	pablo_olavide	8.0	35	rey_jc	0.23	35	la_rioja	0.87	35	extremadura
36	lleida	8.0	36	la_rioja	0.23	36	castilla_mancha	0.86	36	jaume
37	cadiz	7.7	37	cadiz	0.20	37	vigo	0.86	37	poli_valencia
38	girona	7.7	38	pais_vasco	0.20	38	cadiz	0.83	38	la_laguna
39	castilla_mancha	7.5	39	huelva	0.17	39	rey_jc	0.83	39	poli_cartagena
40	burgos	7.5	40	pablo_olavide	0.17	40	jaen	0.82	40	jaen
41	carlosIII_madrid	7.4	41	las_palmas_gran_canaria	0.17	41	a_corunya	0.77	41	pais_vasco
42	las_palmas_gran_canaria	7.3	42	valencia	0.16	42	poli_madrid	0.77	42	a_corunya
43	la_laguna	7.2	43	poli_catalunya	0.13	43	poli_valencia	0.64	43	poli_madrid
44	valladolid	6.9	44	autonoma_barcelona	0.11	44	huelva	0.61	44	cadiz
45	jaen	6.4	45	barcelona	0.11	45	las_palmas_gran_canaria	0.61	45	la_rioja
46	la_rioja	6.0	46	salamanca	0.10	46	poli_cartagena	0.60	46	las_palmas_gran_canaria
47	huelva	5.4	47	jaume	0.09	47	burgos	0.59	47	huelva

Table 3. Knowledge-transfer performance rankings for Spanish public universities. Academic year 2006/2007.

R	University	(%) Patent applied per Teacher Staff (FTE)	R	University	Contracts income/Teacher Staff (FTE)	R	University	Grants income/Teacher Staff (FTE)	Global R	University
1	poli_catalunya	1.17	1	poli_valencia	18.194,64	1	roviraivirg	19.086,22	1	poli_catalunya
2	alcala	0.91	2	cantabria	13.027,82	2	santiago_compostela	17.191,75	2	cantabria
3	cadiz	0.90	3	poli_catalunya	12.282,57	3	poli_catalunya	17.167,04	3	poli_valencia
4	poli_valencia	0.87	4	autonoma_madrid	10.108,11	4	pompeu_fabra	16.973,66	4	poli_madrid
5	almeria	0.80	5	roviraivirg	9.737,44	5	cantabria	16.174,14	5	autonoma_madrid
6	vigo	0.64	6	poli_madrid	8.508,77	6	autonoma_madrid	13.351,17	6	sevilla
7	poli_cartagena	0.63	7	santiago_compostela	7.569,99	7	almeria	12.876,17	7	publica_navarra
8	poli_madrid	0.62	8	carlosIII_madrid	6.205,59	8	cordoba	12.724,78	8	almeria
9	cantabria	0.55	9	autonoma_barcelona	6.035,96	9	sevilla	12.166,14	9	cordoba
10	burgos	0.49	10	barcelona	5.730,56	10	pablo_olavide	11.684,91	10	roviraivirg
11	sevilla	0.48	11	poli_cartagena	5.639,60	11	poli_valencia	10.872,12	11	santiago_compostela
12	cordoba	0.47	12	publica_navarra	5.373,72	12	cadiz	10.844,45	12	barcelona
13	publica_navarra	0.43	13	zaragoza	5.344,54	13	granada	10.724,67	13	cadiz
14	leon	0.43	14	girona	5.017,49	14	publica_navarra	10.481,99	14	pompeu_fabra
15	malaga	0.42	15	miguel_hernandez	4.921,00	15	barcelona	10.354,15	15	miguel_hernandez
16	miguel_hernandez	0.40	16	extremadura	4.898,06	16	poli_madrid	9.849,82	16	alcala
17	granada	0.36	17	valencia	4.359,03	17	girona	9.630,28	17	carlosIII_madrid
18	is_baleares	0.34	18	sevilla	3.938,14	18	castilla_mancha	8.923,81	18	poli_cartagena
19	alicante	0.33	19	pompeu_fabra	3.900,37	19	carlosIII_madrid	8.882,52	19	girona
20	oviedo	0.31	20	castilla_mancha	3.899,74	20	extremadura	8.845,81	20	zaragoza
21	salamanca	0.29	21	a_corunya	3.852,28	21	is_baleares	8.712,62	21	autonoma_barcelona
22	zaragoza	0.29	22	cordoba	3.666,11	22	lleida	8.712,21	22	extremadura
23	murcia	0.28	23	alcala	3.483,33	23	autonoma_barcelona	8.667,20	23	lleida
24	autonoma_madrid	0.28	24	lleida	3.454,51	24	miguel_hernandez	8.585,45	24	leon
25	jaen	0.22	25	las_palmas_gran_canaria	3.312,88	25	pais_vasco	8.379,65	25	granada
26	barcelona	0.21	26	oviedo	3.217,74	26	valladolid	7.671,90	26	is_baleares
27	complutense_madrid	0.19	27	pais_vasco	3.118,00	27	leon	7.591,73	27	vigo
28	lleida	0.15	28	huelva	3.103,00	28	vigo	7.393,20	28	castilla_mancha
29	huelva	0.13	29	almeria	3.018,03	29	zaragoza	7.298,09	29	pablo_olavide
30	pompeu_fabra	0.12	30	pablo_olavide	2.877,76	30	murcia	6.866,44	30	oviedo
31	girona	0.12	31	jaume	2.856,56	31	jaen	6.853,42	31	pais_vasco
32	rey_jc	0.09	32	alicante	2.816,88	32	huelva	6.765,82	32	murcia
33	carlosIII_madrid	0.07	33	rey_jc	2.812,03	33	jaume	6.275,02	33	valencia
34	las_palmas_gran_canaria	0.07	34	leon	2.765,19	34	alcala	6.262,09	34	huelva

35	pais_vasco	0.07	35	murcia	2.603,14	35	valencia	6.077,58	35	alicante
36	valencia	0.07	36	complutense_madrid	2.540,36	36	rey_jc	6.063,78	36	jaen
37	extremadura	0.06	37	cadiz	2.428,63	37	la_rioja	5.968,08	37	malaga
38	la_laguna	0.06	38	is_baleares	2.306,23	38	complutense_madrid	5.830,97	38	complutense_madrid
39	santiago_compostela	0.05	39	malaga	2.281,29	39	alicante	5.258,03	39	rey_jc
40	autonoma_barcelona	0.04	40	jaen	1.887,81	40	a_corunya	5.018,42	40	burgos
41	pablo_olavide	0.00	41	la_rioja	1.780,14	41	oviedo	4.331,44	41	las_palmas_gran_canaria
42	roviraivirg	0.00	42	salamanca	1.745,29	42	poli_cartagena	4.297,57	42	a_corunya
43	castilla_mancha	0.00	43	vigo	1.528,39	43	la_laguna	3.908,68	43	jaume
44	jaume	0.00	44	valladolid	1.410,71	44	las_palmas_gran_canaria	3.877,49	44	salamanca
45	valladolid	0.00	45	la_laguna	1.222,32	45	malaga	3.771,36	45	valladolid
46	a_corunya	0.00	46	granada	810,74	46	burgos	3.571,30	46	la_rioja
47	la_rioja	0.00	47	burgos	642,59	47	salamanca	2.713,74	47	la_laguna

### **3. Methodology**

Clustering involves grouping data points into homogeneous classes or clusters such that in every class, the items included are as similar as possible. Clustering can be thought of as a form of data compression, where large numbers of samples are converted into a small numbers of representative prototypes or clusters. Depending on the data and the application, different types of similarity measures can be used to identify classes, and to control for how clusters are formed.

In non-fuzzy or hard clustering, data are divided into crisp clusters, in which each data point belongs to exactly one cluster. In fuzzy clustering, data points can belong to more than one cluster; for each point there is an associated membership grade, which indicates the degree to which the data points belong to the different clusters. In real applications the boundaries between clusters are often not sharply defined, so that fuzzy clustering is often preferred. Degrees of membership between zero and 1 are applied in fuzzy clustering rather than the clear assignment of data to clusters. The most prominent fuzzy clustering algorithm is fuzzy c-means (FCM), a fuzzification of k-Means or ISODATA.

The family of objective, function-based, fuzzy clustering algorithms includes, amongst others, the FCM algorithm which are spherical clusters of approximately the same size; the Gustafson-Kessel (GK) algorithm, which are ellipsoidal clusters also of approximately the same size; axis-parallel variants of this algorithm can be used (to an extent) to detect lines; the Gath-Geva (GG) algorithm/Gaussian mixture decomposition (GMD), which are ellipsoidal clusters of varying sizes; axis-parallel variants of this algorithm can be used (to some extent) to detect lines; the fuzzy c-varieties (FCV) algorithm, which detect linear manifolds (infinite lines in 2D); the adaptive fuzzy c-varieties (AFC) algorithm, which detect line segments in 2D data; the fuzzy c-shells

(FCS) algorithm, which detect circles (no closed form solution for prototypes); the fuzzy c-spherical shells (FCSS) algorithm, which detect circles; the fuzzy c-rings (FCR) algorithm, which detect circles; the fuzzy c-quadric shells (FCQS) algorithm, which detect ellipsoids; the fuzzy c-rectangular shells (FCRS) algorithm, which detect rectangles (and variants thereof) (for more detail see Höppner et al., 1999). In this study we apply the FCM algorithm.

FCM is a method of clustering which allows one piece of data to belong to two or more clusters. This method (developed by Dunn in 1973 and improved by Bezdek in 1981) is used frequently in pattern recognition. It is based on minimization of the following objective function:

$$J_m = \sum_{i=1}^N \sum_{j=1}^C u_{ij}^m \|x_i - c_j\|^2, \quad 1 \leq m < \infty$$

where  $m$  is any real number greater than 1,  $u_{ij}$  is the degree of membership of  $x_i$  in the cluster  $j$ ,  $x_i$  is the  $i$ th of  $d$ -dimensional measured data,  $c_j$  is the  $d$ -dimension centre of the cluster, and  $\|\cdot\|$  is any norm expressing the similarity between any measured data and the centre.

Fuzzy partitioning is carried out through iterative optimization of the objective function shown above, with update of membership  $u_{ij}$  and the cluster centres  $c_j$  by:

$$u_{ij} = \frac{1}{\sum_{k=1}^C \left( \frac{\|x_i - c_j\|}{\|x_i - c_k\|} \right)^{\frac{2}{m-1}}}, \quad c_j = \frac{\sum_{i=1}^N u_{ij}^m \cdot x_i}{\sum_{i=1}^N u_{ij}^m}$$

This iteration will stop when  $\max_i \left\{ |u_{ij}^{(k+1)} - u_{ij}^{(k)}| \right\} < \epsilon$ , where  $\epsilon$  is a termination criterion between 0 and 1, and  $k$  are the iteration steps. This procedure converges to a local minimum or saddle point of  $J_m$ . The algorithm is composed of the following steps:

1. Initialize  $U=[u_{ij}]$  matrix,  $U^{(0)}$
2. At  $k$ -step: calculate the centers vectors  $C^{(k)}=[c_j]$  with  $U^{(k)}$

$$c_j = \frac{\sum_{i=1}^N u_{ij}^m \cdot x_i}{\sum_{i=1}^N u_{ij}^m}$$

3. Update  $U^{(k)}$ ,  $U^{(k+1)}$

$$u_{ij} = \frac{1}{\sum_{k=1}^c \left( \frac{\|x_i - c_j\|}{\|x_i - c_k\|} \right)^{\frac{2}{m-1}}}$$

4. If  $\|U^{(k+1)} - U^{(k)}\| < \epsilon$  then STOP; otherwise return to step 2.

## 4. Results

The fuzzy clustering approach produces three main clusters. Two are completely independent, one being the teaching mission and the other the research and knowledge transfer missions. The third one refers to all three main missions combined: teaching, research and knowledge transfer.

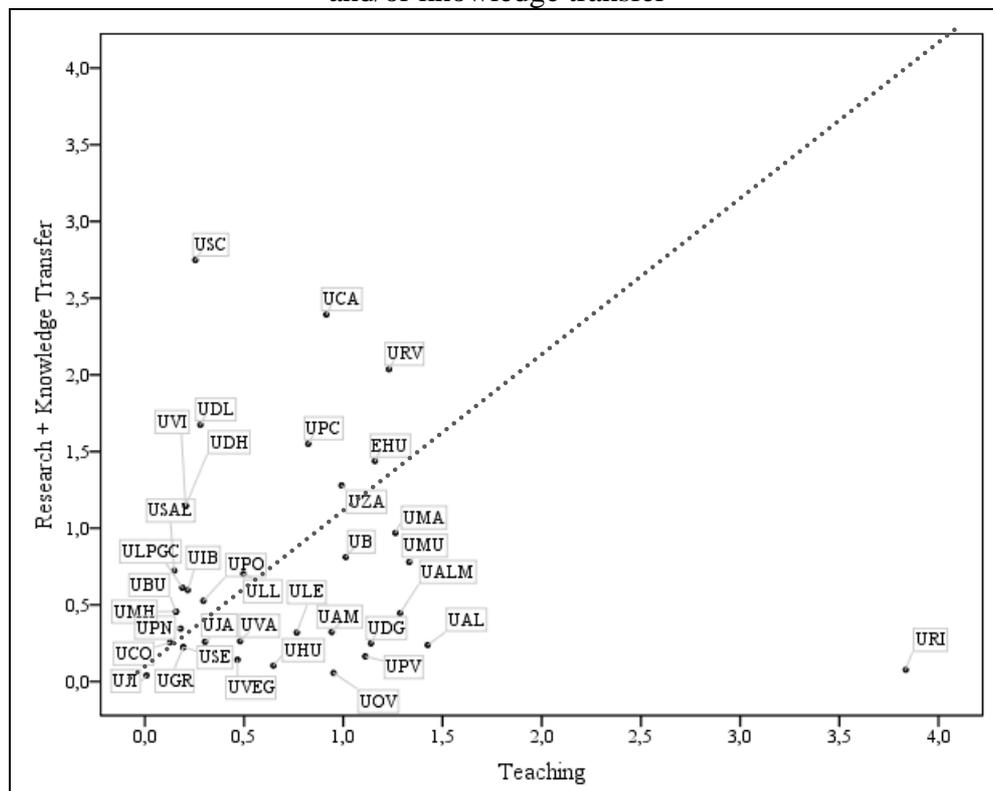
Figure 1 shows the university groups according to their score for each factor. It gives an idea of the possible orientation of the university missions based on the indicators used in this paper. For example, universities below the diagonal are more oriented to teaching. In this group there are 14 universities with the University of Rioja, University of Alicante, Technical University of Valencia, University of Oviedo, University of Girona, Autonomous University of Madrid, University of Huelva, University of Valencia and University of Valladolid receiving high scores for teaching and low scores for research and knowledge transfer. It includes also the University of Leon, University of Barcelona, University of Murcia, University of Malaga and

University of Almeria, which although oriented to teaching, also score high for the other two missions.

Above the diagonal are the universities oriented to research and knowledge transfer. In this group are 18 institutions the highest scoring being the Santiago of Compostela University, the University of Cadiz and the Rovira i Virgili University. In addition, University of Salamanca, University of Leon, University of Vigo and University of Corunya score high for these two missions and low for teaching.

Finally, there are four institutions located very close to the diagonal, which are associated mainly with the third cluster and have a well balanced orientation to all three university missions. These are the University of Jaen, University of Seville, University of Granada and Jaume I University.

Figure 1. Grouping of universities according to their orientation to teaching, research and/or knowledge transfer



## 5. Conclusions

University rankings provide information helpful to both students and parents who are demanding independent analysis of universities, and universities and HE policy-makers who need to know the strengths and weaknesses of academic institutions in an increasingly global education market. It justifies the engagement of researchers in efforts to improve university rankings.

The evaluation of universities has promoted much attention and debate about the key indicators that can be used to assess their activities. Many have expressed doubts about the meaning and purpose of such evaluations, especially where the areas being evaluated and the measures used are unproven. One of the criticisms of university league tables is that scores are based on relative weights applied to several criteria. This is true of the global university rankings compiled by Shanghai Jiao Tong University in China and other international and national rankings, including the particular academic ranking system applied to the Spanish HE System.

This paper proposes an alternative approach. First, we present groups of indicators for each of the three main university missions: teaching, research and knowledge transfer, to classify Spanish public universities according to numerical rankings, for the academic year 2006/07. From this we can calculate a global ranking. We also group Spanish public universities into clusters but without making any assumptions about the relative importance of each criterion, based on a fuzzy clustering approach.

We find considerable variability in the ranking of universities depending on the indicator considered. In the past, consensus has been reached about which universities are “the best” focusing on only one unique indicator, avoiding that the diversity of universities across countries is not appreciated. The fuzzy clustering approach reveals that Spanish public universities are not as homogeneous as has sometimes been

assumed, leaving aside size and number of degrees and fields of study offered. Some universities are focusing more on teaching activities, others more on research or knowledge transfer.

Further analysis is needed to confirm these preliminary findings. Also, account should be taken of the limitations of indicators, which need to be combined with qualitative methods to produce optimal assessments and inform policy. Quality assessment of universities is difficult and requires diverse methods and techniques, and international alliances among HEI. Well-designated university rankings based on rigorous methodological criteria would be effective instruments to support this endeavour.

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