PATTERNS OF EFFICIENCY IN R&D EXPENDITURE.
A COMPARED ANALYSIS OF SPANISH AND ITALIAN REGIONS

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Abstract:
Research and Development activities are key elements in the search of more productive economic outcomes, the generation of new economic sectors and, in general, of a better economic performance at the micro and macro levels.
In many European countries, the responsibility of the design and implementation of R&D policies is shifting from the national level to the regional level, making the regional level a relevant field of analysis. Spain and Italy are examples of this progressive change.
At the same time, the financial, economic and social crisis that is affecting the countries situated in the periphery of the euro area is reducing the budget for R&D activities that firms, universities, public administrations and other institutions can devote to this issue. Again, Spain and Italy are clear examples of economic difficulties and diminishing public and private budgets. In this context, it is crucial to assess and measure the efficiency of all kind of expenditures, especially the ones that are directly linked with the achievement of a more competitive economy. In this way, regions achieving more efficiency should be granted with more funding or, alternatively, not efficient regions should adapt efficient R&D policies to their own institutional and social backgrounds.

In this paper we will use the DEA (Data Envelopment Analysis) methodology in order to measure at the regional level the efficiency ratio between R&D inputs and the outcomes achieved. DEA methodology compares the amount of inputs used with the outcomes achieved, ordering regions in terms of productivity, not in terms of absolute values. Following this path, the best ranked region will be the one that minimizes the use of inputs maximizing the amount of outputs.

Results over time will be discussed and regions will be grouped according to their efficiency level and their evolution in this field over time. In fact, we will compare the evolution of the efficiency level in two different periods of time: the first one before the current economic crisis and the second one in the beginning of it (only for the outputs). Comparisons between regions will be made at the national level (Italian regions on one side and Spanish regions on the other) and also adding all regions from the two countries. Typologies of regions according to their efficiency levels will be outlined and justified.

The paper will conclude with some policy recommendations for each group of regions, so that regions can design policies and adopt measures in order to improve their efficiency and their overall results regarding R&D.

1. INTRODUCTION

R&D investment has become one of the main variables to achieve competitive advantages. These competitive advantages, in the long run, will create higher levels of prosperity in a given region. This idea has been accepted by economic theory since Adam Smith, but it has been in recent times when economic theory has focused in R&D and its connection with policy makers and society in general (Dodgson and Rothwell, 1994; Porter, 1998; Porter et al., 2000).

Once we have highlighted the importance of R&D as a basic tool to achieve higher levels of prosperity in a given society, it would be obvious that the public administration would support R&D activities through a proper public policy. Additionally, the different schools of economic thought are in favor of this kind of behavior (Velasco, 1996). The neoclassical literature accepts that the competitive market underinvests in R&D activities (Mani, 2002). Hence, the level of R&D

investment that maximizes profit for firms is smaller than the level of R&D that maximizes social prosperity (Arrow, 1962; Beije, 1998).

On the other hand, the evolutionary school, linked with the concept of regional innovation system (RIS), proposes the public intervention to strengthen the different economic agents inside a RIS, and also to increase the interaction among these actors (Lundvall, 1992).

A consequence of the positive economic results that governments and firms link with R&D investment has been a non-stop increasing in the public and private funding devoted to R&D in almost all developed economies. Spain and Italy have followed this path, although disparities between regions in Spain and Italy are quite big (Martínez and Aguado, 2009) (Miceli, 2010).

Although the volume of private and public expenditure in R&D activities has been growing for the last decades both at the national and regional levels, there are few studies about the efficiency of this kind of expenditure, specially at the regional level.

In this work we are going to present a comparative study of all regions in Spain and Italy. These two countries share important similarities: cultural features, level of expenditure in R&D, level of economic development, regional disparities, and also some differences, such as the level of political decentralization (much higher in Spain). In this paper we will analyze the efficiency of R&D expenditures taking into account Italian and Spanish regions, in order to build a common taxonomy, discover similarities and disparities between the two countries and contextualize the results achieved by regions in each country.

Some attempts to measure the efficiency of RIS at the Italian, Spanish and European level have been done by different authors in recent times (Navarro, Gibaja, Aguado and Bilbao-Osorio, 2009) (Buesa and Heijs, 2007) (Martínez Pellitero, 2007) (Brioschi, Cassia and Colombelli, 2006). In these studies the conceptual framework of RIS has been used to select a range of variables linked with inputs and outputs of R&D activities. In all these cases, the methodology and statistical use of data has been similar: principal component analysis to highlight the main dimensions that explain regional behavior in R&D activities and then a cluster analysis to gather regions in groups with common features measured in the axes defined previously in the principal component analysis.

This kind of econometric analysis is used to group regions with similar levels of economic development, R&D inputs and R&D outputs. Moreover, it helps in finding the strong and weak points of each group of regions in comparison to the rest of groups.

However, this kind of analysis does not link directly the amount of output achieved with the amount of inputs devoted to R&D. A region (region Y) using a great quantity of R&D inputs and achieving exactly the same output as other region (region Z) that uses a smaller amount of R&D inputs would appear in a higher position in the ranking of innovative regions. In reality, region Z is using its resources in a more efficient way than region Y, so region Z should be highlighted as more efficient and rank in a higher position.

Different authors have tried to measure the efficiency of RIS in Italy and Spain (Buesa and Heijs, 2007) (Miceli, 2010). In these analyses the number of patent applications in the national patent office or in the European Patent Office (EPO) has been used as one of the main or even unique R&D output indicator.

The number of patent applications has been a widely used indicator in the economic literature (Kamien and Schwartz, 1975) (Mani, 2002), and allows quick comparisons between regions and nations. However, the use of this indicator as the only variable to measure the R&D output does not allow to take into consideration the whole result achieved by a region in this field (Álvarez, Aguado and Martínez, 2008). In some economic sectors, the propensity to patent may be very low. In other cases, firms may develop products or processes which are new to the firm, but not to the sector at the global level. In this case, a patent is not possible, although that company has achieved an R&D output. In addition to these limitations, in the case of Spain and Italy, the number of patent applications is very low in comparison with other developed economies (EU average, Japan, USA) (EC, 2009). Due to the aforementioned facts, it may sensible to complement the number of patent applications with other variables in order to have a better measure of the R&D output of regions in Spain and Italy.

The objective of this work is to measure the efficiency (productivity) of Italian and Spanish regions in R&D activities, building a regional taxonomy according to those efficiency levels. In order to fulfill this task we will use the statistical tool Data Envelopment Analysis-DEA. It is also important to notice that this will be a dynamic analysis: we will consider the values of selected indictors in two different time periods: the first one will cover the period just before the current economic crisis started and the

second one covers the period where the crisis has been taking place (especially for outputs).

The paper is developed as follows. In section 2 the evolution of the R&D expenditure in Italian and Spanish regions will be analyzed, in the context of the EU. In section 3 the Data Envelopment Analysis tool will be explained in detail and also its relation with measuring the efficiency (productivity) of R&D activities. In section 4 the methodology followed in this paper will be described and in section 5 the results of the DEA analysis will be presented. The paper ends with a conclusions section.

2. EVOLUTION OF R&D EXPENDITURES IN SPANISH AND ITALIAN REGIONS IN THE CONTEXT OF THE EU

As mentioned in the introduction, the relevance of the productivity of investment in R&D in the long-term growth of the economy is a topic widely accepted in economic literature (Cameron, 1998). In recent years, two articles (Balmaseda and Melguizo, 2007 and Escribá and Murgui, 2007) have been working on the relationship between investment in R&D and production in Spain showing its importance. In Italy, this relationship has also been addressed in relatively recent publications (Miceli, 2010, Brioschi, Cassia and Colombelli, 2006). In this section we will make a brief overview on the status of R&D in EU countries, focusing on Italian and Spanish regions[1].

As seen in Table 1, Spain's position is low in terms of total investment in R&D relative to GDP, under the average of the Euro area in all indicators. In the Italian case the situation is similar: lower values than the ones achieved by the average of the Euro area in all cases. However, the increase of the investment in R&D measured as a percentage of GDP has been positive for both countries in almost all sectors from 2005 to 2010. This positive trend has been of insufficient entity to reach the leading countries, like Sweden and Finland, which exceed 3% by far. As a result of this issue, Italy and Spain remain under the average of almost all indicators for the EU-27 and the Euro area showed in table 1.

[1] A similar work but focusing in the countries of the EU-15 has been carried out by Romero et al., 2007.

Table 1. R&D expenditure by performance sectors, in % of GDP, 2005-10

	Business enterprise sector		Government sector		Higher education sector	
	2005	2010	2005	2010	2005	2010
EU-27	1.15	1.23	0.25	0.27	0.41	0.49
Euro area (EA-17)	1.16	1.27	0.27	0.30	0.40	0.48
Belgium	1.24	1.32	0.15	0.19	0.41	0.46
Bulgaria	0.10	0.30	0.31	0.22	0.05	0.07
Czech Republic	0.86	0.97	0.27	0.30	0.22	0.28
Denmark (1)	1.68	2.08	0.16	0.06	0.60	0.90
Germany	1.74	1.90	0.35	0.41	0.41	0.51
Estonia	0.42	0.81	0.11	0.17	0.39	0.62
Ireland	0.81	1.22	0.09	0.06	0.34	0.51
Greece	0.19	:	0.12	:	0.28	:
Spain (2)	0.60	0.71	0.19	0.28	0.33	0.39
France (3)	1.31	1.38	0.37	0.37	0.40	0.48
Italy (4)	0.55	0.67	0.19	0.18	0.33	0.36
Cyprus	0.09	0.09	0.13	0.10	0.16	0.25
Latvia	0.23	0.22	0.11	0.14	0.23	0.24
Lithuania	0.15	0.23	0.19	0.14	0.41	0.42
Luxembourg (5)	1.35	1.16	0.19	0.29	0.02	0.19
Hungary	0.41	0.69	0.26	0.21	0.24	0.23
Malta	0.38	0.37	0.03	0.02	0.16	0.23
Netherlands	1.01	0.87	0.24	0.22	0.66	0.75
Austria	1.72	1.88	0.13	0.15	0.61	0.72
Poland	0.18	0.20	0.21	0.26	0.18	0.27
Portugal	0.30	0.72	0.11	0.11	0.28	0.59
Romania	0.20	0.18	0.14	0.17	0.06	0.12
Slovenia (2)	0.85	1.43	0.35	0.38	0.24	0.29
Slovakia	0.25	0.27	0.15	0.19	0.10	0.17
Finland	2.46	2.69	0.33	0.36	0.66	0.79
Sweden (6)	2.59	2.35	0.18	0.17	0.78	0.90
United Kingdom	1.06	1.08	0.18	0.17	0.44	0.48
Iceland	1.43	:	0.65	:	0.61	:
Norway (7)	0.81	0.88	0.24	0.28	0.47	0.55
Switzerland	:	:	:	:	:	:
Croatia	0.36	0.32	0.21	0.20	0.30	0.21
Turkey	0.20	:	0.07	:	0.32	:
Japan (8)(9)	2.54	2.70	0.28	0.29	0.45	0.40
United States (9)	1.79	2.02	0.31	0.30	0.36	0.36

(1) Break in series, 2007.
(2) Break in series, business enterprise sector, 2008.
(3) Break in series, business enterprise sector, 2006.
(4) Break in series, higher education sector, 2005.
(5) Break in series, government sector, 2009.
(6) Break in series, business enterprise sector and government sector, 2005.
(7) Break in series, government sector and higher education sector, 2007.
(8) Break in series, higher education sector, 2008.
(9) 2008 instead of 2010.
Source: Eurostat (tsc00001), OECD

Table 2 shows the same kind of analysis at the regional level. In this case, only regions from Spain and Italy have been taken into account.

Table 2. R&D expenditures by sectors of performance, in % of GDP. Years 2000 and 2010. Regions of Italy and Spain.

	2005			2010		
	BERD	GOVERD	HERD	BERD	GOVERD	HERD
SPAIN	0.6	0.19	0.33	0,72	0,28	0,39
Galicia	0.38	0.14	0.36	0,42	0,15	0,37
Asturias	0.33	0.12	0.25	0,44	0,16	0,46
Cantabria	0.17	0.11	0.16	0,39	0,23	0,59
País Vasco	1.15	0.06	0.27	1,52	0,12	0,37
C.F. Navarra	1.1	0.06	0.51	1,42	0,17	0,46
La Rioja	0.44	0.07	0.15	0,53	0,32	0,21
Aragón	0.45	0.16	0.19	0,63	0,24	0,25
C. Madrid	1.04	0.46	0.31	1,12	0,57	0,36
Castilla y León	0.49	0.07	0.32	0,59	0,12	0,39
Castilla-La M.	0.18	0.07	0.17	0,36	0,1	0,23
Extremadura	0.16	0.15	0.37	0,17	0,28	0,43
Cataluña	0.86	0.15	0.34	0,94	0,33	0,39
C. Valenciana	0.37	0.13	0.48	0,43	0,15	0,49
Illes Balears	0.06	0.06	0.15	0,06	0,18	0,18
Andalucía	0.27	0.19	0.37	0,43	0,27	0,51
Región de Murcia	0.33	0.13	0.28	0,36	0,18	0,39
Canarias	0.14	0.17	0.28	0,12	0,2	0,3
ITALY	0.55	0.19	0.33	0,68	0,17	0,36
Piemonte	1.37	0.07	0.25	1,4	0,08	0,3
Valle d'Aosta/Val.	0.23	0.03	0.03	0,43	0,03	0,09
Liguria	0.67	0.24	0.31	0,86	0,26	0,33
Lombardia	0.79	0.07	0.19	0,91	0,07	0,23
P.A. Bolzano	0.21	0.05	0.04	0,36(a)	0,06(a)	0,07(a)
P.A. Trento	0.23	0.49	0.36	1,16(a)	0,47(a)	0,44(a)
Veneto	0.29	0.06	0.21	0,69(a)	0,09(a)	0,28(a)
Friuli-Venezia Gi.	0.53	0.16	0.46	0,83(a)	0,17(a)	0,46(a)
Emilia-Romagna	0.71	0.09	0.36	0,87(a)	0,11(a)	0,38(a)
Toscana	0.35	0.19	0.54	0,53(a)	0,13(a)	0,56(a)
Umbria	0.19	0.08	0.51	0,24(a)	0,05(a)	0,7(a)
Marche	0.25	0.04	0.28	0,33(a)	0,02(a)	0,36(a)
Lazio	0.51	0.88	0.38	0,65(a)	0,68(a)	0,44(a)
Abruzzo	0.49	0.17	0.37	0,38	0,11	0,43
Molise	0.04	0.07	0.3	0,04	0,08	0,37
Campania	0.42	0.14	0.55	0,46	0,14	0,56
Puglia	0.16	0.09	0.4	0,19	0,12	0,4
Basilicata	0.2	0.1	0.24	0,15	0,32	0,24
Calabria	0.03	0.05	0.29	0,03	0,05	0,38
Sicilia	0.21	0.12	0.46	0,23	0,1	0,47
Sardegna	0.04	0.13	0.41	0,05	0,12	0,5

(a): Data from 2009

Source: Eurostat and own elaboration

In the case of Spain Madrid, Navarra, Basque Country and Catalonia have the higher total expenditure in R&D on GDP in 2005 and 2010, with a clear differentiation from the rest of Spanish regions. By sector of performance, the public administration in Madrid is very significant in comparison with other regions, although the most important sector is the business one. This situation is due in part to the concentration of the main public research organizations (PROs) in the capital. By contrast, in Navarra and the Basque Country companies show the highest investment rate. In the case of the Basque Country we must consider that its powerful network of Technology Centers is included in the corporate sector for statistical purposes (Aguado, 2007). Catalonia has a more balanced distribution. Those four regions are the only ones above the average R&D expenditure in Spain, situated in the level of 1,39% of GDP in the year 2010. In the Italian case the national average expenditure in R&D for the year 2010 was 1,21% of GDP. Only eight Italian regions had the same or a higher level of expenditure: Piemonte, Liguria, Lombardia, P.A. Trento, Friuli-Venezia Giulia, Emilia-Romagna and Lazio. While the weight of the university is high in regions such as Toscana, Campania, Sardegna and Umbria, businesses play a key role in Piemonte , P.A. Trento, Friuli-Venezia Giulia and Emilia Romagna. The weight of the public sector is prominent in Lazio, for similar reasons to what happens to Madrid in Spain: the Italian public administration focuses its PROs in the capital, Rome.

3. ASSESSING R&D EFFECTIVENESS AND PRODUCTIVITY USING DATA ENVELOPMENT ANALYSIS

In many economic studies performance/productivity is defined or measured as the quantity of resource (*inputs*) needed to obtain some quantity of product (*outputs*).

This performance analysis leads us to the study of efficiency: how to obtain the best mix of resources for obtaining those results.

In general terms, the modelling approach to measuring comparative performance could be summarized in two groups:

- Parametric methods, like the Stochastic Frontier Analysis (SFA), which uses multivariate techniques to analyze the variation in the production rate or cost rate among different organizations running the same activity (i.e. financial services, hospitals, …)

- Non parametric methods, like Data Envelopment Analysis (DEA), that tries to measure the efficiency of those homogeneous entities estimating the optimum level of product as function of the type and quantity of available resources (Smith and Street, 2005).

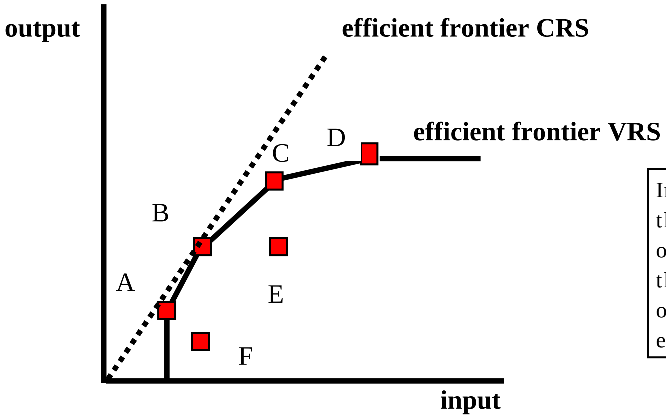
In this paper DEA[2] is being used as it was coined by Coelli, 1996. Other sources about DEA models have been taken into account, such as the work of Charnes et al (1978) in their seminal paper on DEA, based on a previous work by Farell, 1957. DEA is for measuring relative efficiency, so an organization that consumes fewer resources for getting the same quantity of product can be considered as more efficient.

With such premise, this methodology starts from the definition of Decision Making Unit (DMU) as the unit of assessment or entity whose efficiency would be relatively measured. The efficiency ratio can be defined as a weighted sum of outputs to a weighted sum of inputs.

How to obtain the weight factors? A linear programming is, then, used to get those numbers where the objective function is the efficiency ratio of a DMU and the constraint set is defined by the fact that the efficiency ratio of the rest of DMUs cannot be upper than 1 (or 100%).

Repeating the analysis for each DMU allows us to build up an efficiency frontier where more efficient DMUs are located (those which minimize inputs levels for given outputs levels or alternatively, maximize the output for given inputs levels). All those efficient DMUs have an efficiency score equal to 1 while the rest will get a lower value.

Figure 1. Efficient Frontier



In this figure, A, B, C an D are efficient DMU under VRS. On the contrary, E and F are relative inefficient units. It can be observed that unit C achieves greater output level than E with the same input level, while unit B achieve the same level of output than E with smaller level of input. Under CRS the only efficient DMU is B.

[2] A thorough study of this methodology can be found in Cooper et al., 2004, Thanassoulis, 2001 and Coelli et al., 1998.

DEA models could be classified regarding two criteria:

- The Pareto Definition: two possibilities are given:
    - the one labelled “*output oriented*”- when outputs are controllable (i.e. hospitals and resources such as doctors), determine a firm’s potential output given its inputs if it operated efficiently as firms along the best practice frontier and,
    - the one labelled “*input oriented*” – when inputs are controllable (i.e. schools and students’ attainments), how much the input use of a firm could contract if used efficiently in order to achieve the same output level
- The focus on the technical efficiency, that is
    - Constant Returns to Scale (CRS) models (Charnes et al., 1978)
    - Variable Returns to Scale (VRS) models (Banker et al., 1984).

As R&D investment is mainly focused in the obtaining of results (output maximization), an output oriented CRS model has been selected. This election is consistent with the analysis of R&D expenditure made by other authors, such as Graves and Langowitz, 1996.

Following Lee and Park, 2005, let us assume that we have *n* DMUs ($k = 1, 2, ..., n,$), using *r* inputs to secure *s* outputs.

Let x_{jk} ($j = 1, 2, ..., r,$), be the input levels used by DMU *k* and y_{ik} the levels of output *i* ($i = 1, 2, ... ,s$) secured by DMU *k*. Let u_j be the weight factor assigned to input *j* and v_i the weight factor assigned to output *i*.

The following linear programming model can be stated:

$$
\begin{aligned}
& min \sum_{j=1}^{r} u_j x_{jk} \\
& s.a. \sum_{i=1}^{s} v_i y_{ik} = 1, \\
& \sum_{i=1}^{s} v_i y_{il} - \sum_{j=1}^{r} u_j x_{jl} \leq 0, \qquad l = 1,2,...,n \\
& u_j \geq \varepsilon > 0, \qquad j = 1,2...,r \\
& v_i \geq \varepsilon > 0, \qquad i = 1,2...,s
\end{aligned}
\qquad (1)
$$

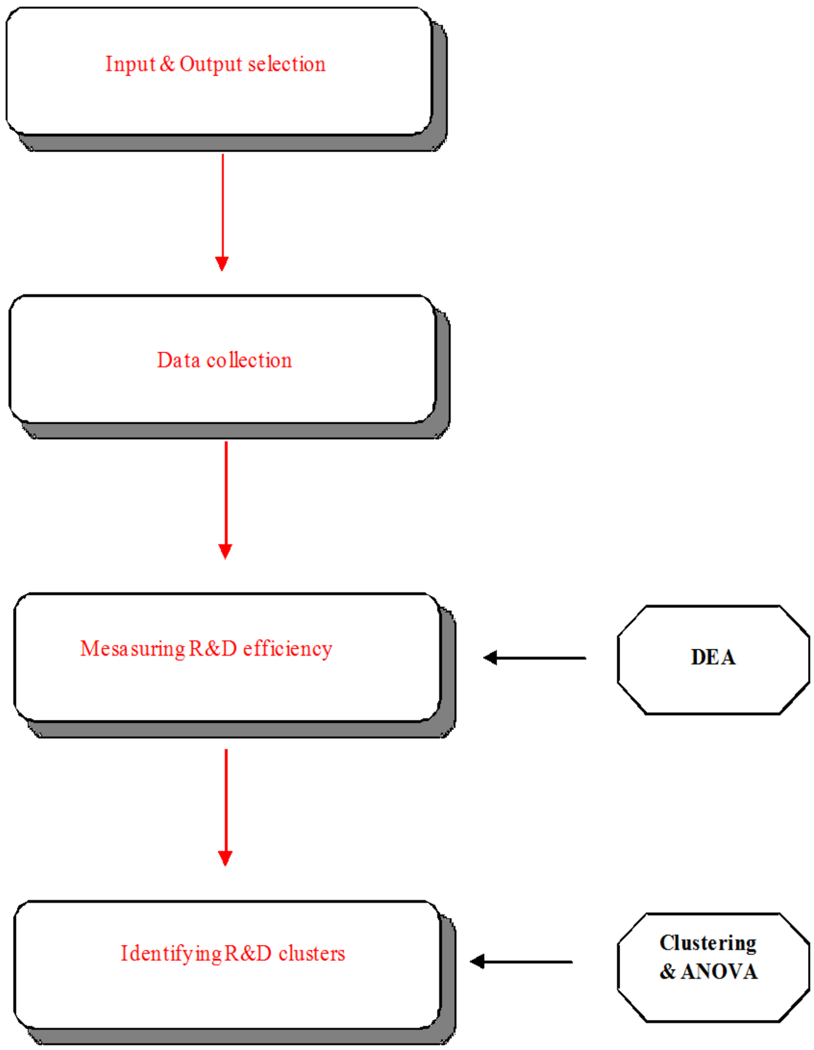
where ε is a very small positive number to avoid null weight factors.

4. METHODOLOGY

The methodology used in this paper is straightforward and it is depicted in Figure 2.

- Firstly, the input-output variables have been selected following recommendations found in previous studies that analyze efficiency in R&D expenditure.
- Secondly, data from 38 regions (17 Spanish regions and 21 Italian regions) have been collected.
- Next, R&D activities' efficiency have been measured based on DEA models.
- Finally, an exercise of clustering the analyzed regions has been made according to the previous findings and results.

Figure 2. A four- step methodology



Source: own elaboration based upon Lee y Park, 2005

On building the efficiency models 3 inputs and 3 outputs have been considered. Table 3 summarizes their key characteristics.

As this is a dynamic analysis, we are going to compare the evolution of the efficiency levels in two periods of time: the first one before the current economic crisis started and the second one in the beginning of the crisis (for the outputs only). Although the crisis situation has hit badly the two countries, the economic and social situation in Spain has worsened at a higher degree (OECD, 2012) in comparison with Italy.

Table 3. Input and Output Variables

Variable	Description	Unit of Measurement	Source	Variable as Used on DEA
INPUT GOVERD	Expenditure in R&D made by Public Administrations	% GDP	Eurostat	1) Average 1998-2001 2) Average 2004-2007
INPUT BERD	Expenditure in R&D made by the business sector	% GDP	Eurostat	1) Average 1998-2001 2) Average 2004-2007
INPUT HERD	Expenditure in R&D made by High Education Institutions	% GDP	Eurostat	1) Average 1998-2001 2) Average 2004-2007
OUTPUT GDPpc	GDP per cápita	€/million pers.	Eurostat	1) 2004 2) 2009
OUTPUT Patents	Ordered Patents EPO per cápita	patents/million pers.	Eurostat	1) 2003 2) 2009
OUTPUT Employment	Knowledge intensive services and High & mid tech manufacturing employment	%	Eurostat	1) 2004 2) 2008

Source: own elaboration based on Eurostat data

For measuring R&D outputs three variables have been selected: GDP per capita, knowledge intensive services and high & mid tech manufacturing employment and the number of patents applied for in the European Patent Organization. Those indicators (one of them alone, or a combination of the three) have been used in relatively recent literature in order to measure R&D outputs. For example, Buesa et al., 2007; Navarro, Gibaja, Aguado and Bilbao-Osorio, 2009 used the number of patents, while Martínez-Pellitero, 2002 and 2007, and Buesa and Heijs, 2007 used GDP per capita and knowledge intensive services and high & mid tech manufacturing employment as output variables.

On selecting the two time periods covered by input and output data, a lag has been used, as R&D inputs are not turned into outputs instantaneously. Some studies (i.e. Lee and Park, 2005) state that there is a three to five years lag since R&D inputs is reverted into outputs. In this paper, inputs are being measured as the average of the values obtained in the periods 1998 – 2001 and 2004-2007, while output data has been gathered from 2003-04 data in the first case and 2008-2010 in the second case.

The whole dataset have been obtained from Eurostat. Four Italian regions have been excluded (Valle d'Aosta, P.A. Bolzano, Molise and Calabria) as their levels of expenditure by activity sector in R&D were lower than 0,01% over GDP (BERD, GOVERD and/or HERD) in at least one of the two time periods, and final results could have been distorted.

5. RESULTS

This section shows the results of measuring the efficiency of R&D investment of the 34 regions using data envelopment analysis (DEA). First, we made the analysis of efficiency using the basic model (which includes all inputs and outputs). Then, we have proceeded to the execution of partial models that combine a single output with all inputs. In this way, it is possible to measure the efficiency in R&D for each selected output (to analyze which region is more efficient minimizing the use of inputs in order to maximize the selected output).

For example, the DEA model that includes all inputs and considers patents as output can be understood as the model that measures the efficiency oriented to the achievement of patents. In the end, we have estimated three additional models apart from the basic model (which includes all inputs and outputs): the production efficiency-oriented model, the patent efficiency-oriented model and the employment efficiency-oriented model. Table 4 shows inputs and outputs included in each of the four DEA models that have been calculated.

The four models have been calculated for the two time periods considered in this study. Results will be discussed in this section.

Table 4. Inputs and Outputs considered in the DEA models

DEA MODEL	Input			Output		
	BERD	GOVERD	HERD	GDPpc	Patents	Employment
Basic Model	❍	❍	❍	❍	❍	❍
Production efficiency-oriented	❍	❍	❍	❍		
Patent efficiency-oriented	❍	❍	❍		❍	
Employment efficiency-oriented	❍	❍	❍			❍

Source: Own elaboration

Table 5 shows the results of the efficiency of R&D for the 34 regions in the four DEA models in the first time period. Seven regions achieve maximum efficiency in the basic model: Basque Country, Navarra, La Rioja and the Balearic Islands in Spain and Veneto, Marche and Lombardia in Italy. In contrast, the most inefficient regions (less than 40% efficiency) are Extremadura and Andalucía in Spain and Sicilia, Puglia and Campania in Italy. The rest are in an intermediate position between these two extremes. It is noteworthy that one of the regions 100% efficient in the basic model shows a small level of R&D investment over GDP compared to others, such as Madrid, Cataluña, Lazio and Emilia-Romagna, which have higher levels of use of inputs (see section 2). The results of efficiency of each region vary significantly from model to model. For example, the Basque Country achieves 100% efficiency in the production-oriented model (GDP per capita), but only 40% in the patent-oriented model. It seems clear, then, that the Basque Country has a strong point in productivity measured by GDP per capita, showing a clear weakness in patenting. These specific data would have remained undeveloped in the case of estimating only the basic model.

In table 6 the results achieved by Spanish and Italian regions in the second time period are shown. In the new situation none of the Spanish regions is able to reach 100% efficiency in the basic or in any other model. In contrast, 7 Italian regions are able to achieve 100% efficiency in the basic model. These regions are composed by the three ones that had this level of efficiency in the first period (Lombardia, Veneto and Marche) and new four regions (Piemonte, Friuli-Veneza Giulia, Campania and Sicilia). In the other hand, the most inefficient regions in Italy (those with efficiency below 40% in the basic model) were 5 regions in first time period and only 3 in the second one. It is important no notice that while in the first period the most inefficient regions were

divided between Spain (3) and Italy (2), in the second period all the three most inefficient regions are located in Spain.

In general terms both in Spain and in Italy the three inputs taken into account in this study (BERD, GOVERD and HERD) have increased slightly. However, in Spain this increase has been bigger than in Italy. Regarding to outputs, in general they increased until 2007 and they started to go down from 2008 and onwards. However, in Spain output levels have fallen down deeper than in Italy, especially in the last year of the survey. This explains why, in relative terms, Italian regions have gained efficiency in comparison to the Spanish ones. Anyway, we must highlight the case of some southern Italian regions (Sardegna, Sicilia, Campania, Puglia) and other center-north Italian regions (Liguria, Friuli-Venezia Giulia, Toscana) were increases in efficiency have been especially high.

These results differ markedly from those obtained by Buesa and Heijs (2007) for Spanish regions using a DEA model based on patent application as the only output for R&D investment. For Buesa and Heijs, the more efficient regions tend to coincide with that showing the highest R&D expenditure per capita and in absolute terms (Cataluña, Madrid, Valencia, Basque Country, Andalucía). However, in this study, those regions are in an intermediate position. In contrast, some regions with a reduced R&D, both in absolute and relative terms (see Section 2), are capable of reaching the highest level of efficiency. To reach this level of efficiency, regions with high input values such as Madrid, Cataluña and Lazio should get better results in the output variables.

Considering two of the output variables used to estimate the DEA models (patents and employment in knowledge intensive services and in high & mid high tech manufacturing) we have conducted a cluster analysis of the 34 regions included in the models. In order to perform this cluster analysis we have followed the Ward method (Kaufman and Rousseeuw, 1990). The results of this analysis are shown in figure 3 for the first time period and figure 4 for the second time period.

Table 5. Results of the four DEA models for the Spanish and Italian regions in percentage. First time period.

Code	Region	Basic Model	Production efficiency-oriented model	Patent efficiency-oriented model	Employment efficiency-oriented model
es11	Galicia	43.8	33.7	3.3	43.8
es12	Asturias	45.4	43.1	6.5	45.4
es13	Cantabria	65.3	59.8	10.6	65.3
es21	País Vasco	100.0	100.0	40.2	100.0
es22	C.F. Navarra	100.0	100.0	100.0	100.0
es23	La Rioja	100.0	98.5	46.2	75.6
es24	Aragón	94.1	73.4	22.5	94.1
es3	Madrid	74.7	57.8	13.9	74.7
es41	Castilla y León	56.1	55.9	14.2	56.1
es42	Castilla-la Mancha	76.3	74.5	9.8	76.3
es43	Extremadura	33.6	29.1	9.6	33.6
es51	Cataluña	77.4	61.2	36.1	77.0
es52	C. Valenciana	53.3	50.5	18.6	52.4
es53	Illes Balears	100.0	100.0	43.1	100.0
es61	Andalucía	37.3	31.9	10.2	37.3
es62	Murcia	48.8	45.2	8.2	48.8
es7	Canarias	47.6	42.5	15.1	47.6
itc1	Piemonte	94.4	78.6	91.8	86.6
itc3	Liguria	47.0	38.1	26.5	45.4
itc4	Lombardia	100.0	100.0	100.0	100.0
itd2	P.A. Trento	84.2	72.2	77.7	73.2
itd3	Veneto	100.0	90.4	100.0	92.3
itd4	Friuli-Venezia G.	44.4	38.8	35.4	41.3
itd5	Emilia-Romagna	82.4	55.5	82.4	60.1
ite1	Toscana	47.7	32.2	45.3	33.8
ite2	Umbria	55.2	42.0	36.2	51.9
ite3	Marche	100.0	84.8	100.0	83.4
ite4	Lazio	52.2	49.2	18.3	52.2
itf1	Abruzzo	49.0	35.8	19.4	48.0
itf3	Campania	25.0	19.5	5.2	24.9
itf4	Puglia	37.0	32.7	15.7	36.8
itf5	Basilicata	41.8	35.7	17.1	41.7
itg1	Sicilia	31.9	27.0	12.2	30.8
itg2	Sardegna	60.1	50.4	19.1	60.1

Source: Own elaboration

Table 6. Results of the four DEA models for the Spanish and Italian regions in percentage. Second time period.

Code	Region	Basic Model	Production efficiency-oriented model	Patent efficiency-oriented model	Employment efficiency-oriented model
es11	Galicia	52.1	32.1	18.8	52.1
es12	Asturias	37.8	28.5	8.4	37.8
es13	Cantabria	86.6	81.7	51.8	78.3
es21	País Vasco	69.4	43.0	18.6	69.4
es22	C.F. Navarra	43.9	24.6	9.8	43.9
es23	La Rioja	39.6	39.6	3.6	36.6
es24	Aragón	55.1	50.8	36.3	27.1
es3	Comunidad de Madrid	56.2	56.2	9.7	51.5
es41	Castilla y León	67.9	67.9	11.3	65.1
es42	Castilla-la Mancha	52.9	49.5	33.9	45.8
es43	Extremadura	90.0	61.7	26.4	90.0
es51	Cataluña	49.4	49.4	33.6	14.0
es52	Comunidad Valenciana	39.8	39.8	17.7	33.0
es53	Illes Balears	80.9	49.6	80.9	55.3
es61	Andalucía	44.6	30.9	1.7	44.6
es62	Murcia	67.7	36.1	67.7	51.6
es7	Canarias	39.5	39.5	7.6	25.5
itc1	Piemonte	100.0	100.0	23.9	100.0
itc3	Liguria	95.5	93.0	26.8	58.6
itc4	Lombardia	100.0	41.4	15.7	100.0
itd2	P.A. Trento	71.9	45.6	40.2	71.9
itd3	Veneto	100.0	100.0	100.0	100.0
itd4	Friuli-Venezia Giulia	100.0	100.0	100.0	100.0
itd5	Emilia-Romagna	94.5	94.5	44.7	86.0
ite1	Toscana	81.1	68.2	64.9	81.1
ite2	Umbria	46.0	45.3	17.6	40.8
ite3	Marche	100.0	46.3	100.0	64.4
ite4	Lazio	56.6	42.4	23.1	56.1
itf1	Abruzzo	41.2	41.0	8.5	28.7
itf3	Campania	100.0	82.5	41.5	100.0
itf4	Puglia	62.2	35.9	13.9	62.2
itf5	Basilicata	59.7	41.1	53.2	46.3
itg1	Sicilia	94.8	71.6	45.0	93.9
itg2	Sardegna	100.0	84.4	100.0	100.0

Source: Own elaboration

Figure 3. Typology of regions, based on efficiency in patents and employment, first time period

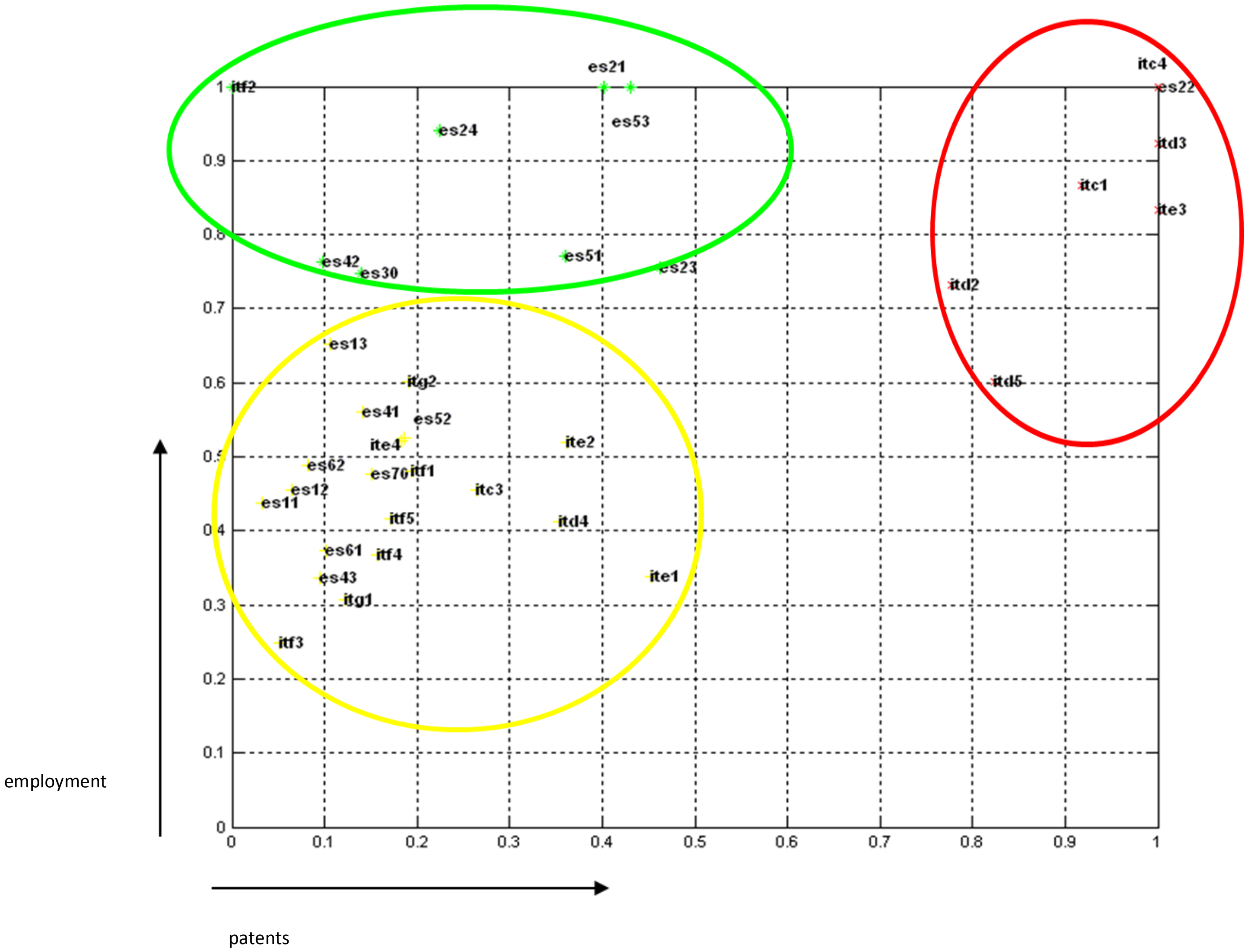


Table 7. Averages of the 3 groups of regions in the two variables considered, first time period

Cluster	Patents	Tec Employment
1	26,4809	87,2161
2	17,3234	44,8607
3	93,1311	85,0821
General Average	34,5781	62,5862

Source: Own elaboration

Figure 4. Typology of regions, based on efficiency in patents and employment, second time period

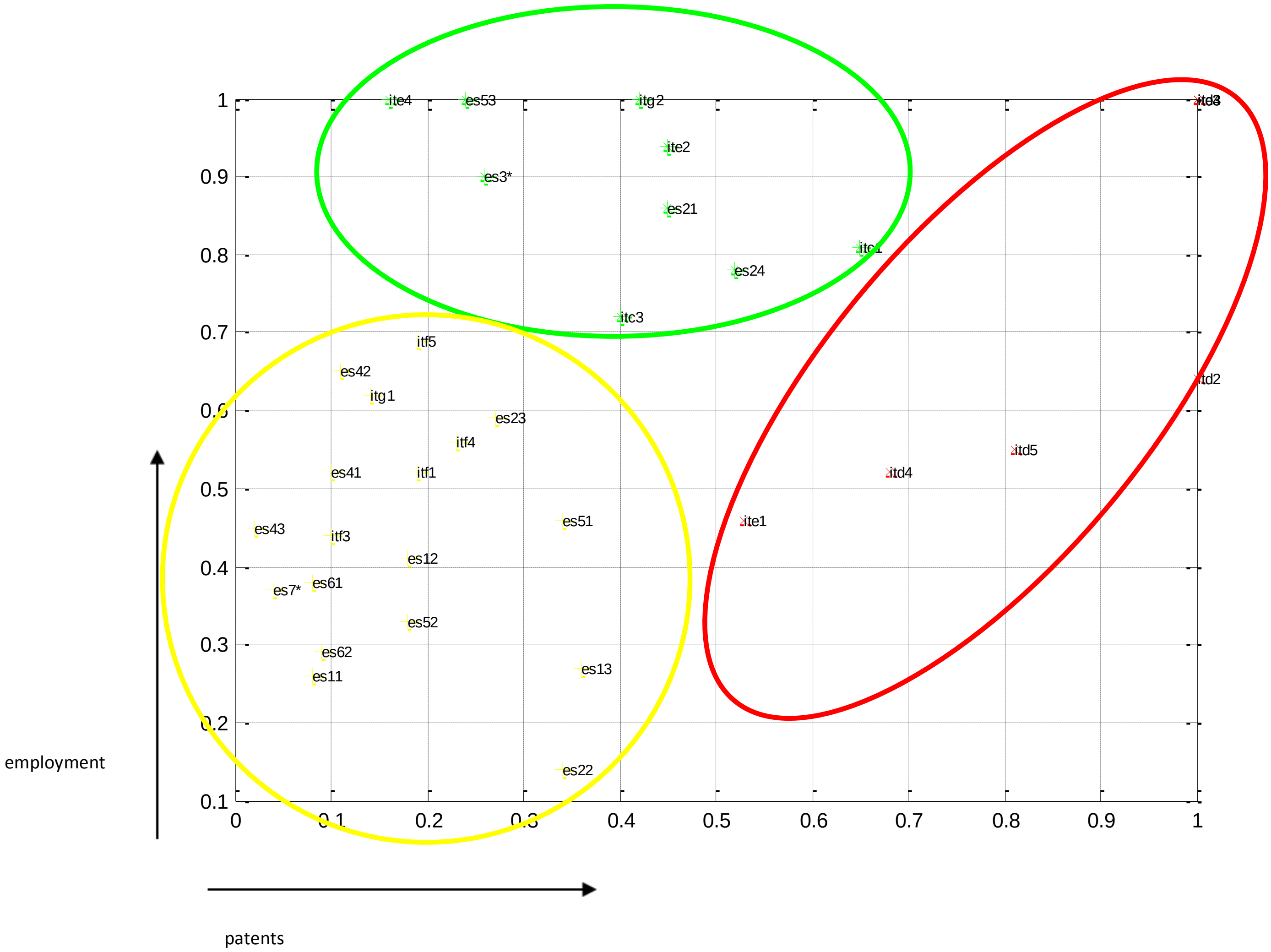


Table 8. Averages of the 3 groups of regions in the two variables considered, second time period

Cluster	Patents	Tec Employment
1	39.4444	89.0000
2	16.8889	44.1667
3	86.0000	73.8571
General Average	37.0882	62.1471

Source: Own elaboration

In both time periods we can distinguish 3 groups of regions (figures 3 and 4):

- Group 1: Efficient regions in employment (knowledge intensive services and high & mid high tech manufacturing)
- Group 2: Low efficiency regions
- Group 3: leading regions in efficiency both in patents and employment (knowledge intensive services and high & mid high tech manufacturing)

Each group presents averages in the two variables under study that are different with statistical significance (tables 7 and 8).

In tables 9 and 10 we show which regions are in each of the three groups in the first and second time periods.

Table 9. Groups of regions resulting from cluster analysis, first time period

Code	Region	Cluster	Number	Cod.	Region	Cluster	Number
es21	País Vasco	1	8	es11	Galicia	2	20
es23	La Rioja			es12	Asturias		
es24	Aragón			es13	Cantabria		
es3*	Madrid			es41	Castilla y León		
es42	Castilla-la Mancha			es43	Extremadura		
es51	Cataluña			es52	C. Valenciana		
es53	Illes Balears			es61	Andalucia		
itf2	Molise			es62	Región de Murcia		
es22	C. F. Navarra	3	7	es7	Canarias		
itc1	Piemonte			itc3	Liguria		
itc4	Lombardia			itd4	Friuli-Venezia Giulia		
itd2	P. A. Trento			ite1	Toscana		
itd3	Veneto			ite2	Umbria		
itd5	Emilia-Romagna			ite4	Lazio		
ite3	Marche			itf1	Abruzzo		
				itf3	Campania		
				itf4	Puglia		
				itf5	Basilicata		
				itg1	Sicilia		
				itg2	Sardegna		

While group 3 presents higher efficiency values in the two variables, group 2 presents the lowest results. In group 1, the result is high on the efficiency of job creation (analogous to group 3) and low in the efficiency directed to patent creation (but higher than in group 2). Figure 3 shows the geographic distribution of regions in the three clusters for the first time period.

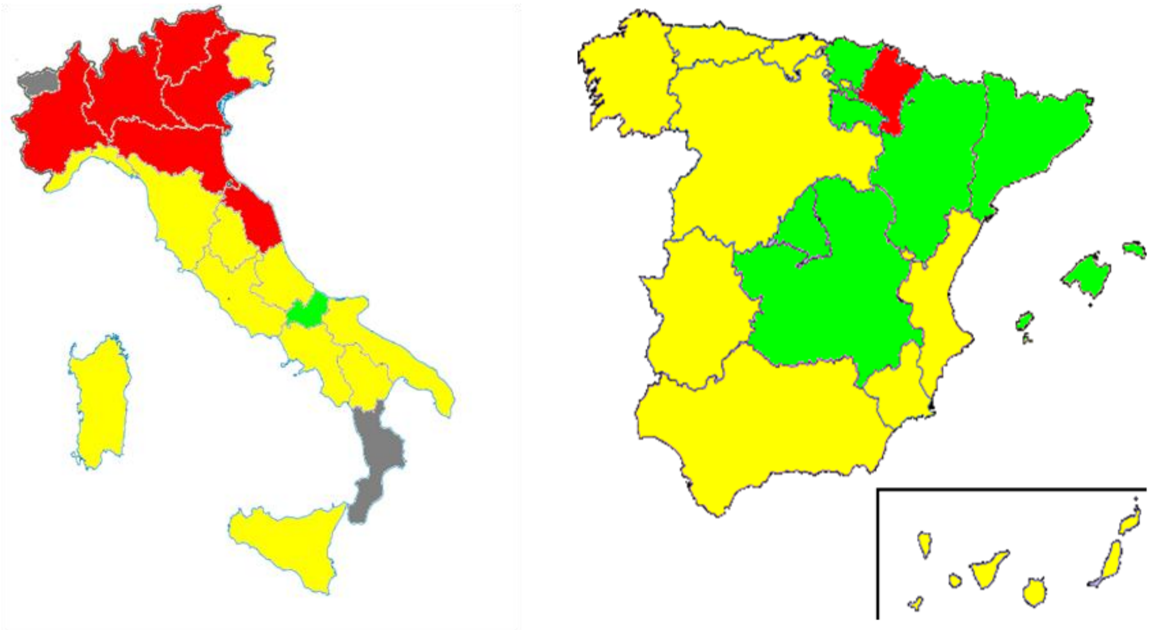
Table 10. Groups of regions resulting from cluster analysis, second time period

Code	Region	Cluster	Number	Cod.	Region	Cluster	Number
es24	Aragón			itf1	Abruzzo		
es3	Comunidad de Madrid			es61	Andalucia		
es53	Illes Balears			itf5	Basilicata		
ite4	Lazio			itf3	Campania		
itc3	Liguria	1	9	es7	Canarias		
es21	País Vasco			es13	Cantabria		
itc1	Piemonte			es41	Castilla y León		
itg2	Sardegna			es42	Castilla-la Mancha		
ite2	Umbria			es51	Cataluña		
itd5	Emilia-Romagna			es22	C.F. Navarra	2	18
itd4	Friuli-Venezia Giulia			es52	Comunidad Valenciana		
itc4	Lombardia			es43	Extremadura		
ite3	Marche	3	7	es11	Galicia		
itd2	P.A.Trento			es23	La Rioja		
ite1	Toscana			es12	Asturias		
itd3	Veneto			itf4	Puglia		
				es62	Región de Murcia		
				itg1	Sicilia		

In this case, group 3 gathers the most efficient regions both in terms of job creation and patents generation. In group 2 we can find the low efficiency regions, whereas in group 1 we find regions with a high efficiency level in job creation and an intermediate level in patent generation.

If we compare the situation in the first and second time periods, it is true that the percentage of regions belonging to the three groups is roughly the same. However, it is very different the internal composition of the three groups in each of the time periods. In the first period there are 9 Spanish regions and 11 Italian regions in the low efficiency group (2). In the second period, there are only 5 Italian regions in this group and 13 Spanish regions. In the group efficient in terms of employment (1) there were 8 Spanish regions and one Italian region in the first time period. In the second time period, there are 5 Italian regions and 4 Spanish regions. Cluster 3 groups the most efficient regions in terms of employment and patents creation. In the first time period, we had 6 Italian regions and one Spanish region. In the second time period we have seven Italian regions and zero Spanish regions. Considering all this information it seems clear that, in relative terms, Italian regions have increased their efficiency level in terms of job and patents generation in comparison to the Spanish regions in the analyzed period.

Figure 5. Geographical representation of cluster analysis, first time period



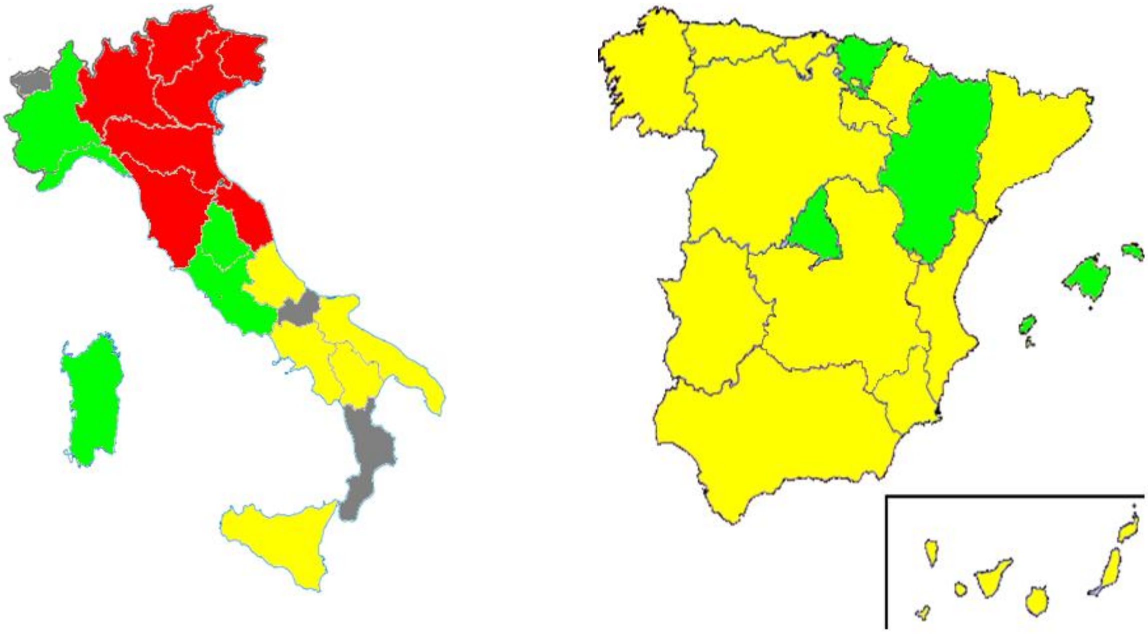
Source: Own elaboration

In figure 5 we can observe the geographic concentration of the leading regions in efficiency (red), the regions with a high level of efficiency regarding to employment in knowledge and technology intensive sectors (green) and regions with a low efficiency level (yellow). This figure is representing the efficiency situation for the first time period. In both countries the largest group of regions is the one with a low level of efficiency. While in Spain these regions are spread throughout the geography, in the Italian case these regions are concentrated mainly in the south area and in the islands. In contrast, the leading regions in efficiency are concentrated in northern Italy (six regions), while only one region in Spain (Navarra) is part of the leading group (group 3). Efficient regions only in employment in knowledge and technology intensive sectors are abundant in Spain (6 regions, including Madrid and Cataluña), while in Italy only one region is in this cluster (green cluster, group 1).

The analysis of the first time period is telling us that in Italy there was a strong geographic polarization among the leading regions (located in the north) and the low efficiency regions (islands and south), with only one region in between. By contrast, in Spain there was only one region within the leading group (group 3) whereas the number of regions of intermediate efficiency belonging to group 1 (efficient only in

employment in knowledge and technology intensive sectors) is high. In both countries the largest group in the one with low efficiency regions.

Figure 6. Geographical representation of cluster analysis, second time period



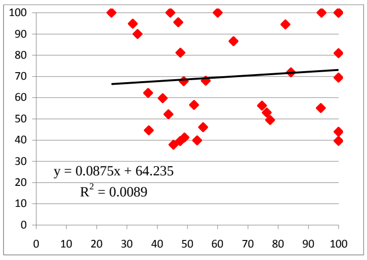
Source: Own Elaboration

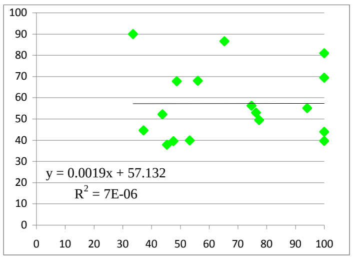
If we analyze the geographical map regarding efficiency in Spanish and Italian regions in the second time period, we must highlight a first conclusion: efficiency levels in Italian regions have moved upwards, while efficiency levels in Spanish regions have moved downwards. In fact, there are no Spanish regions in the leading group (3). Moreover, only four Spanish regions (Madrid, Aragón, Baleares and the Basque Country) are in group one (efficient regions in terms of employment). The rest of the Spanish regions (13 out of 17) are in low efficiency group (2). On the other hand, 7 Italian regions are in leading efficiency group (3), four are in the efficient group in terms of employment (1) and five are in the low efficiency group (2). As it happened in the first time period, there is no a clear geographic pattern for Spanish regions in terms of efficiency levels. By contrast, the geographic polarization of leading efficiency regions in the north part of Italy is still present in the second time period. Regions situated in the north part of the country belong to groups 3 and 1, whereas regions situated in the south part belong to the low efficiency group. Sardegna is a positive

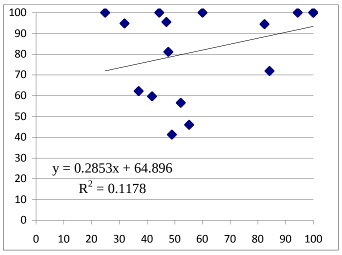
y=a**x** + b; **x**: efficiency first time period, **y**: efficiencysecond time period.

Basic Model

All data *Spain* *Italy*

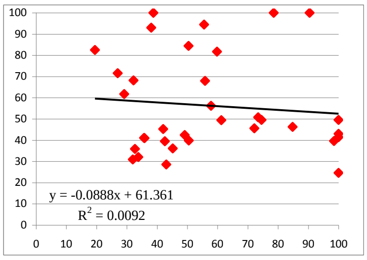


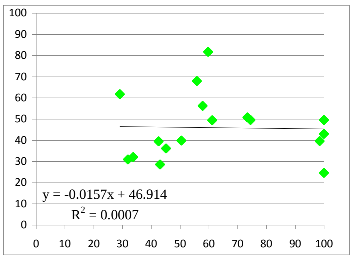


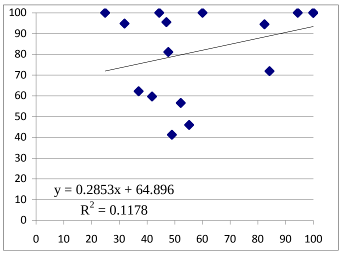


GDP

All data *Spain* *Italy*

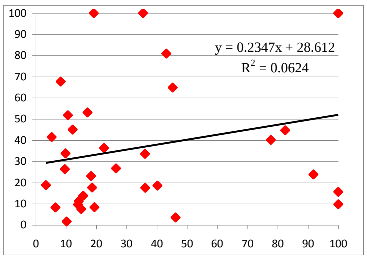


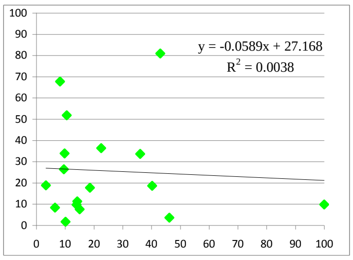


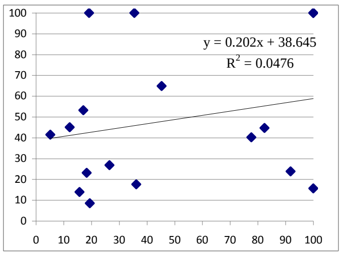


Patent

All data *Spain* *Italy*

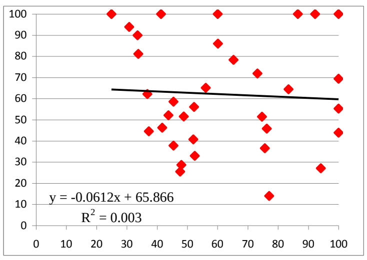


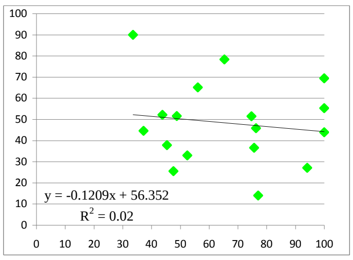


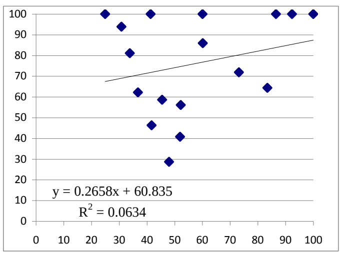


Employment

All data *Spain* *Italy*







exception, moving upwards from group 2 to group 1. In general terms, regions situated in the south (Sicilia, Puglia, Campania) have improved their efficiency levels and have reduced the efficiency gap with northern regions. However, this trend needs to be sustained in time in order to produce an effective catch-up between northern and southern regions in Italy, in terms of efficiency.

6. CONCLUSIONS

The aim of this study has been to measure the efficiency of R&D activities performed at the regional level in Spain and Italy using the data envelopment analysis (DEA), comparing the evolution of this efficiency in two time periods. In addition to the basic model (that model includes 3 inputs and 3 outputs) we have built 3 models in order to measure the efficiency of individual outputs. After analyzing the four DEA models we have grouped all regions in 3 different clusters, according to the efficiency levels achieved in the DEA models in terms of employment and patents generation.

The results of this study could be used to assess the regional R&D policy in Spain and Italy. The final objective of DEA is to give each region a tool to ameliorate the efficiency of regional expenditures in R&D and also to offer a context to compare the results of each region with the results of other regions located in the same economic and cultural environment. With this tool non-efficient regions could calculate the increase in output needed to become 100% efficient. Regional policy makers could benefit from this tool and take into account the efficiency level of their region in order to design policies to improve it. Policy makers in low efficiency regions should consider this low level of efficiency in their territories and analyze its causes. These causes may differ from region to region. Madrid and Cataluña (they concentrate more than 50% of total R&D investment in Spain), for example, obtain dissimilar results in the two time periods, but both regions show a clear weakness in terms of EPO patent application. If these regions improve their situation in that field, they could achieve higher levels of efficiency. In Italy, Lazio region presents a lower efficiency level in comparison to the leading regions situated in the north part of the country. These northern Italian regions are the leading regions not only among Italian regions, but also considering regions in Spain. This situation remains true for the two time periods. Although southern Italian regions have improved their efficiency levels in the second time period, they should

maintain this trend during a longer period of time in order to achieve an effective catch-up with northern regions in terms of efficiency levels.

On the other hand, Spanish regions have undertook a general loss of efficiency in the second time period, due to a higher increase in inputs and a clear reduction in output levels.

The limitations of this study are twofold. On one hand, the DEA models we have estimated have been built using constant returns to scale, following the vast majority of authors presenting this kind of analysis. On the other hand, the number of input and output indicators used in this work is very limited. A wider range of the indicators taken into consideration in this study could be beneficial in order to strengthen the final outcome.

A qualitative analysis of the regional innovation systems (RIS) taken into consideration in this study could clarify the reasons why some regions are more efficient than others. Using the concept of regional innovation system, it could be possible to conclude whether the lack of interaction between RIS agents, the lack of investment and/or the lack of an institutional framework at the regional level are lowering the efficiency of regional R&D activities.

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