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Measuring the territorial effort in research, development, and innovation from a multiple criteria approach: Application to the Spanish regions case

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ABSTRACT

Research, development and innovation are fundamental for the socioeconomic growth of the territories. Consequently, many governments set spending targets for research and development (R&D), for example the EU has a goal of reaching a spending target of 3% of the Union's GDP. However, recent literature emphasizes that spending on R&D may not be the most appropriate indicator to measure the innovative efforts of a particular territory. Multidimensional indicators are required to measure the different elements that reflect the capacity of each scientific and innovative system to transmit the scientific results into productivity and competitiveness advancements. In this context, the objective of this paper is to propose a method that produces a synthetic indicator to rank various territories as an aid to understanding the multidimensional complexities of the innovation process. To reach this objective, the methodological approach proposed is a modified version of the unweighted TOPSIS (UW-TOPSIS) method. In this paper, this multiple criteria decision-making method is used to rank the 17 Spanish autonomous communities in terms of their innovation efforts. The obtained results show the capacity of the proposed technique to evaluate the relative situation of each community using a multidimensional approach. However, it also allows us to provide policy guidance to political decision-makers on socioeconomic aspects that can be improved in each region.

1. Introduction

The relationship between the economic development of a territory and its capacity to innovate and experience technological progress has been clearly described by economic science since Robert Solow's seminal work "*Technical progress, capital formation and economic growth*" [1]. This relationship was already perfectly described in the work of Francis Bacon and had been very present in economic thought long before Solow's work. However, Solow is credited with modelling and formalizing the ideas in neoclassical terms. In his neoclassical growth model, Solow concludes that the only way to escape the *stationary stage* that leads to diminishing returns is through increasing the *capital endowments per worker* and *technological progress*. Although Solow describes *technological progress* as an exogenous phenomenon, later works regard it as endogenous, to the extent that investment efforts in the scientific and innovative system of a specific territory are those that allow achieving results in terms of technological progress and, therefore, the promotion of economic growth [2]. Subsequent works have empirically explored the relationship between innovative effort and growth, evidencing the importance of a region making strong investments in R&D to ensure growth and a beneficial convergence of economic dynamics; see among others [3] or the OECD report [4].

Consequently, one of the political priorities for countries and regions in current times has been to improve their scientific and innovative

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systems. In particular, the European Union has mainly focused its development and territorial cohesion policy on promoting innovation in all the European regions. In 2000, the *Lisbon strategy* for the European Union set itself the ambitious goal to become, by 2010, "*the most competitive and dynamic knowledge-based economy in the world*". Investment in R&D became a key element of this strategy, following the Barcelona European Council's objective to raise R&D investment to 3% of GDP by 2010. However, there has been a very uneven spatial evolution in achieving this objective. As detailed in Ref. [5], at the end of the second decade of the new millennium, most of the European regions made innovative efforts significantly below the 3% of GDP target, although there are very intense differences between territories. It is also notable that the territories that would have to make a more intense innovative effort are precisely those with the lowest percentage of GDP allocated to spend on R&D.

However, more importantly than the fact that the spatial differences are remarkable, it is surprising to observe that it is not always the case that the territories that spend more on R&D in Europe achieve better results in terms of productivity or growth [5]. Andres Rodríguez-Pose [6] found differences in the results of R&D spending between European regions, which he attributes to what he calls the "social filter", the existence of different environments and social structures that allow more profitable investments in the scientific and innovative sectors. In Ref. [7], different regions at different levels of disaggregation were analysed, identifying the importance of national development in sub-national (regional) behaviour as well as the relevance of interrelationships and networks to understand the differences in the results of spending on R&D. Similarly, in Ref. [8], the importance of spillovers between regions is identified, incorporating the importance of location in the materialization of the results derived from R&D spending efforts.

In 2010 [9], all this evidence was systemized, and it was discovered that generation of technological progress models is much more complex than initially thought. As in Ref. [9], a set of multidimensional conditions are required that have to do with human capital, institutional relations and the weight of the private sector. Networks, both within, between companies, and local research centres, as well as outside, between the regions and the most innovative places internationally, must also be considered.

In light of all the accumulated literature, the European Union has recently highlighted the importance of having broader indicators that reflect this multidimensionality of *technological progress*. In Ref. [5], among others reports, the European Commission points out the limitation of measuring the quality of regional innovative systems by the spending on R&D. The European Commission proposes specific indicators but basically draws attention to the difficulty of crafting a synthetic indicator that allows ranking of the regions with a multidimensional nature that can help in the understanding of the strengths and weaknesses of each region.

In this context, the objective of this paper is to propose a procedure that allows us to create a synthetic indicator with which to construct a ranking of territories simultaneously helping to understand the multidimensional complexity of the innovative process, that can inform policy-makers about the socioeconomic aspects that can be improved in each geographical region. An indicator of this type can be extremely valuable both for a global orientation, European or national policies and for the local management of regional initiatives.

To reach this objective, the methodological approach proposed is an unweighted TOPSIS (UW-TOPSIS) method. This Multiple Criteria Decision-Making (MCDM) method is an extension of TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) proposed in Ref. [10]. TOPSIS allows the ranking of a set of decision alternatives taking into account two reference alternatives, the Positive Ideal Solution (PIS) and the Negative Ideal Solution (NIS). In a decision problem where all the criteria are of the type "the greater the better", the PIS would be composed of the individual maximum of all the criteria, and the NIS would be composed of the individual minimum of all the criteria. Conversely, if all the decision criteria are of the type "the less the better", the PIS would be formed by the individual minimum of the criteria and the NIS by their individual maximum. The philosophy behind TOPSIS is to try to minimize the distance from all alternatives to the PIS, and simultaneously maximize the distance to the NIS. TOPSIS is a popular ranking method due to its mathematical simplicity. It is rational, comprehensible, and efficient from a computational point of view and is also easily understandable by practitioners. The method uses full attribute information and does not require the independence of the attribute preferences.

Some important initial decisions need to be made regarding this process, which are related to the type of data and decision criteria. The degree of precision of the data, data normalization process, weighting scheme, selection of distance metric and determination of PIS and NIS are some examples of the decisions affecting the final ranking. The handling of these issues has given rise to different TOPSIS approaches and extensions. One of the most controversial questions is that related to the subjective weighting schemes. The inherent difficulty of assigning reliable subjective weights has been well addressed by several authors (see Refs. [11–21]). The main criticisms are that the decision-maker cannot always give consistent judgements for different weighting schemes, and the weighting process itself is essentially context dependent [20]. For example, in Refs. [7,12,16], the authors show how criteria weights could affect final decisions by using a sensitivity analysis on the weights. In Ref. [15], decision-makers can select the desirable preference elicitation technique using an interactive method. The authors in Ref. [17] consider the specific characteristics of a decision situation to effectively assign weights. These previous works are only a few examples of the attempts to overcome some of the problems derived from subjectivity in weighting schemes.

UW-TOPSIS was proposed by Refs. [22,23] to address problems with the selection of the weighting scheme. In this approach, weights do not need to be established *a priori* by the decision-maker, which in several decision contexts would be controversial, especially in those situations in which weights are determined subjectively. In contrast, in the proposed approach, weights are considered the decision variables in a set of optimization problems aiming to maximize the relative proximity of each alternative to the PIS. This approach has been successfully applied to different real decision-making problems, such as the ranking of firms based on gender diversity and inclusion criteria, or the ranking of neighbourhoods based on sustainable criteria, [22,23].

In this work, a modified version of UW-TOPSIS is applied to the ranking of Spanish regions based on their innovation efforts. Spain is divided into 17 autonomous regions (Autonomous Communities), where the regions are allowed independence in the design of their scientific and innovation policies, as well as their educational policies. There are strong differences in the development of these regions, with some cases that present levels of development above the European average, such as the Autonomous Community of Madrid. There are others that are at the lowest levels of development in Europe, such as the case of Estremadura. This translates into even greater differences in terms of R&D effort, both in the expenditure variable and in any other variables that reflect specific aspects of each innovative system. All this makes the Spanish case an ideal laboratory to test the capacity of the proposed approach by applying it to real data.

In the first phase, and using the proposed method in this paper, we will identify the relative importance of each decision criterion in determining the position of the alternative in the rank. This information is of great importance for the decision-maker, as it provides the variation intervals of the weights in a descending order of importance of the decision criteria in terms of the relative position of the region in the ranking. In a second phase, the decision-maker can directly make decisions on the weights, considering the information from the previous phase. He/she would be able to maintain the intervals or to select his/her own variation intervals for the weights. However, in this last case, the decision-maker will have information about the lower and upper possible limits of the intervals. That is, fixing a weight lower than the lower extreme obtained in the previous phase would be possible but it would not have any effect on the obtained ranking. The same would happen with the upper limits. Fixing a weight higher than the upper extreme obtained in phase one would not change the ranking.

The paper is structured as follows: In the next section, the proposed methodology is presented, its technical and mathematical details are described. In the third section, the case study chosen for application of the methodological proposal is widely described. In the fourth section, the results obtained are presented and discussed. Finally, a number of conclusions and recommendations for economic policy can be deduced and are summarized in the final section.

2. Two-phase UW-TOPSIS

In what follows, we will present the phases and steps of an algorithm, which is based on UW-TOPSIS [22,23]. As we will see, in the first phase, weights are introduced as unknowns in Step 3 when the distances from the PIS and NIS are determined. Weights are determined in the following step by means of two groups of nonlinear optimization problems that optimize the distance of each alternative to the NIS and PIS. In the first phase, the weights are set completely free in the optimization problems. This allows the determination of the strengths and weaknesses of each alternative in terms of decision criteria. For the sake of simplicity, let us consider a decision problem where all the criteria are of the type "the greater the better". Let us note that this does not detract from the problem's generality since we can always make all criteria "the greater the better" type by normalizing the data (see Ref. [24]).

2.1. Phase I: determination of strengths and weaknesses

Input: Decision matrix $[x_{ij}]$, $1 \le i \le n$, $1 \le j \le m$, where the number of decision alternatives is n and the number of decision criteria is m.
Step 1. Normalize the decision matrix

$$[n_{ij}],\ r_{ij} \in [0,1], \quad 1 \le i \le n,\ 1 \le j \le m. \tag{1}$$

Step 2. Determine the $PIS = (n_1^+, \ldots, n_m^+)$ and $NIS = (n_1^-, \ldots, n_m^-)$

$$n_j^+ = \max_{1 \le i \le n} n_{ij} \quad n_j^- = \min_{1 \le i \le n} n_{ij} \ 1 \le j \le m, \tag{2}$$

Step 3. Let us consider a set of unknown weights $w_j \in [0,1], \sum_{j=1}^{m} w_j = 1$. We define two functions measuring the distance to the PIS and NIS:

$$D_i^+(w) = d\left((w_1 n_{i1}, \ldots, w_m n_{im}), \left(w_1 n_1^+, \ldots, w_m n_m^+\right)\right), \quad 1 \le i \le n, \tag{3}$$

$$D_i^-(w) = d\left((w_1 n_{i1}, \ldots, w_m n_{im}), \left(w_1 n_1^-, \ldots, w_m n_m^-\right)\right), \quad 1 \le i \le n, \tag{4}$$

Step 4. Calculate the function of the relative proximity to the PIS, which will depend on the values of the weights:

$$R_i(w) = \frac{D_i^-(w)}{D_i^+(w) + D_i^-(w)},\ 1 \le i \le n. \tag{5}$$

Step 5. Calculate the values $\overline{R}_i^L(w)$, $\overline{R}_i^U(w)$ for $1 \le i \le n$ solving the two following mathematical programming problems:

$$\overline{R}_i^L(w) = \text{Min}\left\{R_i(w), \sum_{j=1}^{m} w_j = 1,\ w_j \ge 0\right\} \tag{6}$$

$$\overline{R}_i^U(w) = \text{Max}\left\{R_i(w), \sum_{j=1}^{m} w_j = 1,\ w_j \ge 0\right\} \tag{7}$$

From the resolution of (6) and (7) we obtain optimal weights. w_{ij}^{*L}, w_{ij}^{*U}, $1 \le i \le n$, $1 \le j \le m$.

Step 6. Calculate the intervals:

$$w_j^I = \left[l_j^*,\ u_j^*\right], \quad 1 \le j \le m, .. \tag{8}$$

where $l_j^* = \min_i [w_{ij}^{*L}, w_{ij}^{*U}]$ and $u_j^* = \max_i [w_{ij}^{*L}, w_{ij}^{*U}]$, $1 \le j \le m$.

Output. Ranking of the obtained intervals w_j^I, $1 \le j \le m$.

Several methods can be found in the literature for the ranking of interval numbers. In Ref. [25], a review of the main approaches focusing on the attitude of the decision-maker in terms of his/her risk aversion, is presented. In this work, solely for illustrative purposes will we consider three risk scenarios, the worst scenario, the best scenario and a neutral scenario, and we will rank intervals in each of these scenarios. For the worst-case scenario, we consider the lower limit of the intervals, w_j^I. For the best scenario, we will consider the upper limit, and for the neutral scenario, we will take the middle point or average value of each interval:

$$w_j^{mid} = \frac{l_j^* + u_j^*}{2}, \quad 1 \le j \le m. \tag{9}$$

In this phase, the analyst will be able to identify the relative importance of each decision criterion in determining the position of the alternative in the rank. This is one of the main features of the proposed method.

2.2. Phase II: ranking of alternatives considering expert knowledge

In this second phase, we show the decision-maker the weaknesses and strengths of the decision alternatives and their possibilities of improvement, and we start an interactive process to determine the lower and upper bounds for the weights in an attempt to incorporate into the model the knowledge and expertise from the decision-maker and to adjust the obtained ranking. The algorithm in this phase maintains the four previously described steps.

Input: Decision matrix $[x_{ij}]$, $1 \le i \le n$, $1 \le j \le m$, where the number of decision alternatives is n and the number of decision criteria is m.
Step 1. Calculate (1)–(5).
Step 2. Determine the extreme low and upper limits, l_j and u_j, respectively, for the weights, such that $l_j \ge l_j^*$ and $u_j \le u_j^*$ (see (8)).
Step 3. Calculate the values $R_i^L(w)$, $R_i^U(w)$ for $1 \le i \le n$ solving the two following mathematical programming problems:

$$R_i^L = \text{Min}\left\{R_i(w), \sum_{j=1}^{m} w_j = 1,\ l_j \le w_j \le u_j,\right\} \tag{10}$$

$$R_i^U = \text{Max}\left\{R_i(w), \sum_{j=1}^{m} w_j = 1,\ l_j \le w_j \le u_j\right\} \tag{11}$$

Then, we obtain n relative proximity intervals,

$$R_i^I = \left[R_i^L,\ R_i^U\right], \quad 1 \le i \le n. \tag{12}$$

Step 4. We rank the intervals $R_1^I, R_2^I \ldots, R_n^I$.
Output. Ranking of the alternatives according to the ordering of R_i^I, $1 \le i \le n$.

Note: If the decision-maker accepts the limits of the weights obtained in Phase I, that is, if $l_j = l_j^*$ and $u_j = u_j^*$, then $\overline{R}_i^L(w) = R_i^L$ y $\overline{R}_i^U(w) = R_i^U$, $1 \le i \le n$.

Any appropriate method can be used for the ranking of the intervals of relative proximity to the PIS (see Ref. [25] for a recent review of different methods). In this work, we rank the intervals using their average point:

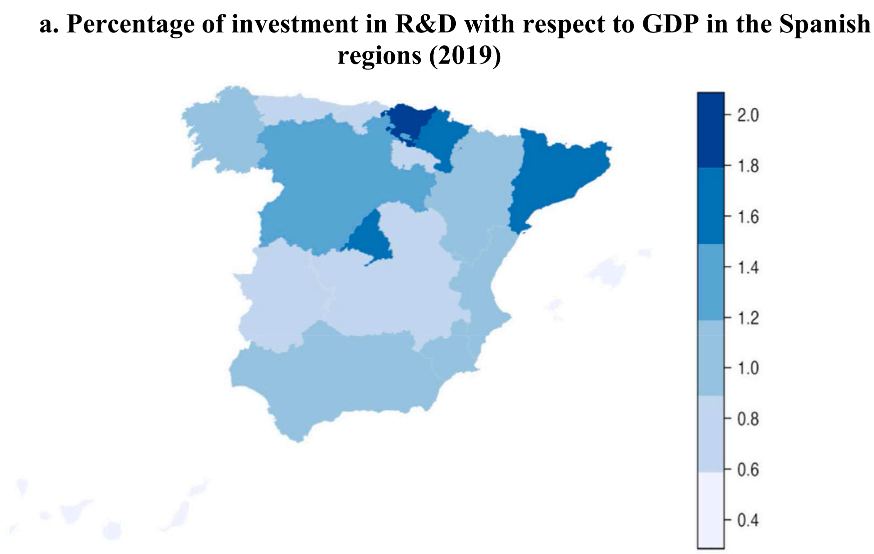
$$average_i = \frac{R_i^L + R_i^U}{2}, \; 1 \le i \le n. \tag{13}$$

3. Case study: the Spanish R&D system, innovation and dataset sources

As indicated in the introduction, the methodology proposed is applied to the Spanish case. Spain is divided into 17 autonomous communities that have been given full independence to design and implement their policies to promote R&D as well as their educational policies, including policies for the higher education system. This means that within the country, there are different intensities of innovative efforts with different levels of development. Fig. 1a and b shows the differences in the intensities of spending on R&D and, as was the case in Europe, there is no greater effort from the less developed regions, contrary to what would be necessary to enter a convergence path supported by increased innovative efforts.

Using several sources (see Tables 1 and 2), we have been able to build a database of variables that try to synthesize, within the limitations of the existing information, descriptive variables of the scientific system of each region, socioeconomic factors and environmental aspects that can potentially condition the scientific and innovative performance. Specifically, the selected indicators cover four dimensions (see Table 1). Dimension 1 includes indicators relative to investment effort in R&D. In a second dimension, we have included indicators related to human capital, taking into account in this category both indicators related to the innate potential of the population and those related to the amount of population employed in jobs related to innovation and research. Dimension 3 includes indicators related to the innovative context of companies, and finally, Dimension 4 includes other indicators normally used to measure research and innovation performance.

Table 2 specifies the variables that are collected in each category and



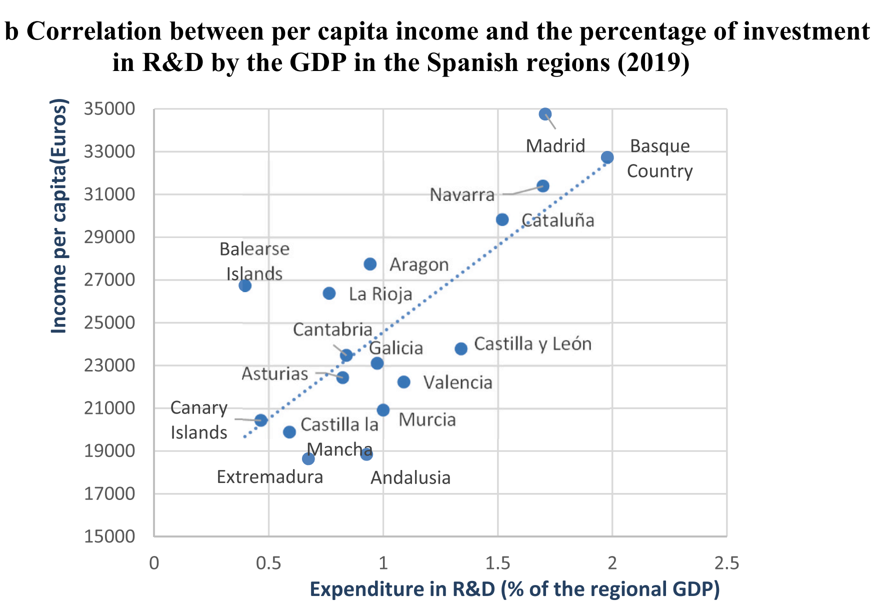


Fig. 1. a. Percentage of investment in R&D with respect to GDP in the Spanish regions (2019)
Source: own using the Spanish National Institute of Statistics (INE), b Correlation between per capita income and the percentage of investment in R&D by the GDP in the Spanish regions (2019)
Source: own using the Spanish National Institute of Statistics (INE).

Table 1
Description of decision dimensions.

Dimension	Criteria
Effort in R&D	Public expenditure in R&D Private expenditure in R&D
Human capital	Occupied in research activities Occupied in innovations activities Occupied in activities of high technology Population with a university degree Doctoral thesis
Innovative context of companies	Intensity of innovation Innovation firms I Innovation firms II Innovation firms III
Other indicators measuring research and innovation	Patents Scientific publications Excellence Internationality

Source: own.

the sources from which they are taken, as well as their main characteristics. In a complementary manner, Table A1 (in the Appendix) presents the values that these variables take. For a quick interpretation of the indicators, the values have been highlighted using four colours depending on the position of each value with respect to the national average. Thus, in red, those regions that are the worst positioned in the considered indicator are highlighted, indicating that these regions reached a value lower than or equal to the fourth quartile of the distribution of values. In orange, the regions whose indicator has a value located between the fourth and third quartiles of the distribution are highlighted. The yellow colour highlights the regions that, in the corresponding indicator, are between the second and third quartiles of the distribution of values. Last, the best positioned regions in the corresponding indicator are distinguished in green, those that are in the first quartile of the distribution.

4. Results and discussion

In what follows, we will present the main results obtained from the application of the proposed methodology. Let us first consider a situation in which the decision-maker does not want to establish *a priori* weights for the individual indicators. These weights will be the variables in the optimization problems presented in (10) and (11). They will determine the minimum and maximum possible values for the relative proximity of each alternative to the Positive Ideal Solution (PIS).

Tables A2 and A3 in the appendix display the optimal weights in a situation where these are free variables. Table A2 displays the optimal weights for the minimum value of the relative proximity interval. This value represents the worst possible scenario in terms of the position of the alternative in the ranking. Table A3 displays the optimal weights for the maximum value of the relative proximity interval, which represents the best possible position of the alternative in the ranking. As in Table 3 and Table 4, values in green represent the principal influencers on the position in the rank of each region.

Table 3 displays an example. Let us consider one of the decision alternatives, Asturias, which is a region in northern Spain. In the worst possible scenario, this region would occupy the 7th position. Criterion 1, *Public expenditure in R&D*, would be the criterion with more importance behind this position. This information gives the decision-maker an idea of the weaknesses of the region in terms of its position in the ranking. In the case of Asturias, its main weakness is the *Public expenditure in R&D*.

Let us now consider the case of the Canary Islands. In this case, there is not a unique clear criterion behind the position of this region in the ranking. We can identify, among others, two weaknesses, Criteria 2 and 8, *Private expenditure in R&D and Intensity of innovation*, respectively.

Castilla la Mancha also shows two weaknesses, *Public expenditure in R&D and Occupied in research activities* but they are the only weaknesses. No other criterion contributes to the position in the rank of this region under the worst scenario, which would be the 14th in the ranking. Extremadura would rank 15th in the worst scenario with one main weakness, *Occupied in activities of high technology,* and several secondary weaknesses. Madrid ranks 8th in the worst scenario with one main weakness, Scientific publications. There are also regions like Murcia, ranking 10th in the worst scenario, where only one criterion appears as a weakness, occupied in activities of high technology.

Table 4 displays the optimal weights in the best scenario for the regions selected inTable 3.

Table 2
Description of decision criteria.

	Criteria	Units	Year	Source
C1	Public expenditure in R&D	% of regional GDP	2019	EUROSTAT
C2	Private expenditure in R&D	% of regional GDP	2019	EUROSTAT
C3	Occupied in research activities	% Researcher personnel over the total regional occupied	2019	INE
C4	Occupied in innovation activities	% Employees in innovation over the total regional occupied	2019	INE
C5	Occupied in activities of high technology	% Employees in high technology activities over the total regional occupied	2020	EUROSTAT
C6	Population with a university degree	% of the regional population between 16 and 65 years	2020	EUROSTAT
C7	Doctoral Thesis	Number of Thesis defended over one million of population	2019	Ministery of Education
C8	Intensity of innovation	% of expenditure in innovation over the total turnover	2019	INE
C9	Innovation firms I	% of firms with innovation activities over the total	2017–19	INE
C10	Innovation firms II	% of firms with innovation activities expenditure over the total	2019	INE
C11	Innovation firms III	% of firms with R&D expenditure over the total	2019	INE
C12	Patents	Number of patents request over one million of population	2019	FECYT
C13	Scientific publications	Number of scientific publications over one million of population	2019	FECYT
C14	Excellence	% of scientific publications among the 10% more quoted	2019	FECYT
C15	Internationality	% of scientific publications with international coauthors	2019	FECYT

Note.
INE: Spanish National Institute of Statistics.
EUROSTAT: European Office of Statistics.
FECYT: Spanish Foundation of Science and Technology.
Source: own.

Credit author statement

Tania García: Data curation Fernando Rubiera.: Data curation, Conceptualization, Investigation, Methodology, Writing – original draft preparation. Vicente Liern: Conceptualization, Methodology, Data curation, Visualization, Investigation, Supervision Blanca

Table 3
Example of optimal weights for.R_i^L

	Asturias	Canary Islands	Castilla la Mancha	Extremadura	Madrid	Murcia
C1	0.93470	0.00000	0.55560	0.00000	0.00000	0.00000
C2	0.00010	0.34100	0.00000	0.00000	0.00020	0.00000
C3	0.00010	0.00000	0.44440	0.00000	0.00040	0.00000
C4	0.00020	0.18780	0.00000	0.00000	0.00030	0.00000
C5	0.00020	0.00000	0.00000	0.58530	0.00010	1.00000
C6	0.00020	0.00000	0.00000	0.11500	0.00110	0.00000
C7	0.00020	0.00860	0.00000	0.00000	0.00020	0.00000
C8	0.00010	0.35910	0.00000	0.00000	0.00130	0.00000
C9	0.00150	0.00000	0.00000	0.09930	0.00130	0.00000
C10	0.00040	0.00000	0.00000	0.00000	0.00290	0.00000
C11	0.00020	0.01830	0.00000	0.00000	0.00110	0.00000
C12	0.00010	0.08520	0.00000	0.00000	0.00020	0.00000
C13	0.00080	0.00000	0.00000	0.00000	0.97420	0.00000
C14	0.00060	0.00000	0.00000	0.17420	0.00600	0.00000
C15	0.06070	0.00000	0.00000	0.02610	0.01080	0.00000
Rank	7	16	14	15	8	10

Source: own.

Table 4
Example of optimal weights for.R_i^R

	Asturias	Canary Islands	Castilla la Mancha	Extremadura	Madrid	Murcia
C1	0.00016	0.00028	0.00000	0.00006	0.76614	0.00002
C2	0.00038	0.00001	0.00000	0.00005	0.00005	0.00002
C3	0.00076	0.00004	0.00000	0.00009	0.00020	0.00007
C4	0.00106	0.00012	0.00000	0.00012	0.00071	0.00008
C5	0.00033	0.00009	0.00000	0.00004	0.11669	0.00001
C6	0.83808	0.00145	0.00000	0.00031	0.02078	0.00022
C7	0.00289	0.00012	0.00000	0.00008	0.09119	0.00085
C8	0.00096	0.00024	0.00000	0.00008	0.00002	0.00004
C9	0.00143	0.00049	0.00000	0.00014	0.00024	0.99642
C10	0.00720	0.00066	0.00000	0.00037	0.00033	0.00094
C11	0.00033	0.00008	0.00000	0.00003	0.00000	0.00004
C12	0.00114	0.00008	0.00000	0.00006	0.00027	0.00007
C13	0.00037	0.00005	1.00000	0.99685	0.00000	0.00002
C14	0.13768	0.00499	0.00000	0.00078	0.00144	0.00048
C15	0.00723	0.99130	0.00000	0.00096	0.00195	0.00072
Rank	11	7	16	15	5	13

Source: own.

Pérez-Gladish: Conceptualization, Methodology, Data curation, Visualization, Investigation, Supervision, Writing- Reviewing and Editing

In the best scenario, if all the regions maximize their distance to the positive ideal solution, Asturias would rank in the 11th position, with the *Population with a university degree* being the factor contributing the most to this position. In the case of the Canary Islands, which would rank 7th, the main strength would be *Internationality*. Castilla la Mancha and Extremadura would rank 16th and 15th, respectively, with a main strength, *Scientific publications*. The rank of Madrid in the 5th position would be mainly due to its *Public expenditure in R&D* and, finally, Murcia ranking the 13th, would have a main strength in the % of firms with innovation activities over the total.

What would be the most relevant indicator in each scenario? In the worst scenario, the most relevant indicator would be a weakness, and in the best scenario, a strength. We have identified these indicators by calculating their maximum and minimum optimal values and the amplitude of the corresponding interval. The most relevant indicator determining the position of the alternatives in the ranking, in general terms, would be the one with greater amplitude. Table 5 displays the ranking of indicators by relevance in the worst scenario.

As we can observe, the most relevant indicator in this scenario, the greatest weakness, is the *% Employees in high technology activities over the total regional occupied*, followed by *Scientific publications* and *Public expenditure in R&D*. Regions with poor performance in these indicators would rank in low positions. Table 6 displays the ranking of indicators by relevance in the best scenario.

Table 5
Ranking of indicators by relevance for.R_i^L

	Max	Min	Amplitude	Ranking
C1	0.93470	0.00000	0.93470	3
C2	0.34100	0.00000	0.34100	6
C3	0.44440	0.00000	0.44440	4
C4	0.18780	0.00000	0.18780	7
C5	1.00000	0.00000	1.00000	1
C6	0.11500	0.00000	0.11500	9
C7	0.00860	0.00000	0.00860	14
C8	0.35910	0.00000	0.35910	5
C9	0.09930	0.00000	0.09930	10
C10	0.00290	0.00000	0.00290	15
C11	0.01830	0.00000	0.01830	13
C12	0.08520	0.00000	0.08520	11
C13	0.97420	0.00000	0.97420	2
C14	0.17420	0.00000	0.17420	8
C15	0.06070	0.00000	0.06070	12

Source: own.

In the best scenario, the most relevant indicator is *Scientific publications*, followed by the *% of firms with innovation activities over the total* and *Internationality*. These indicators can be considered the strengths of the regions. Indicators with high weights represent the strengths of the region in terms of its position in the ranking.

Fig. 2 shows the obtained relative proximity intervals, where we can observe the different amplitudes of the intervals. We have also represented the middle point of the intervals (13), which will serve to rank our intervals.

These intervals give rise to the ranking of the regions, which is displayed in Table 7. We have displayed the ranking for the middle point of the intervals, the average (13). This average point of the relative proximity intervals can be interpreted as a synthetic indicator measuring the innovation effort of the territories.

The best position in the ranking is held by Navarra, followed by the Basque Country, Cataluña and Madrid. The last positions in the ranking are held by Andalusia, Extremadura and Castilla la Mancha.

5. Main conclusions

The idea that science and innovation acts on productivity and economic growth with a linear effect, that is, an increase in spending on R&D leads to growth in productivity and, through it, economic development, led to the idea that it was enough to pay attention to R&D expenditure indicators to assess the innovative effort of a particular

Table 6
Ranking of indicators by relevance for.R_i^R

	Max	Min	Amplitude	Ranking
C1	0.76614	0.00000	0.76614	5
C2	0.00038	0.00000	0.00038	14
C3	0.00076	0.00000	0.00076	11
C4	0.00106	0.00000	0.00106	13
C5	0.11669	0.00000	0.11669	7
C6	0.83808	0.00000	0.83808	4
C7	0.09119	0.00000	0.09119	8
C8	0.00096	0.00000	0.00096	12
C9	0.99642	0.00000	0.99642	2
C10	0.00720	0.00000	0.00720	9
C11	0.00033	0.00000	0.00033	15
C12	0.00114	0.00000	0.00114	10
C13	1.00000	0.00000	1.00000	1
C14	0.13768	0.00000	0.13768	6
C15	0.99130	0.00000	0.99130	3

Source: own.

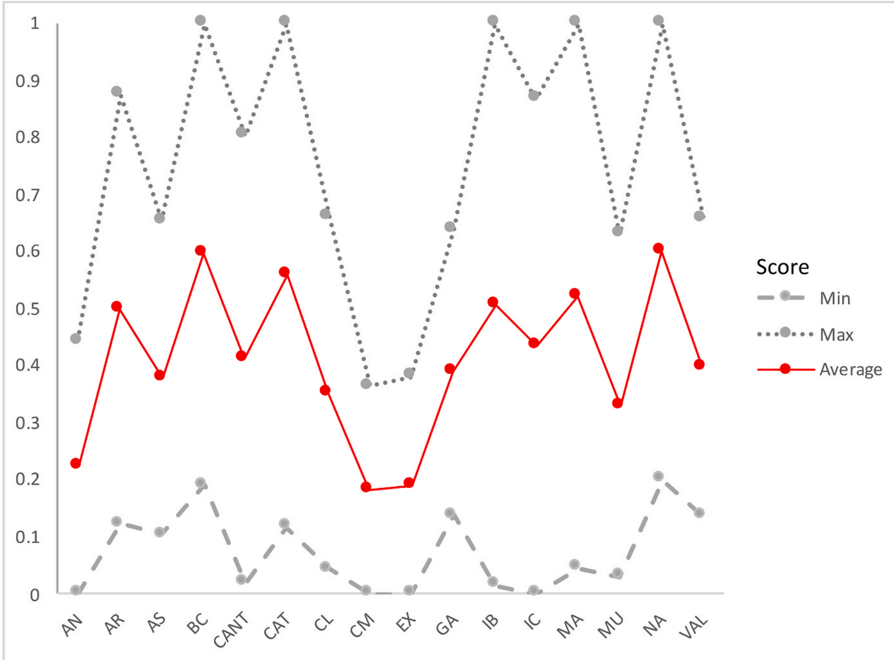


Fig. 2. Relative proximity intervals
Source: own.

Table 7
Ranking taking into account the average.

Position	Alternative	Ri	Position	Alternative	Ri
1	Navarra	0.60001	9	Valencia	0.39693
2	Basque Country	0.59549	10	Galicia	0.38858
3	Cataluña	0.55871	11	Asturias	0.37924
4	Madrid	0.52189	12	Castilla y León	0.35254
5	Baleares Islands	0.50769	13	Murcia	0.33036
6	Aragon	0.49884	14	Andalusia	0.22165
7	Canary Islands	0.43366	15	Extremadura	0.18993
8	Cantabria	0.41061	16	Castilla la Mancha	0.18160

Source: own.

territory. However, more recent studies indicate that the connection between scientific research and economic growth is not necessarily linear. Greater efforts in terms of spending on R&D do not always lead to better results, since the impact of research on growth depends on many other variables, such as the private innovative system, international connections or the quality and capacity of the regional/local scientific system.

Faced with the multidimensionality of the relationships between scientific research and economic development, it is necessary to sophisticate the indicators in order to set targets, design policies, allocate funds and stimulate scientific research. This is the objective proposed in this paper, to propose a methodology to measure and rank different territories in relative terms. The proposed method in this paper is an extension of UW-TOPSIS. UW-TOPSIS is a multiple criteria ranking method that allows the multidimensional assessment of decision alternatives, taking into account several decision criteria but without the *a priori* establishment of a weighting scheme. The obtained synthetic indicator allows a ranking of the alternatives, taking into account their relative proximity to an ideal solution. The method has the additional advantage of being able to identify the main weaknesses and strengths of the alternatives in regard to their position in the ranking. In the first phase, variation intervals for the weights of the decision criteria are obtained. These intervals are ordered to reflect the importance of each decision criterion in the position of each alternative in the ranking. In a second phase, a TOPSIS method is proposed to rank the regions. In this phase, the decision-maker can use the information obtained in the previous phase or can choose to fix his/her own weights considering the limits previously obtained. The ranking method used in this phase could be any other ranking method.

To illustrate the suitability of this methodology, a real case study is presented. Spain is divided into 17 regions, each with high political autonomy. Among these regions, there are some with levels of development higher than the European average and others that are among the less developed regions of Europe. There are also regions that have made R&D their main policy, with significant efforts in all areas, while others have paid very little attention to science and innovation. All this makes the Spanish case especially attractive.

The results obtained clearly reveal how, by incorporating different dimensions, a much more precise ordering of the territories can be achieved. The possibility of having a range of positions in the ranking, instead of a single position given by a single indicator, makes the ranking much more appropriate. All this makes it possible to highlight, with greater clarity, which regions have to make a greater effort in R&D and, what is more important, to identify which variables they must act on to improve their relative position.

The application of this procedure for all European regions, and over a long period of time, would make it possible to identify key development aspects in each territory, design a more sophisticated European R&D policy that was not based only on the spending criterion and have a more stable and conclusive ranking than that which can be derived from a single criterion or from an integration, with subjective weights, of several criteria.

Credit author statement

Tania Férnandez-García: Data curation. Vicente Liern: Conceptualization, Methodology, Writing- Reviewing and Editing. Blanca Pérez-Gladish: Conceptualization, Methodology, Writing- Reviewing and Editing, Supervision. Fernando Rubiera-Morollón: Conceptualization, Methodology, Reviewing and Editing.

Appendix

Table A1
Indicators of the Spanish regions innovation system (2019) (*)
Note: (*) Most of the variables are referred to 2019 year, although in some cases the closer year available have been used (see Table 1).
(**) The indicators are described in Table 2.
Source: own using the sources indicated in Table 2.

Region\Indicators (**)	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
Andalusia	0.180	0.337	0.466	0.797	2.300	32.500	171.138	0.750	0.813	13.300	0.129	21.700	751.628	16.700	46.800
Aragon	0.211	0.527	0.709	1.067	2.400	39.700	174.336	0.940	1.321	20.170	0.342	30.300	1964.184	16.500	44.100
Asturias	0.104	0.478	0.680	0.959	3.500	44.200	193.586	0.970	0.782	15.540	0.255	29.300	1316.599	18.800	42.400
Baleares Islands	0.102	0.141	0.344	0.489	1.700	34.800	80.038	0.580	0.790	9.920	0.097	9.300	1215.087	22.000	51.600
Canary Islands	0.174	0.085	0.284	0.394	2.300	34.400	59.906	0.380	0.714	10.690	0.058	5.900	968.593	16.600	55.500
Cantabria	0.142	0.319	0.508	0.770	2.200	42.500	153.164	0.410	0.726	13.300	0.269	22.400	1754.464	20.400	46.400
Castilla y León	0.085	0.875	0.671	1.070	2.500	39.000	225.876	1.290	0.699	14.200	0.216	23.700	957.267	14.600	42.000
Castilla la Mancha	0.071	0.350	0.212	0.408	2.300	30.800	90.513	0.680	0.724	12.020	0.185	12.800	2043.945	16.300	40.200
Cataluña	0.282	0.909	0.882	1.515	5.300	42.300	310.871	1.430	1.208	20.560	0.364	26.700	1169.394	21.100	57.900
Valencia	0.114	0.517	0.625	0.990	2.700	38.000	197.251	1.150	1.080	17.630	0.315	36.200	1594.439	18.100	46.400
Extremadura	0.138	0.155	0.481	0.658	1.600	26.700	78.673	0.490	0.588	12.050	0.165	14.100	2103.230	13.900	39.800
Galicia	0.133	0.512	0.614	1.012	2.900	40.300	211.891	0.730	0.828	17.420	0.263	18.900	1239.897	16.900	48.300
Madrid	0.387	0.999	1.131	1.792	8.100	50.200	307.801	0.940	1.108	15.760	0.281	42.000	912.970	18.600	50.000
Murcia	0.107	0.476	0.687	1.030	1.800	32.800	206.841	0.780	1.172	15.930	0.323	28.900	1559.947	15.300	42.700
Navarra	0.160	1.134	1.047	1.724	2.900	48.400	285.839	1.360	1.289	20.200	0.717	55.400	2507.722	18.100	47.900
Basque Country	0.132	1.510	1.422	2.102	4.100	53.400	202.013	1.980	1.515	21.640	0.871	33.500	4309.703	19.000	53.100
La Rioja	0.184	0.364	0.568	0.897	1.100	38.500	151.516	0.900	1.332	16.910	0.573	28.700	3784.881	14.400	35.600

Note: (*) Most of the variables are referred to 2019 year, although in some cases the closer year available have been used (see Table 1).
(**) The indicators are described in Table 2.

Table A2
Optimal weights for R_i^L (free weights)

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	Rank
Andalusia	0.0000	0.0001	0.0001	0.0001	0.0002	0.0005	0.0000	0.0001	0.0002	0.0001	0.0002	0.0000	0.9977	0.0004	0.0004	13
Aragon	0.0004	0.0004	0.0005	0.0004	0.9296	0.0021	0.0004	0.0006	0.0006	0.0005	0.0001	0.0000	0.0003	0.0119	0.0520	5
Asturias	0.9347	0.0001	0.0001	0.0002	0.0002	0.0002	0.0002	0.0001	0.0015	0.0004	0.0002	0.0001	0.0008	0.0006	0.0607	7
Baleares Islands	0.0000	0.0000	0.0000	0.0000	0.9697	0.0000	0.0000	0.0000	0.0000	0.0303	0.0000	0.0000	0.0000	0.0000	0.0000	12
Canary Islands	0.0000	0.3410	0.0000	0.1878	0.0000	0.0000	0.0086	0.3591	0.0000	0.0000	0.0183	0.0852	0.0000	0.0000	0.0000	16
Cantabria	0.0001	0.0001	0.0000	0.0001	0.0003	0.0000	0.0000	0.9979	0.0005	0.0001	0.0000	0.0000	0.0000	0.0001	0.0006	11
Castilla y León	0.7648	0.0001	0.0003	0.0003	0.0019	0.0013	0.0001	0.0002	0.0121	0.0017	0.0007	0.0003	0.0365	0.0828	0.0971	14
Castilla la Mancha	0.5556	0.0000	0.4444	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	9
Cataluña	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9996	0.0001	0.0001	6
Valencia	0.9906	0.0002	0.0002	0.0003	0.0015	0.0007	0.0001	0.0000	0.0003	0.0002	0.0001	0.0000	0.0004	0.0010	0.0044	4
Extremadura	0.0000	0.0000	0.0000	0.0000	0.5853	0.1150	0.0000	0.0000	0.0993	0.0000	0.0000	0.0000	0.0000	0.1742	0.0261	15
Galicia	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.9990	0.0002	0.0002	3
Madrid	0.0000	0.0002	0.0004	0.0003	0.0001	0.0011	0.0002	0.0013	0.0013	0.0029	0.0011	0.0002	0.9742	0.0060	0.0108	8
Murcia	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	10
Navarra	0.0033	0.0000	0.0002	0.0004	0.9500	0.0018	0.0006	0.0005	0.0010	0.0012	0.0000	0.0001	0.0006	0.0121	0.0283	1
Basque Country	0.9993	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0002	2

Source: own.

Table A3
Optimal weights for R_i^L (free weights)

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	Rank
Andalusia	0.0003	0.0001	0.0001	0.0002	0.0001	0.0010	0.9668	0.0002	0.0006	0.0014	0.0001	0.0003	0.0001	0.0065	0.0222	14
Aragon	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	6
Asturias	0.0002	0.0004	0.0008	0.0011	0.0003	0.8381	0.0029	0.0010	0.0014	0.0072	0.0003	0.0011	0.0004	0.1377	0.0072	11
Baleares Islands	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	4
Canary Islands	0.0003	0.0000	0.0000	0.0001	0.0001	0.0014	0.0001	0.0002	0.0005	0.0007	0.0001	0.0001	0.0001	0.0050	0.9913	7
Cantabria	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	8
Castilla y León	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	9

(continued on next page)

Table A3 (*continued*)

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	Rank
Castilla la Mancha	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	16
Cataluña	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9779	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0221	3
Valencia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	10
Extremadura	0.0001	0.0001	0.0001	0.0001	0.0000	0.0003	0.0001	0.0001	0.0001	0.0004	0.0000	0.0001	0.9968	0.0008	0.0010	15
Galicia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	12
Madrid	0.7661	0.0000	0.0002	0.0007	0.1167	0.0208	0.0912	0.0000	0.0002	0.0003	0.0000	0.0003	0.0000	0.0014	0.0019	5
Murcia	0.0000	0.0000	0.0001	0.0001	0.0000	0.0002	0.0009	0.0000	0.9964	0.0009	0.0000	0.0001	0.0000	0.0005	0.0007	13
Navarra	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	1
Basque Country	0.0000	0.1985	0.1791	0.0000	0.0000	0.0171	0.0000	0.0380	0.1282	0.1267	0.1937	0.0000	0.1187	0.0000	0.0000	2

Source: own.

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