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Relating the perspectives of the balanced scorecard for R&D by means of DEA ☆

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ABSTRACT

The objective of this article is to propose a framework for analysis of the relationships between the four perspectives of the balanced scorecard (BSC) of Kaplan and Norton. To this end, several different models of efficiency have been developed, utilising data envelopment analysis (DEA). Each of the variables has been extracted from a model of the BSC for research and development (R&D) activities. A study has been carried out with 90 companies to illustrate a case of this analysis.

1. Introduction

The balanced scorecard (BSC), a model for the analysis of strategic information for all types of organisation, was developed by Kaplan and Norton in 1992 and since then has been the subject of much research in respect of its possibilities as a tool for strategic management. However, few references have been found to its development and implementation in companies where research and development (R&D) activities are considered to be critical for their strategy. Moreover, there are very few studies in the literature on the management control and new product development in which relationships are established between the results from these activities, measured by means of the BSC, and the efficiency with which they are performed. For this reason, the objective of this article is to propose a framework for the analysis of these relationships.

With this purpose in mind, the objective we have set ourselves is to study the relationships between the perspectives of the BSC for R&D activities, principally by developing various different models of efficiency, employing the method of data envelopment analysis (DEA). To analyse the relationships between the efficiency ratios given by the various DEA models, we use Pearson's product moment correlation coefficient. Factor analysis is then performed to obtain an overall interpretation of the ratio correlations. The factor analysis approach used in this case is the Exploratory Analysis. This is a two-step procedure: 1. Finding a direct or unrotated solution; this involves extracting and numbering the factors (factorization methods). 2. Finding the indirect or rotated solution (factor rotation).

For this aim, we have used the scale developed by García-Valderrama and Mulero-Mendigorri (2005) for measuring the effectiveness of R&D activities and we have adapted it to the Financial, Customer, Internal Processes and Learning and Growth Perspectives with the addition of an Innovative perspective.[1]

We have structured this paper in two main sections: in the first part, we analyse several experiences of measuring the efficiency of R&D activity using DEA. In the second part, we set out the objectives and methodology employed in the determination of the levels of efficiency in the performance of R&D. Lastly, the results obtained are analysed and the conclusions are presented.

2. Balanced scorecard and efficiency of R&D

The Frascati Manual (OECD, 1994) states that scientific and technological innovation can be understood as the transformation of an idea into the launching of a new or improved product, a new or improved industrial or commercial process, or a new method by which to serve society. The term 'innovation' may take on different meanings in different contexts and the choice of meaning will depend on the specific objectives pursued in its measurement and analysis. Innovation also involves a series of scientific, technological, organisational, financial and commercial activities.

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[1] In order to adapt the scale of García-Valderrama and Mulero-Mendigorri (2005) to a BSC structure, some of the items in the Learning and Growth perspective have been expanded, because we knew that the original scale lacked indicators related to this, particularly those for human resources. Hence the majority of the items of this scale have been employed, because they are clearly associated with the perspectives of finance, customers and processes, but not with that of learning and growth in the BSC.

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Research and development (R&D) is only one such activity and may be present at various stages in the innovation process, not only as the original source of novel ideas, but also as a solution to problems (OECD, 1991).

Both the Frascati Manual (OECD, 1994) and the Survey of technological innovation in firms, INE (1999) define R&D as: '... creative work undertaken on a systematic basis in order to increase the stock of knowledge, including the knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications'.

Traditionally, R&D activities have not formed part of a corporate strategy, and this has been one of the biggest difficulties in the choice of instruments for measuring the returns from this type of activity. Consequently, R&D is a key strategic topic that should be aligned with the corporate strategy (Pearson et al., 2000). The implementation of a strategy requires integrated systems of measurement that capture changes in both the financial and non-financial returns. These systems of measurement are based on aligning the processes of the organisation (R&D, production, marketing and other traditional functional areas) with the corporate strategy, thus utilising drivers of the returns as their measurements.

On this point, Kerssen-van Drongelen and Bilderbeek (1999) consider that, in the literature on R&D, there are relatively few references on the utility of employing measurement techniques for the returns in this type of activity, and they suggest that the BSC could be employed as an integrated system of measurement of the returns from R&D. Moreover, Neufeld et al. (2001) argue that the BSC offers a 'most promising approach' that helps organisations to measure their performance and to achieve their objectives of excellence.

According to Kaplan and Norton (1992, p. 32) the balanced scorecard is 'a new framework or structure created for integrating indicators derived from the strategy, that continues to retain financial indicators of the past actions, completed with inductors of future financial actions. The inductors, which include the customers, the processes and the perspectives of learning and growth, are derived from an explicit and rigorous translation of the strategy of the organisation into tangible objectives and indicators'.

The strategies and the lines of action that would enable the company to achieve its strategic vision should be translated into each of the perspectives. The company's strategies in the perspectives of learning and growth and in internal processes that are important in R&D activities will be those that, in short, help it to meet its strategic objectives related to the satisfaction of its customers and shareholders.

Each measurement is part of a chain of cause-and-effect links. There must be a balance between the measurements of results (against financial, market and customer goals) and the motors driving those results (proposed value, internal processes, learning and growth in R&D) (Kaplan and Norton, 1993, 1996, 2001).

Although there are relatively few examples of the development and implementation of the BSC in measuring the performance of R&D activities (Kerssens-van Drongelen and Cook, 1997; Kerssen-van Drongelen and Bilderbeek, 1999; Li and Dalton, 2003; Neufeld et al., 2001; Neufeld et al., 2001; Bremser and Barsky, 2004), there are even fewer studies dealing with the relationship of the BSC with measures of efficiency in carrying out these activities.

The concept of efficiency, when translated to R&D activities, presents the same difficulties as those noted in respect of measuring its performance. In this case, efficiency should be identified with success in the achievement of the objectives and results pursued by companies in undertaking R&D activities, but these objectives and results need to be related to the optimum allocation of the appropriate material and human resources. In accordance with this line of argument, the R&D department can be considered, following Forrester (1961), as a discrete system within the organisation; in particular, and according to this author, this system is "an assembly of elements, both material and immaterial, that interact in the search for the achievement of common objectives". When R&D activities are undertaken, a series of inputs are consumed, a scientific or technological process is put into action, and later a series of outputs derived from these inputs and processes are obtained; for R&D-based companies, successful outputs are essential for survival and future growth of the company in commercial and financial terms.

Notwithstanding the above, in this study we wanted to widen the concept of efficiency and to relate it to those perspectives of the BSC that are linked more closely to the financial and commercial results (Financial and Customer perspectives, respectively), on the one hand, and with the drivers, or inputs, of those results in the final analysis, on the other (Internal processes, learning and growth perspectives). Therefore, in this study, we have taken efficiency to mean the relationships that hypothetically should apply between the perspectives of the BSC: the final results of the company (financial and customers), with their inputs (Internal processes, and learning and growth). At the same time, following the reasoning of cause-effect relationships that underlies the BSC concept, we consider it appropriate to measure the internal efficiency of the process by relating, in a different model of efficiency, the perspectives of internal processes and of learning and growth.

From a review of the literature on the efficiency of R&D activity, we find that the assessment of this efficiency has been approached from various different points of view. Thus, efficiency is normally measured with the object of determining if the services provided by a company have been produced at a reasonable cost (in relation to price) and with the maximum possible quality (Gattoufi et al., 2004). With respect to the assessment of efficiency in companies' performance of R&D activities, utilising the DEA model, the studies of particular interest are those by Thore and Rich (2002) and Thore and Lapao (2002), in which a methodology for the selection of R&D projects is developed and utilised. In this context, the study of Linton et al. (2002) is also relevant: this gives an illustration of how DEA can be employed in the analysis, ranking and selection of R&D projects by companies. Cook and Green (2000) also apply DEA in the selection of R&D projects considering resources as the limiting factor.

Another important part of the literature on efficiency in performing R&D concerns the utilisation of the DEA model to determine the factors related to inefficiency in R&D activities, starting from the key success factors in these types of activity, and the resources employed in carrying out these activities. On this aspect, it is clear that most of the existing studies have been conducted in the framework of public research centres (García Valderrama and Groot, 2002; Korhonen et al., 2001; Avkiran, 2001), and very few done in companies.

With respect to previous studies relating the balanced scorecard and efficiency using DEA, these are scarce in the literature on R&D; we have found some studies that, in a very general way, evaluate the suitability of the BSC (Rickards, 2003), that relate efficiency and results (Tsang et al., 1999; Rouse et al., 2002; Banker et al., 2004), or that evaluate efficiency in respect of R&D activities in different countries (Wang and Huang, 2007). Concerning the evaluation of research projects using methodology based on the DEA method and the Balanced Scorecard, the papers of Eilat et al. (2006, 2008) are significant. In the first of these, a methodology is proposed and demonstrated for developing and analysing the efficiency, effectiveness and balance of a portfolio of R&D projects that mutually interact. This methodology is based on an extension of the DEA methodology in which are included some of the qualitative concepts incorporated in the BSC. The method of evaluation proposed is carried out in seven phases, commencing with a distribution of resources among the categories associated with the main areas of strategy (product lines, technology areas, etc.); then once the resources have been distributed, the R&D projects are considered as DMUs, evaluated with a DEA–BSC model, and the scores obtained in this phase are utilised to establish the list of candidate projects. The next phase consists of utilising the efficiency scores of each project to perform a control of the risk variability, the efficiency and the balance of outputs; in the subsequent phase, a branch-and-bound model is constructed to generate an alternative portfolio of projects. Lastly, to evaluate the alternative portfolio of products, a DEA–BSC model is employed, finishing with an application of sensitivity analysis, by means of which the best portfolio of projects is chosen.

In the second paper of Eilat et al. (2008), a method is developed and demonstrated for evaluating R&D projects in different stages of their life cycle. The approach combines DEA and BSC, and the measurement of the inputs and outputs is integrated on "cards", associated with a "BSC for R&D projects"; this analytical framework is then applied to a research laboratory that selects and executes a large number of research projects each year.

Only the work of Rickards (2003) closely approaches the objectives of our study. In that study the result of the performance of the BSC is evaluated by calculating different ratios of efficiency by means of DEA, but in no case do these ratios validate the content of the BSC employed, nor are they orientated to company R&D activities.

3. Relating the perspectives of the balanced scorecard by means of DEA

3.1. Objectives

The objective of this study is to relate the perspectives of the BSC for R&D activities by means of DEA. For this aim, we have used the scale developed by García-Valderrama and Mulero-Mendigorri (2005) for measuring the effectiveness of R&D activities and we have adapted it to the financial, customer, innovation, internal processes and learning and growth perspectives (Fig. 1). The reason for including the extra perspective of innovation is the need to separate clearly the commercial and financial results of the company from the value it adds to its customers and shareholders in terms of innovation. In this respect it is important to bear in mind that R&D activities only constitute one part of the process of company innovation, and that with the inclusion of this new perspective, companies would be able to determine the efficiency of their R&D, and to relate this to the resources and capacities of the persons most directly involved in this type of activity, with the foreseeable consequences on its processes and on the degree of innovation really achieved.

In the light of this difficulty, the outputs of R&D processes have traditionally been assessed by the number of patents or utility models obtained, and even by the number and quality of papers published or presented at congresses; in effect, the apparent increase of specialised knowledge acquired by the company from undertaking its R&D activities is used as a surrogate variable (ESEE, 1991; Patell and Pavitt, 1995; Lee et al., 1996; Coombs et al., 1996; Urraca Ruiz, 1998; OECD, 1991, 1994; Holger, 2001). The utility for the company of new technologies, both those acquired externally and those developed internally by the company itself, has also been considered as an output of R&D (ESEE, 1991; Demirag, 1998). They clearly represent intermediate results achieved by these companies, which should foreseeably materialise in improvements in the commercial and financial results of the company (García-Valderrama and Mulero-Mendigorri, 2005.

It should have been made clear previously that, although the DEA is a model that empirically establishes a function of production, without *a priori* specification, the objective of this study is to validate empirically the model of relationships of the BSC by means of five models of efficiency. The research procedure is to demonstrate empirically using DEA the hypothetical relationships between the five perspectives of the BSC.

This leads us to propose the following models of efficiency of the R&D activity (Table 1).

- The objective of the first model (F-C) is to measure the efficiency obtained by the set of companies analysed, taking the indicators of the financial perspective of the BSC for R&D activity as their results or outputs, and taking the indicators of the customers perspective of the BSC as the inputs.
- In the second model of efficiency (C-I) the drivers of the commercial result would be the indicators of the perspective of Innovation. The objective is, therefore, to relate the commercial results of the R&D activity to the efficiency of their Innovation processes.
- The objective of the third model (I-PI) is to relate the results of the innovation output from the R&D activity with the efficiency in the internal processes. For this, the indicators included in the innovation perspective are taken as the R&D results (output), and the indicators of the internal processes perspective are taken as the drivers of this result (input).
- The objective of the model (PI-AC) is to relate the results of the internal processes of the R&D activity with the efficiency in the use of the material and human resources employed. For this, the indicators included in the perspective of internal processes are taken as the R&D results (output), and the indicators of the learning and growth perspective are taken as the drivers of this result (input).
- Lastly, to complete the circular analysis, the last model (F-AC) evaluates the efficiency in R&D by relating the financial results of the companies with their material and human resources employed in performing their R&D activities.

The development of these ratios of efficiency will enable us to test whether the companies that obtain good results in the ratios I-PI and PI-AC are also capable of maximising the values of efficiency in F-C, C-I and F-AC.

Table A of the Annex includes the indicators employed in each of the five models of efficiency. The size of the sample was 90 companies.

3.2. The sample and variables

The population to be studied was selected on the basis of data provided by the Survey on technological innovation by companies, carried out by the Spanish "Instituto Nacional de Estadística" (INE, 2002 and 2004). It was demonstrated in that survey that the companies in the chemical and pharmaceutical industries, together with those in the aeronautical industry, are the most innovatory in Spain. The data on the companies comprising the study sample were obtained from the SABI (Sistema de Análisis de Balances Ibéricos) data base. We have been guided by the classification of economic activity, utilising the code that includes all the chemical and pharmaceutical industries, in delimiting, within the data base, the population constituted by the companies in the Spanish chemical and pharmaceutical industries. The questionnaires were sent by e-mail and by post. Lastly, responses were received from a total of 90 companies (20% response rate). The data have been used to illustrate the possibilities of DEA in the study of the relationships between the perspectives of the BSC.

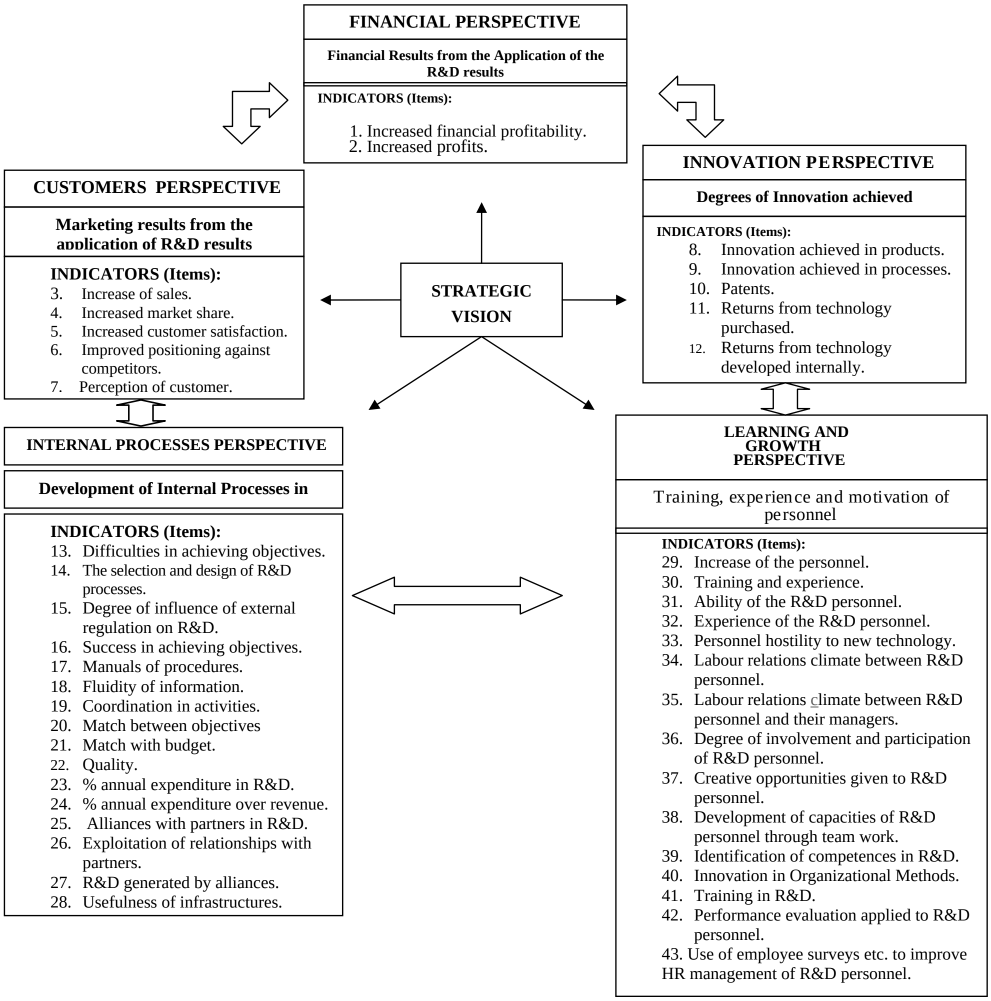

Fig. 1. Indicators of the proposed BSC for R&D. Adapted from the scale validated by García-Valderrama and Mulero-Mendigorri (2005).

Table 1
Efficiency models

Efficiency	Outputs	Inputs	Ratio of efficiency
F-C	Financial perspective indicators	Customers perspective indicators	F-C efficiency $= \frac{\text{Financial perspective indicators}}{\text{Customers perspective indicators}}$
C-I	Customers perspective indicators	Innovation perspective indicators	C-I efficiency $= \frac{\text{Customers perspective indicators}}{\text{Innovation perspective indicators}}$
I-PI	Innovation perspective indicators	Internal processes perspective	I-PI efficiency $= \frac{\text{Innovation perspective indicators}}{\text{Internal processes perspective indicators}}$
PI-AC	Internal processes perspective	Learning and growth perspective	PI-AC efficiency $= \frac{\text{Internal processes perspective indicators}}{\text{Learning and growth perspective indicators}}$
F-AC	Financial perspective indicators	Learning and growth perspective	F-AC efficiency $= \frac{\text{Financial perspective indicators}}{\text{Learning and growth perspective indicators}}$

The procedure has been the following: In Annex, Table A, we use the questionnaire applied to each company,[2] and each item or empirical indicator has been assessed by the respondent in each company on a Likert scale of three items. These values constitute the various different indicators used in the DEA models. Other items of the questionnaire comprise the specific data obtained, by company, such as the variables expressed as percentages.

3.3. Methodology for measuring the efficiency in R&D activities. The DEA model

The methodology employed has been based on the DEA model. This method provides an assessment of efficiency by means of the comparative study between the inputs (resources) and the outputs (products) obtained by each unit (e.g. each company) to be evaluated. This type of analysis can be made provided the units consume the same type of resources in order to obtain the same type of outputs. The model makes a transversal comparison of the different inputs and outputs of each company with those of all the rest. Each company is evaluated by comparing it with the rest of the companies analysed, and from this an indicator of relative efficiency is obtained.

The DEA is a method of estimation that traces the exterior boundary to the set of data observed. The points on this boundary represent the companies that reach efficiency values equal to 1 in relation to the set, whereas those companies that do not reach this boundary are considered inefficient (Charnes et al., 1978).

Because some categorical values have been included in the BSC, the formulation followed in this study will correspond to that developed by Banker and Morey (1986). The idea developed by

[2] It should be stated that the scale employed in this study, included in Table A of the Annex, has been validated previously by the authors, and for each of the variables that form the five dimensions, a validation of content has been applied.

these authors will lead to the modification of the original DEA model, once it has been linearized and considering the dual of Eq. (1), with the definition of two categorical variables d^1 and d^2, for three groups, with values of zero and one respectively. These values are assigned by company in the following way:

$d^1j = d^2j = 0$, belonging to the group of companies with a score of 1 in the item of the BSC.
$d^1j = 1$ and $d^2j = 0$, belonging to the group of companies with a score of 2 in the item of the BSC.
$d^1j = d^2j = 1$, belonging to the group of companies with a score of 3 in the item of the BSC.

The analytical expression of the model of Banker and Morey (1986) corresponds to Eq. (1):[3]

$$\text{Min} \quad w_0 \tag{1}$$

Subject to:

$$\begin{aligned}
&w_0 x_{i0} - \sum_{j=1}^{n} x_{ij}\lambda_j \geqslant 0,\\
&\sum_{j=1}^{n} y_{rj}\lambda_j \geqslant y_{r0},\\
&\sum_{j=1}^{n} \lambda_j d_j^1 \leqslant d_{j_0}^1,\\
&\sum_{j=1}^{n} \lambda_j d_j^2 \leqslant d_{j_0}^2,\\
&r = 1,\ldots,s;\ i = 1,\ldots,m;\ \lambda_j \geqslant 0,\ \forall i,j,r
\end{aligned}$$

where y_{rj} and x_{ij} are, respectively, the observed values of the outputs and inputs of the "*j*" companies of the sample; y_{r0} and x_{i0} are the observable values of the company that we are testing. In our study we are going to employ only the information related to the scores of efficiency or inefficiency (w_0) in Eq. (1) that will allow us to situate the company with respect to the sample analysed according to the BSC for R&D activity. The optimisation generates the optimum $w_0^* = 1$ only if the unit evaluated is efficient. Thus, the objective function will always take values between 0 and 1 for the various units studied; these will be more efficient, the closer the value is to 1.

With respect to the last two restrictions of Eq. (1), both the variable d^1 and the variable d^2 would form the categoric values assigned to each item of the questionnaire for the *j* companies of the sample.[4]

[3] Since our objective was not to monitor the efficiency by the optimization of the output, given certain inputs, nor by the minimization of the input, given certain outputs (since the variables utilized were simply ranges), we decided to apply directly the model of Banker and Morey (1986), with the same restrictions employed in their original study. This was because we understood that this model was closer to the objectives of this study. However, given that the objective of the study was to determine the relationships between the perspectives of the BSC by means of DEA, taking as our basis the relationships that Kaplan and Norton (1992) established hypothetically, it is perfectly feasible to apply models orientated both to the outputs and the inputs.

[4] For the *j* DMU's and for each *item* of each model and for d^1: If company 1 gives a score of 1 to the item 1, it would have a corresponding value for $d_1^1 = 0$. If company 2 gives item 1 a score of 2, it would have a corresponding value for $d_2^1 = 1, \ldots$. and if company 90 gives item 1 a score of 3, it would therefore have a corresponding value for $d_{90}^1 = 1$. The first restriction would take the following form, with the value for $d_{j0}^1 = 1$, since this item was given a score of 3. $\lambda_1 * 0 + \lambda_2 * 1 + \cdots + \lambda_{90} * 1 \leqslant 1$. For *j* DMU's and for each *item* of each model, and for d^2: Company 1 gives the item 1 a score of 1, therefore it would have a corresponding value of $d_1^2 = 0$. Company 2 gives item 1 a score of 2, and would have a corresponding value for $d_2^2 = 0, \ldots$, and company 90 gives item 1 a score of 3, and would therefore have a corresponding value for $d_{90}^2 = 1$. The second restriction would take the following form, with the value for $d_{j0}^2 = 1$, since this item was given a score of 3. $\lambda_1 {}^* 0 + \lambda_2 {}^* 0 + \cdots + \lambda_{90} {}^* 1 \leqslant 1$ and so on for all the items of the questionnaire and for each model of efficiency.

We expect to find that the companies that achieve greater efficiency in the models I-PI and PI-AC (which are considered the "motors" of the R&D results achieved by a company) have also been the most efficient in the models of the results obtained from the R&D, F-C, C-I and F-AC, which are basically the relationships underlying those between the perspectives of the balanced scorecard. The general research model, included as Fig. 2[5] of the paper.

The general procedure was as follows (Fig. 2):

- The first model of efficiency (F-C) would be formed, for the case of the outputs, by the financial variables of financial profitability and profits would represented by the scale items 1 and 2 (Table A Annex); in addition, as indicators of the perspective of customers, the input variables would be represented by the scale items from 3 to 7. The measurement of the variables is illustrated for this first model in Table 2. The example of application of measurement of the DEA–BSC variables is illustrated in the Tables 2 and 3, with data obtained for one particular company (only models F-C and C-I).
- With the second model of efficiency (C-I) we would be analysing efficiency by relating the output obtained by the companies in the customers perspective, to the results of the innovation originating from their R&D departments. In this model, the inputs would be represented by the scale items from 8 to 12. The measurement of the variables for this second model is also illustrated (Table 3).
- The third model of efficiency (I-PI) is the one that is most closely related to the efficiency of the R&D departments, since the direct results derived from the R&D activity would be considered as output, with input variables linked to their internal working processes. This indicator of efficiency could be ranked as a primary indicator of performance of the department. For its measurement we would be utilising the scale items from 13 to 28.
- With respect to the fourth model of efficiency (PI-AC), the items of the BSC for the R&D activity corresponding to the perspective of Internal processes have been taken as output variables; these are exactly the same items that would figure as inputs in the I-PI model of efficiency; however, in this case, the input variables would be formed by the scale items corresponding to the perspective of learning and growth; in particular, for this latter perspective, the items from 29 to 43 would correspond to the inputs of the model.
- The last model of efficiency (F-AC) is intended to corroborate the relationships between the learning and growth perspective and the financial perspective. In this case, the input variables, as in the preceding model of efficiency, would be formed by the scale items of the AC perspective, while the output variables would be formed by financial variables: Financial profitability and profit.

4. Relationships between the different efficiency models

To assess the relationship between the different efficiency models employed in this study, we have ordered the companies by means of DEA. In order to avoid the problems that could arise with variables not having a normal distribution pattern, the efficiency indices were ranked from 1 to 90. This reflected the number of times each company had emerged in the model as a reference unit

[5] The relationships in the BSC are clearly sustained on relationships of efficiency between its perspectives, and the only formula for proving that this is so is to calculate the global efficiency of the BSC model, by obtaining both quantitative and qualitative data on the R&D management as practised by the companies in the same single sector. Those relationships of efficiency have constituted the general idea of the paper; they could be applied equally to a set of research projects, also at the microeconomic level, but this idea was beyond the objectives of this study.

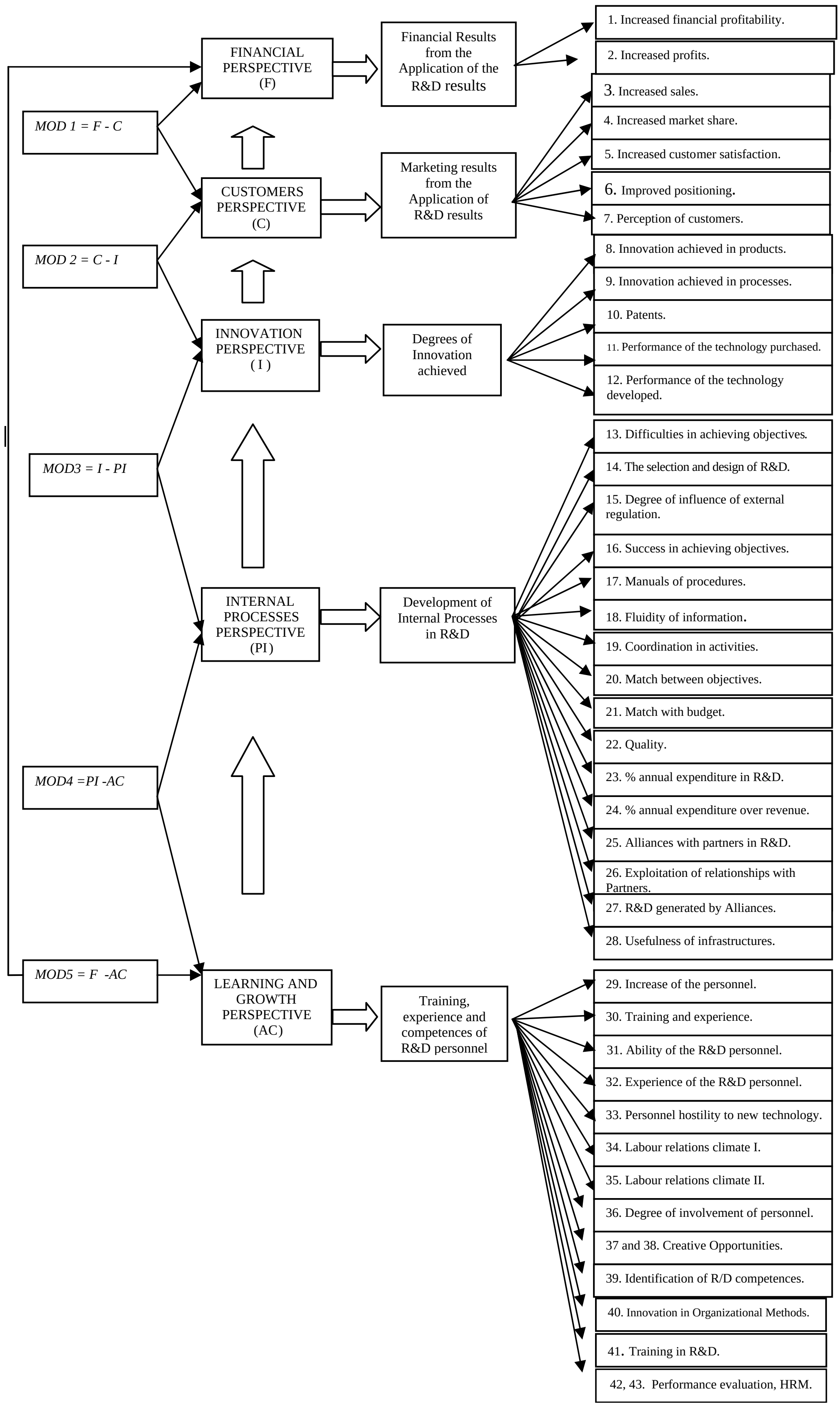

Fig. 2. R&D efficiency models in five steps (general research model).

Table 2
Example of the measurement of variables for one particular company ($DMUj_0$) (Model F-C)

Variables of model 1 (F-C)	Outputs (F) Likert scale of 3	Inputs (C) Likert scale of 3	Categoric variable
1. Estimate the increase of profits of your company in the last 3 years derived from the application of the results of R&D	3		$d^1j_0 = d^2j_0 = 1$
2. Estimate the increase in the rate of financial profitability of your company in the last 3 years, derived from the application of the results of R&D	3		$d^1j_0 = d^2j_0 = 1$
3. To what extent have sales revenues increased due to the application of R&D results?		2	$d^1j_0 = 1$ and $d^2j_0 = 0$
4. What extent have market shares increased due to the application of R&D results?		1	$d^1j_0 = d^2j_0 = 0$,
5. To what extent has customer satisfaction increased due to the application of R&D results?		3	$d^1j_0 = d^2j_0 = 1$
6. To what extent has your company improved its global positioning against its competitors, due to the application of R&D results?		1	$d^1j_0 = d^2j_0 = 0$
7. How do you rate the perception that your customers have of the products and services sold by your company?		2	$d^1j_0 = 1$ and $d^2j_0 = 0$

for the rest of the study sample. This is what determines whether or not the company can be legitimately classed as efficient.

To analyse the relationships between the efficiency ratios given by the various DEA models, we use Pearson's product moment correlation coefficient. Each cell contains a coefficient score prefixed with its significance level $p = 0.01$.

Factor analysis is then performed to obtain an overall interpretation of the ratio correlations and discover whether there are any underlying factors in the matrix. The factor analysis approach used in this case is known as exploratory analysis. This is a two step procedure:

1. Finding or a direct or unrotated solution; this involves extracting and numbering the factors (factorization methods).
2. Finding the indirect or rotated solution (factor rotation).

The factorization method used here is known as principal components analysis. In order to determine how many factors to extract, we use Kaiser's criterion (Kaiser, 1965, 1970), which involves selecting all those factors with eigenvalues of 1 or over. To select the items to be included in any particular factor, we use Stevens' criterion (Stevens, 1992), which is to take any items with a minimum factor loading of 0.40. The solutions are then rotated using the Varimax rotation method (orthogonal rotation) (Kaiser, 1958; Saunders, 1962).

The conceptual interpretation and determination of the underlying factors is done arbitrarily, based on what is known of the relationships between the efficiency ratios and their return processes.

Homogeneity of variables is a necessary condition for the interpretability of factor analysis results and must, therefore, be measured beforehand. In this paper, two criteria, one mathematical, one statistical were used for this.

The first was the correlation "matrix sample adequacy" (MSA) test, which gave a value of 0.690. This is an index proposed by Kaiser (1970) and derived from the work of Guttman (1964) on the application of matrix calculus in factor analysis. Another of the

Table 3
Example of the measurement of variables for one particular company in DEA (Model C[a]-I)

Variables of Model 1 (C-I)	Outputs (C) Likert 3	Inputs (I) Likert 3	Categoric variable
3. To what extent have sales revenues increased due to the application of R&D results?	2		$d^1j_0 = 1$ and $d^2j_0 = 0$
4. What extent have market shares increased due to the application of R&D results?	3		$d^1j_0 = d^2j_0 = 1$
5. To what extent has customer satisfaction increased due to the application of R&D results?	1		$d^1j_0 = d^2j_0 = 0$
6. To what extent has your company improved its global positioning against its competitors, due to the application of R&D results?	3		$d^1j_0 = d^2j_0 = 1$
7. How do you rate the perception that your customers have of the products and services sold by your company?	2		$d^1j_0 = 1$ and $d^2j_0 = 0$
8. How do you rate the results of innovation in products originating from R&D activities?		1	$d^1j_0 = d^2j_0 = 0$
9. How would you assess the results of innovation in processes originating from R&D activities?		3	$d^1j_0 = d^2j_0 = 1$
10. What is the percentage increase/decrease in the number of patents obtained each year by your company, over the last three years?		2	$d^1j_0 = 1$ and $d^2j_0 = 0$
11. Would you say that the technology purchased by your firm for use in R&D activities is bringing about positive results?		3	$d^1j_0 = d^2j_0 = 1$
12. Would you say that the technology developed by your firm for use in R&D activities is bringing about positive results?		1	$d^1j_0 = d^2j_0 = 0$

[a] The biggest range is 3 when we are incorporating the outputs into the model; however, 3 is treated as 1 when we are incorporating the input variable into each model. The objective is to avoid penalizing the companies with the best results in each model whose perspectives are considered as both outputs and inputs.

procedures used to aid correct interpretation of factor analysis is a statistical test. Bartlett's Sphericity test (Bartlett, 1950, 1951) is the multivariate analogy of the statistical significance test for the simple correlation coefficient. It is used to determine whether a correlation matrix gives a set of non-zero coefficients, thus indicating that correlation is not the result of random effect.

To summarise, the objective of performing an analysis as described above is to check how the values of efficiency of the five models are inter-related, taking into account that, according to the hypothetical cause–effect relationships of the BSC, what we expect to find is that those companies that achieve maximum efficiency in models 3 and 4 are the same companies that achieve maximum values of efficiency in models 1, 2 and 5. This would be the basis of the relationships underlying the balanced scorecard of Kaplan and Norton. Subsequently, having calculated the matrix of correlations, the next step is to apply a factorial analysis, with the extraction of the principal components, with the object of confirming that the five models form part of a single structure of results of the performance of an organisation. Therefore, as we intend to demonstrate in our study, the five models form a single factor, as established by Kaplan and Norton (Fig. 2).

5. Results of the relationships between the different efficiency models

The results of the study carried out are presented in Tables 4–6. Table 5 gives the frequency of companies whose efficiency values

Table 4
Correlation matrix

	Model (F-C)	Model (C-I)	Model (I-PI)	Model (PI-AC)	Model (F-AC)
Model (F-C)	1	0.786*	0.544*	0.552*	0.609*
Model (C-I)		1	0.784*	0.542*	0.321*
Model (I-PI)			1	0.486*	0.665*
Model (PI-AC)				1	0.736*
Model (F-AC)					1

* Significant at 0.01.

Table 5
Frequency of the efficiency scores

Efficiency scores	F-C	%	C-I	%	I-PI	%	PI-AC	%	F-AC	%
1	25	27.7	35	38.8	17	18.8	68	75.5	50	55.5
0.9	1	1.1	3	3.33	4	4.4	3	3.3	2	2.2
0.8	2	2.2	6	6.6	2	2.2	1	1.1	5	5.5
0.7	10	11.1	15	16.6	4	4.4	2	2.2	8	8.8
0.6	8	8.8	6	6.6	11	12.2	6	6.6	6	6.6
0.5	7	7.7	5	5.5	11	12.2	3	3.3	6	6.6
0.4	11	12.2	9	10	12	13.3	3	3.3	6	6.6
0.3	17	18.8	3	15.5	14	15.5	2	2.2	3	3.3
0.2	4	4.4	2	2.2	8	8.8	2	2.2	2	2.2
0.1	5	5.5	4	4.4	7	7.7	0	0	2	2.2
Total	90	100	90	100	90	100	90	100	90	100

Table 6
Factor weightings (Orthogonal "Varimax" solution)

Efficiency models	F1	F2
MD (F-C)	0.869	0.087
MD (C-I)	0.752	0.054
MD (I-PI)	0.870	0.126
MD (PI-AC)	0.751	−0.049
MD (F-AC)	0.845	−0.009

are ranked by scores ranging between 1 (totally efficient) and 0.1 (extremely inefficient).

Table 4 includes the correlations that should apply between the five indices of efficiency calculated for each model and for each company. As can be observed, if there is a high correlation between the five models of efficiency analysed, particularly between the F-C and PI-AC models (0.552), this would mean that those companies that had been classed as efficient in the F-C model would also be classed as efficient in the utilization of their material and human resources, devoted basically to the improvement of their internal processes in R&D activity (model PI-AC). On the other hand, if there were a high correlation between the F-AC, PI-AC and I-PI models, (0.736 and 0.665, respectively) this would confirm to us that those companies that had been classed as efficient in respect of the utilization of their resources, in respect of their internal processes and in Innovation results, should also have obtained good financial results.

To corroborate these results, we used the factorization method as principal components analysis, and in order to determine how many factors to extract, we used Kaiser's criterion. We obtained two eigenvalues: one equal to 3.509, which explains 52.95% of the variance of the correlations matrix, and the other equal to 1.955, which explains 24.14% of the total variance. Applying Kaiser's criterion, the first factor has a larger eigenvalue which explains a higher percentage of the variance, and this tells us of the existence of a factor that relates a series of models of efficiency. Subsequently, a Varimax Orthogonal Rotation analysis can be applied, in which one single factor that covers the five models of efficiency should be found.

To determine if these are actually the five models of efficiency under the hypothesis of relationship between the five perspectives, we apply Stevens' criterion (Table 6), obtaining five values of saturation higher than 0.4 for the first factor, and values of saturation less than 0.4 for the second factor; this is confirmation that the first factor is formed by the five models of efficiency. As observed in Table 6, the values of factor 1 were all higher than 0.4, and they all saturate on this same factor. This means that the five models of efficiency are highly correlated with each other for all the companies studied, and from this we can state that relationships exist between the five perspectives of the BSC. These results could mean that the relationships between the five perspectives of the BSC are validated, since they would be indicating how these efficient companies are achieving their superior efficiency, by employing models that correlate variables in the BSC linked to each of those hypothetical cause–effect relationships.

6. Conclusions

The objective of this study is to propose a framework for analysing the relationships of efficiency between the perspectives of the BSC, focusing on R&D activities. Due to the wide differences of view on the choice of the correct indicators, found in the literature, and to the lack of consensus on the most appropriate methodology for measuring the concept of R&D, we have framed our proposal within the methodology for the validation of scales. From the validation of this instrument of measurement we are able to obtain qualitative information on a set of companies; this type of information is particularly important in cases where no large data bases are available.

The need to evaluate the efficiency of R&D activities has led us to propose five models of efficiency whose input and output variables have been extracted from the items of the validated scale. These models of efficiency have in turn allowed us to analyse the hypothetical cause-effect relationships between the perspectives of the BSC, since each dimension has been considered as an input or output variable in the different models.

The result has been the establishment of the framework for the analysis of the relationships between the R&D results or yield and the efficiency with which the R&D activity is organised, managed and performed; for this we have employed different but complementary methodologies. Understanding these relationships between results and efficiency in R&D is extremely important for the more innovative companies: they need to know how successful their internal policies are in respect of the development and execution of new research projects, and how these relate to the relatively large amounts of resources invested in R&D activities. This is, therefore, a study that defines a suitable framework for analysing the success of companies, in respect of the achievement of their financial, commercial and organisational objectives, from the starting point of the resources employed and the processes carried out in an increasingly strategic activity such as R&D.

Appendix

Table A: Dimensions, objectives and indicators of the balanced scorecard for R&D

Dimension	Indicators (objectives)	Definition	Questionnaire items[a]
Financial results perspective	Success in the achievement of financial results due to the application of the R&D results	Measurement of the achievement of the financial objectives of the company in terms of increased profits and financial profitability	1. Estimate the increase of profits of your company in the last 3 years derived from the application of the results of R&D
			2. Estimate the increase in the rate of financial profitability of your company in the last 3 years, derived from the application of the results of R&D
Customers perspective	Marketing and commercial success due to the application of the results of R&D	Measurement of the achievement of the objectives of the company in terms of sales revenue, market share and customer satisfaction, due to the application of the results of R&D	3. To what extent have sales revenues been increased due to the application of R&D results?
			4. To what extent have market shares been increased due to the application of R&D results?
			5. To what extent has customer satisfaction increased due to the application of R&D results?
			6. To what extent has your company improved its global positioning against its competitors, due to the application of R&D results?
			7. How do you rate the perception your customers have of the products and services sold by your company?
Innovation	Degree of Innovation achieved:	The company manages to offer innovative products, in comparison with its competitors, in accordance with its R&D objectives	8. How do you rate the results of innovation in products originating from R&D activities?
	– New materials	The company manages to innovate in production processes and achieve good results in reducing costs and improving the quality of its products	9. How would you assess the results of innovation in processes originating from R&D activities?
	– New components or intermediate products – New design or presentation – New functions for existing product – New machinery – New working methods – Both aspects (new machinery and methods)		
	Degree of match between the resources deployed and R&D results achieved	Rate of growth of the number of patents obtained	10. What is the percentage increase/decrease in the number of patents obtained each year by your company, over the last three years?
	Origin of the technology employed in R&D	The technology utilised for R&D by the company is external in origin	11. Would you say that the technology purchased by your firm for use in R&D activities is bringing about positive results?
		The technology utilised for R&D by the company is internal in origin	12. Would you say that the technology developed by your firm for use in R&D activities is bringing about positive results?

(*continued on next page*)

Table A (*continued*)

Dimension	Indicators (objectives)	Definition	Questionnaire items[a]
Internal processes perspective	Match between company strategy and its R&D objectives and planned activities	Measurement of the degree of match or consistency between, on the one hand, the R&D objectives set and the R&D activities, and on the other, the current reality of the company and its business situation	13. How do you rate the effectiveness of the process of planning the R&D objectives and activities of your company?
			14. How satisfactory do you consider the selection and design of R&D processes?
	Degree of influence of external regulation on R&D	Degree of influence of external regulation on the planning of R&D objectives and activities	15. Indicate the degree of influence of external regulation on the R&D objectives and activities of your firm
	Match between the R&D budget and the objectives set	Measurement of success in setting realistic R&D budgets in accordance with specific objectives set for the department	16. How do you rate the problems faced by the R&D department in reaching the objectives set in the plans and budgets of the department?
	The existence in the company of Manuals of procedures for R&D activities	Set routines for formalized activities in the R&D department	17. Does the company have manuals of procedures for R&D activities?
	Fluidity of information flow between departments of the company	Degree of communication between the R&D department and the other departments of the company	18. How well are the R&D objectives and activities communicated to the R&D personnel, and to the personnel of the rest of the company?
	Coordination between R&D, production and marketing	Measurement of the degree of coordination between the activities undertaken in the R&D department and those undertaken in the departments of marketing and production	19. How do you rate the coordination between the activities undertaken in the R&D department and those undertaken in the marketing and production departments?
	Difficulties in achieving the objectives set in the R&D plans and budgets	Problems facing the company in reaching the objectives set in the plans and budgets for R&D activities	20. How do you rate the match between the R&D objectives and the financial resources needed to achieve them?
	Degree of success in keeping costs to budget	Measurement of the problems faced by the company in implementing new activities proposed by the R&D department, which may not agree with those set in the annual plan	21. How difficult is it for the R&D department to keep within its budgets?
	General quality of work undertaken in R&D activities	Measurement of the degree to which quality parameters in R&D activities are achieved. Compliance with quality standards on cost levels in the R&D department, parameters on research results, time, etc	22. To what extent have parameters been established for measuring quality in R&D activities? To what extent are such quality parameters achieved?
	Effort in R&D	The company allocates funds to cover activities related to R&D by reference to the average of previous years.	23. What is the % increase in annual expenditure on R&D in the three last years, compared with the average of previous years?
		The company allocates investments in R&D as a % of the total income, with reference to the average % of previous years	24. What is the rate of increase in R&D expenditure as a % of total revenue in the three last year, compared with the average of previous years?
	Alliances with partners in R&D	Degree of involvement of the firm's various partners in determining its R&D objectives and activities	25. Estimate to what extent your company identifies opportunities for establishing alliances in R&D with other organisations
		Cost-benefit ratio of these investments	26. To what extent are the key competences of the partners in R&D exploited in mutual development?

Table A (*continued*)

Dimension	Indicators (objectives)	Definition	Questionnaire items[a]
			27. Estimate to what extent an innovative and creative philosophy in R&D is generated and supported by means of such alliances
	Usefulness of the infrastructures utilized in R&D		28. What do you estimate is the cost-benefit ratio for the infrastructures utilised in R&D processes and activities?
Learning and growth perspective	Increase in the R&D personnel	Increase of the number of persons in the R&D department, compared with the increase in the number and size of projects	29. How does the rate of increase in numbers of R&D personnel compare with the increase in the number and size of R&D projects?
	Training of the R&D personnel	Measurement of the level of training of the R&D personnel, according to the number of qualified engineers, graduates, etc., as a percentage of the total employed	30. Number of persons with degree-level qualifications as a percentage of the total R&D personnel. Number with intermediate qualifications, as a percentage of the total
	Aptitude and Attitude of the R&D personnel for this type of work	Skills, abilities and experience possessed by the R&D personnel.	31. How do you rate the level of ability of the R&D personnel, in general?
			32. How do you rate the level of experience of the R&D personnel, in general?
	Adaptability of the R&D personnel to the technological changes adopted by the company and utilized in R&D	Conflicts among the R&D personnel faced with the utilisation of new research technologies	33. How do you rate the capacity of the R&D personnel to adapt to the technological changes adopted by the company?
	Labour relations climate among the R&D personnel and between them and their supervisors	Measurement of the health of the human relationships among members of the R&D department, and between them and their supervisors	34. How do you rate the personal relationships between the R&D personnel?
			35. How do you rate the personal relationships between the R&D personnel and their managers?
	Degree of involvement and participation of R&D personnel I + D	Measurement of the involvement of persons engaged in R&D activities in formulating the policies, strategies and plans of the company	36. Indicate the degree of involvement of the persons employed in the R&D departments in developing the policies, strategies and plans of the company
			37. To what extent does your organisation provide opportunities to the employees of R&D so that their innovatory behaviour is stimulated?
	Identification of competences in R&D and training	Measurement of the degree to which the capacities of R&D personnel are identified, and policies of training in the capacities required	38. Estimate the development of the capacities of the R&D personnel through teamwork...
			39. Estimate the degree of identification, classification and suitability of the knowledge and competences of the R&D personnel, to the needs of the organisation
			40. Indicate the degree to which your company employs innovatory organisational methods to improve the way people work. For example, restructuring the logistic chain, or working in flexible teams

(*continued on next page*)

Table A (*continued*)

Dimension	Indicators (objectives)	Definition	Questionnaire items[a]
			41. How do you consider that training and personal development plans for the R&D personnel are prepared and utilised? What contribution do these plans make to ensuring that the R&D personnel are fitted for the current and future capacities necessary for performing R&D activities?
	Evaluation of the performance of R&D personnel	Measurement of the degree to which Performance Evaluation of R&D personnel is implemented, and its utilisation for continuous improvement	42. Estimate the degree to which the performance of the R&D personnel is evaluated. How much help does your organisation give them to improve their performance?
			43. Indicate the degree to which personnel surveys, or any other information sought from the employees, are utilised, to improve the HR policies, strategies and plans related to R&D

Questionnaire items.
[a] Questionnaire adapted from García-Valderrama and Mulero-Mendigorri (2005).

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