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Evaluating firms' R&D performance using best worst method

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Research Highlights

- A multi-criteria framework for firm's R&D performance evaluation is proposed
- Best Worst Method (BWM) is used to identify the weights (importance) of R&D measures
- R&D performance of 50 high-tech Dutch SMEs is measured using the proposed methodology
- Assigning weights to different R&D measures results in different ranking of the firms
- The proposed methodology allow SMEs to improve their R&D performance

Abstract – Since research and development (R&D) is the most critical determinant of the productivity, growth and competitive advantage of firms, measuring R&D performance has become the core of attention of R&D managers, and an extensive body of literature has examined and identified different R&D measurements and determinants of R&D performance. However, measuring R&D performance and assigning the same level of importance to different R&D measures, which is the common approach in existing studies, can oversimplify the R&D measuring process, which may result in misinterpretation of the performance and consequently fallacy R&D strategies. The aim of this study is to measure R&D performance taking into account the different levels of importance of R&D measures, using a multi-criteria decision-making method called Best Worst Method (BWM) to identify the weights (importance) of R&D measures and measure the R&D performance of 50 high-tech SMEs in the Netherlands using the data gathered in a survey among SMEs and from R&D experts. The results show how assigning different weights to different R&D measures (in contrast to simple mean) results in a different ranking of the firms and allow R&D managers to formulate more effective strategies to improve their firm's R&D performance by applying knowledge regarding the importance of different R&D measures.

Keywords: R&D performance; R&D measures; Best Worst Method (BWM); small-to-medium-sized enterprises (SMEs).

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1. Introduction

Research and development (R&D) activities are viewed as determinants of the productivity, growth and competiveness of firms. Lazzarotti et al. (2011) argue that, generally speaking, in firms, R&D includes various activities and resources. They list a number of main activities, such as basic research, applied research, development, and some support activities, like technology intelligence, technology scouting, and market analysis. They also identified three types of R&D resources: (i) people, (ii) tangible resources (e.g. laboratories), and (iii) intangible resources (e.g. know-how). The importance of R&D activities makes measuring R&D performance a main concern for firms (Bilderbeek, 1999; Lazzarotti et al., 2011; Moncada-Paternò-Castello et al., 2010). Because the complexity and variety of technical and scientific knowledge have made R&D activities costly and risky, measuring R&D performance has become a critical issue for firms (Tidd et al., 2005). Generally speaking, R&D managers have several reasons to be concerned about measuring R&D performance: (i) the market is becoming more dynamic, customer needs are changing very quickly and the number of competitors is growing, (ii) knowledge is produced very quickly and so is the variety of products and services, and (iii) the complexity of knowledge incorporated into products and services is increasing (Lazzarotti et al., 2011).

It has been found that applying structures and techniques to measure R&D performance enhances the performance of firms (Griffin, 1997). However, uncontrollable factors make measuring R&D performance a challenging task for managers (Lazzarotti et al., 2011). There are several studies that have focused on R&D performance (see, for instance, Bilderbeek, 1999; Kim and Oh, 2002b; Roberts and Bellotti, 2002; Bremser and Barsky, 2004; Jefferson et al., 2006; Lazzarotti et al., 2011). Bilderbeek (1999), as an extension of Kaplan and Norton (1996), after a survey and a series of in-depth interviews, identified quantitative indicators for measuring R&D from four different perspectives of R&D performance: financial, customer, innovation and learning, and internal business. Literature is unclear, however, how a firm can measure its R&D performance with respect to these criteria. It is obvious that not all of these indicators have the same share in the overall R&D performance of a firm. Measuring R&D performance while assigning different levels of importance to different perspectives and to different measures (indicators) of each perspective has thus far been neglected in existing literature. In other words, existing studies assign the same level of importance to different measures of R&D performance. A better understanding of this issue would be highly beneficial to R&D managers and help them improve the R&D performance of their firms. Chiesa et al. (2009) found that firms have different objectives when measuring their R&D performance. While some firms may want to find a way to increase their profits, others may try to find a way to motivate their R&D employees. By acquiring knowledge about the level of importance of different R&D perspectives, and about the different measures of each perspective, R&D managers can formulate more effective strategies to improve their R&D performance. Thus, the main contribution of this study is to propose a systematic approach to measuring R&D performance, taking into account the levels of importance of different measures, using a recently developed multi-criteria decision-making method called Best-Worst Method (BWM) to identify the different weights (importance) of R&D measures. Finally, the R&D performance of 50 high-tech small -to-medium-sized enterprises (SMEs) in the Netherlands is measured, using data gathered through a survey among SMEs and R&D experts. There are some reasons for doing this study among SMEs in the Netherlands. Firstly, due to practical reason. This study is done in the Netherlands and the data was gathered from SMEs in this country. Secondly, because SMEs are important for the economy of the Netherlands as it is for other advanced economies. Based on the EU definition, 99.6% out of the total 864,000 Dutch companies in 2010 were SMEs. The significant importance of SMEs is not only related to their number but also, SMEs are considered as key growth driver for the Netherlands. In other words, SMEs have huge contributions to the employment and value added. In the Dutch non-financial business economy, SMEs account for two thirds of total employment (in 2016) and for the 63% of value added (European Commission, 2016). Furthermore, since R&D is one of the most critical determinant of the productivity, growth and competitive advantage of firms, and more importantly SMEs tend to have a higher R&D productivity than larger firms in the Netherlands (Van Hemert, 2013), measuring R&D performance in SMEs has become the core of our attention in this paper.

The remainder of this paper is organized as follows. The next section contains a review of earlier related studies. In Section 3, the methodology is described, while the findings, implications, and discussions are presented in Section 4 and the conclusion in Section 5.

2. Theoretical background

Existing literature on the firm's R&D performance has looked at this topic from different angles, as explained below.

Some researchers have studied the incentive system in the R&D context (see, for instance, Kim and Oh, 2002a, 2002b; Kunz, 2010). Kim and Oh (2002b) argue that R&D managers, by using an effective mechanism to measure R&D performance, can increase the motivation and satisfaction of their R&D scientists. They conducted a survey among 1200 R&D scientists and engineers in Korean R&D organizations, and concluded that a fair performance evaluation of R&D scientists increases their R&D performance.

In economic theory, technical changes are viewed as the key source of productivity and growth (Wang, 2007; Moncada-Paternò-Castello et al., 2010). Furthermore, the main source of technical changes is R&D (Guellec and Van Pottelsberghe de la Potterie, 2004), which is a process that consists of the creation, production, diffusion and application of knowledge (Wang, 2007). In fact, R&D contributes to new product innovation, productivity and profitability (Jefferson et al., 2006). Many studies have examined the economic aspects and effects of R&D activities regarding the performance of different industries in different countries, and have found that R&D activities enhance productivity and consequently improve the return on investment (see, for instance, González and Gascón, 2004; Tsai and Wang, 2004; Jefferson et al., 2006).

In addition to R&D activities improving return on investment, R&D collaboration has positive impact on innovation outputs. In the economic literature of the 1980s, the importance of R&D collaboration to firms attracted the attention of several researchers (see, for instance, Wang and Wu, 2012; Arroyabe et al., 2015). The importance of knowledge spill-overs in R&D collaboration and their impact on market performance in the form of increased return on investments/profits are the main incentives for firms to be involved in R&D collaboration (Leahy and Neary, 1997). Czarnitzki et al. (2007) investigated the relationship between R&D collaboration and R&D performance. They analyzed the effects of R&D collaboration and public incentives on the R&D expenditures and innovative outputs of firms, based on their patenting activities. They found that collaboration has a significant positive impact on innovative output. Fey and Birkinshaw (2005) also identified a relationship between the external sourcing of knowledge of R&D firms and high R&D performance as a result of partnerships, including university partnering, alliance partnering and contracting. Fey and Birkinshaw (2005) found that university partnering has positive impact on R&D performance, with interaction between firms and universities increasing the learning and knowledge assets of firms.

Subsequent studies continued to look at other elements that affect R&D performance, such as firm size. In literature, there are different arguments regarding the effect of firm size on the R&D productivity. While some studies argued that because, in large firms, R&D costs can be spread over its outputs, these firms can realize higher R&D returns (Link, 1981; Cohen and Klepper, 1996; Legge, 2000), other researchers argue that, due to some of the characteristics of large firms, such as a loss of marginal control or high level of bureaucratic control, R&D performance actually decreases (Scherer and Ross, 1990). Tsai and Wang (2005) studied 126 manufacturing firms and found that there is a U-shape relationship between a firm's size and its R&D productivity. More precisely, they found that R&D performance is higher in small and large scale firms compared to medium-sized firms. Wang (2007) extended also looked at the economic aspects of R&D, by measuring the efficiency of R&D activities, using a cross-country production model to evaluate the efficiency of R&D activities of 30 countries and taking R&D capital stock and manpower as input and patents and academic publications as output. The main result of Wang's study was that there is a positive relationship between using R&D resources in an efficient way and higher income and country growth.

Furthermore, a large number of studies have focused on the determinates of R&D performance and R&D measurements (including Schumann Jr et al., 1995; Werner and Souder, 1997; Kim and Oh, 2002b; Tsai and Wang, 2005; Wang, 2007; Chiesa et al., 2009; Bassani et al., 2010; Kunz, 2010). Reduced time-to-market, increased quality and reduced costs are three performance measures identified by Pawar and Driva (1999). Several researchers applied the Balanced Scorecard (BSC) approach to R&D performance (Kaplan and Norton,1996,2005;

Amaratunga et al., 2010), identifying four perspectives: quality, which is related to the 'customerperspective', efficiency and timeliness, which are related to the 'internal business process perspective', innovativeness, which is related to the 'innovation and learning perspective', and contribution to profit, which is related to the 'financial perspective' (Kerssens van Drongelen and Cooke, 1997). In other words, the customer perspective refers to the extent that R&D satisfies the needs of customers; the financial perspective relates to the financial and economic aspects of R&D; the business process perspective refers to the efficiency that is needed to carry out specific processes and tasks, and the innovation and learning perspective refers to the extent that R&D facilitates knowledge creation and innovation opportunities (Chiesa et al., 2009).

Kerssens van Drongelen and Cooke (1997) and Bilderbeek (1999) state that, although the parameters for measuring R&D are determined by the purpose of the subject of measurement and the objectives formulated for the subject of measurement, the measurement procedures are affected by contingency factors. Organizational level, type of R&D, type of industry, and organization size are some examples of influential factors of the R&D measurement that are considered in Bilderbeek (1999) empirical study on the effectiveness of R&D performance measurement in the Netherlands. He measured the R&D performance through four perspectives which is initially offered by Kaplan and Norton (1996): customer, internal business, innovation and learning, and financial, while considering the effect of contingency factors on the measurement of R&D performance. Different performance measures that were used by Bilderbeek (1999) are shown in Table 1. In this study, we use this conceptual framework because it is a comprehensive framework that includes different perspectives as well as detailed measurements for each perspective, and because it has been widely adopted by many researchers.

Table 1 Measures of performance, adopted from (Bilderbeek 1999)

Measures
Customer perspective:
Customer satisfaction/market response
% of products succeeding in the market
Professional esteem to customers
Internal business perspective:
Agreed milestone/objectives met
Number of products/projects completed
Speed
Efficiency/keeping within budget
Quality of output/work
Behavior of people involved in R&D activities
Planning accuracy
Innovation and learning perspective:
No. patents
No. ideas/findings
Creativity/innovation level
Network building activities of the firm
Financial perspective:
Expected or realized IRR/ROI *
% of sales by new products
Profit due to R&D
Market share gained due to R&D

Note: numbers represent % of respondents measuring the performance of the indicated subject.

*Internal rate of return (IRR) is also called the dollar-weighted rate of return. IRR is calculated as the interest rate that makes the present value of the cash flows from all the sub-periods in an evaluation period plus the terminal market value of the portfolio equal to the initial market value of the portfolio.

*Return on investment (ROI) is a profitability measure that evaluates the performance of a business. ROI can be calculated in various ways. The most common method is Net Income as a percentage of Net Book Value (total assets minus intangible assets and liabilities).

Chiesa et al. (2009), using these systematic and conceptual perspectives and relying on a case study analysis of 15 Italian technology-intensive firms, examined the problem of measuring R&D performance, and found that firms have different objectives when they measure R&D, i.e. monitoring the progress of activities, evaluating the profitability of R&D projects or motivating researchers. These objectives are determined by the characteristics of the context in which R&D measurement takes place, such as type of R&D, firm size and type of industry. They argued that the objectives affects a firm's decision to measure R&D performance, in addition to a particular perspective (i.e. customer, internal business, innovation and learning, and financial). Lazzarotti et al. (2011) also provide a model for measuring R&D performance based on quantitative indicators from different performance perspectives (customer, financial, internal business, innovation and learning, alliances, and networks).

As mentioned above, firms have different objectives when measuring R&D performance, which leads us to consider the different perspectives, and their different levels of importance. A major shortcoming of earlier studies is that they all assign the same weight to measurements (of different perspectives) when measuring R&D performance. In this paper, we propose a multi-criteria decision-making method (MCDM) to identify and apply different weights to different perspectives and measures of R&D performance (see Table 1). We then use the proposed methodology to measure the R&D performance of 50 high-tech SMEs in the Netherlands.

In existing literature, different types of MCDM methods are used to solve different problems in the field of R&D. Perhaps one of the most frequently examined R&D problems in this regard is that of ranking and selecting R&D projects, which is solved using different MCDM methods (see, for instance, Mehrez and Sinuany-Stern, 1983; Linton et al., 2000; Tonn, 2001; Linton et al., 2002; Bitman and Sharif, 2008; Eilat et al., 2008; Huang et al., 2008). Moreover, Lee et al. (2010)

measured the relative efficiency of R&D performance in the national hydrogen energy technology development using the integrated fuzzy analytic hierarchy process (fuzzy AHP) and the data envelopment analysis (DEA). Another problem that is solved using MCDM methods is that of allocating limited resources to different R&D projects (Hunt et al., 2008). However, although MCDM methods have been applied to R&D topics, so far R&D performance has not been approached as an MCDM problem. We think that, as R&D performance is inherently a multi-criteria problem, MCDM methods can significantly contribute to its measurement, which is the main focus of this study.

3. Methodology

As discussed above, because R&D performance is a multi-criteria concept, to measure it, we should use MCDM method. MCDM methods allow us to consider multiple criteria with different weights. There are several MCDM methods that have been applied in literature (Triantaphyllou, 2013). In this study, we use a newly developed MCDM method called best worst method (BWM) (Rezaei, 2015, 2016). Compared to similar existing methods, BWM requires less data, as it does not need a full pairwise comparison matrix, and it produces more consistent results due to its structured pairwise comparison system, which is the main reason we use it in this study. It is also perceived by the decision-makers as simple and very close to the way they judge and reason while making decision. This method has been applied to some practical problems such as risk assessment (Torabi et al., 2016), supplier segmentation (Rezaei et al., 2015), supplier selection (Rezaei et al., 2016, Gupta and Barua, 2017), sustainable supply chain management (Ahmadi et al., 2017, Wan Ahmad et al., 2017), water scarcity management (Chitsaz and Azarnivand, 2016), innovation management (Gupta and Barua, 2016), Measuring efficiency of university-industry Ph.D. projects (Salimi and Rezaei, 2016), and scientific output evaluation (Salimi, 2017). Nonetheless, its application in the field of R&D is new.

Here, we briefly describe the steps of the BWM.

Step 1. Determine a set of decision criteria.

In this step, we identify the decision criteria, which may be presented at different levels.

Step 2. Determine the best (B) (e.g. the most desirable, the most important) and the worst (W) (e.g. the least desirable, the least important) decision criteria based on the decision-maker(s)/expert(s) opinion.

Step 3. Determine the preference of the best decision criterion (B) over all the other decision criteria, using a 9-point scale (numbers between 1 and 9; 1: *B* is equally important to *j*; 9: *B* is extremely more important than *j*). The result is a best-to-others (BO) vector as follows.

$$A_B = (a_{B1}, a_{B2}, \dots, a_{Bn}),$$

where a_{Bj} represents the preference of *B* over *j* and $a_{BB} = 1$.

Step 4. Determine the preference of all the decision criteria over the worst criterion (W), using a 9-point scale (numbers between 1 and 9; 1: *j* is equally important to *W*; 9: *j* is extremely more important than *W*), which results in the others-to-worst (OW) vector as follows.

$$A_W = (a_{1W}, a_{2W}, \dots, a_{nW})^T,$$

where a_{jW} represents the preference of *j* over *W* and $a_{WW} = 1$.

Step 5. Find the optimal weights $(w_1^*, w_2^*, \dots, w_n^*)$.

The optimal weights should be determined such that the maximum absolute differences $\left\{\left|w_B - a_{Bj} w_j\right|, \left|w_j - a_{jW} w_W\right|\right\}$ for all j is minimized, or equivalently:

$$\min \max_j \left\{\left|w_B - a_{Bj} w_j\right|, \left|w_j - a_{jW} w_W\right|\right\}$$

s.t.

$$\sum_j w_j = 1 \tag{2}$$

$$w_j \geq 0, \text{for all } j$$

Problem (2) is equal to the following linear problem:

$$\min \xi^L$$

s.t.

$$\left|w_B - a_{Bj} w_j\right| \leq \xi^L, \text{for all } j$$

$$\left|w_j - a_{jW} w_W\right| \leq \xi^L, \text{for all } j \tag{3}$$

$$\sum_j w_j = 1$$

$$w_j \geq 0, \text{for all } j$$

Solving problem (3), we can determine the optimal weights $\left(w_1^*, w_2^*, \ldots, w_n^*\right)$ and the optimal objective function value ξ^{L*}.

ξ^{L*} is the consistency index, it's values close to zero show a high level of consistency of the pairwise comparisons provided by the decision-maker(s)/expert(s).

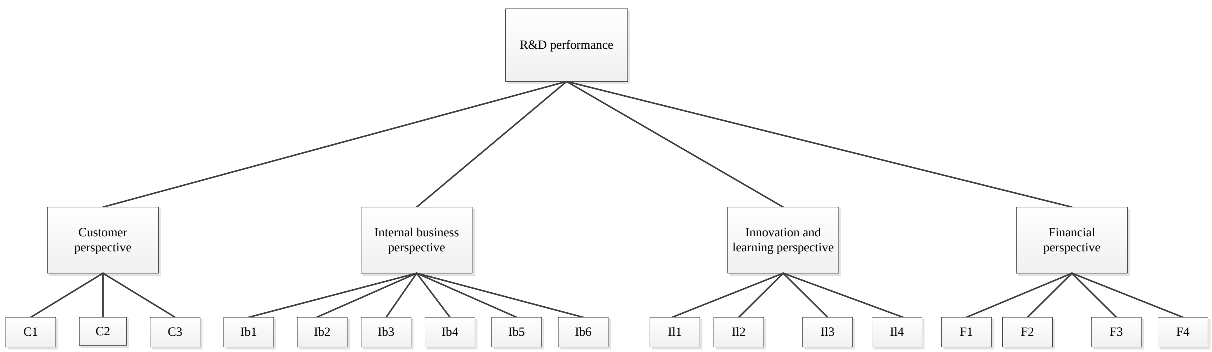
For MCDM problems with more than one level, we should identify the weights for different levels following the BWM steps, after which we can multiply the weights of different levels to determine the global weights.

Using BWM, the optimal weights of the criteria $(w_1^*, w_2^*, \ldots, w_n^*)$ are obtained. We should also evaluate firm *i* (*i* = 1, …, *m*) with respect to its R&D measurement *j* (*j* = 1, …, *n*), x_{ij} using, for instance, a 7-point scale (very low to very high). To determine the overall R&D performance of firm *i*, $R\&D_i$ we use the following formula.

$$R\&D_i = \sum_{j=1}^{n} w_j^* x_{ij}, \quad i = 1,\ldots, m. \tag{4}$$

4. Results and discussion

Here, we first present the conceptual framework, adopted from Bilderbeek (1999), to measure R&D performance as a multi-criteria decision-making problem, as shown in Figure 1.



- ***Customer perspective:*** **C1:** Customer satisfaction/market response, **C2:** % of products succeeding in the market, **C3:** Professional esteem to customers.
- ***Internal business perspective:*** **Ib1:** Agreed milestone/objectives met, **Ib2:** Number of products/projects completed, **Ib3:** Speed, **Ib4:** Efficiency/keeping within budget, **Ib5:** Quality of output/work, **Ib6:** Behavior of people involved in R&D activities.
- ***Innovation and learning perspective:*** **Il1:** No. patents, **Il2:** No. ideas/findings, **Il3:** Creativity/innovation level, **Il4:** Network building activities of the firm.
- ***Financial perspective:*** **F1:** Expected or realized IRR/ROI, **F2**: % of sales by new products, **F3:** Profit due to R&D, **F4:** Market share gained due to R&D.

Figure 1 A hierarchy of the R&D performance problem

Figure 1 is, in fact, a visualization of Table 1, representing four perspectives (main criteria) to measure R&D performance (customer, internal business, innovation and learning, and financial), as well as the items (sub-criteria) of each perspective (3 sub-criteria to measure customer perspective, 6 sub-criteria to measure internal business perspective, 4 sub-criteria to measure innovation and learning perspective, and 4 sub-criteria to measure financial perspective).

As mentioned before, to measure the R&D performance of a firm we need two sets of data: the optimal weight for the criteria, $(w_1^*, w_2^*, \dots, w_n^*)$ and the firm's score on the various criteria, x_{ij} .To determine the optimal weights, we used expert opinions, while, to determine the scores, we used data from a survey among the managers of 50 high-tech SMEs in the Netherlands. In the following section, we first describe the weights and then the scores, and finally the use of (4) to determine the overall R&D performance of each firm.

4.1.Weights of R&D measures

To find the weights of the criteria and sub-criteria, we interviewed eight experts in the field of R&D individually, collecting comparison data needed for BWM. Next, we determined the weights using BWM for these experts. Finally, we used aggregation (based on a simple average) to determine the overall weights for the criteria and sub-criteria. Table 2 shows the aggregated weights of the four main criteria and their items (sub-criteria) based on the input provided by the experts (see also Figures 2 and 3). The consistency ratios are all close to zero ranging from 0.03 to 0.17, which shows the high reliability of the results.

Table 2 Relative importance (weights) of the criteria and sub-criteria

Criteria	Criteria weights	Sub-criteria	Local weights of sub-criteria	Global weight of sub-criteria
Customer perspective	0.293	Customer satisfaction/market response	0.424	0.124
		% of products succeeding in the market	0.353	0.104
		Professional esteem to customers	0.223	0.066
Internal business perspective	0.161	Agreed milestone/objectives met	0.185	0.030
		Number of products/projects completed	0.141	0.023
		Speed	0.144	0.023
		Efficiency/keeping within budget	0.177	0.029
		Quality of output/work	0.246	0.040
		Behavior of people involved in R&D activities	0.107	0.017
Innovation and learning perspective	0.312	No. patents	0.179	0.056
		No. ideas/findings	0.216	0.068
		Creativity/innovation level	0.313	0.098
		Network building activities of the firm	0.291	0.091
Financial perspective	0.234	Expected or realized IRR/ROI	0.183	0.043
		% of sales by new products	0.233	0.054
		Profit due to R&D	0.238	0.056
		Market share gained due to R&D	0.347	0.081

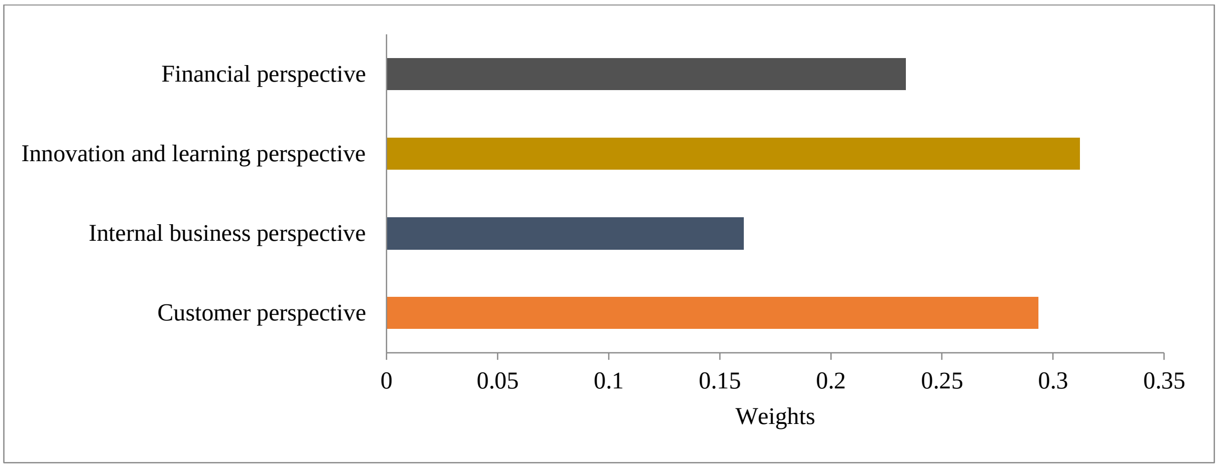


Figure 2 The relative importance of the main criteria

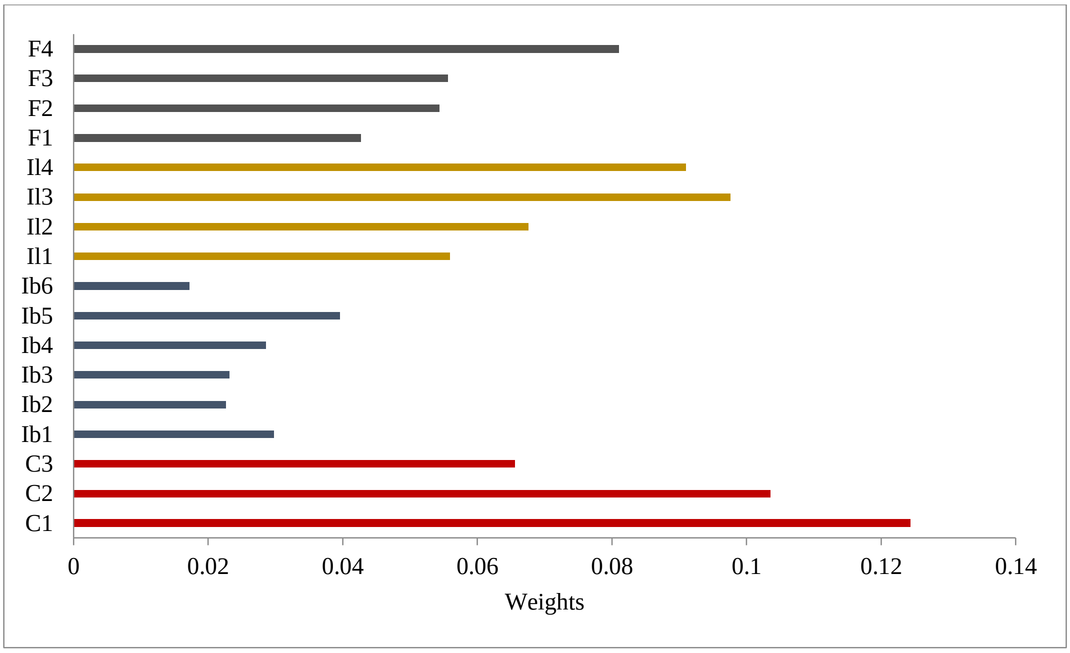


Figure 3 The relative importance of the sub-criteria

- ***Customer perspective: C1***: Customer satisfaction/market response, **C2:** % of products succeeding in the market, **C3:** Professional esteem to customers.
- ***Internal business perspective:*** **Ib1:** Agreed milestone/objectives met, **Ib2:** Number of products/projects completed, **Ib3:** Speed, **Ib4:** Efficiency/keeping within budget, **Ib5:** Quality of output/work, **Ib6:** Behavior of people involved in R&D activities.
- ***Innovation and learning perspective: Il1***: No. patents, **Il2:** No. ideas/findings, **Il3:** Creativity/innovation level, **Il4:** Network building activities of the firm.
- ***Financial perspective:*** **F1:** Expected or realized IRR/ROI, **F2:** % of sales by new products, **F3:** Profit due to R&D, **F4:** Increased market share due to R&D.

As can be seen from Table 2, Column 2, Innovation and learning (weight = 0.312) perspective is the most important R&D perspective, followed by Customer perspective (weight = 0.293), and Financial perspective (weight = 0.234). Internal business perspective (weight = 0.161) is by far the least important R&D perspective.

In recent decades, knowledge creation and innovation have become core elements of R&D. As (i) life-cycles of some products have become shorter, (ii) new products and services are being introduced faster, (iii) innovation speed has increased, and (iv) the importance of developing and applying new knowledge has increased, knowledge creation and innovation are considered as main elements of R&D (Lazzarotti et al., 2011). Our result is in line with existing literature, which emphasizes the importance of R&D to facilitate knowledge creation and innovation opportunities. As shown in Table 2, Column 2, innovation and learning perspective are the most important elements.

Moreover, in line with what we found in Table 2, Kerssens van Drongelen and Cooke (1997), by focusing on the effectiveness of R&D performance measurements in the Netherlands, found that, although effectiveness is achieved through a combination of all the perspectives (criteria), involving customers in the evaluation of R&D activities and taking the level of their satisfaction into account enhance R&D performance. In other words, the capability of R&D function to meet the customer needs influences positively the success of an innovation (Chiesa and Masella, 1996).

The global weights of the sub-criteria (the multiplication of the weights of the sub-criterion by the weights of the main criterion to which it belongs) are reported in Table 2, Column 5.

Based on these results, for the customer perspective, the most important item is customer satisfaction/market response, while professional esteem for customers is the least important item. Customer satisfaction is viewed as an engine of the economic performance of a firm (Bolton et al., 2004). In fact, customer satisfaction has a positive effect on customer loyalty and user behavior (Bolton, 1998). Consequently, customer satisfaction increases secure future revenues, and reduces the probability of customer defection as well as the costs related to warranties (Mithas et al., 2005).

Quality of output/work, one of the six items of internal business perspective is the most important item, followed by efficiency/keeping within budget. Behavior of people involved in R&D activities is the least important item. In existing literature, the quality of the output of R&D performance has been considered a source of productivity growth, not only at firm level, but also at a macroeconomic level (Guellec and Van Pottelsberghe de la Potterie, 2004). Moreover, staying within R&D budget has always been one of the challenges facing firms. Consequently, financial issues have persuaded firms to rely more on external sources to improve their R&D performance (i.e. gaining access to basic knowledge produced in universities through collaboration with universities (Fey and Birkinshaw, 2005).

For the innovation and learning perspective, creativity/innovation level is the most important item, followed by network building activities of the firm. The least important item from this perspective is number of patents. Wang et al. (1999) found that creativity leads to improved productivity and R&D performance. In fact, within a competitive business environment, innovation is one of the significant ways for R&D firms to gain a competitive advantage. Moreover, building and fostering networks help the firms facilitate more innovation, new knowledge, mutual learning and, finally, improve their R&D performance (Tsai, 2001).

Finally, market share gained due to R&D is the most important item of financial perspective. Expected or realized IRR/ROI is the least important items. In existing literature, market share has been recognized as a key to profitability (Buzzell et al., 1975). In fact, increasing market share leads to higher profit margins, improved quality and higher priced products, as purchases-to-sales ratio and marketing costs are reduced (Buzzell et al., 1975; Ailawadi et al., 1999; Ghosh, 2004).

4.2. R&D item-scores of high-tech SMEs

In a survey among the managers of 50 high-tech SMEs in the Netherlands, they provided us with their R&D item-scores (see Table 3).

We asked the respondents to rate the R&D level of their companies based on items from different R&D perspectives (customer, internal business, innovation and learning, and financial) on a nine-point Likert-type scale.

Table 3 R&D item-scores of 50 SMEs

	Customer perspective			Internal business perspective						Innovation and learning perspective				Financial perspective			
Firm No.	C1	C2	C3	Ib1	Ib2	Ib3	Ib4	Ib5	Ib6	Il1	Il2	Il3	Il4	F1	F2	F3	F4
1	6	5	6	6	5	6	7	6	6	2	3	6	6	6	7	6	6
2	6	5	6	5	6	6	5	5	5	1	5	5	5	5	5	4	4
3	5	6	5	3	3	3	4	3	4	6	5	6	5	5	5	5	5
4	6	6	6	5	5	4	4	5	6	3	6	7	6	5	6	6	6
5	6	6	7	5	5	5	5	5	5	6	6	6	6	6	6	6	6
6	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
7	5	5	4	4	5	4	4	3	3	5	4	5	3	4	5	3	3
8	6	6	7	6	4	7	6	6	6	4	4	5	3	6	5	3	2
9	5	4	5	5	5	4	3	5	1	1	1	1	3	3	1	1	1
10	4	5	6	5	5	5	6	6	5	2	4	5	5	5	6	6	6
11	5	4	5	3	4	4	3	5	5	3	5	5	4	4	4	5	5
12	5	6	6	5	6	6	5	6	4	1	3	3	5	5	6	3	3
13	5	9	5	4	4	4	4	7	4	5	5	6	4	9	3	4	3
14	5	4	5	4	5	5	4	4	5	4	4	5	5	5	4	4	6
15	5	5	4	4	4	4	4	4	4	9	4	4	3	9	5	4	4
16	6	5	6	6	5	4	4	4	7	4	4	4	6	5	6	4	6
17	4	4	5	5	5	6	4	6	1	1	3	5	4	5	1	1	1
18	6	6	5	5	5	6	5	4	4	3	4	5	5	4	5	5	4
19	5	4	5	5	4	5	4	4	5	6	5	5	4	4	5	4	5
20	5	5	6	4	4	3	3	5	5	1	5	5	4	4	5	5	5
21	6	6	5	4	5	3	5	6	4	1	3	6	2	5	3	4	2
22	6	6	6	6	6	5	4	6	5	4	5	5	4	5	7	6	6
23	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
24	4	4	4	4	4	5	5	5	5	1	6	6	5	9	5	4	5
25	6	6	7	5	7	6	6	6	6	1	5	5	5	5	3	5	4
26	4	4	4	5	3	3	5	5	5	2	4	6	5	4	3	3	3
27	5	3	4	3	3	6	6	6	6	1	5	6	5	5	2	4	3
28	5	5	5	5	5	2	5	6	5	5	4	6	2	4	6	4	4
29	4	5	4	4	5	4	5	4	3	6	4	5	3	4	5	4	6
30	5	5	5	4	4	4	4	6	5	2	5	6	4	5	3	3	4
31	5	5	5	5	5	5	5	5	5	1	1	4	5	4	4	1	1
32	5	4	5	4	6	4	3	4	4	1	3	5	6	5	5	5	9
33	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
34	5	4	4	4	4	6	5	5	4	4	4	5	5	6	5	4	4
35	5	5	6	5	6	5	6	5	5	1	3	3	4	4	3	2	2
36	4	5	4	4	6	5	5	6	4	3	5	5	5	4	4	4	5
37	6	6	6	6	6	7	7	7	7	7	6	7	6	6	6	5	6
38	6	5	6	4	4	3	4	6	7	2	4	4	6	5	3	4	4
39	5	4	6	4	4	6	4	6	5	7	7	7	4	5	4	5	5
40	7	6	7	6	6	4	4	6	5	3	6	7	6	4	5	4	6
41	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
42	5	6	7	5	6	7	7	6	5	6	7	6	5	5	6	7	7
43	6	6	7	7	6	7	6	7	7	2	5	5	5	4	5	4	3
44	5	6	6	5	6	6	5	5	6	5	5	6	6	6	6	6	5
45	6	6	7	6	6	7	6	5	6	6	5	6	6	6	7	7	6
46	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
47	4	5	5	4	6	6	6	5	5	2	3	4	5	6	3	3	3
48	6	6	6	5	5	6	4	6	6	2	6	6	5	6	6	7	5
49	4	5	6	6	6	3	6	6	6	1	5	3	4	5	2	5	5
50	5	5	5	4	5	4	4	5	6	2	4	5	4	4	5	5	4

As shown in Table 3, the scores of the various SMEs are determined for different items of each perspective. If we make a simple mean with equal weights for the items, we see that there are several firms with the same R&D mean. For instance, we have the same average of 4.58 for firms 32, 34, 36, 49, and an average of 5.41 for firms 4, 22, 40, 43. Although the R&D mean of these firms is the same, assigning different weights (level of importance) to different items could make the overall value of R&D performance of these SMEs different from each other, which obviously could result in a different ranking of these firms.

4.3. Measuring R&D performance of high-tech SMEs

In this section, we measure the R&D performance of 50 SMEs using R&D item-scores (Table 3) and the weights of R&D measures (Table 2). Table 4 contains the aggregated R&D performance of the various firms with respect to different perspectives (Columns 2, 4, 6, 8), as well as the ranking of each firm based on each perspective (Columns 3, 5, 7, 9). Furthermore, the overall aggregated R&D performance of each firm based on items of all perspectives and overall ranking based on this aggregated number are shown in Table 4, Columns 10 and 11 respectively.

Table 4 R&D performance of 50 high-tech SMEs

Firm No.	Agg C[1]	Rank C[2]	Agg Ib[3]	Rank Ib[4]	Agg Il[5]	Rank Il[6]	Agg F[7]	Rank F[8]	Agg overall[9]	Rank overall[10]
1	5.647	16	6.036	4	4.633	16	6.233	5	5.530	10
2	5.647	16	5.285	16	4.283	29	4.416	28	4.875	21
3	5.353	22	3.284	49	5.492	10	5.000	16	4.981	17
4	6.000	9	4.786	28	5.775	7	5.817	9	5.692	7
5	6.223	4	5.000	21	6.000	4	6.000	7	5.905	5
6	4.000	45	4.000	43	4.000	37	4.000	34	4.000	43
7	4.777	32	3.788	48	4.201	34	3.648	41	4.174	41
8	6.223	4	5.862	8	4.021	36	3.667	40	4.881	20
9	4.647	34	4.075	41	1.583	50	1.366	50	2.832	50
10	4.800	30	5.423	11	4.246	31	5.817	9	4.965	18
11	4.647	34	3.990	47	4.350	28	4.584	23	4.434	36
12	5.576	20	5.424	10	3.224	46	4.064	33	4.464	35
13	6.411	3	4.738	29	5.021	11	4.335	30	5.223	13
14	4.647	34	4.391	38	4.604	18	4.876	19	4.646	27
15	4.777	32	4.000	43	4.605	17	5.147	15	4.685	24
16	5.647	16	4.832	24	4.583	21	5.342	14	5.113	15
17	4.223	43	4.786	27	3.558	43	1.731	49	3.524	48
18	5.777	14	4.791	26	4.425	26	4.470	25	4.891	19
19	4.647	34	4.436	36	4.888	13	4.579	24	4.672	25
20	5.223	23	4.031	42	3.991	40	4.817	20	4.552	31
21	5.777	14	4.666	33	3.288	45	3.257	44	4.233	38
22	6.000	9	5.395	12	4.529	23	6.050	6	5.455	11
23	9.000	1	9.000	1	9.000	1	9.000	1	9.000	1
24	4.000	45	4.674	31	4.812	14	5.493	13	4.711	23
25	6.223	4	5.956	6	4.283	29	4.188	32	5.099	16
26	4.000	45	4.431	37	4.558	22	3.183	45	4.052	42
27	4.071	44	5.021	20	4.595	20	3.371	43	4.224	39
28	5.000	25	4.815	25	4.222	33	4.465	27	4.602	28
29	4.353	41	4.212	39	4.380	27	4.926	17	4.473	34
30	5.000	25	4.599	35	4.483	24	3.712	39	4.473	33
31	5.000	25	5.000	21	3.104	47	2.247	48	3.765	47
32	4.647	34	4.105	40	4.141	35	6.387	4	4.809	22
33	4.000	45	4.000	43	4.000	37	4.000	34	4.000	43
34	4.424	40	4.711	30	4.604	18	4.598	22	4.567	29
35	5.223	23	5.318	15	2.933	49	2.598	47	3.910	46
36	4.353	41	5.095	19	4.641	15	4.347	29	4.561	30
37	6.000	9	6.674	3	6.492	2	5.762	11	6.206	2
38	5.647	16	4.668	32	4.224	32	3.950	37	4.649	26
39	4.871	29	4.886	23	6.126	3	4.767	21	5.240	12
40	6.647	2	5.251	18	5.775	7	4.926	17	5.748	6
41	3.000	50	3.000	50	3.000	48	3.000	46	3.000	49
42	5.800	13	6.029	5	5.925	5	6.402	3	6.016	4
43	6.223	4	6.682	2	4.462	25	3.886	38	5.201	14
44	5.576	20	5.391	13	5.604	9	5.653	12	5.573	8
45	6.223	4	5.898	7	5.784	6	6.470	2	6.092	3
46	4.000	45	4.000	43	4.000	37	4.000	34	4.000	43
47	4.576	39	5.277	17	3.716	42	3.548	42	4.180	40
48	6.000	9	5.319	14	4.991	12	5.891	8	5.550	9
49	4.800	30	5.569	9	3.366	44	4.302	31	4.360	37
50	5.000	25	4.600	34	3.954	41	4.470	25	4.486	32

1. Aggregated R&D performance of firm from *customer* perspective, 2. Firm's ranking from *customer* perspective, 3. Aggregated R&D performance of firm from *internal business* perspective, 4. Firm's ranking from *internal business* perspective, 5. Aggregated R&D performance of firm from *innovation and learning* perspective, 6. Firm's ranking from *innovation and learning* perspective, 7. Aggregated R&D performance of firm from *financial* perspective, 8. Firm's ranking from *financial* perspective, 9. Aggregated R&D performance of firm from all the four perspectives, 10. Firm's ranking from all the four perspectives.

Assigning weights to different items (sub-criteria) and to different perspectives (main criteria) produces significant differences in the overall (and perspective-based) R&D score of different firms. For instance, as mentioned in section 4.2, firms 32, 34, 36, and 49 have the same unweighted R&D average (4.58). However, the different weights assigned to R&D items changes the ranking among these firms, not only involving their overall R&D ranking, but also from each individual perspective (see Table 4). To be precise, firms 32, 34, 36, and 49 are now ranked 22nd, 29th, 30th and 37th overall R&D ranking, respectively, while firms 4, 22, 40 and 43 now rank 7th, 11th, 6th and 14th, respectively, even though they have the same unweighted overall R&D mean (5.41). It is also interesting to see the position of each SME from different perspectives. While two SMEs may have (almost) the same overall R&D ranking, they can end up in different places with respect to the four R&D perspectives. For example, comparing firms 32 and 49 (which have the same unweighted R&D performance average), we see that firm 32, from the perspectives of customer, internal business, innovation and learning and financial is ranked 34th, 40th, 35th and 4th, respectively, while firm 49 is ranked 30th, 9th, 44th and 31st from these perspectives. The same is true when we compare other firms with (almost) the same unweighted R&D average.

The results show the importance of taking into account the weights of different R&D items, which allows each firm to determine not only its overall R&D position, while at the same time providing accurate information of its position with regards to each perspective. Moreover, firms can improve their R&D performance based on the importance of each perspective. For example, firm 1 has a better R&D performance with regards to the internal business perspective (ranking 4th) compared to firm 5 (ranking 21st). If firm 1 wants to maintain or improve this ranking, it should focus more on the quality of output/work which has the highest importance among all items of internal business perspective (see Table 2). Firm 5 shows the best performance from the customer and innovation and learning perspectives (ranking 4th in both cases), while firm 1 has the lowest ranking from these two perspectives (ranking 16th). These results allow firms to determine their position and, based on their objectives, decide to consolidate or improve their position.

Moreover, in some situations, where the aim is not to compare the position of firms with each other or such a comparison is impossible to make, knowing the importance of each perspective and the items involved can help firms improve their performance based on their main objectives. More precisely, if a firm wants be prominent in innovation and learning, it should focus on and invest in creativity, since the results in Table 2 show that the creativity/innovation level is the most important item from an innovation and learning perspective. Moreover, by changing their objectives, firms can change their strategy and invest more in specific perspective(s) in line with their new objectives. For instance, if a firm has thus far focused more in the financial perspective, focusing more on customer aspects can help the firm improve its R&D by looking at customer satisfaction, since the results in Table 2 show that customer satisfaction is the most important measurement within the customer perspective. Therefore, regardless of knowing its position relative to other firms, based on the weight of the items of different R&D perspectives (Table 2), a firm can identify which item(s) can improve or change its R&D performance from each perspective. As such, these results can help firms improve their overall performance.

The methodology proposed in this study can be used in two general contexts: (i) as a systematic way to compare the R&D performance of a set of firms. In this context, the results can be used by the firms themselves to determine their competitive position in the market. The results can also be used by other stakeholders, for instance allowing venture capitalists to identify the best investment opportunities; (ii) as a systematic way to determine the importance (weight) of different perspectives and measurements for a single firm. In this context, the results can be used by the firm in question to formulate effective R&D strategies that are aligned to its competitive strategy.

5. Conclusions

Measuring R&D performance has been studied in recent years by a number of researchers (Schumann Jr et al., 1995; Werner and Souder, 1997; Kim and Oh, 2002b; Tsai and Wang, 2005; Wang, 2007; Chiesa et al., 2009; Bassani et al., 2010; Kunz, 2010), who have proposed different ways to measure R&D performance, such as reduced time-to-market, increased quality and reduced costs. These indicators are also investigated from four different perspectives of R&D performance: financial, customer, innovation and learning, and internal business (Bilderbeek, 1999). In all these studies, R&D performance has been measured while assigning equal importance to all relevant aspects. Understanding the importance of different R&D measures helps managers spend more time, money, energy and resources on the vital aspects on their objectives, since as has been shown by Chiesa et al. (2009), firms have different objectives when measuring their R&D performance. As such, R&D managers can improve the R&D performance of their firms based on their objectives. Based on our results, innovation and learning aspects of R&D play the most important role in enhancing R&D performance, which means that, if the objective of the firm involves innovation and learning aspects, focusing more on the creativity and innovation measurements will improve the firm's R&D performance, as this measure is the most important of all innovation and learning measurements. For other perspectives, this study also determines which item is the most important and how R&D managers can improve their firms' R&D performance based on different objectives.

Our findings have important managerial implications. Firstly, positioning is an important contributor to R&D performance, since it provides a good basis for firms to compare their R&D performance to that of other firms. Secondly, regardless of positioning, having knowledge about the importance of different R&D perspectives, and about the different items of each perspective, R&D managers can formulate more effective strategies to improve their R&D performance based on their own objectives.

The methodology proposed in this study used to determine the weight and importance of different aspects of overall firm performance, such as identifying the importance of environmental and organizational factors. This gives managers have a good view of critical aspects of performance and allows them to focus more on the important aspects. In this study we only consider R&D performance from four perspectives (financial, customer, innovation and learning, and internal business) which have been used in the literature. However, considering some other perspectives such as environmental and social perspectives provide more complete view of R&D performance. In fact, how firms' R&D are beneficial for society and environment can be two other perspectives which are missing in the current framework. Moreover, the effect of alliances and networks on the R&D performance are also neglected. Therefore, it would be interesting to examine the R&D performance not only from four mentioned perspectives, but also from environmental, social and networking perspectives. Finally, as mentioned earlier, there are some factors that affect R&D performance, such as type of R&D, type of industry, firm size, reliability of products, stability and flexibility of design which we did not consider them in our study. Therefore, another interesting line of research may be to measure R&D performance while taking into account the relative importance of these influential factors.

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