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Measuring innovation best practices: Improvement of an innovation index integrating threshold and synergy effects

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Abstract

Innovation, as a competitive economic factor, is a process that requires a continuous, evolving and mastered management. Therefore innovative companies need to measure their innovation capacity. Literature attests of research in the field of innovation measurement or the innovation abilities evaluation. One major theoretical problem consists in elaborating mathematical models that consider the threshold effect and synergy between innovation practices and verify their validity. In this article, mathematical approaches supplementing multi-criteria models are suggested.

Keywords: Innovation capacity; Metrology; Index; Ranking; Data mining

1. Introduction

Top management attention was formerly directed toward cost reduction, delivery time reduction and quality in order to become and remain competitive on the market. By extension, new criteria are emerging to successfully face competitors: among others—innovation. The ability of companies to meet consumer expectations depends deeply on their ability to innovate and deliver new products at competitive prices. Innovation is a key driver to achieve sustainable competitive advantages and, more particularly, becomes one of the key challenges for small and medium enterprises (SMEs) (O'Regan et al., 2006).

Many definitions of innovation are proposed in the literature. According to Schumpeter (1934), it consists in the introduction of new products and production methods, the opening of new markets, the discovery of new raw materials and the implementation of new organizations. Innovation affects manufacturing and process industries, trade activities and social services. The Organization for Economic Co-operation and Development (OECD) states that innovation is "either the transformation of an idea into a new product or the improvement of an existing product or an operational process" (OECD, 1981). Taxonomies have been developed aiming at a better understanding of this complex process (Garcia and Calantone, 2002). Sternberg et al. (2003) established a classification through eight reference groups of companies. "Replication" represents the lower level of Sternberg's scale, while "Integration" is the higher.

Other authors outline the cognitive dimension of the innovation process. According to Vandervert, one major aspect is the relationship between the short-term memory and the cognitive perception function, i.e. brain function, and more precisely the construction of new representations of the environment from perceptions. He demonstrates that the concept of generalization capacity and the establishing of dynamic cerebral models (commands that allow generalization capacities) are innovation key factors (Vandervert, 2003). As a consequence, value creation through innovation is depending on the restructuring of the cognitive dimension of those involved in the process. Moreover, innovation relates to a learning process.

Furthermore, evidence of a necessary constructivist approach in innovation management was demonstrated, particularly within the SME's sector (Boly et al., 1999). Success of an innovation relies on the ability to identify and seize opportunities. Hence, top management has to: direct attention toward the definition of global development

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orientations, launch projects and organize an on-going improvement of innovative project management approaches. As a result evaluation of the innovation capacity becomes a major concern in order to ensure a continuous development of these management practices.

This article focuses on the measurement of the innovation capacity of industrial firms. More precisely, innovation measurement integrates both the evaluation and the comparison of the innovation capacity of companies. This capacity is correlated to a set of competencies, knowledge, tools and financial resources. Our research is in concern with various aspects of metrology, including: criteria definition, data collection and treatment methods and reference model elaboration.

In the field of metrology, "measuring" is defined as an operation allowing the determination of the value of a variable through various features. For instance, measuring is inseparable from social practices. Besides mathematical knowledge, measuring requires knowledge related to institutions, social practices (Vuola and Hameri, 2006) and measuring techniques (Jedrzejewski, 2002).

Literature attests of researches in the field of innovation capacity evaluation (for a company or a country) (Furman, 2003). These approaches are generally based on the evaluation of the innovation process outcomes and of the resources devoted to it. All these statements may be considered through three analytical levels (setting aside the individual and collective cognitive level) (Boly, 2004):

- *Level A*: The *permanent and global* innovation management of the company. This level integrates all the strategic tasks, the organization of new projects launching and the improvement of innovation management practices.
- *Level B*: The outcomes or inputs of a particular *project*. This level is characterized by a limited period and is concerned with the transformation of an idea up until an innovative product.
- *Level C*: The material characteristics of the innovative *product* resulting from the new product development process. This level represents the artefact of Level B.

This approach suits our special interest in establishing links between evaluation and operational management tasks.

The evaluation of Level C is very common in engineering through the definition of the future specifications of the innovative product and its relating performances.

Literature is mostly concerned with Level B evaluation. Many authors propose approaches to determine the balance between the outcomes and inputs of innovation. Generally, financial and commercial variables are taken into account (Griffin and Page, 1996; Huang et al., 2004; Kangmao et al., 2005). Financial evaluations are based on classical ratio including financial margins and returns on investment (Crepon et al., 2000). Moreover, specific financial criteria dedicated to innovation resources are suggested: they generally measure time and cost development (Grant and Pennypacker, 2006). Marketing variables include qualitative and quantitative aspects, such as new market shares and customer satisfaction (this last example is dedicated more to product's Level C than to the project's Level B). Strategic considerations, such as competitive advantage, are integrated to evaluate the balance between outcomes and inputs. Several authors (Archibugi and Pianta, 1996; Abraham and Moitra, 2001) add technological criteria, such as the number of patents, to conduct this evaluation.

Chiou et al. (1999) suggest a technology-oriented productivity measurement model (TOPMM), more suitable with global management Level A. TOPMM takes into account all the outcomes of the innovation process: the final new product but also intermediary results (prototypes, models, as well as competencies).

From a systemic point of view a strong limitation exists: the activities linking the resources to the outcomes of the innovation process are not evaluated. Thus, our special focus is the innovation management activities evaluation at Level A. Chiesa et al. (1996) has elaborated a scorecard to evaluate four phases of a project (Level B): concept generation, product development and related production process elaboration and technology acquisition. We proposed the calculation of an index based on 13 innovation practices identified by Boly as the best practices for innovation (Boly, 2004; Corona Armenta, 2005). Our objective is to take into account threshold effects in the realization of the practices. Hence, innovation management activities are not independent from each other. Moreover, the choice of preference profiles has to be possible according to the fundamental needs of the evaluator.

2. Proposition of an innovation measurement system

Our research is based on two hypotheses:

- the innovation capacity of a company is measurable and
- the principles of an innovation measurement system depend on the properties (practices) of the innovation process. A reference list of innovation process practices is determined. They are measurable only if they are expressed in terms of directly observable innovation management sub-practices (Boly, 2004).

Literature attests of researches about innovation best practices. Among others, Cormican and O'Sullivan (2004) defined five key factors that facilitate product innovation management: strategy and leadership, culture and climate, planning and selection, structure and performance, communication and collaboration. Innovation practices can also be classified according to three aspects: operational, internal and external best practices (Beaumont, 2005). Bessant et al. distinguish firstly best practices for "steady state" innovation process, essentially formal innovative activity within known or knowable selection environments ("Do better" activities). Secondly, they tried to develop a routine which can be implemented to enable "discontinuous innovation", which requires a much more open-ended agile approach of managing within emergent field ("Do different" activities (Bessant et al., 2005)).

Basically, the proposed evaluation approach integrates a list of reference practices established thanks to a bibliography investigation and consulting the innovation experts (Morel and Boly, 2005). The measurement system is completed with an index allowing the evaluation of these innovation practices (Corona Armenta, 2005). The 13 innovation practices are:

Practice 1: *Design tasks* are organized in order to develop the new product and ensure technology evolution.
Practice 2: A *follow-up* of each innovative project is structured.
Practice 3: A global supervision of new innovative projects (budget, deadline, main technical decisions, etc.) allows an *integration of the strategic decisions* elaborated by top management.
Practice 4: Within *the project's portfolio*, top management ensures a coherent achievement among different initiatives.
Practice 5: Top management team and project managers *control* and *receive feedbacks* on innovation processes in order to improve the practices of the people involved in innovation.
Practice 6: *Suitable context and working conditions* are organized in order to stimulate innovation.
Practice 7: Top management attention is directed toward the necessary *competence allocation* to the innovation process.
Practice 8: *Moral support* is provided by top management and the project managers to innovation process participants.
Practice 9: A *collective learning* approach is available during the project.
Practice 10: *Know-how and knowledge acquired* during the former projects are *capitalized* in order to be re-used for forthcoming projects.
Practice 11: *Survey Tasks* (technological, competitive, economic, managerial, intelligence) are planed in order to open up the company to its environment.
Practice 12: The company is integrated into technological *networks*.
Practice 13: *New ideas* from research, marketing or propositions from the employees are continuously collected and *creativity* sessions are organized, allowing continuous projects launching.

One basic principle of our metrological approach is to assess the innovation capacity of a given company according to the realization level of these 13 practices (note that the list can be enhanced as new innovation management methods emerge). However, it is difficult to assess innovation capacity because mainly overlooked intangible measures of performance have to be taken into account (Beaumont, 2005). Actually, the 13 proposed practices do not constitute either directly observable nor measurable attributes. Links with observable phenomena must be determined, as Furman did in evaluating the national innovative capacity of a country (Furman et al., 2002). Hence, the 13 innovation practices are subdivided into directly observable and measurable "sub-practices": facts that any evaluator can confirm (Table 1). A 129 sub-practices are proposed.

A mark may be affected to each single "sub-practice": one when the sub-practice is achieved (the phenomenon is observed) and zero in the opposite situation. Hence, to obtain an overall innovation score, two levels of aggregation are required. A first aggregation is conducted to

Table 1
The 13 practices (attributes of the innovation process) and a selection of relating sub-practices (45 observable phenomena among 129)

Practice 1	*Design tasks are planed*
1.1	Reports on new production processes design tasks
1.2	Report on new product design tasks
1.3	Use of CAD
1.4	Use of functional analysis
1.5	Structured technological road map
Practice 2	*Follow up of projects is carried out*
1.1	formalized projects management process
1.2	Expenditure monitoring
1.3	Future activities costs monitoring
1.4	Structured projects reviews
Practice 3	*Integration of strategic decisions*
3.1	Strategy information given to designers
3.2	Strategic meetings take place between CEO and project managers
3.3	Use of decision aid tools to define the company strategy
3.4	Use of Value management tools
Practice 4	*Projects portfolio management*
4.1	Portfolio is reviewed by top managers
4.2	A manager is allocated to portfolio coordination
4.3	Performance indicators are used
4.4	coherence is fulfilled between the projects thanks inter-projects meetings
Practice 5	*Retrospective actions on the innovation process*
5.1	Meetings are carried out to analyze the development activities
5.2	Methodological experts attend to internal meetings
5.3	"Wise" group meets the project managers
Practice 6	*Suitable context and working conditions*
6.1	Each project has a manager
6.2	Projects teams are composed of members from different departments
6.3	Venture groups are encouraged

Table 1 (*continued*)

Practice 7	*Necessary competence allocation to the innovation process*
7.1	Staff is hired according to skills needed for future projects
7.2	Training are planned to develop skills relating to innovation for future projects
7.3	Mobility is encouraged for top managers
Practice 8	*Moral support to innovators*
8.1	Innovation is stimulated through media (Intranet, Magazine…)
8.2	Rewards are given to innovators
8.3	Material resources are allocated to innovators
Practice 9	*Collective learning is ensured*
9.1	Methodologies for collective learning are used
9.2	Assessment meetings are held at the end of projects
9.3	Some managers are in charge of collective learning tasks
Practice 10	*Know-how and knowledge are capitalized*
10.1	Know-how assessment and mapping are organized
10.2	KM tools are used
Practice 11	*Survey tasks are planed*
11.1	Data collection methodologies are used
11.2	Workshops for data analysis are organized
11.3	Meetings are held to transform collected information into innovation projects
11.4	Salesman back-up information from customers
Practice 12	*Association with technological networks*
12.1	The company is member of industrial networks
12.2	A manager is allocated to networks management
12.3	The company contracts with engineering subcontractors
Practice 13	New ideas are gathered during creativity cessions
13.1	*The company has a R&D department*
13.2	Ideas are gathered from staff, R&D and marketing services
13.3	Data bases capitalizing ideas, technical data, experimental results, etc. is used
13.4	The company has a R&D budget for external laboratory cooperation

determine a score for each practice. A second aggregation based on the practices scores gives the global innovation capacity evaluation of the company. Fig. 1 provides an example of this subdivision.

A clinical experimentation was conducted on a panel of 20 innovative companies. The objective was to validate the index. Selection criteria include: geographic area (proximity), top management commitment to innovation strategy and financial funds received from public innovation support systems. Data were collected using an observation grid, which was filled in by executives involved in the innovation process of each company. Appendix A summarizes the collected data: the value of the 13 practices for the 20 companies.

For practice j, each company i has a score p_{ij}, which corresponds to the observed sub-practices and is calculated as follows:

$$p_{ij} = \frac{\sum \textit{Observed sub-practices for practice } j}{\textit{Number of sub-practices relating to practice } j} \qquad (1)$$

To calculate the overall score reflecting the innovation capacity for each company, various methods were developed. The first method uses the multi-criteria analysis approach and presents several drawbacks, which were highlighted by Corona Armenta. As a consequence, other methods were developed and are presented in the following section.

3. Different approaches to aggregate innovation measures

3.1. Potential innovation index (PII): description and limitations

Corona Armenta (2005) suggested the development of an index referred as the *PII*. One asset of this approach consists in integrating the particular objectives of the evaluator. Hence, one specific stage of the data treatment method is dedicated to a preference scale definition. In line

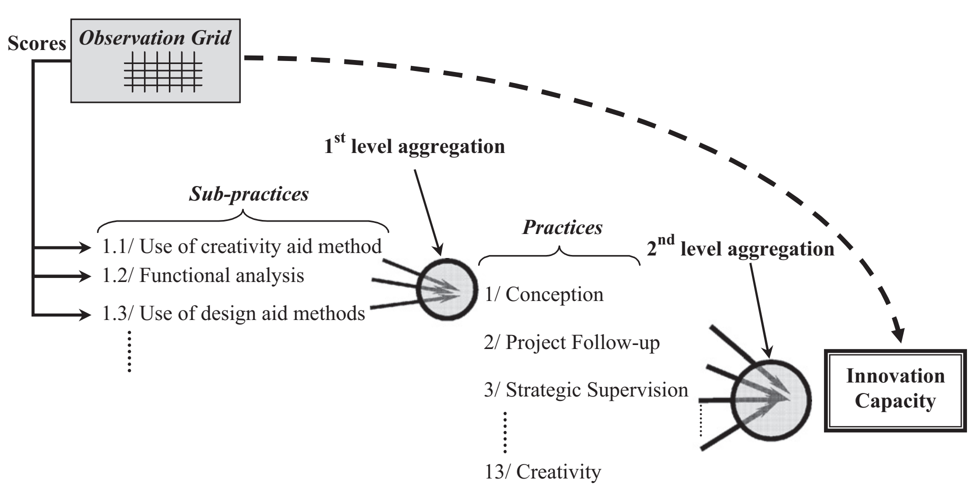


Fig. 1. Innovation subdivided into practices and sub-practices (*source*: Corona Armenta, 2005).

Table 2
Company ranking and values according to *PII*

Rank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Company	**E18**	**E06**	**E12**	**E02**	**E14**	**E13**	**E08**	E19	E01	E15	E09	*E05*	*E20*	*E10*	*E17*	*E16*	***E04***	***E11***	***E07***	***E03***
PII value	**0.74**	**0.68**	**0.67**	**0.66**	**0.65**	**0.62**	**0.60**	0.56	0.50	0.42	0.41	*0.38*	*0.38*	*0.37*	*0.36*	*0.35*	***0.29***	**0.27**	**0.26**	**0.10**
Class				**Proactive**					Preactive					*Reactive*				***Passive***		

with its special interests, the evaluator can modify the weight of the variables and characteristics of the company classification. Moreover, effective innovation management is less about doing one particular practice than about being able to manage a system of innovation based on several practices (Bessant et al., 2005). For this purpose, a multi-criteria decision aid (MCDA) procedure was adopted for this index. The utility function below, in its general form, was selected for the development of the index

$$F(score(x)) = \sum_j w_j G_j(f_j(x)) \quad \text{with} \sum_j w_j = 1 \tag{2}$$

The index suggested for company E_i is defined below

$$PII(E_i) = \sum_{j=1}^{13} w_j p_{ij} \quad \text{with} \quad \sum_{j=1}^{13} w_j = 1 \tag{3}$$

$PII(E_i)$ is the value of the innovation potential for company E_i and $0 \leqslant PII(E_i) \leqslant 1$; w_j is the weight of practice j according to its importance. These weights were assigned by evaluator or may result from an expert enquiry; p_{ij} is the degree of development of the practice j for company E_i and $0 \leqslant p_{ij} \leqslant 1$.

The validation of the index is conducted thanks to a comparison between this method and two other MCDA methods: electre and analytic hierarchy processing (AHP). A great similarity in the classification of the companies' level arises, although the results are not entirely identical.

Then, based on the *PII* value of each company, a classification is established. This typology is confronted to the categorization of Godet, 1998. Four types of companies are identified in accordance with various visions of the future. "Proactive" companies cause changes by adopting an anticipatory scenario and a voluntary and aggressive strategy. "Preactive" companies are facing changes by creating exploratory scenarios and preventive strategies. "Reactive" companies wait for change and react only to external events. They do not have a clear scenario and adopt an adaptive strategy. Finally, "Passive" companies come under changes. The *PII* values for each company and for each category are given in Table 2.

Finally, the *PII* helps to clarify outstanding management practices. It allows the characterization and the rigorous comparison of various innovation processes. However, *PII* calculation uses a linear combination of the innovation practices scores. This model contains strong limitations. Among others:

- Companies are classified within four groups using the same criteria; in other words, the same weighting system is used for each category and no specific theoretical reference is defined. This unique preference profile is not totally relevant with the objectives to determine different profiles within innovative companies' processes.
- Innovation practices are not independent; this is referred as the "synergy effects".
- A given practice generally attests of growth and maturity phases: this is the so-called "threshold effect".

As a result, improvements to this index are proposed. The first proposed method leads to a better characterization of the classes of companies distinguished with the index by focusing on a better attribution of the practice weights.

3.2. Variable potential innovation index (PII_{var})

As mentioned above in the *PII* method, the weights given to the practices remain the same within the four company categories (proactive, preactive, reactive and passive). However, each category attests of specific aspects. Therefore the 13 practices may not have the same importance for each group. Moreover experts and top management need a variety of reference models to take decisions aiming at the improvement of the innovation capacity of the considered company. As a result an adjusted index PII_{var} was calculated based on a specific weight set.

This new index PII_{var} uses an algorithmic method. First, all 20 companies are ranked using the first weights corresponding to the proactive class. The ranking method is the same as the one of the *PII* model. Then, "well-ranked" companies are extracted: they are the proactive companies. The remaining companies underwent the same treatment. Finally, two more iterations are required to reach the composition of preactive, reactive and passive groups.

Using this algorithm, the issue related to the determination of the weights and the manner for extracting "well-ranked" companies can be raised. First, in order to determine the weights, the value-test concept was used, which classifies variables according to their importance for the selected group. For practice X and group k (proactive, preactive, reactive and passive), the test value $t_k(X)$ is defined as follows:

$$t_k(X) = \frac{\bar{X}_k - \bar{X}}{s_k(X)} \quad (4)$$

$\bar{X}_k$ is the mean value of practice X within group k, $\bar{X}$ is the general mean value of practice X and $s_k^2(X)$ is the variance of practice X within group k.

A large value test corresponds to a significant difference between the general mean value for a practice and the mean value within the group. Hence, if the test value is high, practice j is significant or characteristic of group k. As the test value reflects the importance of the practices, the weights are calculated in proportional to it. The new weights, which are calculated for each group, are given in Table 3.

Secondly, in order to select the "well-ranked" companies, a Pareto's method is used. This method is developed in the field of Quality Management to reveal the most important defects. In our case, a percentage of 50% is used (instead of 80% generally used in Pareto).

The results given by the combination of these two methods (weight calculation and company selection) are compared with *PII* results in Table 4.

Comparing these results, few changes are observed in term of ranking, as illustrated in Fig. 2a and b. The shift from the first bisector line indicates a change in rank or index value. A great shift indicates a great modification within the classification.

The most significant change is observed in the case of company E09. Indeed PII_{var} relegates E09 from the 11th position to the 18th position; companies E05, E16, E10,

Table 3
Previous and new weights

Practice	New weights				Previous weights
	Proactive	Preactive	Reactive	Passive	
Conception	12	9	4	0	38
Project follow-up	7	14	12	3	3
Integrated strategy	6	8	0	15	20
Portfolio management	5	14	9	8	1
Innovation process evolution	11	6	3	4	2
Suitable organisation	9	12	5	3	10
Competence management	9	0	11	9	1
Moral support	9	3	3	11	2
Collective learning	5	4	15	11	5
Knowledge management	7	3	15	7	4
Survey tasks	1	13	10	15	2
Network animation	9	5	13	3	2
Research/creativity	9	8	0	10	10

Table 4
Classification comparison determined with fixed weights as well as variable weights

Rank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
PII	**E18 0.73**	**E06 0.68**	**E12 0.67**	**E02 0.66**	**E14 0.65**	**E13 0.62**	**E08 0.60**	E19 0.56	E01 0.50	E15 0.42	E09 0.41	*E05 0.38*	*E20 0.38*	*E10 0.37*	*E17 0.36*	*E16 0.35*	**E04 0.29**	**E11 0.27**	**E07 0.26**	**E03 0.10**
PII_{var}	**E12 0.74**	**E18 0.73**	**E06 0.70**	**E02 0.67**	**E08 0.65**	**E14 0.58**	E13 0.62	E19 0.59	E01 0.55	E20 0.46	E15 0.44	*E05 0.44*	*E16 0.42*	*E10 0.39*	**E04 0.38**	**E11 0.34**	**E17 0.24**	**E09 0.23**	**E07 0.23**	**E03 0.05**

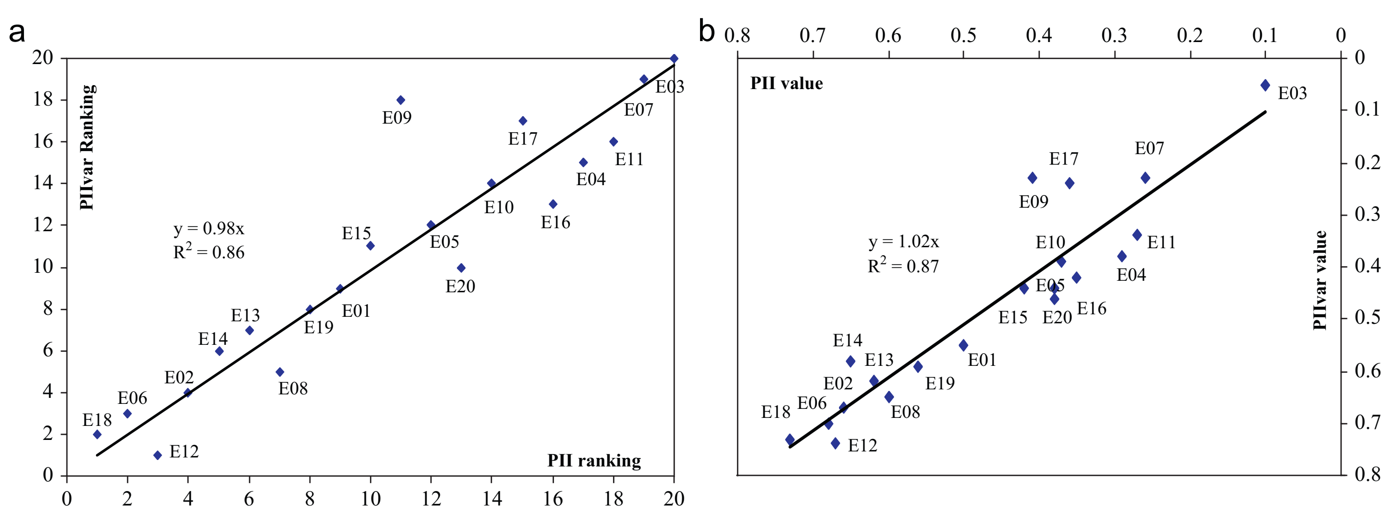


Fig. 2. Comparison between the ranks and the index values (*source*: our research).

E04, E11 and E17 overtake E09. E09's score decreases from 0.41 to 0.23. This is principally due to the most significant decrease of the following weights practices: Design, Integrated Strategy and Suitable Organization. For these practices, E05, E16, E10, E04, E11 and E17 (the companies that achieve higher rankings than E09) had lower scores than E09, and the impact of the weight change is therefore lower. This example illustrates how weight variations can yield important changes in rank and in index value.

3.3. Potential innovation index with threshold effect ($PII_{threshold}$)

As seen above *PII* (as well as the version integrating variable weights PII_{var}) does not integrate threshold effect phenomena. When practices reach high degrees of realization, the innovation capacity tends to stabilize and reach a threshold. For example, the implementation of a new methodology (like the Standard Functional Analysis) often provides results in term of innovation after a training period. But in the long term its impact remains the same. The major concern is then: how to determine this threshold effect? What kind of model can be applied to it?

A new index is developed thanks to the following fundamental principles:

- Analogies are possible with models illustrating threshold effects in the field of physics, biology and chemistry.
- The threshold effects are analysed for and at the level of each practice (each practice is described with a particular model). The characteristics of the mathematical representations are discussed with experts.
- A linear combination of 13 models allows the calculation of the new global index $PII(E_i)_{threshold}$. Then, only one aggregation is required at the practice level. Note that the practice values are not used directly to determine the innovation capacity index. Utility functions are introduced to correct the initial values of the practices.

These principles are summarized in Fig. 3.

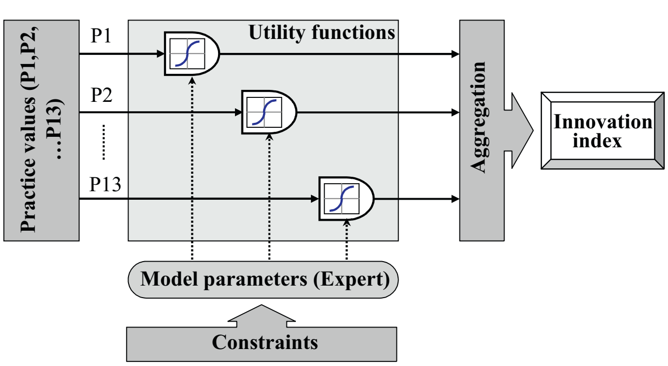


Fig. 3. Procedure for model parameters calculation for a practice P_j (*source*: our research).

3.3.1. Searching for models

Authors suggest two models to formalize a threshold effect: the "S-curve" and the "condenser load" models. These two models are relevant with our special interest and moreover are known in the field of technology management.

S-curves were used to represent the relation between cumulative efforts devoted to a process or a product improvement and the results obtained due to this investment. According to this model, progress starts slowly at first, then, by dedicating further resources, know-how is better controlled and progress accelerates. Finally, the performance level becomes marginal even if the investment increases. Therefore, a limit is reached (Foster, 1986). The S-curves illustrate a very interesting threshold effect and can fully illustrate innovation (Fig. 4).

One equation relating to this model is the Richard Equation or Generalized Logistic Curve. It is used to describe growth phenomena in biology (represented by Y in the model in Eq. (5) as a function of time (represented by t variable). Its general form is represented by the following sigmoid equation (t is the time variable; B, C and M are model parameters):

$$Y = A + \frac{C}{(1 + T\mathrm{e}^{-B(x-M)})^{1/t}} \tag{5}$$

A particular case of sigmoid function is provided by the logarithmic curve model, whose equation is (with k, a, $b > 0$)

$$Y = \frac{k}{1 + b\mathrm{e}^{(-at)}} \tag{6}$$

For the purposes of simplicity, this model was used. In the case of innovation, the model for practice P_j may be adapted and written in the following form:

$$Innovation\ (P_j) = \frac{k}{1 + b\mathrm{e}^{(-aP_j)}} \tag{7}$$

P_j represents the j practice's score.

The following stage consists in determining the model's parameters: k, a and b.

The second model considered is the condenser load model. Maintained at a continuous and fixed voltage,

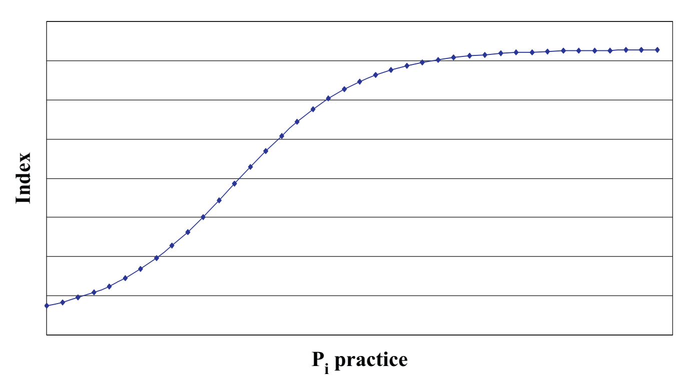


Fig. 4. A threshold effect with the S-curve.

a condenser is loaded until its voltage reaches a maximum value. For enough time of loading, this maximum value is the generator voltage (Duffin, 1990) (Fig. 5).

The equation of the condenser voltage takes the following form:

$$U = U_0(1 - e^{-t/\tau}) \tag{8}$$

where t is the time variable, U_0 is the generator voltage and τ is the time-constant (parameter of the model). In the case of innovation, the model could be adapted and written in the following form:

$$Innovation\ (P_j) = k(1 - e^{-aP_j}) \tag{9}$$

P_j is the j practice's score, k and a are the model parameters.

The second stage consists in determining parameters k and a for the model.

As a consequence, each practice may be affected to the appropriate model among those selected. The global innovation capacity is established by a combination of these models obtained individually (Fig. 6).

3.3.2. Search for the model's parameters

In the case of the S-curve model, let us reiterate the model formula applied to innovation

$$Innovation\ (P_j) = \frac{k}{1 + be^{(-aP_j)}} \tag{10}$$

The function varies within the [0;1] interval and the practice scores are always located in this interval.

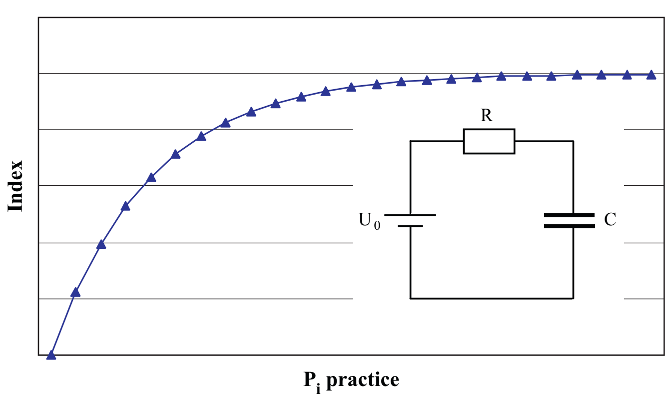


Fig. 5. Condenser load diagram (Duffin, 1990).

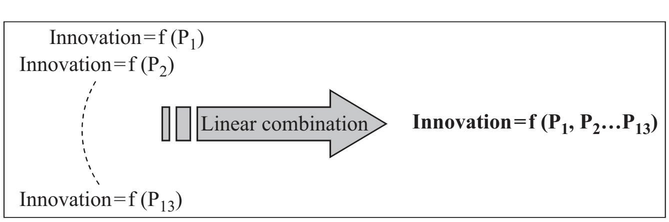


Fig. 6. Innovation according to all of the practices (*source*: our research).

In order to determine the parameters, certain conditions related to the following variables must be established:

- higher horizontal asymptote, which has the equation $y = k$,
- coordinates (x_{inf}, y_{inf}) of the inflection point (point at which the curve changes),
- gap between the curve and the horizontal asymptote at point $x = 1$ (Fig. 7).

As the innovation capacity is modelled using an index ranging between 0 and 1, the horizontal asymptote equation must be $y = 1$ and then $k = 1$. In addition, it is easily demonstrated that the ordinate of the model inflection point is always equal to $\frac{1}{2}$. Therefore, $y_{inf} = \frac{1}{2}$.

It only remains to set the values of variables x_{inf} and α in order to determine the two remaining parameters of the model a and b. The choice of x_{inf} and α will condition the curve shape. This choice cannot be taken arbitrarily. Therefore, one expert in innovation is consulted. Actually, the use of innovation practices is closely dependent on the context and to the strategy of the company. For instance, managers' culture has an impact on their priorities toward innovation practices (and as a consequence on practices weights). Moreover, the national innovation policy is not similar in every country. For this reason, priorities have to be defined by experts or group of experts themselves. Thus, our evaluation system may be used as a genuine diagnosis tool. To test our method, innovation weights have been defined by an expert. The expert has been selected upon his experience: innovative projects manager, academic research and management of an innovative company's network. Note that one consequence of making the hypothesis of the contextualization of innovation practices priorities is that taking into account the average parameters evaluated by a group of experts or taking into account the opinion of a single expert has no impact on the pertinence of the diagnosis model. Thus, no statistical approach for the model's parameters determination has been achieved. More precisely, our expert does not directly state the two parameter values a and b. He has

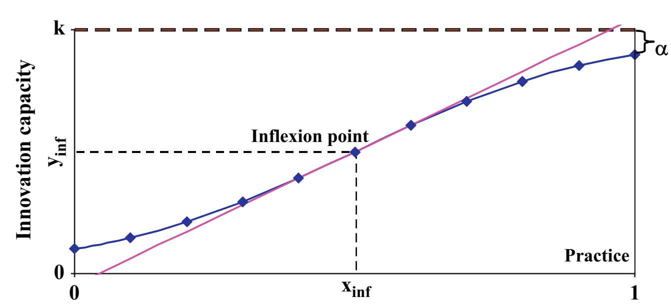


Fig. 7. Parameters to be determined in order to determine the equation of the S-curve model.

to choose between various shapes of curves representing the variation of innovation capacity according to each practice and various values of x_{inf} and α. The choices suggested to the expert are summarized in Appendix B.

Similarly, the same reasoning is to be applied to the second model (condenser load diagram), which has the following formula:

$$Innovation\ (P_j) = k(1 - e^{-aP_j}) \tag{11}$$

The conditions for the model parameters are:

- higher horizontal asymptote, which has equation $y = k$ and
- point of the curve, whose coordinates are $(x_\alpha;\alpha)$ and which will determine the shape of the curve.

Like the first model, the first condition results in $k = 1$.

The second condition is used to define the shape of the curve. The parameters that characterize the speed with which the curve tends towards asymptote $y = 1$ must be determined. It is only necessary to provide the abscissa of the point that reaches 90% of the index maximum value. Therefore, $\boldsymbol{\alpha = 0.9}$. Then, x_α value must be provided (Fig. 8).

Like the first model, an innovation expert is consulted. The curve shapes proposed to the expert are provided in Appendix C.

Finally, Appendix D provides all the expert's answers.

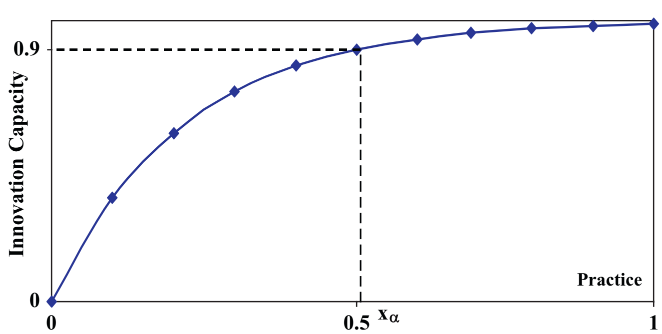


Fig. 8. Parameters to be determined in order to determine the "condenser" model equation.

Thus, the selected models were used to adjust the practice values. A calculation example for companies E07 and E18 is presented in Table 5. E18 is the highest ranking company; E07 is among those with the lowest *PII* index classification. This choice illustrates the impact of the threshold effect model for low and strong values in innovation practices.

With regard to company i, P_{ij} is the value relating to practice j. The terms "*Innovation* (P_j)" correspond to the corrections of P_{ij} using the appropriate model.

The corrections effected are not very significant when model 1 (first alternative for S-curve models) is selected. For example, the value of practice 1 (design activities) increases from 0.15 to 0.18 for company E07, and practice 5 (evolution of the innovation process) decreases from 0.8 to 0.79 in the case of company E18. The explanation for this weak correction lies in the definition of model 1. Indeed, the curve shape is very close to the first bisector (line $y = x$) (see figure in Appendix B). Significant changes can be observed only for the upper and the lower bounds of the interval (for weak or strong values). On the other hand, in the case of model 5 (first alternative to the condenser load model), corrections are clearer and more tangible. In the example of company E07, the practice P11 value (Survey Tasks) increases from 0.20 to 0.37, whereas for company E18, practice P10 value (knowledge capitalization) varies from 0.67 to 0.79. It is evident that the scope of the correction using this model decreases for significant practice values to become lower than the initial value. This is the case of practice P12 (animation of networks) for company E18: the value decreases from 0.89 to 0.87. The comparison between these two companies demonstrates that considering the threshold effect through an appropriate model has an impact on the entire innovation index. As a result, the choice of the model and its parameters is very important. Note that consulting experts to choose the models has the advantage of using tacit knowledge. However, it can be a limitation when the model is close to the first bisector.

In the following section, the corrected global index case will be discussed and will be calculated according to corrections affected individually to each practice.

Table 5
Example of calculations for companies E07 and E18 P_{ij} is the company i, value of practice j, "*Innovation* (P_j)" corresponds to the correction of P_{ij} using the appropriate model

Practice P_j	1	2	3	4	5	6	7	8	9	10	11	12	13
Model number	*1*	*1*	5	5	*1*	5	5	5	*1*	5	5	5	*1*
E07													
P_{ij}	*0.15*	*0.18*	0.50	0.50	*0.20*	0.57	0.20	0	*0.17*	0	0.20	0.44	*0.07*
Innovation (P_j)	*0.18*	*0.20*	0.68	0.68	*0.21*	0.73	0.37	0	*0.19*	0	0.37	0.64	*0.13*
E18													
P_{ij}	*0.75*	*0.55*	0.75	0.63	*0.80*	0.714	0.80	0.83	*0.67*	0.67	0.73	0.89	*0.71*
Innovation (P_j)	*0.75*	*0.55*	0.82	0.76	*0.79*	0.80	0.84	0.85	*0.68*	0.79	0.82	0.87	*0.72*

Table 6
Weights to be considered (*source:* Corona Armenta, 2005)

Practices	1	2	3	4	5	6	7	8	9	10	11	12	13
Weight provided by the experts	0.38	0.03	0.20	0.01	0.02	0.10	0.01	0.02	0.05	0.04	0.02	0.02	0.10

Table 7
Index values and company classification

Rank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
PII	E18 0.73	E06 0.68	E12 0.67	E02 0.66	E14 0.65	E13 0.62	E08 0.60	E19 0.56	E01 0.50	E15 0.42	E09 0.41	E05 0.38	E20 0.38	E10 0.37	E17 0.36	E16 0.35	E04 0.29	E11 0.27	E07 0.26	E03 0.10
$PII_{threshold}$	E18 0.77	E06 0.72	E02 0.71	E12 0.69	E14 0.68	E08 0.67	E13 0.66	E19 0.60	E01 0.56	E15 0.49	E09 0.47	E05 0.45	E10 0.44	E20 0.44	E17 0.42	E16 0.42	E11 0.36	E07 0.34	E04 0.36	E03 0.19

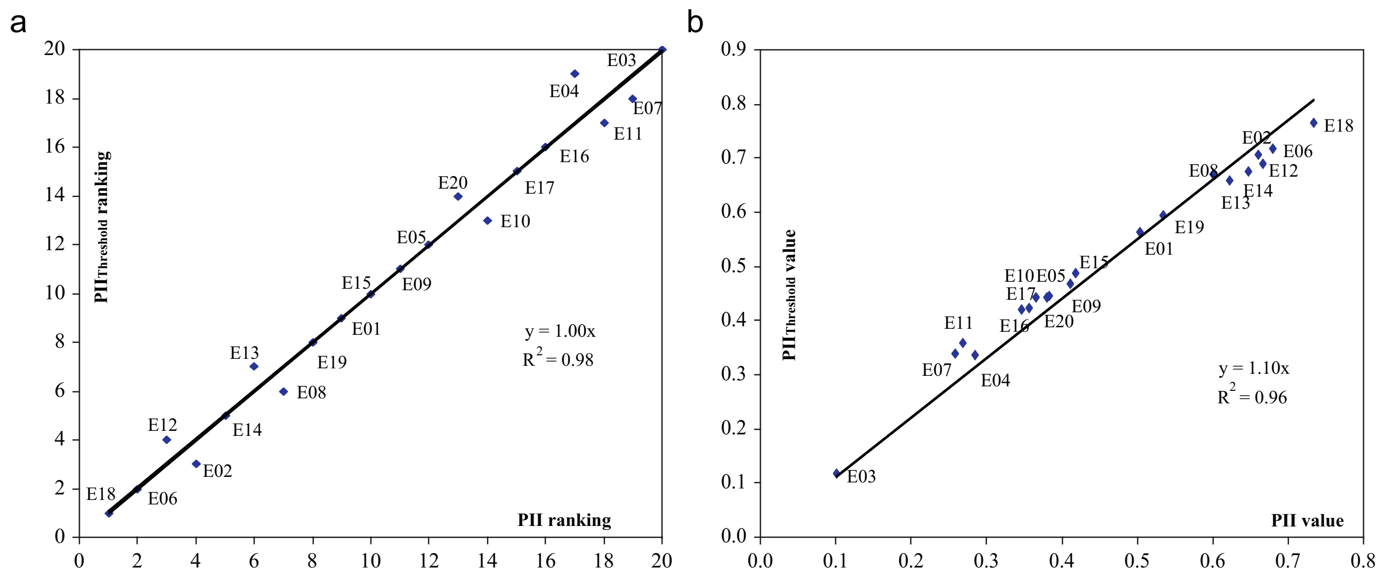


Fig. 9. Comparison between classification and index values for *PII* and $PII_{threshold}$ (*source*: our research).

3.3.3. Calculation of the total innovation index

The innovation capacity of each company E_i, denoted $PII(E_i)_{threshold}$ is calculated in the same way as the *PII*:

$$PII(E_i)_{threshold} = \frac{\sum_{j=1}^{13} w_i \; Innovation\;(P_j)}{\sum_{j=1}^{13} w_j} \tag{12}$$

In order to calculate the total index $PII(E_i)_{threshold}$, various weights may be studied and used. To compare the results obtained by *PII* and $PII_{threshold}$ indexes, the same weight set is maintained. Table 6 provides the reminding weights to be considered.

Table 7 is an illustration of the classification of companies according to *PII* and $PII_{threshold}$ indexes, as well as the score for each company.

E18 remains the leader and E03 remains the last on the scale of innovation. Plotting $PII_{threshold}$ as function of *PII* classification provides a clearer illustration of the position changes for each company.

In Fig. 9a, any gap in a company's position compared with first bisector indicates a different classification when using the two indexes. Most points are very close to the line and therefore no company had taken a great leap forward in the classification. The correlation coefficient for the two sets of data (data of *PII* and $PII_{threshold}$) is 0.99. The most significant leap is observed for company E04, which had lost two places with $PII_{threshold}$ to be classified in the nineteenth position. A comparison of the two index values (Fig. 9b) demonstrates a global stability. The greatest variation is observed for company E11: its $PII_{threshold}$ value is 0.36 versus a *PII* value of 0.27. Fig. 9b shows a linear regression between the two indexes. The tendency line is close to the first bisector ($PII_{threshold} = 1.10 PII$). The regression coefficient between the sets of data and this line is 0.96.

Thus, the $PII_{threshold}$ index does neither cause significant changes to the companies' classification level nor to the index value level. Various reasons may be suggested.

Firstly, the same global model is used to calculate the two indexes, namely the MCDA model. Secondly, expert's choice for modelling threshold effect for each innovation practice was restricted to two models only among the eight ones elaborated. These models (models 1 and 5) provide values closer to the bisector, and cause minor corrections. Moreover the values to be corrected are mainly at the centre of the interval [0;1] (52% of practice values range between 0.3 and 0.7). In this case, the corrections are minor because the threshold effect is more visible at the interval's extreme limits rather than within for interval's centre.

However, this method leads to an index that takes into account the threshold effect on practices. Note that generally a model explains the observed variation of the output variables according to the input variables, and is based on the calculation of the parameters via a mathematical method (for example, the least-squares method). In our case, this process cannot be applied because the outputs of the index are unknown.

Elaborating more diversified models may improve the method. In addition, the extension of the panel size may avoid the concentration of values at the middle of the interval [0;1], and as consequence grant a greater prominence to the threshold effect.

Finally, through the index $PII_{threshold}$, the classification is structured on the same basis as the *PII*. Nevertheless, it is possible to combine indexes PII_{var} and $PII_{threshold}$ in order to obtain an index that takes into account threshold effect and leads to a classification of companies in different categories. Using weights different from those used for *PII* will lead to more diversified results.

3.3.4. Data mining

In this section, a complementary statistical data mining approach is proposed, to characterize groups of companies and demonstrate synergy effects between practices.

To reduce the number of variables (the 13 practices) and to establish new variables referred as "principal factors", the principal components analysis (PCA) technique is used. Thanks to PCA, 13 new variables (or factors) are firstly determined, each factor is a linear combination of the original 13 variables (13 practices), and secondly classified considering their decreasing importance order. More precisely the importance of a factor is correlated to the inertia of the 20 companies considering this factor. Thus, the eigenvalues of each factor are calculated (Lebart et al., 2000). Among the several methods (many of them are empirical and subjective), we develop the eigenvalues histogram in order to select the significant new factors (Diday et al., 1983). The Table 8 gives the outcomes of the PCA approach.

To simplify this explanation, a figure with only two axes (corresponding to the first and the second factor) is proposed: it explains 62% of the total inertia (Fig. 10). Note that the three-factor model explains 71% of the total inertia. This projection of the 13 practices leads to a better understanding of the companies' distribution. In addition, with PCA, some variables may be used to help diagram's interpretation. These special variables are referred to as "illustrative variables". In this case, attention is directed toward *PII* as illustrative variable and as a consequence its position in the factorial plan has been studied.

All practices are closed to the two factors and located on the same side. As a result all variables are correlated in the same way with the first factor, which could be considered as an innovation factor. Moreover, the *PII* is aligned with it on this figure. Indeed, the *PII* index is a linear combination of the 13 practices. As a conclusion, this first factor is relevant with the *PII*.

The closest practices from the first factor are "Portfolio Management", "Innovation Process Evolution", "Moral Support", "Collective Learning" and "Network Animation". These are the practices with smaller weights, respectively, 1, 2, 2, 5 and 2 (see Table 2). Considering the similarity between the first factor and the *PII*, the most significant weighted variables should be closed to the first factor ("Conception", "Integrated Strategy" and "Suitable Organization"). This could be a consequence of our

Table 8
Eigenvalues histogram

Number	Eigenvalue	Percent	Cumulative percent	
1	6.3657	48.97	48.97	**
2	1.6402	12.62	61.58	*********************
3	1.3320	10.25	71.83	****************
4	0.9803	7.54	79.37	*************
5	0.9115	7.01	86.38	************
6	0.4220	3.25	89.63	******
7	0.3851	2.96	92.58	*****
8	0.3232	2.49	95.08	*****
9	0.2744	2.11	97.19	****
10	0.1634	1.26	98.44	***
11	0.1246	0.96	99.40	**
12	0.0549	0.42	99.83	*
13	0.0227	0.17	100	*

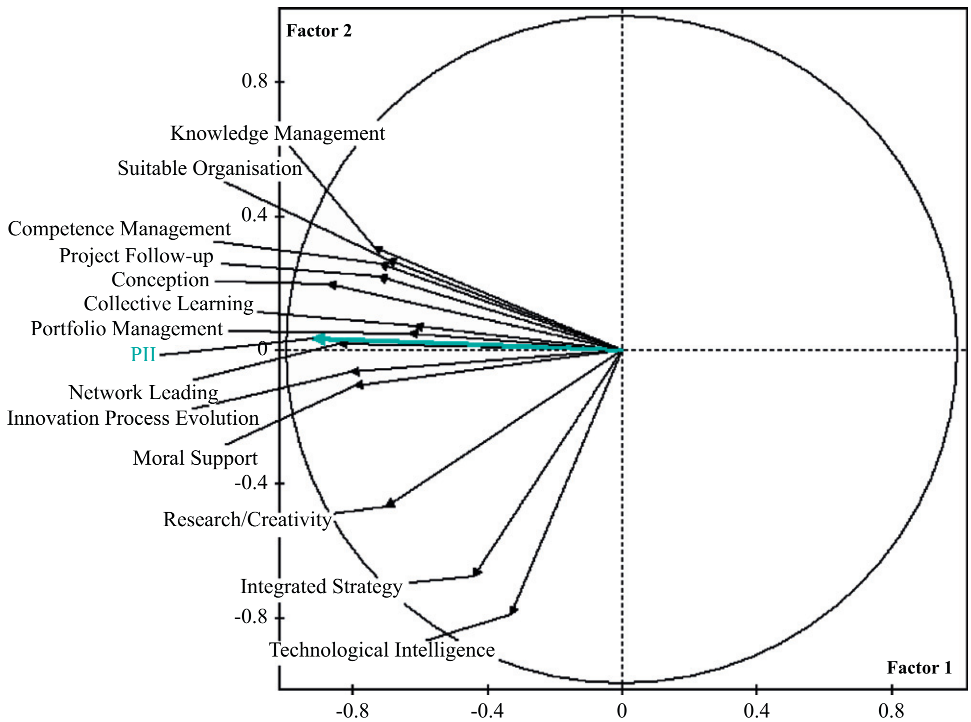


Fig. 10. The PCA plot (*source*: our research).

corporate panel composition being mainly composed with SMEs.

All practices are located on both sides close to the second factor. On the lower side are practices related to external knowledge (Survey Tasks, Research/Creativity, Integrated Strategy, etc.), whereas on upper side are practices related to internal knowledge (Knowledge Management, Suitable Organization, etc.). Therefore, the second factor expresses information flows and related treatment tasks. These results are summarized in Fig. 11.

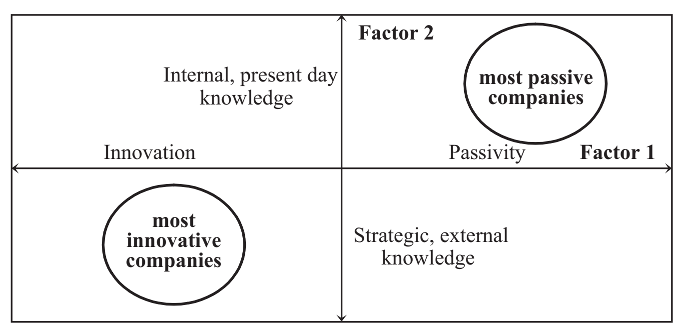


Fig. 11. The two factors interpretation (*source*: our research).

The same analysis has been developed considering three PCA factors. Succinctly, practices related on the organization scale (Integrated Strategy, Suitable Organization and Innovation Process Evolution) are correlated positively with the third factor. On the other hand, practices concerning the individual scale (Moral Support, Learning and Knowledge Management) are correlated negatively with it. The third factor may be interpreted as the human dimension of the innovation process.

Finally, an aggregation approach is achieved. At the end of this clustering method a hierarchal tree plot is obtained. It highlights the relations between sample companies using a similarity measurement. Considering an adequate level, groups of subjects (partitions) are defined. In our case, at level index 4.68 two main groups emerged as illustrated in Fig. 12.

The representation of the companies and the two partitions according to the two principal factors is described in Fig. 13.

The two partitions are symmetrically distributed towards the first axis. Since the first factor is interpreted as the *PII*, the results are coherent with the previous analyses. The hierarchal tree visually distinguishes innovative and non-innovative companies. The first partition represents the group of innovative companies, whereas partition 2 gathers the less innovative ones.

The specific cases of companies E18 and E12 is relevant with our special interest about synergy effects. These two companies have two opposite positions toward the second factor. Detailed analysis of their practices and sub-practices attests the main differences in the field of knowledge management (Fig. 14).

This case suggests a synergy effect between technological intelligence, strategy integration, research/creativity, suitable organization and moral support. High scores within

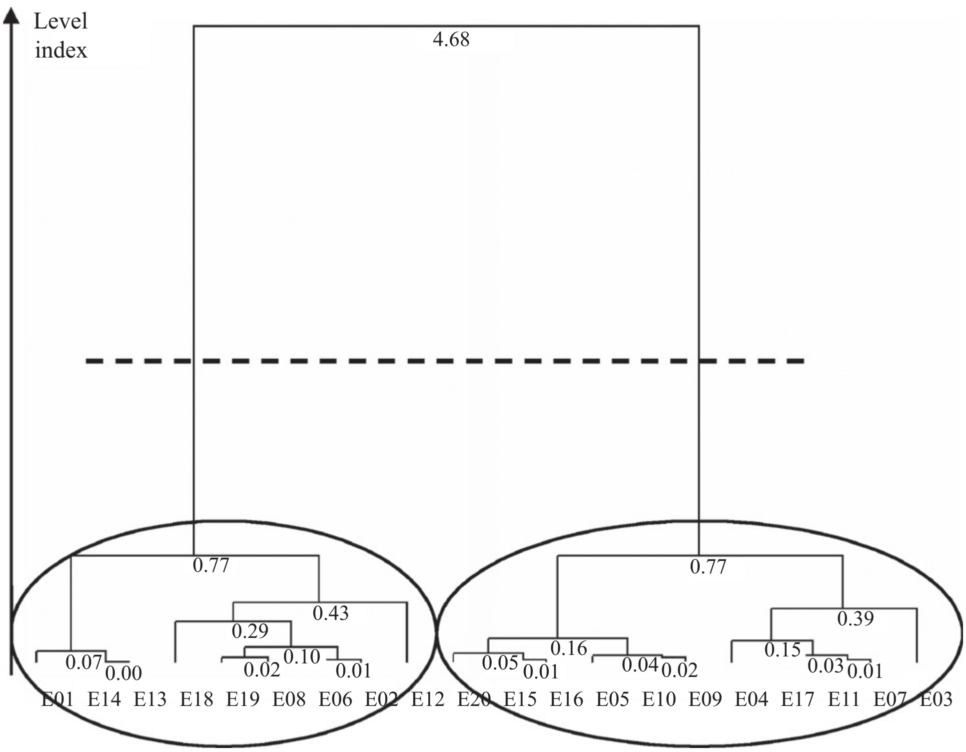


Fig. 12. Hierarchal tree (*source*: our research).

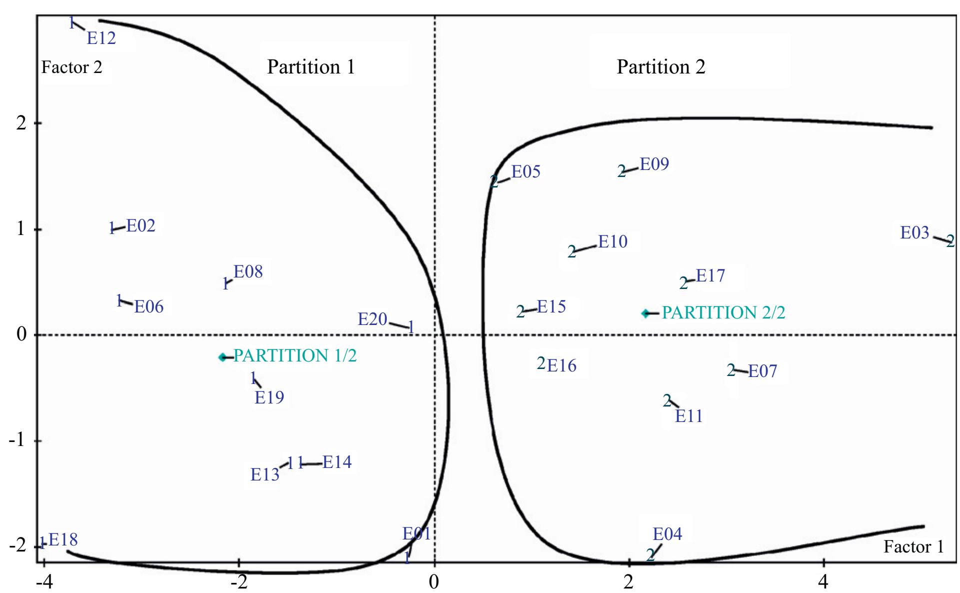


Fig. 13. Representation and subdivision of the companies in two groups (*source*: our research).

these practices are equivalent to maximum scores in Project Management, Suitable Organization and Moral Support. In order to be innovative, a company may choose between two strategies: achieve a top level (100%) in practices focusing on short-term company growth and internal knowledge building (left side of Fig. 14), or be more or less effective (approximately 75%) in practices aiming at future growth and external knowledge gathering (right side of Fig. 14). This result is consistent with Griffin and Page's study about Product Development Success and Failure. These authors suggest that "prospectors" (these companies being "first" with new products, markets and technologies are similarly to the "most innovative" group of our panel), when assuming the return on experience about their

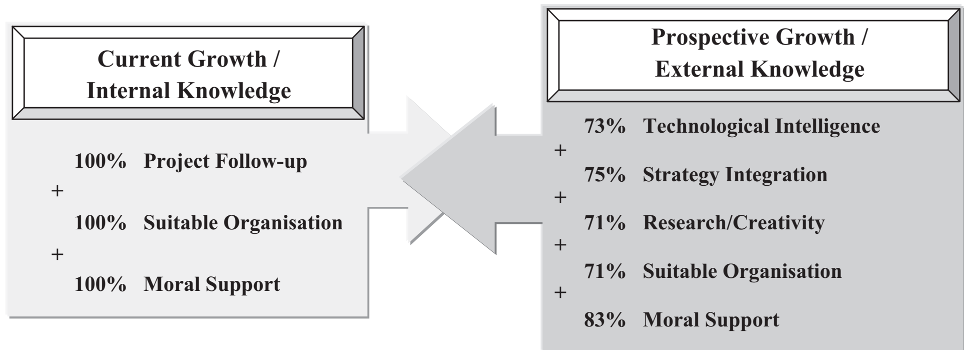


Fig. 14. Synergy effect (*source*: our research).

product development process, distinguish two aspects: the current and future company growth rate (Griffin and Page, 1996).

4. Conclusion

This survey offers some thoughts regarding innovation evaluation. Although the study is exploratory, propositions are formulated in the field of evaluation criteria definition and data treatment.

Innovation capacity evaluators gain useful insights by considering attributes of the process (practices) and directly observable phenomena (sub-practices). This approach grants a better similarity between the evaluations of different evaluators analysing the same company. In fact, the achievement of each sub-practice can be proved by facts or documents. The census of practices may be enriched without modifying the principles of the further data treatment steps. Nevertheless, sub-practices scoring still represents a limitation. Sub-practices scores are either one or zero (observation or not of sub-practices in the company). But score of a sub-practice being implemented remains problematic. Using fuzzy-sets logic may help solving this problem.

Focusing on data treatment, two first indexes were proposed: the potential innovation index (*PII*) and the *variable PII* (PII_{var}). The advantage of the latest lies in the attribution of different weights to each category of companies. Its dynamic character allows a more realistic classification of companies considering their innovation capacity. The typology is based on the realization of the specific group's key practices. A second proposition deals with the threshold effect $PII_{threshold}$. The innovation capacity evaluation takes into account a threshold effect, which is a function of innovation practices. Several possible models expressing a threshold effect were suggested. An expertise phase (using a questionnaire) led to the selection of appropriate models, resulting in a new index. However, it does not provide significantly different results in comparison with index *PII*. Conducting a broader study, proposing other models and broadening companies' sample size may correct this limitation. Finally, the third method is based on data mining, more precisely, the joint application of the Principal Component Analysis (PCA) and the hierarchical classification. This method does not lead to a quantitative classification like the *PII*. Nevertheless, it allows for the more innovative companies to be differentiated from the others, and to mathematically prove the existence of a synergy effect. It was demonstrated that to be innovative, companies may choose between two different visions and strategies in the field of information management.

On a methodological point of view, this research is a contribution to an innovation metrology framework. It aims at the definition of an innovation scale. Software applications have to be developed aiming to an easier use of these approaches. Particularly, it would simplify the selection of the profile preferences (weighing definition) according to the objectives of the evaluators including: top management, experts, academics or public structures.

On a practical point of view, evaluation approaches help to clarify outstanding activities and allow accurate research for better innovation management practices to be pursued. Complementary to in situ observation campaigns, evaluation contributes to a better understanding of innovation phenomena. Hence, synergy effects have been described. Evaluation approaches represent a rigorous way to assess efficiency of new management practices. Moreover the development of common evaluation methods within the management of technology academic community would contribute to enrich our empirical background.

Appendix A

Thirteen practices and a selection of relating sub-practices are shown in Table A1.

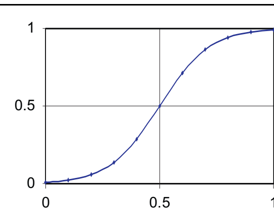
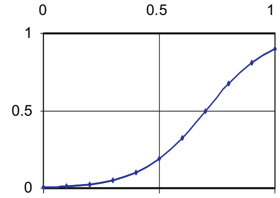
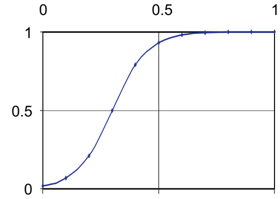
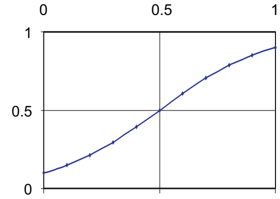
Table A1
Development of innovation practices for the companies' panel (*source*: Corona Armenta, 2005)

Companies	Conception	Project follow-up	Integrated strategy	Portfolio management	Innovation evolution	Suitable organisation	Competence management	Moral support	Collective learning	Knowledge management	Survey tasks	Network animation	Research/ creativity
E01	0.50	0.82	0.58	0.50	0.40	0.57	0.40	0.50	0.33	0.00	0.73	0.39	0.50
E02	0.80	0.82	0.33	0.63	0.40	0.86	1.00	0.50	0.83	0.67	0.47	0.83	0.50
E03	0.20	0.00	0.00	0.00	0.00	0.00	0.40	0.00	0.00	0.00	0.00	0.00	0.21
E04	0.15	0.36	0.67	0.38	0.00	0.00	0.60	0.50	0.17	0.00	0.40	0.22	0.43
E05	0.35	0.91	0.42	0.13	0.40	0.71	0.80	0.00	0.17	0.33	0.13	0.61	0.14
E06	0.75	0.64	0.50	0.88	0.60	1.00	0.60	1.00	0.50	0.67	0.27	0.72	0.57
E07	0.15	0.18	0.50	0.50	0.20	0.57	0.20	0.00	0.17	0.00	0.20	0.44	0.07
E08	0.80	0.55	0.33	0.50	1.00	0.57	0.60	0.83	0.00	0.67	0.13	0.78	0.64
E09	0.50	0.64	0.33	0.38	0.20	0.86	0.40	0.00	0.17	0.33	0.07	0.00	0.14
E10	0.45	0.64	0.25	0.38	0.20	0.57	0.40	0.17	0.17	0.33	0.33	0.50	0.14
E11	0.20	0.36	0.33	0.38	0.00	0.43	0.40	0.33	0.33	0.33	0.60	0.11	0.14
E12	0.85	1.00	0.33	0.88	0.60	1.00	1.00	1.00	0.67	0.67	0.00	0.78	0.21
E13	0.65	0.64	0.75	0.75	0.80	0.86	0.40	0.17	0.33	0.33	0.53	0.67	0.36
E14	0.75	0.73	0.67	0.13	0.60	1.00	0.80	0.67	0.00	0.00	0.53	0.61	0.50
E15	0.60	0.45	0.25	0.75	0.40	0.57	0.40	0.00	0.00	0.00	0.33	0.78	0.29
E16	0.40	0.36	0.33	0.50	0.40	0.14	0.40	0.33	0.50	0.33	0.40	0.56	0.21
E17	0.45	0.18	0.33	0.50	0.00	0.57	0.40	0.00	0.33	0.00	0.13	0.28	0.21
E18	0.75	0.55	0.75	0.63	0.80	0.71	0.80	0.83	0.67	0.67	0.73	0.89	0.71
E19	0.50	0.64	0.50	0.75	0.40	0.71	0.60	0.67	0.50	0.67	0.53	0.72	0.43
E20	0.40	0.45	0.17	0.75	0.20	0.43	0.60	0.67	0.33	0.67	0.53	0.50	0.43

Appendix B

Company ranking and values according to PII is shown in Table B1.

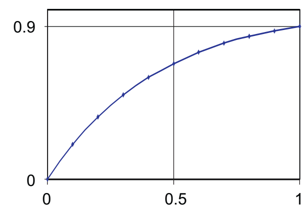
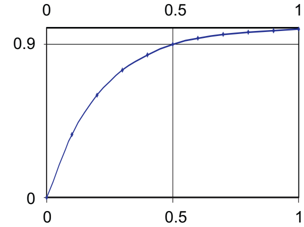
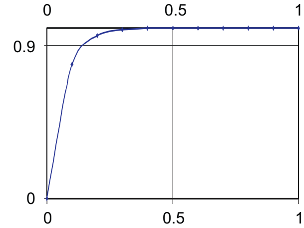
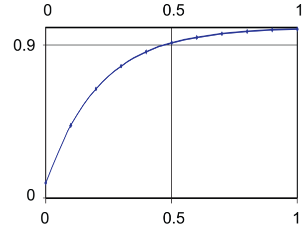
Table B1
The four plots proposed for the S-curve model and their parameters (see model formula 10 in the text for parameters definitions)

Choice	k	y_{inf}	x_{inf}	α	a	b	Plot	Features
1	1	0.5	0.5	0.01	**9.19**	**99**		● Symmetric growth ● Quite rapid learning ● Quick growth ● Maximal efficiency is reached quickly
2	1	0.5	0.7	0.1	**7.32**	**168.5**		● Asymmetric growth ● Rapid learning ● Quick growth ● Maximal efficiency is reached at the end
3	1	0.5	0.3	0.0001	**13.6**	**51.79**		● Asymmetric growth ● Very rapid learning ● Quick growth ● Maximal efficiency is reached quickly
4	1	0.5	0.5	0.1	**4.39**	**9**		Innovation capacity has initial value and does not reach the maximal value

Appendix C

Previous and new weights are shown in Table C1.

Table C1
The four plots proposed for condenser model and their parameters (see model formula 11 in the text for parameters definitions)

Choice	k	α	x_α	a	Plot	Features
5	1	0.9	1	**2.3**		• Slow growth • Maximal efficiency is reached slowly
6	1	0.9	0.5	**4.61**		• Quick growth • Maximal efficiency is reached quickly
7	1	0.9	0.15	**15.35**		• Very quick growth • Maximal efficiency is reached quickly
8	1	0.9	0.5	**4.61**		• Quick growth • Innovation capacity has an initial value

Appendix D

Classification comparison determined with fixed weights as well as variable weights is shown in Table D1.

Table D1
Experts' answers to the threshold effect questionnaire

Innovation practices	Proposed models for threshold effect							
	S-curve model				Condenser model			
	1	2	3	4	5	6	7	8
1 Conception	X							
2 Project follow-up	X							
3 Strategy integration					X			
4 Project portfolio management					X			
5 Innovation evolution	X							
6 Suitable organisation					X			
7 Competence management					X			
8 Moral support					X			
9 collective learning	X							
10 Knowledge management					X			
11 Survey tasks					X			
12 Network animation					X			
13 Research/creativity	X							

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