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# Modeling to assess the influence of knowledge on the technological innovation performance capacity in high complexity environments: Towards Brazilian multinationals companies

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**The present paper aims to contribute to the knowledge and innovation planning guidelines in the high complexity environments. Thus, a modeling proposal is presented to assess the influence of knowledge on the technological innovation performance capacity of multinationals companies. This procedure was prepared according to the following phases: Phase 1: Determination of the conceptual model; and Phase 2: Verification of the conceptual model, systematized in the following steps: Step 1: Modeling the overall influence of knowledge on the technology innovation performance capacity of multinationals companies; Step 2: Determination of the correlation of the knowledge and multinationals companies' technological innovation capacity; and Step 3: Modeling of the optimal efficiency rate of knowledge influence on the company's technology innovation performance capacity. The research was conducted based on the specialized literature and a survey of brazilian multinationals companies. The research involved the intervention of experts knowledgeable on the object studied, selected by technical-scientific criteria. The data were extracted using an assessment matrix. To reduce subjectivity in the results achieved, the following methods were used complementarily and in combination: multicriteria analysis, multivariate analysis and neurofuzzy technology. The results were satisfactory, validating the modeling approach.**

**Key words:** Modeling; Assessment; Influence of Knowledge; Technological Innovation Performance Capacity; High Complexity Environments; Brazilian multinationals companies.

## Introduction

Recently, relevant changes have made organizational boundaries more fluid and dynamic in response to the rapid pace of knowledge diffusion (Abrahamson, 1991; Griliches, 1990; Teece, 1986), innovation and international competition (Chesbrough and Rosenbloom, 2002; Christensen, 2003; Damanpour, 1996). This helps to reconsider how to succeed with innovation (Teece et. al., 1997; Tidd, Bessant, and Pavitt, 1997; Teece, 1986; Wheelwright and Clark, 1992). Thus, innovative companies make use of their capabilities to appropriate

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the economic value generated from their knowledge and innovations (Griliches, 1990; Teece, 1986). Therefore, the supply of innovative products is presented as a quality standard in the race for pressing demands. It is believed that companies that can offer their products to customers more efficiently and faster will probably be in a better position to create a sustainable competitive advantage (Prahalad and Hamel, 1990; Amit and Schoemaker, 1993; Nonaka and Takeuchi, 1995) due to knowledge and innovation (Tidd, Bessant, and Pavitt, 1997; Nonaka and Takeuchi, 1995; Johannessen, Olsen and Olaisen, 1999). In this dichotomy, technical efficiency is a parameter of the developing capacity of innovative products, which translates into one of the most remarkable logical arguments to potentialize and encourage competitive advantage (Wheelwright and Clark, 1992). One of the main challenges is to develop products in high complexity environments. Solutions to these challenges have been offered by the companies' equally innovative technical capabilities, greater efficiency, productivity and high quality (Wheelwright and Clark, 1992).

It is true that a new product or process can represent the end series of knowledge initiatives and the beginning of a process value creation, which, under conditions imposed by various parties, can produce efficient results in the global performance of the value chain, reaching not only businesses that innovate, but also correlated companies (Klette et. al., 2000; Beugeldjck and Cornet, 2001). Knowledge can lead to performance improvements of other co-related or co-located companies (Klette et. al, 2000). The knowledge may represent a strategic tool, increasing the institutional capacity of the Entrepreneurs in their assignments of formulation, evaluation and execution of such projects (Fletcher, Yiannis, and Polychronakis, 2007). The knowledge would work as a facilitator instrument of improvement, contributing for the quality of services and the enhancement of the agility to decide. Thus, the knowledge should be a mechanism to have incremental gains and competitive advantage. And the innovation is a dynamic process and perhaps the most dynamic of all industrial activities (Schumpeter, 1943). This requires the combined effort of various innovative activities, a condition of limited resources.

Traditionally, the literature references two main types of innovation activities: internal and external (Veugelers and Cassiman, 1999; Cassiman and Veugelers, 2006). External activities are related to licensing knowledge access through external sources, research and development (R&D) outsourcing and hiring highly qualified researchers, with relevant knowledge (Arora and Gambardella, 1990) and others. Internal innovation activities use the firm's internal capacities (Vega-Jurado et al., 2008), where knowledge production is internalized. Recently, the state of the art introduced a third innovation activity route, cooperation with other partners to develop innovations (Chen and Yuan, 2007), which can be considered a combination of internal and external innovation (Pisano, 1997). Deciding on an ideal balance regarding innovation activities is a complicated issue (Chen and Yuan, 2007), there are barriers to be challenged and substantially reconfigured (Assink, 2006) in order to obtain an optimal and combined convergence of the various activities in confluence with the firms' desired and acceptable performance. Innovation activities are admittedly complex and risky. Thus, it is difficult to accurately assess (Afuah, 1998; García-Muin and Pez Navas-lo, 2007) the innovation capacity and also discern the firms' range of acceptable performance. All these elements are difficult to accurately define and interpret. As it is a procedure in which attributes have subjective characteristics, reference methods and compliant and robust assessment techniques have to be reformulated, considering not only the objective attributes, but also the subjective dynamics produced within the decision context. Recently, studies have referenced knowledge and innovation as a key factor affecting the performance of firms. Companies make use of its innovative capacities to achieve sustainable competitive advantage. The present paper aims to contribute to the knowledge and innovation planning guidelines in the high complexity environments. Thus, a modeling proposal is presented to assess the influence of knowledge on the technological innovation performance capacity of brasilian multinationals companies. Within this context, this paper is structured according to the following sections: methodlogy, which presents the conceptual model and the methodlogical procedures; verification of the conceptual model and analysis of the results; implications for management practice, the paper concludes with the final considerations.

## METHODOLOGY

### Conceptual Model: Constructs and hypotheses

This section examines the conceptual model (Figure 1) and presents the hypotheses to be tested throughout this work.

Acknowledged as one of the most significant forms of globalization, technological innovation stands out as a potential to ensure the firms' long-term survival and growth (Schumpeter, 1939; Ancona and Caldwell, 1992; Baumol, 2002). Therefore, technological capacity is understood as an organization's complete set of characteristics that facilitates and supports its technological innovation strategies (Burgelman et al., 2004). Within this outlook, it is possible that R and D is the central component of firms' technological innovation activities. It is believed that the organizational efficiency in these activities that lead to innovation enables the firms to achieve the satisfactory and desired performance, traditionally measured by sales growth, net income growth and return on investment (Tallon et al., 2000).

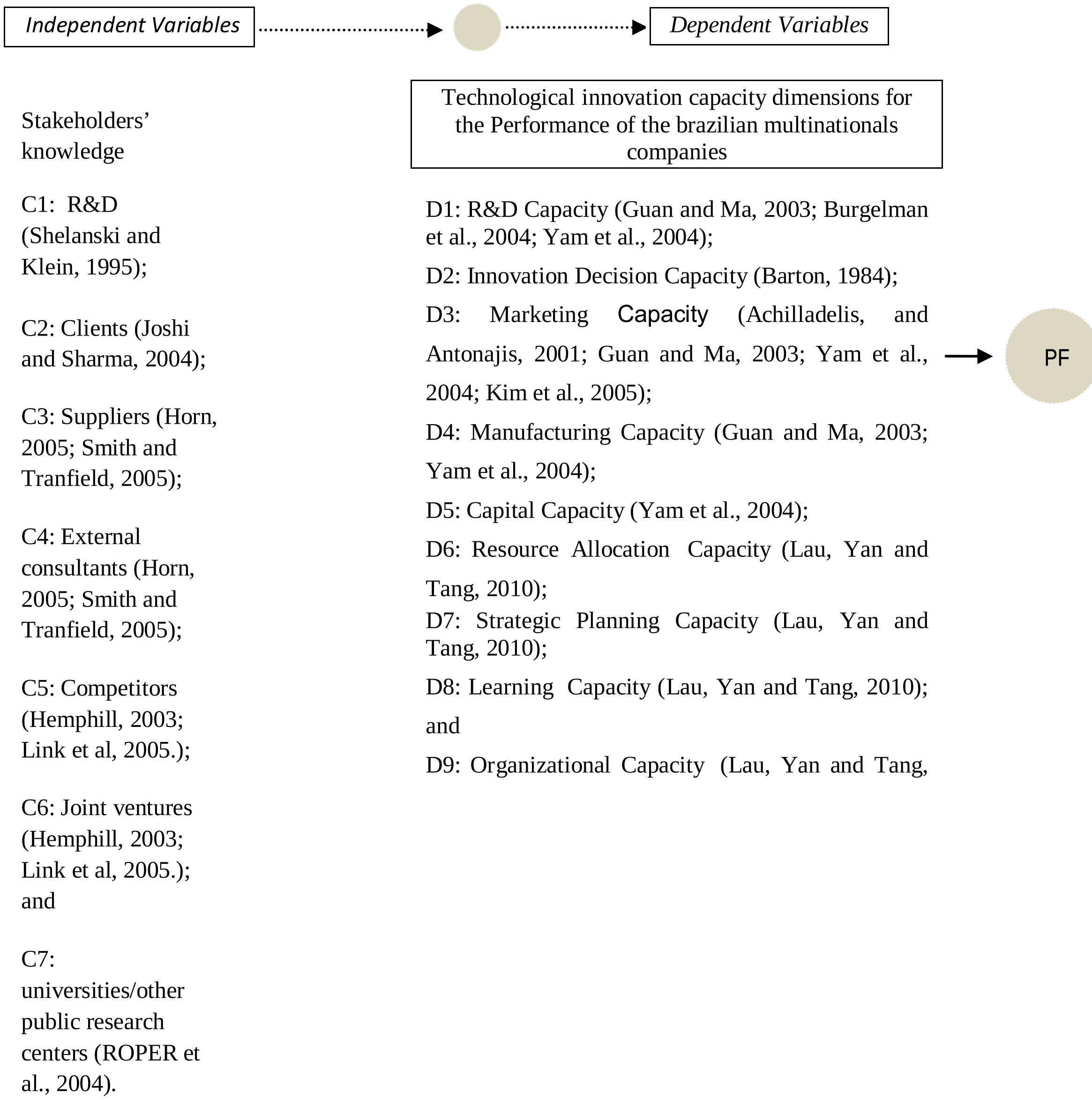


**Figure 1.** Conceptual Model of the Study

Guan et al. (2006) have defined technological innovation capacity as consisting of seven capability dimensions, namely learning capability, R and D capability, manufacturing capability, marketing capability, resource exploiting capability, organization capability and strategic capability. Adler and Shenbar (1990) defined four innovation capabilities: (1) ability to satisfy market requirements by developing new products; (2) ability to manufacture new products using appropriate techno-logical processes; (3) ability to satisfy future market needs by developing and marketing new products and technological processes; and (4) ability to effectively respond to unanticipated technological activities by competitors and unforeseen market forces (Wang, Lu, and Chen, 2008). Recent studies have advocated the impact of technological innovation capabilities on firms' competitive performances. Specifically, R and D, resource allocation, learning and strategy planning capabilities can signifycantly improve the innovation sales. R and D and resource allocation capabilities can also significantly improve new product introduction (Lau, Yan, and Tang, 2010).

The building-up and managing of the companies require highly complex analytical approaches, which include subjective elements. Hence, the technical mastery of various technological, legal, financial and political aspects and the procedures required. In this context, the knowledge can represent a strategic tool, increasing the institutional capacity of the companies to assign the formulation, evaluation and execution of such projects. The knowledge factor could work as an instrument that facilitates improvement, contributing to the quality of services and enhancing the agility to decide. Knowledge should be considered as the most important information factor, as it includes precise context, concrete meaning, respective interpretation and reflection, in addition to personal wisdom. It also considers far ranging implications (Davenport And Prusak, 1998). Thus, is fundamental to assess the influence of knowledge on the technological innovation performance capacity in brazilian multinationals companies, to both researchers and practitioners. From the theoretical excerpts, the following variables and hypotheses of this study were raised.

***Independent Variables:*** The independent variables were extracted from the specialized literature and assessed by experts for confirmation. The following independent variables were identified: Stakeholders' knowledge: C1: R and D (Shelanski and Klein, 1995); C2: Clients (Joshi and Sharma, 2004); C3: Suppliers (Horn, 2005; Smith and Tranfield., 2005); C4: External consultants (Horn, 2005; Smith and Tranfield, 2005); C5: Competitors (Hemphill, 2003; Link et al, 2005); C6: Joint ventures (Hemphill, 2003; Link et al., 2005.); and C7: Universities/other public research centers (Ropper et al., 2004). For the Clients dimension, the construction used is based on Joshi and Silva (2004); Sansão and Terziovski (1999). For the suppliers variable (Horn, 2005; Smith and Tranfield, 2005), the content was derived from the construction used by Dow et al. (1999) and Forza and Filippini (1998). For the R and D variable, the construct was mainly derived from Shelanski and Klein (1995); Gupta et al. (2000) and Chiesa et al. (1996), which capture two important R&D aspects: capabilities and connections. As for the variable External Consultants, the construct is based on Horn (2005); Smith and Ranfield (2005). The variable Competitors is based on Hemphill (2003); Link et al (2005). Finally, the variable Joint Ventures is based on Hemphill (2003) and Link et al (2005).

***Dependent variables:*** The dependent variables were extracted from the specialized literature and assessed by experts for confirmation. The following independent variables were identified: Technological innovation capacity dimensions for the Performance of the brazilian multinationals companies: D1: R and D Capacity (Guan and Ma, 2003; Burgelman et al., 2004; Yam et al., 2004); D2: Innovation Decision Capacity (Barton, 1984); D3: Marketing Capacity (Achilladelis, and Antonajis, 2001; Guan and Ma, 2003; Yam et al., 2004; Kim et al., 2005); D4: Manufacturing Capacity (Guan and Ma, 2003; Yam et al., 2004); D5: Capital Capacity (Yam et al., 2004); D6: Resource Allocation Capacity (Lau, Yan and Tang, 2010); D7: Strategic Planning Capacity (Lau, Yan and Tang, 2010); D8: Learning Capacity (Lau, Yan and Tang, 2010); and D9: Organizational Capacity (Lau, Yan and Tang, 2010). The following hypotheses were formulated using the conceptual model: *Hypotheses:* The knowledge has positive influence on the multinationals companies' technological innovation capacities.

## Research Design

### *Scope of the Study*

The brazilian multinationals companies are very sensitive to technology advancement and demonstrate high innovation growth. These are industries characterized by high intensive capital, highly technical level and complex production process, short life cycle and high R and D investments. These companies require robust and efficient tools to support their decisions.

## Sample and Data Collection

The present paper aims to contribute to the innovation planning guidelines in the high complexity environments. Thus, a modeling proposal is presented to assess the effects of knowledge on the technological innovation performance capacity of brazilian multinationals companies. The researcher selected the well-known firms. The data collection was performed using a scale/ matrix assessment questionnaire. The technique used was the stated preference. In this classification framework, the research interviews and consultations with the experts are highlighted. Before applying the final collection instrument, a pretest was conducted with five experts to clarify whether the instructions were clear and objective; to verify that the questions were objective and without interpretation ambiguity and to investigate possible comprehension problems by the experts on the expected responses. There were few adjustment suggestions. Next, a survey was conducted with 38 experts, selected according to their technical-scientific criteria. The researcher regarded the new product project managers, experienced product planning personnel, innovation managers, organizational managers, R and D managers, knowledge management, technology managers, planning, technological innovation and modeling managers. The data collection instrument was sent to thirty-five experts. Of this total, twenty returned answered. The phases and steps of the model were based on the following methods: Multivariate Analysis; multicriteria: Compromise Programming, Promethee II, Electre III and neurofuzzy tecnology. Next, these procedures were detailed.

## Conceptual Model Verification and Underlying Analyses

This section is structured in three phases:

Phase 1: Modeling the overall influence of knowledge on the technology innovation performance capacity of multi-nationals companies;

Phase 2: Determining the correlation of the knowledge and multinationals companies' technological innovation capacity; and
Phase 3: Modeling of the Optimal Efficiency Rate of Knowledge Influence on the Company's Technology Innovation Performance Capacity (OERP). These different phases are detailed here.

**Phase 1; Modeling the overall influence of knowledge on the technology innovation performance capacity of multinationals companies.**

This section evaluates the dimensions of knowledge on the technological innovation performance capacities of companies. Thus, we first identified the following stakeholders (knowledge sources): cluster (i) research and development – R and D (Shelanski and Klein, 1995); cluster (ii) Customers (Joshi and Silva, 2004); cluster (iii) Suppliers (Horn, 2005; Smith and Tranfield, 2005); cluster (iv) External consultants (Horn, 2005; Smith and Tranfield, 2005); cluster (v) Competitors (Hemphill, 2003; Link et al., 2005.); cluster (vi) Joint ventures (Hemphill, 2003; Link et al., 2005.); and cluster (vii) universities/ other public research centers (Roper et al., 2004). After the knowledge sources survey, the stakeholders' main spectrum of knowledge considered in the personal development planning/ photodynamic therapy (PDP/PDT) were identified. The knowledge identified were: I – Project Scope; II – Concept Development; III – Prototype Development; IV – Integration of Subsystems; V – Prototype Production; VI – Market introduction; VII – Post Product Launch. It should be noted that the activities presented for the case in question are for the technology development process (PDT). The results obtained are as follows: I – Invention; II – Project Scope; III – Concept Development; IV – Concept Development; V – Technology Optimization; VI – Technology Transfer. After identifying the technology development stages, the next step was to identify the knowledge needed to converge each of the stages in the PDT stages. The results showed the following knowledge according to the PDT steps (Clark and Weelwright, 1992): (i) Strategic Planning of the company; (ii) Technology Strategy determination; (iii) technology; (iv) consumer; (v) Generation of ideas; (vi) project scope development; (vii) mapping future plans; (viii) patent survey; (vix) identifying opportunities; (x) identifying potential ideas under certain conditions through preliminary experiments; (xi) identifying necessary resources and solutions for the shortcomings identified; (xii) projection of product platforms; (xiii) creation of QFD for technology (technology needs); (xiv) conducting available benchmarking technology; (xv) development of partner networks; (xvi) defining new technology functionalities; (xvii) identifying technology impact on the Company; (xviii) documents analysis and generation of technology concepts; (xix) selection and development of the superior technology concept; (xx) definition of commercial products and processes and possible processes; (xxi) decomposition of system functions into subfunctions; (xxii) definition of system architecture; (xxiii) definition of system architecture; (xxiv) use of mathe-matical models that express the ideal function of technology; (xxv) prototype development and testing; (xxvi) identification of market impact and manufacture of these possibilities; (xxvii) preparation to implement the business case; (xxviii) identification and evaluation of critical parameters; (xxix) technology optimization from its critical parameters; (xxx) analysis of factors that can result in platforms; (xxxi) development of the platform subsystems; (xxxii) carrying out optimizing experiments; (xxxiii) design of integrated subsystems platform; (xxxiv) system performance tests and (xxxv) defining the technology selection criteria. After this procedure, then evaluates the dimensions of knowledge (clusters) on the technological innovation performance capacities of companies.

This procedure was developed using the multi-criteria analysis. The methods used were Compromise Program-ming, Electre III and Promethee II. The results achieved confirm Hypothesis 1: The knowledge have positive effect on the technological innovation performance capacities of multinationals companies and assigning values to each criterion, we arrive at a matrix of Criteria x Alternatives that together with the vector weights provides the necessary support to apply the multicriteria methods. In other words, one applies the selection and classification methodology of alternatives, using the Compromise Programming, Promethee II and Electre III methods. The Compromise Programming due to its wide diffusion and application simplicity and understanding renders, it is an alternative to evaluate problems as referenced in this application. The problem solution compromise is the one that comes closest to the alternative. This method was designed to identify the closest solution to an ideal one, therefore it is not feasible, using a predetermined pattern of distances. In Promethee II there is a function of preferences for each criterion among the alternatives which must be maximized, indicating the intensity of an alternative to the other one, with the value ranging from 0 to 1. Of the Electre family (I,II,III,IV and V), Electre III is the one considered for the cases of uncertainty and inaccuracy to evaluate the alternatives in the decision problem.

All these methods enable to analyze the discrete solution alternatives and taking into consideration subjective evaluations represented by numerical scores and weights. As these are problems involving subjective aspects, the methods that best fit the situation of this research are the methods of the family Electre and

**Table 1.** Assessment of preferences – Knowledge x Innovation Capacity Performance of multinationals companies

| Knowledge | Classification | | |
|---|---|---|---|
| | Promethee II | Compromise Programming | Electre III |
| R&D (Shelanski and Klein, 1995) | 1ª | 1ª | 1ª |
| Clients (Joshi and Sharma, 2004) | 2ª | 2ª | 3ª |
| Suppliers (Horn, 2005; Smith and Tranfield, 2005); | 3ª | 3ª | 2ª |
| Universities/other public research centers (ROPER et al., 2004)/ C6: Joint ventures (Hemphill, 2003; Link et al, 2005) | 4ª | 4ª | 2ª |
| Competitors (Hemphill, 2003; Link et al, 2005.)/ C4: External consultants (Horn, 2005; Smith and Tranfield, 2005) | 4ª | 4ª | 3ª |

Promethee. It should be mentioned that although the Compromise Programming method is not part of this classification, it has similar characteristics, showing much simplicity in order to understand its operation, which makes it feasible for this application. Within this perspective, the multicriteria methods are viable instruments to measure the performance of the innovation capacity dimensions for the performance of high-tech companies. The results produced by this prioritization enable managers to better focus their efforts and resources on managing the capacities that perform best, which results in achieving the goals sought by the companies The structure of this prioritization (classification by hierarchical analysis) is proposed at three planning levels in a judgment matrix, in which at the first hierarchical structure level it defines the goal, which is to achieve the overall performance of the companies that will feed the system; the criteria are in the second level, which are the knowledge. The dimensions of Technology innovation capacities are in the third level. The prioritization process obeys the judgment of the evaluators (experts). With the results of the judgment matrix, the methods were applied: Promethee II, Electre III and Compromise Programming to evaluate the knowledge on the innovation performance capacities. Table 1 shows the results produced.

The results produced by the methods demonstrate the knowledge of R and D as the most significant ones to ensure the innovation performance capacity of multinational companies. When comparing the results in terms of performance, the Compromise Programming and Promethee II methods did not differ in their classifications. For Electre III, the results were incompatible. And this is because the p, q and v veto thresholds, respectively, of indifference, strong preference and veto or incomparability have a discrepancy in the structure of their results (classification). Electre III presents a set of solutions with a more flexible hierarchical structure. This is due to the conception of the method, as well as the quite explicit consideration of the indifference and incomparability aspect between the alternatives. The results referenced by the Promethee II and Compromise Program-ming methods reflect the preference, according to the experts, for R and D in the technological innovation capacities. The essence of the technological innovation process is the accumulation of knowledge over time. The increase of the knowledge volume is produced by different mechanisms associated with different learning modes, such as: learning derived from R and D or Learning before doing (Pisano, 1997). Traditionally the greatest importance goes to R and D than to the other learning modes (Nieto, 2004). Based on the specialized literature R and D has a strong impact on a com-pany's performance. R and D is a core component of the technological innovation activities of firms. In fact, many studies on innovation use R and D as technology innovation indicators. R and D is considered a key aspect of innovative activities. Next, the degree of correlation between the dimensions of knowledge and innovation capacities was determined. For this Spearman's multivariate statistical technique was used. The technique adapts to the case in question.

## Phase 2: Determining the correlation of the knowledge and multinationals companies' technological innovation capacity

In this section the correlations between knowledge and technological innovation capacities of the companies are determined. Spearman's correlation is often used to describe the relationship between two ordinal characteristics. The data were extracted by the experts from a judgment matrix. Table 2 shows the results.

Grouping the knowledge and capacity dimensions, there is a strong correlation between the knowledge of R and D / Universities/other Public Research Centers and Strategic Planning Capacity and R and D Capacity / Innovation Decision Capacity / Learning Capacity. R and

**Table 2:** Correlation of the knowledge and technological innovation capacity dimensions of the multinationals companies

| Variables: Knowledge dimensions | Knowledge On The Technological Innovation Capacity Performance Of The Multinationals Companies | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| R and D / Universities/other public research centers | 1 | | | | | | | | |
| Suppliers / Clients | 0,81 | 1,00 | | | | | | | |
| Joint ventures / Competitors / External consultants | 0,72 | 0,92 | 1,00 | | | | | | |
| R&D Capacity / Innovation Decision Capacity / Learning Capacity | 0,85 | 0,50 | 0,52 | 1,00 | | | | | |
| Strategic Planning Capacity | 0,74 | 0,55 | 0,46 | 0,59 | 1,00 | | | | |
| Resource Allocation Capacity / Organizational Capacity | 0,25 | 0,27 | 0,14 | 0,15 | 0,70 | 1,00 | | | |
| Manufacturing Capacity | 0,13 | (0,02) | (0,06) | 0,32 | (0,17) | (0,24) | 1,00 | | |
| Capital Capacity | 0,47 | 0,30 | 0,33 | 0,50 | 0,53 | 0,08 | 0,40 | 1,00 | |
| Marketing Capacity | 0,45 | 0,35 | 0,06 | 0,16 | 0,62 | 0,35 | (0,10) | 0,32 | 1,00 |

D efficiency reflects the product development process dynamics, reduces time-to-market, improves product profitability, increases productivity, as well as other benefits. Studies on R and D efficiency have many applications as a management tool. R and D is strong performance measure, similar to return on investment (ROI). It can also be used as a means of comparison (benchmark). R and D efficiency is also an aggregate measure of the overall success of a company's product in the development effort. R and D brings the percentage of researchers employed; success rate of R and D products; patent number and R and D intensity; the decision for innovation capacity informs the degree of innovative R and D ideas; the collaboration intensity with other companies or R and D centers; R and D sharing capacity; forecast and evaluation of innovative technology initiatives for business innovation. Technological innovation is multi-dimensional in nature and no single model is sufficient to explain the performance of technological innovation and innovative behavior of multinationals companies, especially when it comes to evaluating the organization's technological innovation activities. However, learning is often used to describe the innovation process. It is true that companies innovate through constant learning processes that generate new technological knowledge (Nonaka and Takeuchi, 1995). Here the main features of the technological innovation process are (Teece, 1986) continuous in nature; irreversible and affected by uncertainty. The essence of the technological innovation process is the accumulation of knowledge over time. The increase of the knowledge volume is produced through different creative mechanisms associated with different learning modes, such as: learning from R and D or "Learn before doing" (Pisano, 1997); "Learning by doing", which arises spontaneously in the production process (Arrow, 1962); "Learning by using" (Rosenberg, 1982); and "Learning by failing", from the analysis of bad decisions by top managers (Maidique and Zirger, 1985). Such learning modes, particularly the last three, have a clearly progressive nature in that it generates a continuous flow of technological innovations or new knowledge. Traditionally, more importance has been given to R and D than to other learning modes. And technological innovation in companies is a learning process through a stream of new knowledge. And the capacities are generated for the companies to mobilize and expand their technology, human and financial resources in the innovation process. Resources are always a critical factor for all kinds of activities and processes. Evangelista et al. (1997) propose that technology resources will increase its importance as a strategic factor for the company's performance in the near future. Some studies have also found that resource allocation capacity enables to sustain competitiveness (Yam et.al., 2004; Guan and Ma, 2003). Then, an overall performance evaluation of technological innovation capacity was developed for the dimensions considered in the performance of multinationals companies.

**Phase 3: Modeling of the optimal efficiency rate of knowledge influence on the company's technology innovation performance capacity (OERK)**

This phase focuses on determining the optimal efficiency rate (OERK) of knowledge influence on the multinationals companies' technology innovation performance capacity using neurofuzzy modeling. It is a process whose attributes usually possess high subjectivity characteristics, in which the experience of the decision maker is very significant. Thus within this spectrum there is the need for a tool that allows adding quantitative and qualitative variables that converge towards a single evaluation parameter (Cury and Oliveira; 1999; von Altrock, 1997). This model combines the Neural Networks and Logic Fuzzy technology. Here this model supports the planning of technological innovation capacities of high-tech companies, as it allows evaluating the desirable rate toward the acceptable performance of high-tech companies. The model shown here uses the model of Cury and Oliveira (1999). Based on the neurofuzzy technology, the qualitative input data are grouped to determine the comparison parameters between the alternatives. The technique is structured by combining all attributes (qualitative and quantitative variables) in inference blocks (IB) that use fuzzy-based rules and linguistic expressions, so that the preference for each alternative priority decision of the optimal rate of technological innovation performance determinants, in terms of benefits to the company, can be expressed by a range varying from 0 to 10. The model consists of qualitative and quantitative variables, based on information from the experts. The neurofuzzy model is described below.

***Determination of Input Variables (IV):*** This section focuses on determining the qualitative and quantitative input variables (IV). These variables were extracted (15 variables/ranking) from the independent variables (knowledge of multinationals companies). The linguistic terms assigned to each IV are: High, Medium and Low. Accordingly, Phase 1 shows the IVs in the model, which are transformed into linguistic variables with their respective Degrees of Conviction or Certainty (DoC), with the assistance of twenty judges opining in the process. The degrees attributed by the judges are converted into linguistic expressions with their respective documents, based on *fuzzy* sets and IT rules (aggregation rules), next (composition rules).

***Determination of Intermediate Variables and Linguistic Terms:*** The qualitative input variables go through the inference fuzzy process, resulting in linguistic terms of intermediate variables (IVar). Thus, the linguistic terms assigned to IVar are: Low, Medium and High.

The intermediate variables were obtained from: K1: R and D performance; K2: Clients / Suppliers / Competitors Performance; K3: External consultants Performance; K4: Joint ventures Performance; and K5: universities/other public research centers Performance. The architect-ture proposed is composed of eight expert fuzzy system configurations, four qualitative input variables that go through the *fuzzy* process and through the inference block, thus producing an output variable (OV), called intermediate variable (IVar). Then, the IVars, which join the other IVar variables form a set of new IVars, thereby configuring a sequence until the last layer in the network. In the last layer of the network the output variable (OV) of the *neurofuzzy* Network is defined. This OV is then subjected to a defuzzification process to achieve the final result: optimal efficiency rate of knowledge influence on the technological innovation capacity performance of multinationals companies. In summary, the fuzzy inference occurs from the base-rules, generating the linguistic vector of the OV, obtained through the aggregation and composition steps. For example, when the experts' opinion was requested on the optimal efficiency rate for the knowledge on the tech-nological innovation capacity performance of the company A, the response was 8.0. Then the fuzzification (simulation) process was carried out, assigning LOW, MEDIUM and HIGH linguistic terms to the assessment degrees at a 1 to 10 scale. Degree 8, considered LOW by 0% of the experts, MEDIUM by 55% and HIGH by 45% of the experts. In summary, the expert's response enabled to determine the degree of certainty of the linguistic terms of each of the input variables using the fuzzy sets. The generic fuzzy sets were defined for all qualitative IVars, which always exhibit three levels of linguistic terms: a lower, a medium and a higher one. After converting all IVars into its corresponding linguistic variables with their respective DoC, the *fuzzy* inference blocks (IB), composed of IF-THEN rules, are operated based on the MAX-MIN operators, obtaining a linguistic value for each intermediate variable and output variable of the model, with the linguistic terms previously defined by the judges. With the input variables (features extracted from product development projects), the rules are generated. Every rule has an individual weighting factor, called Certainty Factor (CF), between 0 and 1, which indicates the degree of importance of each rule in the *fuzzy* rule-base. And the *fuzzy* inference occurs from the rule-base, generating the linguistic vector of OV, obtained through the aggregation and composition steps.

***Determination of Output Variable – Optimal Efficiency Rate of Knowledge Influence on the Technological Innovation Performance Capacity***

The output variable (OV) of the neurofuzzy model proposed was called Optimal Efficiency Rate of Knowledge on the Technological Innovation Performance Capacity in multinationals companies.

The fuzzification process determines the pertinence functions for each input variable. If the input data values are accurate, results from measurements or observations, it is necessary to structure the fuzzy sets for the input variables, which is the fuzzification process. If the input variables are obtained in linguistic values, the fuzzification process is not necessary. A fuzzy set A in a universe X, is a set of ordered pairs represented by Equation 1.

$$A=\{(\mu_A(x),x)|x \in X\} \quad 1)$$

Where *(x)* is the pertinence function (or degree of pertinence) of x in *A* and is defined as the mapping of *X* in the closed interval [0.1], according to Equation 2 (PEDRYCZ and GOMIDE, 1998).

$$\mu_A(x):X\rightarrow [0.1] \quad (2)$$

***Fuzzy Inference:*** The fuzzy inference rule-base consists of IF-THEN rules, which are responsible for aggregating the input variables and generating the output variables in linguistic terms, with their respective pertinence functions. According to Von Altrock (1997), a weighting factor is assigned to each rule that reflects their importance in the rule-base. This coefficient is called Certainty Factor (CF) and can vary in range [0,1] and is multiplied by the result of the aggregation (IT part of inference). The fuzzy inference is structured by two components: (i) aggregation, that is , computing the IF rules part and (ii) composition, the THEN part of the rules. The Degree of Certainty (DoC) that determines the vectors resulting from the linguistic processes of aggregation and composition are defined with Equation 3.

$$DoC;:max[FC_1 \ . \ min\{GdC_{A11},GdC_{A12},...,GdC_{1n}\},...,FCn \ . \ min\{GdC_{An1},GdC_{An2},...,GdC_{Amn}\}| \quad (3)$$

*Defuzzification:* For the applications involving qualitative variables, as is the case in question, a numerical value is required as a result of the system, called defuzzification. Thus, after the fuzzy inference, fuzzification is necessary, that is, transform linguistic values into numerical values, from their pertinence functions (Von Altrock, 1997). The IT Maximum Center method was popularized to determine an accurate value for the linguistic vector of OV. Based on this method, the degree of certainty of linguistic terms is defined as “weights” associated with each of these values. The exact value of commitment (VC) is determined by considering the weights with respect to the typical values (maximum values of the pertinence functions), according to Equation 4 presented below (Von Altrock, 1997; Cury and Oliveira, 1999).

$$OV = \frac{\sum_{i=1}^{n} DoC_i \, . \, X_i}{\sum_{i=1}^{n} DoC_i \, . \, X_i} \quad (4)$$

Where i DoC represents the degrees of certainty of the linguistic terms of the final output variable and i X indicates the end of the typical values for the linguistic terms, which correspond to the maxima of fuzzy sets that define the final output variable. By way of demonstration, using assigned IT (average) hypothetical (Company A) enters-IT into the calculation expression of Rate TPKTj with GdCi of the following linguistic vector of the output variable, also hypothetical: LOW=0.30, MIDDLE=0.49, HIGH=0.14. The numerical value of optimal efficiency rate (OERK) of knowledge influence on the multinationals companies’ technology innovation performance capacity at a 0 to 1 scale corresponds to 0.7352, resulting from the arithmetic mean of the values resulting from the defuzzification of each of the simulated twenty judges. This value corresponds to an average value for OERK. With this result (optimal efficiency rate: 0.7352) produced for a better combination and interaction of knowledge strategic that converged toward a single parameter, it is feasible to assert that this combination of knowledge of the firm at this time, can at least ensure the performance desired by the firm at that time. It is plausible that the company maintains at least this value (0.7352), which ensures the desired performance. It is also plausible to state that, to some degree, there is efficiency in the management of those planning innovation in this category of companies. To illustrate this, assuming that the study-object companies demonstrate the following optimal efficiency rates. The expected reference performance for companies is hypothetical (Figure 2). It is concluded that, Companies A and E show efficiency in the combination of their knowledge strategies, based on the performance expectations (C1: R and D (Shelanski and Klein, 1995); C2: Clients (Joshi and Sharma, 2004); C3: Suppliers (Horn, 2005; Smith and Tranfield, 2005); C4: External consultants (Horn, 2005; Smith and Tranfield, 2005); C5: Competitors (Hemphill, 2003; Link et al., 2005.); C6: Joint ventures (Hemphill, 2003; Link et al., 2005.) and C7: universities/other public research centers (ROPER et al., 2004). The priorities of knowledge are dynamic and dependent on constraints and uncertainties that come from the environment at any given time. Companies B, C and D are not efficient in combining their strategies of knowledge, since they do not meet the desired performance expectations. The environmental contingencies are crucial and essential to adapt the strategies. The modeling approach presented here enables this sophistication refinement for every contingency presented.

## Implications for management practice

The last few decades have seen a growing number of

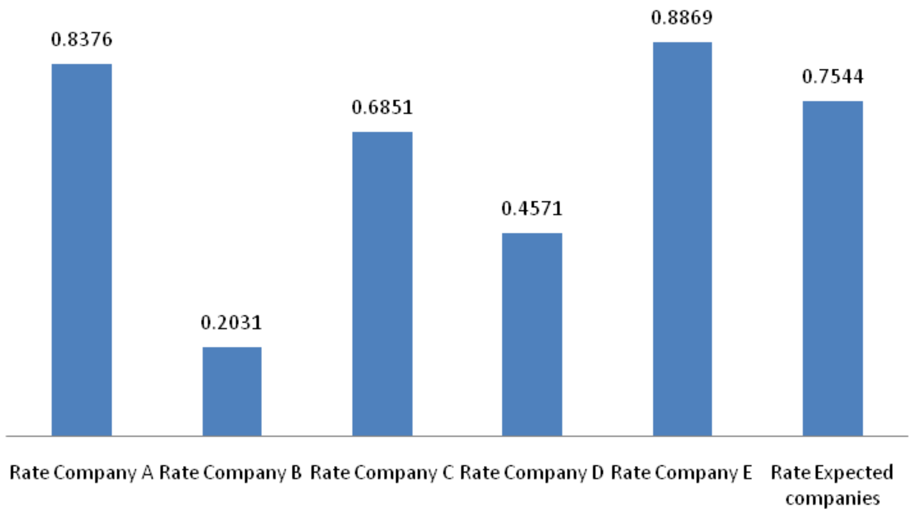


**Figure 2.** Optimal efficiency rate of knowledge influence on the technological innovation performance capacity

studies on knowledge and innovation. Knowledge and innovation are essential to the competitiveness of firms. With the development of the knowledge-based economy, research has shifted its focus from technological change to innovation, that is, to the creation and diffusion of new knowledge through novel products and processes. Knowledge is one of the most important strategic resources (Tappeiner et al., 2008), but in a competitive environment, knowledge developed by one firm may be appropriated by other firms at hardly any cost, or at least at a much lower cost than would be required to develop that knowledge from scratch (Montoro-Sa´nchez, Ortiz-de-Urbina-Criado and Mora-Valentı´n, 2011). An assessment of the influence of knowledge for innovation capacity performance is relevant, because it informs both firms in their strategic decisions. In firms, varieties of specialized knowledge are distributed among individuals, teams and units. In fulfilling its purpose of producing goods and services, a firm has to bring together specialized knowledge from different sources (Kumar and Ganesh, 2009). In this study, knowledge management is a widely accepted factor of success for multinational companies brasilian […] (Wilkesmann, Fischer and Wilkesmann, 2009). As such, investments in knowledge management continue to increase dramatically from year to year (Mills and Smith, 2010). Knowledge management supports the process of decision of firms. Specifically, the capacity for innovation.

## CONCLUSIONS AND LIMITATIONS

The present paper aims to contribute to the knowledge and innovation planning guidelines in the high complexity environments. Thus, a modeling proposal is presented to assess the influence of knowledge on the technological innovation performance capacity of brazilian multi-nationals companies. The study strived to fill a gap in the existing literature of the influence of knowledge on the technological innovation capacity in brasilian multi-nationals companies. Technology innovation capability is a complex, elusive and uncertainty concept that is difficult to determine. Technological innovation capabilities engender multi-dimensional difficulties that involve numerous organizational functions and resource integration among various departments (Wang, Lu, and Chen, 2008).

There are of course several issues to be further explored in other such studies and is hoped that it contributed to a plausible methodological discussion, with much still to be explored. Innovation admittedly poses significant challenges to both research and practice, requiring the need for active learning in high-tech companies. This learning capacity involves not only the development of new capabilities within a company, but also crosses borders. Interactions with other companies, other knowledge sources and experts are becoming an important and emerging focal point for technological innovation.

The presence of R and D creates an organizational setting that is favorable to questioning, promoting corporate/company flexibility, with an ability to integrate new concepts and adaptability to market changes (Freel, 2000). In addition, the knowledge and past experience gained with R and D, as well as their lasting and not sporadic existence, renders it instrumental to innovation (Brouwer and Kleinknecht, 1996). R and D and innovation are susceptible to sectorial influences [...] (Becheikh et.al., 2006). Product innovation is considered stronger in multinationals companies. Moreover, the central element is the internal role of R and D to maximize the benefits of innovation from other forms of knowledge (Love and Roper, 1999, 2001). It should be noted that companies with a strong customer focus are able to anticipate the needs of current and latent customers (Paladino, 2007). Bastic and Leskovar-Spacapan (2006) state that customer-focused companies focus on Product innovation versus process innovation and continuously collect information on the needs of competitors and target customers and check their ability to use this information to create superior customer value. A company's strong customer-focus can lead to an emphasis on innovation that is derived from the desire to continually adapt to customer needs (Santos-Vijande and Alvarez-Gonzalez, 2007). Rowley (2002) calls attention to the fact that client knowledge enables the companies' regrouping and creation of incremental value. And within this perspective, Garcia-Murillo and Annabi (2002) show that companies should take every opportunity to interact with customers in order to enrich their customer knowledge base. Consequently, a company can gain a thorough understanding of its customers, thus better able to meet their demands.

Thus, of the different dimensions, the results show a predominance of R and D efforts. However such innovation capabilities have to keep up with up-to-date changes and should be viewed as a priority of the present moment, with regards to systemic efforts guided by defining and redefining the performance of high-tech companies over time. It is plausible that building capacities occur over a continuous process and converge to the desired performance, which is in constant transformation through the new demands. Therefore, the innovation policy for companies in this category should be anchored by efficient planning. Hopefully the R and D capacities can open way, hence allowing multinationals companies to expand their existing technologies and to establish new technologies or improve the R and D functions. It is also evident that the knowledge and technological innovation capacities are a dynamic list of priorities, depending on the essential and desired existing capacities that emerge over practice time, always bringing new concepts and demanding new behaviors, new content and technical implementations, thus fundamentally requiring to permanently reconfigure the new capacities for the new innovation performances. Innovation admittedly poses significant challenges to both research and practice, requiring the need for active learning in high-tech companies. This learning capacity involves not only the development of new capabilities within a company, but also crosses borders. Interactions with other companies, other knowledge sources and experts are becoming an important and emerging focal point for technological innovation.

In this perspective, the modeling approach presented gains emphasis, such diversity of methods when combined are valuable tools with great potential and significant added value, contributing to the robustness of the modeling. This proposal is an additional tool available to managers, which helps to greatly reduce the uncertainty of technological innovation decisions. There are of course several issues to be further explored in other such studies and is hoped that it contributed to a plausible methodological discussion, with much still to be explored.

In this study, the innovation decision capacities refer to the capacity to enforce innovative technology decisions in the companies. These capacities include the degree of R and D innovation, the collaboration intensity with other companies or R and D centers (Lefebvre et al., 1998; Achilladelis and Antonajis, 2001), the R and D capacity to share knowledge (Guan and Ma, 2003), forecasting and evaluating technological innovation (Yam et al, 2004; Burgelman et al., 2004), and business innovation initiatives (Guan and Ma, 2003). These capacities are evaluated subjectively. Marketing resources indicate a solid capacity to promote and sell products based on demand, which is primarily influenced by the market (Manu and Sriram, 1996), degree of competitiveness of new products, monitoring of market forces (Guan and Ma, 2003), marketing specialized unit (Achilladelis and Antonajis, 2001) and the percentage of exports (Sterlacchini, 1999; Guan and Ma, 2003). All these variables are subjective in nature. Secondly, the efforts are for production capacity, in which companies must transform R and D into results of product and technical improvement and product quality. Manufacturing capacities, such as advanced manufacturing technology (Guan and Ma, 2003), the level of product quality, success rate of commercialization (Yam et al., 2004), quality level of production personnel (Yam et al., 2004) and product cycle time (Guan and Ma, 2003) are evaluated subjectively. Finally, capital capabilities that are necessary to ensure that the advance of the companies' technological capacities are mainly from fundraising capabilities, optimal allocation of capital inflow (Burgelman et al., 2004), capital intensity (Sterlacchini, 1999; Guan and Ma, 2003) and return on investment (Manu and Sriram, 1996). It is also evident that the technological innovation capacities are a dynamic list of priorities, depending on the essential and desired existing capacities that emerge over practice time, always bringing new concepts and demanding new behaviors, new content and technical implementations, thus fundamentally requiring to permanently reconfigure the new capacities for the new innovation performances. In addition, the knowledge may represent a strategic tool, increasing the institutional capacity of the companies in their assignments of formulation, evaluation and execution of such projects (Fletcher, Yiannis and Polychronakis, 2007). In this context, the knowledge is a facilitator instrument of improvement, contributing to decide. Regarding this effort, the research on such priorities should be applied permanently and periodically.

relationships between variables. Furthermore, a survey
In the research, cross-sectional data used in this study

may not be appropriate to establish fundamental was developed for brazilian companies in a static context, which may represent a limiting factor. Therefore, it is recommended to reproduce and replicate the model in companies from other countries in order to confirm the results. It is also recommended that the innovation capacity dimensions should be extracted from the state of the art, but strongly confirmed by the state of practice, by the judgment of other experts (from other countries), taking into account that values, beliefs, cultures and experiences are determinants in the assessment, which can overturn the effects on the results. It is also underscored that the methodologies and technical basis of this modeling should undergo evaluation by a multidisciplinary team of specialists permanently and periodically, hence proposing possible additions or adjustments to these methodologies. And also replace some of the technical implementations used herein by others, in order to provide a similar role to verify the robustness of the model. It is clear that innovation and knowledge are vital to organizational success. We hope the current paper provides an impetus for future research in this area.

## Conflict of Interests

The author have not declared any conflict of interests.

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