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The next frontier: Open innovation and prospecting of knowledge in highly complex environments – Towards value creation in high tech Industries

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This article aims to contribute to a policy of innovation management. To do so, it presents the influence practices of open innovation in the prospecting of knowledge for value creation in highly complex environments. The research was conducted in the light of theoretical excerpts and application of a survey to specialists, with knowledge about the investigated object, selected by scientific and technical criteria. The survey was addressed to high tech industries in Brazil. The data were extracted by means of a matrix of judgment in which experts made their judgments about the variables investigated. In order to reduce subjectivity in the results achieved, the following methods were used: multicriterial analysis, artificial neural networks and neurofuzzy technology. The produced results were satisfactory, validating the presented proposal.

Key words: Open innovation practices; prospecting of knowledge; high tech industries.

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; Teece et al.,1997), innovation and international competition (Chesbrough and Rosenbloom, 2002; Christensen, 2003; Damanpour, 1996). This helps to reconsider how to succeed with innovation (Teece, 1986; Teece, Pisano, and Shuen, 1997), 1997; Wheelwright and Clark, 1992). Innovation events, such as the introduction of a new product or process, represents the end of a series of knowledge and the beginning of a value creation process that can result in improvement in business performance marked by the ability to counteract the vulnerability of the globalization of business. However, the ability to design and provide innovative products with great incremental value to customers in a specific issue requires technical expertise of different knowledge derived from internal and external sources of knowledge (Chesbrough, 2003). But it is also true that organizations need to properly use the knowledge derived from different sources and check the business status of their activities and therefore, innovations should be used as increments of the process of interaction of knowledge. Different innovations depend on different types and sources of knowledge. This way, it is believed that assessing the relative importance of the

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different sources of knowledge for the performance of innovation is relevant because it informs the companies in their strategic decisions about the development of different channels for knowledge acquisition (Frenz and Ietto--Gillies, 2009).

The sources of knowledge (P and D, Universities and research Centers among others) have multifaceted nature (Kline and Rosenberg, 1986; Von Hippel, 1988) and show different impacts on a company's business, since the innovation performance is strongly dependent on and boosted by knowledge and its respective sources (Frenz and Ietto--Gillies, 2009). With the widespread diffusion of knowledge, all the knowledge necessary for creating innovations is no longer present within the firm's boundaries. They need to acquire knowledge from other sources. In fact, knowledge expands the potential for creating business value (Roper et al., 2008). However, the capacity of prospecting of knowledge is a complex challenge. Several studies have referenced the importance of the collaboration from knowledge and innovation generation (Chesbrough, 2003). This takes to evaluate the influence of innovation practices, in particular open innovation in the prospecting of knowledge. Open innovation is a new way of thinking of innovation for firms, where firms explicitly cooperate with others to create new innovations (Chesbrough, 2003). Open innovation is a model that assumes that firms can and should use external as well as internal ideas and internal and external paths to market, as they look to advance their technology (Chesbrough, 2006). Open innovation can be thought of as systematically exploring a wide range of internal and external sources for innovation opportunities, consciously integrating that exploration with the firm's capabilities and resources, and broadly exploiting those opportunities through multiple channels (West and Gallagher, 2006;Grotnes, 2009). Thus, this article aims to contribute to a policy of innovation management. To do so, it presents the influence of practices of open innovation in the prospecting of knowledge for value creation in highly complex environments. The article is divided according to the following sections: Methodology, verifycation of the conceptual model and subjacent analyzes, conclusions and implications.

DESIGNER OF RESEARCH

Conceptual model framework: Constructs and hypotheses

This section examines the conceptual model (Figure 1) and presents the hypotheses to be tested throughout this work. The open innovation paradigm (Chesbrough, 2003) can be characterized by its porous innovation process, and the strong interaction of the company with its environment. By integrating a large number of individuals into the innovation process, new creativity and know-how is brought into the organization (inbound open innovation). Von Hippel (1988) suggested using lead users and other stakeholders as external sources of innovation (Schroll and Mild, 2011). Not only can this attract more talent, it can also transfer idle innovative ideas and R&D technology externally to other companies. Enterprises use the concept of open innovation, in which internal innovative ideas can flow outward and external ideas and technologies can flow inward within an enterprise. Chesbrough (2003a) proposed the concept of open innovation which indicated that businesses should become more open to innovation processes and value creation. Value is generated by nurturing informal relations and encouraging a free, horizontal flow of knowledge across organizational boundaries by opening new channels of communication and sustaining propagation of new ideas (Grimaldi and Cricelli, 2012). In this perspective the knowledge has forced firms to ground their value creation. The open innovation approach explores knowledge acquired from external sources (competitors, universities and partners) (Grimaldi and Cricelli, 2012). Business exposure to internal and external knowledge promotes the generating value (St-Jean and Audet, 2012; Fosfuri and Tribo, 2008; Norman, 2004). In contexts where knowledge is a crucial asset, companies increase their dependency on external sources to improve firm performance (Morgan and Berthon, 2008). In this perspective, knowledge emerges as one of the most important strategic resources for the companies. To raise the capacity of value and innovation creation, the organizations must be able to create this value. Thus, from the theoretical excerpts, the following variables and hypotheses of this study were raised.

Independent Variables: From the findings in the literature (Lopes and Teixeira, 2009; Moreira et. al.2008) the following open innovation practices were identified (Trentini et.al., 2012):

Value Chain: The value chain of innovation is one of the most popular practices, because it increases significantly the incremental value of business. Chesbrough (2006) shows that open innovation assumes that useful knowledge is widely distributed and that even more capable of organizations of R&D should identify, connect and boost external sources of knowledge as an elementary process for innovation.

Product development through patent licensing: It is a very common practice. The occurrence of technology licensing has been mainly concentrated in the chemical industry - pharmaceutical, electrical and electronic equipment, computers and industrial machinery.

Partnerships for co-development: It is a practice that has become business models that enables increasing innovation reducing P&D costs and facilitates the expansion and dissemination of innovation.

Relationship between companies and scientific and technological system**:** It is a practice that enables the research developed at universities and research centers supports the industrial requirements, allowing the specialization of each entity with return for both parties. Moreira et al. (2008) report some of the challenges to be overcome, such as: relationship difficulties, lack of communication, divergent goals and visions, deadline mismatches, the distribution model of knowledge in universities that hinders the identification of researchers and research made, and the steps of assessment and valuation of technologies.

Spin-offs **are companies created to develop opportunities generated by the parent company*:*** They aim to explore new business conditions in order to minimize negative impacts on the parent company. In this kind of practice, projects that do not have any internal interest may generate new business.

Mergers and acquisitions: Mergers and acquisitions are aimed at absorbing knowledge and external technology, allowing a faster establishment in new markets and impeding the entry of new

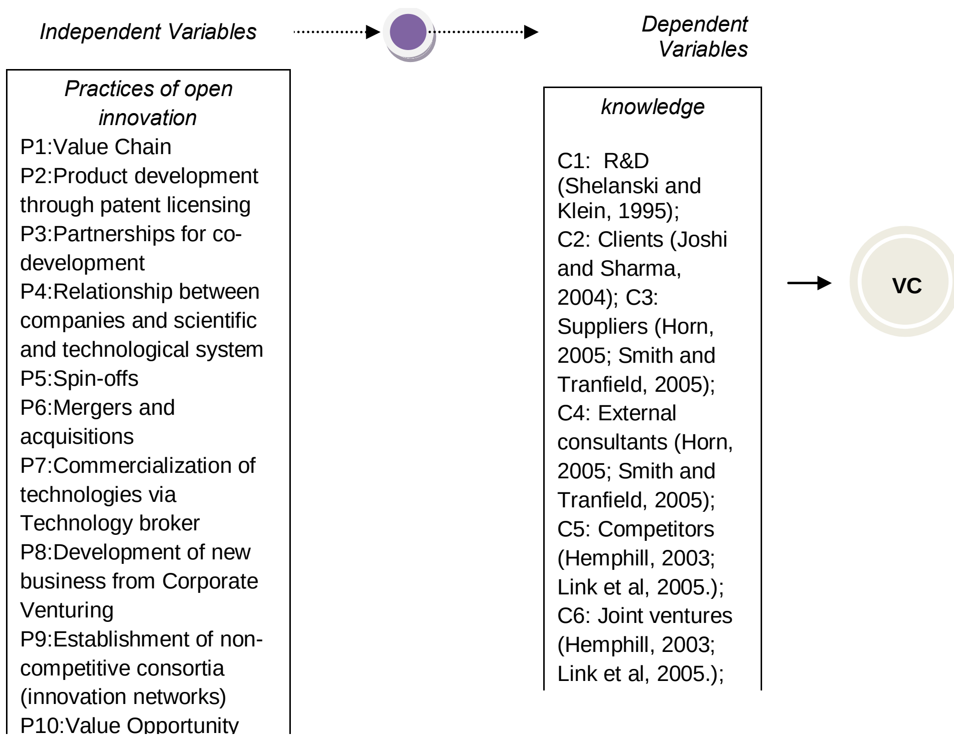

Figure 1. Conceptual model

competitors, as well as reducing costs and increasing the possibility of releases.

***Commercialization of technologies via Technology broker*:** It is a practice of open innovation in which a professional assists in finding, rating, marketing and managing the transfer of certain technology / knowledge through a network of contacts.

***Development of new business from Corporate Venturing*:** It is a form of investment in which companies invest capital in new-born businesses with innovations that may or may not be related to the business and have a high level of risk, but with great potential for growth.

Establishment of non-competitive consortia (innovation networks): It is a collaborative practice in which P&D companies associate with universities, research centers or competing companies with the goal of generating knowledge and products that would hardly be possible in an individual way.

V*alue opportunity web – VOW*: Is a practice of capturing and analyzing potentially valuable data on the external environment and transforming that information into winning products for consumers. The goal of a VOW is to analyze the data obtained taking into account new needs, new ways of doing things, new product features and new models the company may deliver value to the customer.

Dependent 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&D (Shelanski and Klein, 1995); C2: Customers (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 Customer 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&D variable, the construct was mainly derived from Shelanski and Klein (1995); GUPTA, Wilemon, and Atuahene-Gima (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 venture is based on Hemphill (2003) and Link et al (2005). From the conceptual model, the following hypotheses were made: Hipothesis - *H1*: The practices of open innovation influence to a greater or lesser degree the prospecting of knowledge for value creation in highly complex environments. *H2*: The optimal rate of value creation depends on the combination and interaction of the influence of the practices of open innovation in the prospecting of knowledge in highly complex environments.

RESEARCH DESIGN

Scope of the study

The Brazilian high-tech 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&D investments. These companies require robust and efficient tools to support their decisions.

Sample and data collection

This research treated Brazil's high-tech industries as the empirical targets. The researcher selected the more well-known firms. The data collection was performed using a scale/matrix assessment questionnaire. The technique used was the stated preference, taking into account that these methods work with the preferences of the decision makers, revealed by the choice made among the alternatives selected from a set of real alternatives, or not. In this classification framework, the research interviews and consultations with the experts are highlighted. With this procedure, the information collected can be set apart in different parts by adjusting the phases and steps of the model. A survey was conducted with 20 experts, selected according to their technical-scientific criteria. The researcher regarded the new product project managers, knowledge managers, experienced product planning personnel, innovation managers, organizational managers, R&D managers, technology managers, planning, technological innovation and modeling managers. The targeted respondents of the survey were senior product development managers, vice presidents and directors. They were requested to fill out the questionnaire, follow-up phone interviews. The questionnaire respondents should have complete understanding towards the innovation product development. Cury (1999) recommends a sample of twenty to thirty experts. Next, these procedures were detailed, which contributed significantly to the analysis of the results achieved in each phase and step of the modeling.

Conceptual model verification and underlying analyses

To solve the research problem and achieve the desired goal, the practices of open innovation of the high tech industries were identified and then evaluated according to their influence on the prospecting of knowledge according to the respective sources of knowledge. Finally, the optimal rate of value is modeled from the interaction between all dependent variables.

Phase 1: Modeling influence of the open innovation practices in the prospecting of knowledge of the actors (sources)

This phase is systematized in the following steps:

Step 1*) Identification practices of open innovation:* Thus, the following practices of open innovation from the specialized literature were identified and confirmed by experts: Value Chain; product development through patent licensing; partnerships for co-development; relationship between companies and scientific and technological system; Spin-offs; mergers and acquisitions; commercialization of technologies via technology broker; development of new business from corporate venturing; establishment of non-competitive consortia (innovation networks); and VOW.

Step 2) *Identification of the sources of knowledge and their respective knowledge:* The identification is systematized in the following: C1: R&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).

Step 3) *Evaluation influence practices of open innovation in the prospecting of knowledge in high tech industries:* This procedure was developed using the multi-criteria analysis electre III, promethee II e compromise programming and artificial neural network (ANN). Next, these procedures were detailed. The methods used were compromise programming, electre III and promethee II. The results achieved confirm Hypothesis 1:

The practices of open innovation influence to a greater or lesser degree the prospecting knowledge of the actors, 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 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

Table 1. Assessment of preferences – Influence of practices of open innovation in the prospecting of knowledge for value creation in highly complex environments

Practices of open innovation	Classification		
	Promethee II	Compromise Programming	Electre III
Value Chain / Partnerships for co-development	1[a]	1[a]	1[a]
Product development through patent licensing	2[a]	2[a]	3[a]
Relationship between companies and scientific and technological system	3[a]	3[a]	2[a]
Value Opportunity Web – VOW / Spin-offs Commercialization of technologies via Technology broker	4[a]	4[a]	2[a]
Development of new business from Corporate Venturing	3[a]	4[a]	3[a]
Mergers and acquisitions / Establishment of non-competitive consortia (innovation networks)	3[a]	4[a]	4[a]

situation of this research are the methods of the family electre and 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 pers-pective, the multicriteria methods are viable instruments to measure the performance practices of open innovation in the prospecting knowledge for value creation in the high tech enterprises. The results produced by this prioritization enable managers to better focus their efforts and resources on managing the practices of open inno-vation 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 value creation of the companies that will feed the system; the criteria are in the second level, which are the knowledge (prospecting) of actors: K1: R&D (Shelanski and Klein, 1995); K2: Clients (Joshi and Sharma, 2004); K3: Suppliers (Horn, 2005; Smith and Tranfield, 2005); K4: External consultants (Horn, 2005; Smith and Tranfield, 2005); K5: Competitors (Hemphill, 2003; Link et al, 2005.); K6: Joint ventures (Hemphill, 2003; Link et al, 2005.); and K7: universities/other public research centers (Roper et al., 2004). The practices of open innovation of the companies are in the third level, the alternatives, which are: P1: Value Chain; P2 Product development through patent licensing; P3: Partnerships for co-development; P4: Relationship between companies and scientific and technological system; P5: Spin-offs; P6: Mergers and acquisitions; P7: Commercialization of technologies via Technology broker; P8: Development of new business from Corporate Venturing; P9: Establish-ment of non-competitive consortia (innovation networks); and P10: Value Oppor-tunity Web – VOW. The prioriti-zation 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 innovation capacities in relation to the performance of the com-panies. Table 1 shows the results produced.

Table 1: Assessment of preferences – Influence of practices of open innovation in the prospecting of know-ledge for value creation in highly complex environments

Open innovation networks introduce highly complex and multifaceted inter-organizational relationships (Jarvenpaa and Wernik, 2011). The results produced by the methods demonstrate the value chain and Part-nerships practices of open innovation as the most signifi-cant ones to ensure the knowledge prospecting and value creation for the companies. In fact, value chain provides enterprises with the opportunity to identify their core competencies and position themselves in the marketplace according to their competitive abilities (Al-Mudimigh et al., 2004). Once value chains are com-posed, all partners hold a definite vision of the coherence within the industry value system to become a colla-borative value chain. All members of a given value chain must work together to respond to the changes of market demands rapidly (Chiang and Trappey, 2006). Organi-zations create values for themselves and their customers via executing primary and supporting tasks. In the 1980s, value creation mainly depended on cost reduction and industry automation, but modern companies focus on value chain integration to achieve time-to-market and to enhance customer satisfaction (Garetti et al., 2005; Chiang and Trappey, 2006).

Thus, the value chain concept offers management a means by which they can evaluate both existing and new strategic opportunities to create customer and partner value (Walters and Rainbird, 2007). Essentially the value creation system is an analytical tool; it facilitates the identification and evaluation of strategic alternatives (Walters and Rainbird, 2007). Value chain analysis identifies the flow of added value through the value crea-tion processes within both the industry and the firm. In the business model of the future, value chains compete rather than individual companies, and the connectivity and process excellence are key challenges (AeIGT: 2003 cited in Johns et al. (2005). In addition, the cooperation in the value chain requires a complex repertoire of behaviors in that member's organizations need to learn to mitigate the risks stemming from the other's opportunism but also to avoid lapses in their respective knowledge-sharing (Jarvenpaa and Wernik, 2011). Increasingly, it has been argued that, innovative capacity is dependent upon building linkages through collaborative relationships (Coombs et al., 1996) […] this enables learning which adds to an organization's existing knowledge base and the creation of completely new knowledge (Inkpen, 1996) and also contributes to "novelty and variety in the economic system" by creating "new economic resources which otherwise simply would not exist" (Coombes et al., 1996). Such collaboration might involve sub-contracting, strategic alliances or joint ventures […] (McLoughlin, 1999; Walters and Rainbird, 2007). Partnership/ cooperative innovation combines elements of process innovation management and product innovation management within a network structure that neither partner can create using its own resources to meet customer/market determined expectations for product and/or service performance at an economic (viable) cost. Thus, the value chain concept offers management a means by which they can evaluate both existing and new strategic opportunities to create customer and partner value. Essentially the value creation system is an analytical tool; it facilitates the identification and evaluation of strategic alternatives (Walters and Rainbird, 2007).

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 programming methods reflect the preference, according to the experts, for value chain and partnerships. The essence of the practices of open innovation is the accumulation of know-ledge over time. Next, is the influence practice of an open innovation in the knowledge prospecting. For this ANN was used. The technique adapts to the case in question.

Prospecting of knowledge using the artificial neural networks – ANN

The artificial neural networks - ANN is understood to simulate the behavior of the human brain through a number of interconnected neurons. A neuron executes weighed additions for the activations of the neurons representing nonlinear relations. The ANN has the capacity to recognize and to classify standards by means of processes of learning and training. The training of the net is the phase most important for the success of the applications in neural network. The topology of the net can be better determined by subjective form, from a principle that consists of adopting the lesser intermediate number of possible layer and neurons, without compromising the precision. Thus, in this application, the layer of the entrance data possess 10 neurons corresponding the 10 variable referring to practices of open innovation.

The intermediate layer possesses 8 neurons, and the exit layer possesses 1 corresponding neuron in a scale value determined for the ANN. The process of learning supervised based in the back propagation algorithm applying software easy NN determines the weights between the layers of entrance and intermediate, and between the intermediate and exit automatically. The training process was finished when the weights between the connections had allowed minimizing the error of learning. For this, it was necessary to identify which configuration that would present the best resulted varying the taxes of learning and moment. After diverse configurations have been tested, the net of that presented better resulted with tax of an equal learning 0,40 and equal moment 0,90. The data had been divided into two groups, where each period of training one third of the data is used for training of net and the remain is applied for verification of the results. The net was trained for attainment of two results' group for comparison of the best-determined scale for the networks.

In the first test the total judgment of the agents was adopted, however only as the test got better scales, which was next represented method of the multi-criteria analysis. With this, the last stage of the modeling in ANN consisted of testing the data of sequential entrance or random form, this process presented resulted more satisfactory. The reached results had revealed satisfactory, emphasizing the subjective importance of scale's methods to treat questions that involve high degree of subjectivity and complexity. How much to the topologies of used networks, the results gotten of some configurations of the ANN and compared with the multicriteria analysis, were observed that ANN 1, is the one that is better, if approached to the classification gotten for the multi-criteria analysis. Thus, even other topologies do not Tenaha been the best ones, it had been known however close in some practices of open innovation of the multi-criteria analysis. The results can be observed in Table 2 that follows.

In fact, the goal knowledge is to create value from organizational and individual knowledge. The benefits derived from good knowledge are multiple, and include: reduced duplication of effort, creation of new knowledge,

Table 2. Classification practices of open innovation using artificial neural networks and multicriteria analyis Methods

	Multicriteria analysis			ANN
	Promethee II	Compromise programinng	Electre III	RNA
Value Chain / Partnerships for co-development	1[a]	1[a]	1[a]	1[a]
Product development through patent licensing	2[a]	2[a]	3[a]	2[a]
Relationship between companies and scientific and technological system	3[a]	3[a]	2[a]	2[a]
Value Opportunity Web – VOW / Spin-offs				
Commercialization of technologies via Technology broker	4[a]	4[a]	2[a]	3[a]

and increased efficiency and productivity. knowledge and innovation are the building blocks of sustainable competitive advantage (Porter, 1985), and therefore they are source for sustainable development and growth for enterprises. Thus, an innovation is the use of innovative knowledge so as to create effective value for the stakeholders in the value chain. From the perception of the innovation, the innovation value chain may be represented differently. Indeed, innovation starts from an idea that is often embedded with an innovative knowledge, to become somehow a prototypical invention, to finally become an innovative product or piece of technology that is industrially exploited or even commercialized. Porter (1985) argues that firms that optimize their value chain activities vis-a-vis competition stand a better chance of leveraging valuable capabilities into sustainable competitive advantage (Prajogo et al., 2008). Clearly any partnership innovation must be beneficial to all parties (Walters and Rainbird, 2007).

The results produced in the light of artificial neural networks confirm value chain and partnerships as the practice of open innovation that shows the most (in greatest degree) influence in the prospecting of knowledge. The value chain is supported by a particular value that creates a logic and its application results in particular strategic postures. Adopting a network perspective, a new economic value is configured to the organizations. Traditionally, value chain has been used as a concept and a tool to understand the analysis of industries and proved to be a useful mechanism for portraying the threaded engagement of traditional activities in industries (Porter, 1980). Moreover, it also shaped the thinking about value and value creation. The value chain of a company relates to other chains and knowledge coming from different sources (suppliers, competitors, channels and customers, among others), which then become a value chain of the industry. At the same time, a company can make analyzes of the links in the value chain between its suppliers, manufacturers and customers chain in order to find ways to increase the competition. For the concept of value network, value is co-created by a combination of actors in the network. Business networks are independent. After all, how is value created? A traditional answer to this question is simply the value chain. In this perspective, the knowledge is certainly one of the best resources and the only sustainable competitive advantage.

Phase 2: Modeling of the optimal effectiveness rate of value creation in the light of the influence of the practices of open innovation in the prospecting of knowledge of the actors

This phase focuses on determining the optimal efficiency rate (OERVC) for value creation in the high-tech companies 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 (neurofuzzy technology).

Here this model supports the planning practices of open innovation on the knowledge and value creation 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 value creation 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 (10 variables: Value Chain; product development through patent licensing; partnerships for co-development;

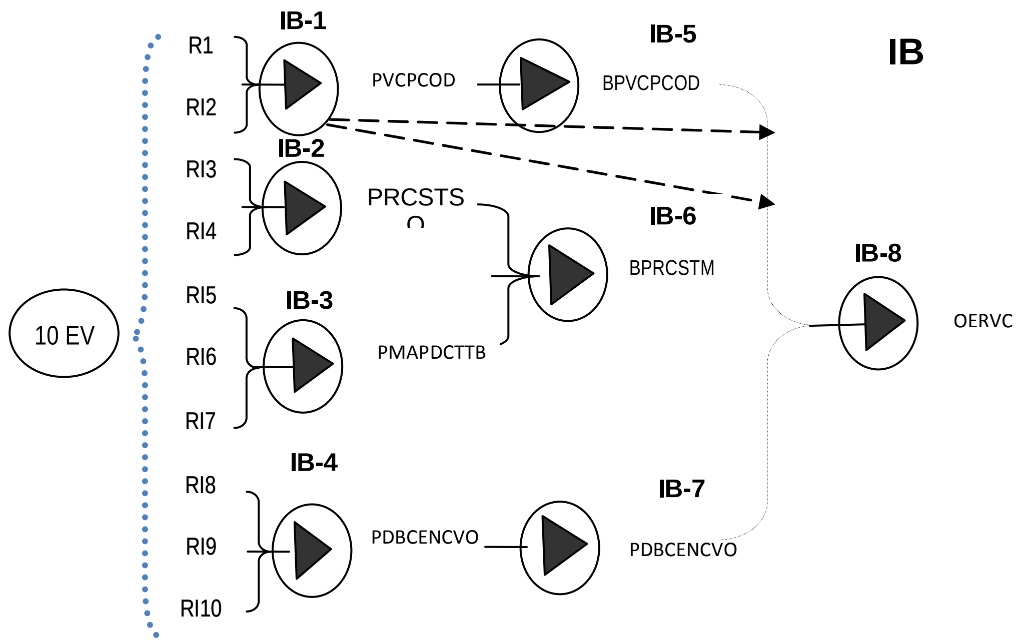

Figure 2. Neurofuzzy model

relationship between companies, scientific and technological system; spin-offs; mergers and acquisitions; commercialization of technologies via technology broker; development of new business from corporate venturing; establishment of non-competitive consortia (innovation networks); and VOW from the independent variables (dimensions of results Influence of practices of open innovation in the prospecting of knowledge for value creation in highly complex environ-ments. The linguistic terms assigned to each IV are: High, medium and low.

Accordingly, Table 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 DoCs, based on fuzzy sets and IT rules (aggregation rules), next (composition rules). Figure 2 shows the Neurofuzzy model.

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: Performance of the value chain and partnerships for co-development: PVCPCOD; performance of relationship between companies and scientific and technological system and Spin-offs: PRCSTSO: Performance of mergers and acquisitions, product development through patent licensing and commercialization of technologies via technology broker: PMAPDCTTB; performance development of new business from corporate venturing, esta-blishment of non-competitive: DNBENC consortia (innovation networks); and performance of VOW): PDBCENCVO. The architecture proposed is composed of eight expert fuzzy system configurations, fourqualitative 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 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 value creation of high-tech 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 technological innovation capacity performance of 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 certainty of the linguistic terms of each of the input variables using the fuzzy sets. The results confirm the *H2:* The optimal efficiency rate depends on the combination and interaction of the innovation capacities of the high-tech companies. 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 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 value creation

The OV of the neurofuzzy model proposed was called optimal efficiency rate of value creation in high-tech 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 TPCITj with GdCi of the following linguistic vector of the output variable, also hypothetical: LOW=0.20, MIDDLE=0.53, HIGH=0.17. The numerical value of OERVC at a 0 to 1 scale corresponds to 0.9417, 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 OERP. With this result (optimal efficiency rate: 0.9417) produced for a better combination and interaction of strategic practices of open innovation that converged toward a single parameter, it is feasible to assert that this combination of technological innovation activities 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 (0.9417), 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 for value creation of compnies: A – 0.8892; B-0.5149; C-0.6628; D-0.3871;

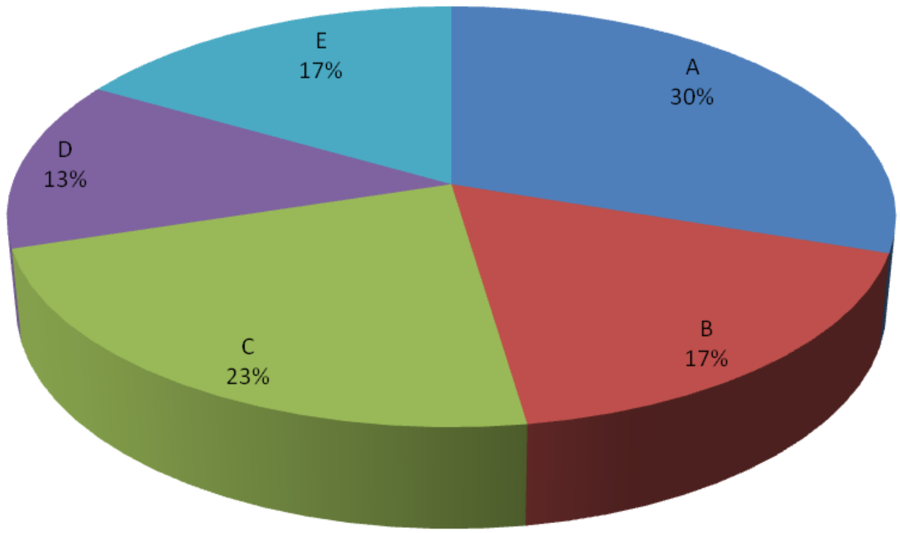

Figure 3. Optimal efficiency rate of value creation

AND-0.4921. The expected reference for value creation for all firms is 0.6827 (hypothetical) (Figure 3). It is concluded that:

Company A show efficiency in the combination of their practices of open innovation, based on the prospecting of knowledge and value creation. The priorities practices of open innovation for value creation are dynamic and dependent on constraints and uncertainties that come from the environment at any given time. Companies B, C, D and E are not efficient in combining their strategies practices of open innovation for prospecting knowledge and value creation, 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.

The innovation has been thoroughly studied by many authors in the academic community. In addition, open innovation concept has received tremendous attention from, both academicians and practitioners. The concept has been an explosion in the innovation function of many firms since it was introduced by Chesbrough (2003). He defines open innovation as “paradigm that assumes that firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as the firms look to advance their technology.” (Hossain, 2013). Open innovation concept emphasis on sharing knowledge within and among organizations (Abouzeedan and Hedner, 2012; Hossain, 2013). Necessary knowledge relevant to accomplish activities largely resides beyond a firm’s boundaries (Lakhani and Panetta, 2007).

Thus, it is important look at the practices of open innovation in the prospecting of knowledge and value creation. Value capture implies focusing on getting the biggest possible cut of the pie, whereas value creation involves innovation that establishes or increases the consumer’s valuation of the benefit of consumption (Priem, 2007). This research investigated the influence of practices of open innovation in the prospecting of value and value creation enhancing innovation and value creation. The knowledge is the recipient for success of open innovation. We have also seen a change in focus on how value is created. This leads us towards a long-ignored knowledge (and sources of knowledge) lens on both innovation and value creation in high tech companies.

CONCLUSIONS AND LIMITATIONS

This article aims to contribute to a policy of innovation management. To do so, it presents the influence practices of open innovation on the development of knowledge for value creation in highly complex environments. The study attempted to cover an existing space in the literature about innovation management based on the practice of open innovation in the prospecting of knowledge and value creation for highly complex environments, which is the case of high tech companies. The research was based on an extensive literature review, in which the components of the conceptual model (dependent and independent variables) were raised. The study is based on the state of the art to establish the structure and contents of the model. In fact, the innovation is not simply closed (that is, in-house developed) or open, rather it varies in a continuum between the above extreme modes.

Open innovation has been defined as ‘‘both a set of practices for profiting from innovation and also a cognitive mode, for creating, interpreting and researching those practices'' (Chesbrough, 2006), ''the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively'' (Chesbrough et al., 2006) and ''systematically performing knowledge exploration, retention and exploitation inside and outside an organization's boundaries throughout the innovation process'' (Lichtenthaler, 2011; Bellantuono et al., 2013). Open innovation practices, in general, provide greater opportunities for firms to advance and commercialise their technologies and hence, enhance their innovation capability and international competitiveness (Chesbrough, 2003; Laursen and Salter, 2004; Clausen and Pohjola, 2009; Gassmann et al., 2010; Wynarczyk, 2013). In addition, open innovation allows for internal ideas to be taken to market through external channels, outside the firm's internal mechanisms, in order to generate additional value. Vanhaverbeke et al. (2008) have identified four broad advantages associated with open innovation practices, namely: (1) benefit from early involvement in new technologies and/or business opportunities; (2) access to other organizations' technological capabilities and R&D, through the combination of internal and external channels to market; (3) accessing venture capital funds; and (4) providing educational investments and joint venturing in potential projects at universities or research laboratories (Wynarczyk, 2013).

According to Huizingh (2011), open innovation practices are the processes that managers start when deciding ''when, how, with whom, with what purpose, and in what way should they cooperate with external partners''. Here, the practices of open innovation support the external knowledge prospecting and value creation in high tech industries. In fact, the benefits derived from good knowledge management are multiple, and include: reduced duplication of effort, creation of new knowledge, and increased efficiency and productivity, knowledge and innovation are the building blocks of sustainable competitive advantage (Porter, 1980), and therefore they are a source for sustainable development and growth for enterprises. The innovation is the use of innovative knowledge so as to create effective value for the stakeholders of the industry (Van Horne, Frayret, and Poulin, 2006). Here, the best practices of open innovation have been the value chain and partnerships and collaborations. In fact, all value chain activities are equally important as firms strive toward specific strategic goals. Porter (1980) suggests that achieving competitive advantage begins with an effort to develop deeper organizational expertise in performing certain competitively critical value chain activities (Prajogo et al., 2008).

In the research, cross-sectional data used in this study may not be appropriate to establish fundamental relationships between variables, but as referenced by Kenny (1979), the relationships that use cross sections are satisfactory and popularly accepted in relationship tests. Furthermore, a survey 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 practices of open innovation 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. Of the research findings, the high-tech industries undertake the ever-fast changes, intense competition and a highly uncertain and risky environment.

The effect produced by technology on the development of new products is equally intensive. Prospecting knowledge of R&D is crucial for practices of open innovation. It confirms the state of the art. Shanklin and Ryans (1984) suggest that high-tech companies anticipate potential technical and scientific capabilities that provide quick responses to the existing techniques, enabling to meet the market demands to be constructed or altered. It is reasonable to focus efforts on knowledge of R&D, thereby creating an internal stock of scientific knowledge (Feinberg and Majumdar, 2001; Griliches, 1979; Hall and Mairesse, 1995), which enables to develop and introduce new products, lower production costs, more competitive prices and greater financial return (Kafouros, 2008a, 2008b). Knowledge of R&D has indirect effects on increasing the organizational learning, enables to understand external ideas and technologies and apply them to the ultimate business outcome (Cohen and Levinthal, 1989) and also contributes to identifying areas that are still technologically unexplored (Miller et al., 2007). This logic will be maintained, however only through opening spaces for the various strata: partners, suppliers and customers. Nevertheless, the practices of open innovation in the prospecting of knowledge of high-tech companies will have to be anchored in efficient planning policies. One can argue that Brazil's high-tech industry still has a long way to go and also has tremendous growth potential. Hopefully Brazil can become a technological and competitive nation.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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