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A FUZZY LOGIC APPROACH TOWARDS INNOVATION MEASUREMENT

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ABSTRACT

Innovation is a convened critical factor for firm success in today's economic environment. As academics and practitioners acquire knowledge on innovation, tendencies, points of view and practices arise. Yet measurement approaches meant to help decision makers to evaluate their current innovative position do not follow a main stream, moreover much of the information needed for an accurate evaluation tends to be qualitative or subjective. The objective of the present investigation is to review how Fuzzy Logic is currently dealing with subjective complex data in innovation management approaches, results will turn as implications for further applications in innovation measurement. An examination of new methodologies towards innovation measurement is presented and linked to a systematic review on Fuzzy Logic applications to innovation management. Results convey that there is no ultimate model to address innovation measurement in firms, yet a set of innovation measurement key issues are described in novel frameworks. Fuzzy Logic stands as a viable way to adopt decision-making due to its capacity of dealing with uncertain and subjective conditions. According to results, the use of Fuzzy Logic to evaluate qualitative and subjective factors in innovation measurement is encouraged.

JEL: O320, M100, M420

KEYWORDS: Innovation Measurement, Fuzzy Logic, Uncertainty, Decision Making

INTRODUCTION

Research on the concept of innovation has been evolving since the last decades, currently there is no manager or decision maker that could affirm that innovation does not carry competitiveness, it is in some way a given fact. As Porter (1990) states *Companies gain advantage against the world's best competitors because of generating innovations*. The results of innovative activities in firms and organizations can range from effects on sales and market share up to the improvement of productivity and efficiency. The significant impacts in the sector of activity are the evolution of international competitiveness and the total productivity of the factors; the knowledge spillovers of innovations produced by enterprises and the growth in the volume of knowledge that flows over the network. Since there is a convened positive impact regarding innovation activities, scholars from diverse expertise address the topic. Gopalakrishnan and Damanpour (1997) identify three main groups of researchers: Economists, whose perspectives centers on growth at industry level and evaluate the impact of radical product and process innovation. Technologists, whose studies center ~~in~~ around the process of generating and improving new technology~~,~~ with a focus on radical and incremental product process innovations. Sociologists, whose studies mainly focus on the organizational features and the adoption of innovations within firms, and who study technical and administrative product and process innovations. As an effect of such widespread research, there are diverse approaches around the concept of innovation, in some way leading to inconsistencies. Several studies assess this gap by reviewing the evolution of the research on innovation (García and Calantone, 2002; Hansen and Wakonen, 1997; Landry et al., 2002).

Due to the broad range of ways that the concept of innovation can be addressed, there is no definition that covers all the aspects of innovation. The earliest definition of innovation was established by Schumpeter (1934) stating *innovation is what we call in a non-scientific way "economic progress", which means in essence the use of productive resources in ways not tested yet in practice, and the retirement of the uses that have had so far*. In a market oriented standpoint Drucker (1987) has pointed out that *innovation is the tool in which innovative entrepreneur's exploit the change as an opportunity for new*, and Kanter (1983) claims that *innovation refers to the process of establishing any new idea, which resolves a problem*. A broader definition of innovation is established by the UK Department of Trade and Industry's (DTI, 1998) implicating that innovation is *the successful exploitation of new ideas.* The Oslo Manual (OECD, 2006), mentions that *innovation is the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations.*

Topics within the definition of innovation compile concepts such as: progress, success, solution of problems, etc. Hence, knowing how innovative activities affect companies' performance is also needed to be discussed, as it opens the path to attend an important challenge, which is to determine in a systematic way whether innovative efforts within firms are justified, objectives are being reached and the further generation of incentives (Cordero, 1990). The formula is somehow logic, we use information acknowledged in large studies concerning success and failure around innovation, then generate a checklist with the most relevant features and apply a scorecard with the best practices (Tidd and Bessant, 2013). However such logic faces complicated challenges as conceptions, terminology, and standpoints around innovation differ from authors and studies. Cooper (1979) centered attention on the evaluation of 77 success/failure *key activities* on product innovation. De Brentani (1991) expands the discussion introducing the study of service firms. Rothwell (1992) in a large-scale empirical study evaluated successful industrial innovations. Atuahene-Gima (1995) addressed market and project performance with 2 success dimensions. Benedetto (1999) took a product launch performance orientation, and Gerwin and Moffat (1997) addressed the challenge of evaluating 3 successful dimensions in order to establish relations between companies' cultural activities and innovation. The mentioned works do not pretend to be an exhaustive list, instead show how authors focus on different types of innovation and measurements to evaluate firm's performance often dealing with subjective, incomplete or vague information.

Through the last years uncertainty, understood as imprecision and imperfect or vague information in innovation management has been acquiring attention, see e.g. Macdonald et al. (1994); Gales & Mansour-Cole (1995); Hansen et al. (1998); Tidd (2001); Lane & Maxfield (2005); Hidalgo et al. (2008); Buddelmeyer et al., (2009); O'Connor & Rice (2013); among others. As stated by Tidd and Bessant (2013) "by its nature innovation is about the unknown, about possibilities and opportunities associated with doing something new and so the process involves dealing with uncertainty".A correct evaluation, quantification and comparison of the innovative competences of contemporary organizations is difficult since there is no single or main trend to assess innovation measurement (Frenkel et al., 2000). Yet a generalized measurement framework would provide a useful basis for managers to monitor and evaluate their innovation processes and create incentives around them (Cebon and Newton 1999). The objective of the present investigation is to address this gap by revising the main trends on practical frameworks of innovation measurement, identifying common critical elements and utilizing Fuzzy Logic to deal with subjective complex data. We have structured the paper as follows. The first section presents a literary review, containing preliminaries of the study, initial theories, framework to address innovation measurement and the main challenges of the topic. The second section comprehends the methodology that we used for the systematic review on the updated roll that Fuzzy Logic has on innovation management. The third section, results and discussion, presents the main findings of our study and analyze how Fuzzy Logic could aid decision makers in innovation management measurement. Finally we present our concluding comments.

LITERATURE REVIEW

When trying to assess performance measurement of innovation, we must establish some ground classifications. Neely et al. (1995) emphasize the need for a proper performance measurement of systems. They define performance *measurement as the process of quantifying the efficiency and effectiveness of action.* A performance measure can be defined as *a metric used to quantify the efficiency and/or effectiveness of an action* and a performance measurement system can be defined as *the set of metrics used to quantify both the efficiency and effectiveness of actions.* However positive managerial implications of a correct innovation performance measurement system have been (Simons 1990; Gimbert et al., 2010), scholars have not yet reached consensus on a definite approach (Nilsson et al., 2012). The widespread vision on innovation, its definitions and related inconsistencies addressed in the introductory section tend to be resilient challenges (Gopalakrishnan and Damanpour, 1997). Even though there is no definite consensus around the measurement of innovation, significant advances have flourished over the last years. Approaches like Adams et al. (2006) whose work focuses on the description of a holistic framework retrieving successful critical factors over the years of innovation measurement. Crossan and Apaydin (2010), whose work reveals extensive research on innovation, consolidating fundamental theories around innovation academic approaches; Edison et al., (2013) whose empirical studies describe a specific (yet scalable) industry framework; and the evaluation of dichotomies and established practices (Nilsson et al., 2012; Jensen and Webster, 2009).

Initial Theories

In order to understand the latest advances on innovation measurement we first must address the basic concepts on innovation, its principles and theories. Crossan and Apaydin (2010) compile peer-reviewed scientific academic research done over 27 years (1981-2008). The analysis includes a systematic review of 367 highly cited (minimum 5 citations per year using 2009 as base year) articles and organized them by level (individual, organization, macro, multilevel). Table 1 presents the quantity of researched articles found.

Table 1: Innovation Measurement Framework Areas

	Multilevel	Macro	Organization	Micro
Institutional	1	3	2	
Economics and evolution	2	3	3	
Network	2	4	2	
Resource-based view and dynamic capabilities			4	
Learning, knowledge management, adaptation, change	2	2	11	2
Other theories	1	1	1	5

Source: Adapted from Crossan and Apaydin (2010)

Learning, knowledge management, adaptation and change theories prevailed as the most concurred with 17 articles, followed up by 8 articles with foundations on Network theories and also 8 articles with roots on economics and evolution. In spite of these findings, authors conclude on not finding *a strong underlying theory, and the theoretical perspectives that were employed tended to be quite disparate and generally operating at a single level*. Conclusions on a lack of coherent and explicit theoretical base pair with those of Hobday (2005); Rothwell (1994); Tidd et al. (2006); Velasco & Zamanillo (2008), works that focus on reviewing the evolution of innovation models, finding again dissimilar approaches, e.g. Static and Dynamic Innovation (Afuah, 1998); Organizational Model of Technological Innovation (Kelly and Kranzberg, 1978); Model of Innovation of Schumpeter, Conversion Models, Technology – Push and Market – Pull Models, Marquis Model (Myers and Marquis, 1969); Strategic Option model (Freeman and Soete, 1997), Abernathy and Clark (1985) Model, Tushman and Anderson (1986) model. The S Curve model Foster (1986), Abernathy and Utterback (1978) model, Tushman and Rosenkopf Model (1992).

A Framework to Address Innovation Measurement

Since there is no ultimate model or theory to address innovation measurement, authors have chosen to develop frameworks that represent the main focus areas to consider. One of the latest approaches has been developed by Adams et al., (2006), work based on a review of six innovation models (Cooper and Kleinschmidt, 1995; Chiesa et al. 1996; Goffin and Pfeiffer, 1999; Cormican and Sullivan, 2004; Burgelman et al. 2004; Verhaeghet and Kfir, 2002) that proposes a seven-factor framework of categories specified in terms of the necessary structural capabilities in a firm to make and manage change. This holistic framework takes into account multiple perspectives e.g. Cooper and Kleinschmidt (1995) whose work focuses on the generation of five techno-centric factors for new product performance, yet overlooking the non-technical context of innovation; Chiesa et al. (1996) whose technical innovation audit tool explores a wide variety of indicators that are meant to evaluate the performance of systems and tools that managers hold in order to enable "hard innovations". Corrnican and Sullivan (2004) explore the continuous and cross-functional connections needed inside an organization to produce effective product innovations. Table 2 shows the holistic framework proposed by Adams et al., (2006).

Table 2: Innovation Measurement Framework Areas

Framework Category	Measurement Areas
Inputs	People
	Physical and financial resources
	Tools
Knowledge management	Idea generation
	Knowledge repository
	Information flows
Innovation strategy	Strategic orientation
	Strategic leadership
Organization and culture	Culture
	Structure
Portfolio management	Risk/return balance
	Optimization tool use
Project management	Project efficiency
	Tools
	Communications
	Collaboration
Commercialization	Market research
	Market testing
	Marketing and sales

Source: retrieved from Adams et al., (2006)

Rather than giving specific measurement proxies of each category described in their framework, Adams et al., (2006) focus their attention on shedding light on useful implications around innovation measurement topics. Concluding remarks in the category inputs, reflect a need for the literature to balance, not only raw financial R&D and NDP key measurements, but also process and business model innovations. Tacit and softer skills that deal with knowledge and creativity require more attention on further input measurement. Knowledge management has to deal with explicit and implicit knowledge held by the organization in idea generation, knowledge reposition and information flows. Putting special emphasis on the correct measurement of codified information such as patents. Innovation strategy is found to follow two main orientations; the first is the measurement of whether the firm has an established innovation strategy and identifiable roles for new products and services. The second trend measures whether innovation strategy is *a defined instrument that shapes and guides innovation in the organization*. Special attention has to be brought to the measurement of the leaders or innovation "champions" as they have proven to be a driver towards innovation and strategic performance. Organization and culture must be measured in line with both structural and psychological standpoints, as work environment stands as a known variable on the level of innovation in organizations. In this section the authors emphasize that much literature has been focusing in culture and organization, yet little is known about structural shift and flexibility in organizations. Portfolio management is a relatively new key topic in the literature, reflectors turn into this area as it deals with the allocation of scarce resources of the enterprise (money, time, people, machinery, etc.) on potential projects under uncertain conditions. Performance can be measured in this subject from different angles. Evaluation on quantity, quality, organizational capability, correct alignment to business objectives and balance in both risk and timespan seem to be some conductive approaches to measure portfolio management. Project management is one on the most challengeable topics, as it needs to measure the capability of an enterprise to create marketable innovations through specific inputs.

The plethora of dissimilar business activities makes it almost impossible to have a valid measurement layout, however, the evaluation of efficiency, tools, communication and collaboration on how a firm generates outputs is commonly addressed. Other factors such as internal collaboration, synergy and transparency had been named to be important, however not yet tested. The authors catalogue commercialization as the least attended topic in innovation management studies. Assessing the measure of marketing, sales, distribution and joint ventures, commercialization is one of the most important activities as it is the final step of the chain, and the real test for ideas to become successful innovations. Products launched per period, market analysis and monitoring tend to be the recurrent measures, although launch proficiency and post – launch reviews are new trend topics.

Challenges on Innovation Measurement

Encompassed with the early-discussed discrepancies, extent visions and differences in terminology, innovation measurement holds implicit challenges for decision makers. Nilsson et al. (2012) present a frame in which challenges assessed as dichotomies represent the main problems when attending radical and incremental innovation measurement in firms. Topics as uncertainty, defined not only as the inherent risk of an innovative project, but also as the possibility of different outcomes in a given situation (Loch et al., 2008), complexity and unfamiliar relations (Bordia et al., 2004) and lack of information (McLain, 2009). Time, distinguished as the management of different perspectives on timespan by a radical or an incremental innovation project. The flexibility of the companies' processes, to launch a radical or an incremental innovation, while the structure and allocation of resources are some of the main constraints in pairing both perspectives (Adams et al., 2006). Control understood as the way firms manage the culture and working environment to pull up both incremental and radical innovations at the same time. Table 3 gathers the main dichotomies in innovation management found by Nilsson et al., (2012).

The dichotomies presented show the importance of a holistic framework, taking into account several perspectives in order to perform a measurement system that actually adds value to the company (Kaplan and Norton 1992; Micheli et al. 2010). Since our main objective is to identify main approaches on innovation measurement, the theories and models presented are addressed in a general and illustrative perspective; a robust theoretical review would need extensive depth, an issue that overreaches our present work scheme.

DATA AND METHODOLOGY

In order to appreciate how Fuzzy Logic could be useful to the resilient challenges that innovation measurement drags, we must first know which advances of the Fuzzy Logic theory had reached the scope of innovation management. In order to do so, we propose a systematic literature review (Denyer and Neely, 2004), this clear and reproducible procedure has shown increasing interest among scholars (Adams et al., 2006) and has proven efficiency in dealing with large amounts of information, establishing main paths: development of clear objectives, pre-plan auditable methods, quality execution of the search and synthesis of impartial results using clear frameworks. In our case our main objective is to utilize peer-reviewed journals in order to explore the quantity and quality of articles that have a Fuzzy Logic methodology to address innovation. We concentrated the search in Thomson Reuters database ISI Web of Science, since it compiles one of the foremost influential pools of peer-reviewed articles (Crossan and Apaydin, 2010). Articles within the timespan of January 1986 until September 2014 were included in the search.

Table 3: Dichotomies in Innovation Management

Dimension In Dichotomies	Issue In Measurement
Uncertainty	Radical innovation:
	Requires a higher number of market and external environmental measures than incremental
Technical	
Market	Need to be measured on sales growth rather than profitability in the commercialization stage in contrast to incremental innovation
Project scope	
Strategy	
Resources	Requires high amount of data from different sources compared to incremental
	Need to not be measured using strategic, operational and business model fit as a requirement why the opposite is needed for incremental
	Prototypes or probes may replace traditional project management measures in the development of radical innovation
Time	Valuation and selection of idea and projects require different measures: ex. ROI, net present value (for incremental) vs. Opportunity cost (for radical).
Long and short (Length)	
Discontinuous and continuous (Rhythm)	Radical need to be supported by measures that trace rapid and unexpected events and incremental measures that traces alignment to a predefined path.
Rapid and slow (Pace)	
Flexibility (vs. stability)	Incremental innovation benefit from using the same measures for a long period of time
	More measures for external communication and for measuring relations needed for radical innovation.
Process	
Structure	Radical innovation:
Strategy	Requires a broad number of quantitative and qualitative measures that can easily be exchanged
	Requires measures to support strategy development i.e. what works and what does not why measures that control the alignment to goals and strategies are sufficient for incremental innovation.
Control (vs. freedom)	Measure identification and implementation for radical innovation require both audit (bottom up) and need driven procedures (top down) why incremental innovation is supported by a need driven procedure alone.
Roles	
Leadership	
	Measurements need to be aligned to and support both radical and incremental recognition and reward systems

Source: retrieved from Nilsson et al., 2012.

In order to reach inclusion of a relevant set of articles, the selection criteria utilized was defined first by the Keywords: "Fuzzy Logic" *and* Innovation*. Document type: Article and Review. No further restriction selections were made. A total of 66 articles were retrieved, this initial set was fixed for further analyses. However, 19 papers were selected for deep analyses due to our criterion of including papers that have Fuzzy Logic as a methodological foundation. Table 4 presents how articles are scattered around different journals, from environmental and pollution to artificial intelligence topics. The diverse fields that Fuzzy Logic techniques covers describe the flexibility of the methodologies to address different problems of various scientific topics.

Table 4: Most Cited Journals

Journal	Times Cited
Proceedings of the IEEE	61
International Journal of Production Economics	53
Technovation	33
Engineering Applications of Artificial Intelligence	17
International Journal of Environment and Pollution	17
Production Planning and Control	10
Journal of Intelligent Manufacturing	7
Renewable Energy	5
Scientific World Journal	2
International Journal of Computers Communications & Control	1

Source: retrieved from Web of Science 2014.

Figure 1 denotes an increasing trend of publications addressing innovation management with Fuzzy Logic techniques; also it shows the novelty of these kinds of studies in the formal sciences. The increment of publications shows the rising interest from scholars to adopt diverse perspectives to address innovation management.

Figure 1: Growth of Articles Assessing Innovation through a Fuzzy Logic Approach

Source: retrieved from Web of Science 2014.

Our methodology has certain limitations e.g. the utilization of the ISI Web of Science narrows the scope of search. A depth analysis discriminated 47 papers out of the original 66 due to diverse issues; the main one is the fact that authors catalogue their work as "innovative"; the introduction of that keyword misleads the search and results obtained.

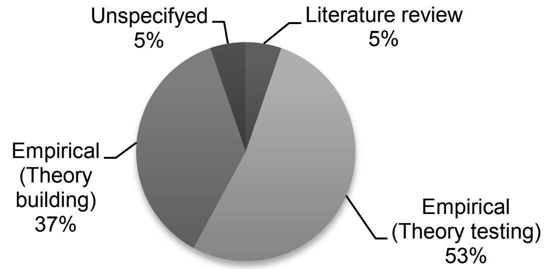
RESULTS AND DISCUSSION

In this section we present the main findings of the systematic review. We firstly present aggregated results, a specific quantification of article type, followed up by an analysis of the innovation areas that the publications address. Secondly, we present a classification of the main approaches of the chosen articles.

Aggregated Results

From the 19 articles chosen for deep revision, the majority, 10 articles, present an empirical theoretical testing structure, putting into practice diverse Fuzzy Sets theories, being the most recurred theories the use of linguistic variables and fuzzy triangular numbers, thus dealing with imprecision or vagueness in information. A total of 7 articles propose the construction of theoretic frameworks, new approaches to deal with innovation management challenges with emphasis on uncertainty management and expert support systems. From the pool of articles only 1 describes a literature review, mainly focusing on soft computing industrial applications. Figure 2 shows the aggregated results by paper type of the 19 articles chosen for deep examination.

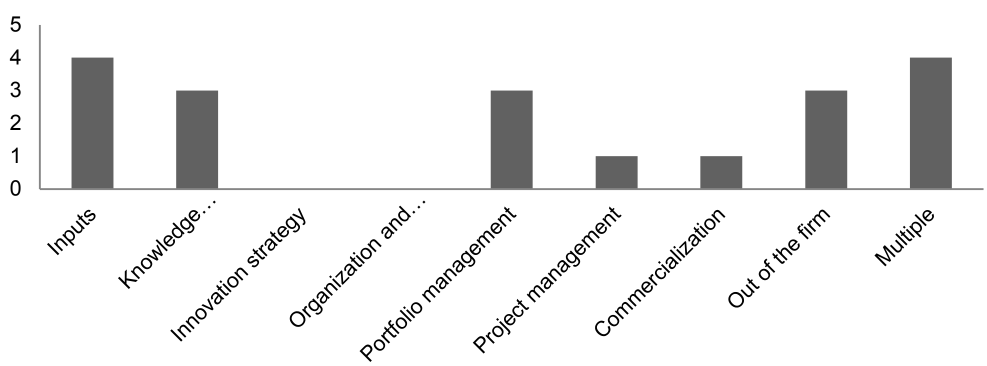
Figure 2: Aggregated Results by Paper Type



Quantification of results of the selected papers differentiated by type: empiric, literature review or theoretic. Source: Self-elaborated.

Continuing with the results, the selected papers were catalogued by the innovation area they address (Adams et al., 2006). The majority of the papers reach the scope of innovation inputs and multiple stages; the first oriented to new product development tools and the second addressing several areas of innovation within firms, no main trend of innovation management approach was identified. Knowledge management, portfolio management and actions outside of the firm were recurrent categories; surprisingly we did not find many publications specifically addressing innovation strategy nor organization and culture. It is encouraged to fulfill such gaps in the near future because of its importance in the survival of firms. Figure 3 shows the aggregated results of the 19 papers selected for deep examination by innovation area as proposed by (Adams et al., 2006).

Figure 3: Aggregated Results and Innovation Area



Number of articles differentiated by innovation area that selected papers attend. Source: Self-elaborated.

Categorization of Articles

A deep categorization of empiric and methodologically robust articles was performed. 14 out of the initial 19 articles were classified first by area of specialization, i.e. the main focus of their research paper. Secondly, the approach adopted towards innovation management. Thirdly the specific Fuzzy Logic methodology applied to address the area of specialization. Lastly, the articles were catalogued by the approach they carried out towards the definition of uncertainty. Table 5 presents the main findings over the deep examination of the selected papers.

Table 5: Categorization of Articles

Author	Area of Specialization	Approach	Methodology	Uncertainty Approach
Büyüközkan and Feyzıoğlu, (2004)	New product development	Fuzzy logic decision making support system	Pseudo-order fuzzy preference model (Roy and Vincke, 1984; Wang, 1997), the fuzzy weighted average (FWA) method (Vanegas and Labib, 2001), fuzzy analytic hierarchy process (FAHP) (Triantaphyllou, 2000)	Information defect (Spender, 1993)
Taşkin et al., (2004)	Technological intelligence as competitive advantages	Technological survey analysis	Fuzzy expert system (Frantti and Mähören, 2001; Ordoobadi and Mulvaney, 2001)	Fuzzy logic to encapsulate partial truths (Ross, 1995)
Maravelakis et al., (2006)	Innovation benchmark for SME's	Three-dimensional fuzzy logic approach for measuring innovation	Fuzzy sets (Zadeh 1965)	Fuzzy Logic qualitative, subjective nature and linguistically expressed values (Yager and Zadeh 1992)
Kaklauskas and Zavadskas, (2007)	Pollution minimization and mitigation	Combined expert and decision support systems	Fuzzy relation model (Zhou et al., 2004)	Environmental uncertainty
Wang et al., (2008)	Technology innovation capability	Quantitative and qualitative multi-criteria analytical approach.	Triangular fuzzy numbers. Fuzzy averaging technique and defuzzying method (Chen and Klein (1997)	Technological innovation uncertainties (Afuah 1998)
Kong et al., (2008)	Evaluation of technological innovation capability	Fuzzy decision support models	Triangular fuzzy sets; Fuzzy Vikor Algorythm (Opricovic, 1998)	Uncertainty in the subjective judgments.
Lin et al., (2011)	Tourists service management	Fuzzy model for the evaluation of performance in the service sector	Fuzzy Quality Function Deployment (Hisdal, 1988)	Uncertainties in the tourism service design process (Chien & Tsai, 2000)
Zouggari and Benyoucef, (2012)	Supplier selection based on innovative characteristics	Fuzzy logic decision making support system	Fuzzy Analytic Hierarchy Process (Chang 1996, Wang et al., 2008b); Fuzzy Technique for Order Performance by Similarity to Ideal Solution (Hwang andYoon,1981)	Uncertainty as imprecision associated with information (Zadeh 1965)
Echeverri et al., (2012)	Group product development	Fuzzy model for the evaluation of group contributions	Fuzzy sets (Zadeh 1965)	Uncertainty in the subjective judgments.
Hsueh and Yan, (2013)	Facilitating Green Innovation	Fuzzy logic inference system	Fuzzy sets (Zadeh 1965; 1976; 1996); Triangular functions, bell shaped functions (Yu and Skibniewski 1999)	Complexity, and tolerance for imprecision used in natural language
Segev et al., (2013)	Multilingual knowledge innovation in Patents	Fuzzy Logic reasoning and decision making process	Fuzzy Logic Knowledge Interface (Aliev & Aliev, 2001)	Vagueness in linguistics can be captured mathematically by applying Fuzzy Sets (Lin & Lee, 1996).
Serrano and Robledo, (2013)	Evaluating Innovation Capabilities at University Institutions	Combination between a fuzzy logic system and the experience or knowledge of experts	Fuzzy inference system (Medina, 2006; Kosko, 1994; Mizutani and Sun, 1997)	Multi-value logic that allows reasoning about a world of objects as relational entities (Pedrycz and Gomide, 1998).
Achiche et al., (2013)	New product development	Fuzzy decision support models	Triangular fuzzy sets (Achiche et al. 2006; Duda 2001), Genetically generated Fuzzy Models (Achiche et al., 2004)	Approximate characterization of phenomena that are too complex or illdefined (Zadeh 1975)
Sorayaei et al., (2014)	Marketing strategy	Fuzzy logic decision making support system	Fuzzy Analytic Hierarchy Process (Saaty, 2000; Chang 1996)	Uncertainty in the subjective judgments.

Selected papers categorized by specialization, main approaches, methodological structure, and treatment of uncertainty. Source: Self-elaborated.

A deep analysis shows how authors tend to create decision making support models based on Fuzzy Logic to face the inherent characteristics of innovation (Segev et al., 2013). Moreover, they tend to focus models to a specific domain, e.g. Büyüközkan and Feyzıoĝlu, (2004); Achiche et al., (2013) for product development, Kong et al., 2008 for technological innovation capability. Zouggari and Benyoucef (2012) for partner selection models. Innovation is a complex activity, diversified, with a high amount of components that interact with each other creating new sources of ideas and it is difficult to discover the consequences that new events can develop, Escorsa & Valls (2003), in that issue, authors on Fuzzy Logic have combined rough quantitative indicators mixed with expert qualitative information (Kaklauskas and Zavadskas, 2007) to create a robust set of tools to assess innovation e.g. Taşkin et al., (2004); Serrano and Robledo (2013) for the evaluation of technological innovation capabilities for firms and institutions. The different factors such as competition, rapid markets, highly changing trends and advanced technology have to meet the shifting interests of the firm's stakeholders, a correct visualization of the transversal innovation capabilities is needed, for that matter Maravelakis et al., (2006); Lin et al., (2011) propose Fuzzy Logic based holistic models for the evaluation of innovative capabilities, the first focusing on SME's and the second on service sectors. Even with the diverse approaches to assess innovation, there is a common thing between the articles; the utilization of Fuzzy Logic techniques to address uncertainty in innovation management, whether faced as subjective judgments, partial truths (Ross, 2009), or approximation and characterization of phenomena that are too complex or ill-defined (Zadeh, 1965).

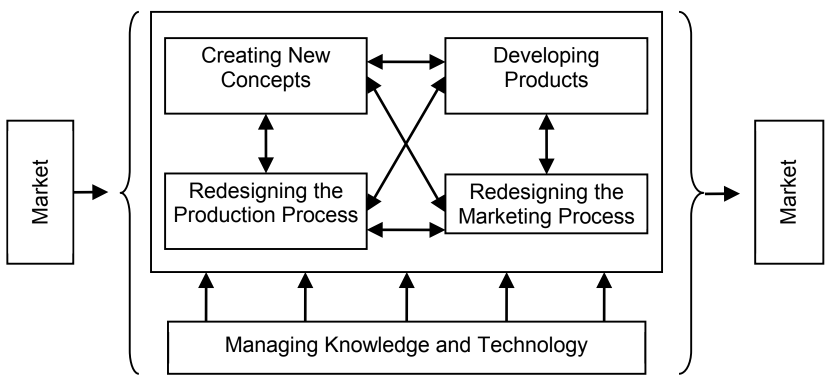
<u>Uncertainty and Innovation</u>

Uncertainty is an attribute of information, Zadeh (2006). Not simply the absence of information but inadequate, inexact, unreliable and border with ignorance, Funtowicz & Ravetz (1990). Information is the key of the concept because it can increase or decrease the level of uncertainty phenomena express, more knowledge illuminates that our understanding is more limited or that the processes are more complex than thought before, Van der Sluis (1997). For detailed studies about uncertainty, its evolution and diverse perspectives see Walker et al. (2003); Perminova et al. (2008). In the present study we will follow the idea in which uncertainty is present whenever an outcome of a process is not known due to the attributes on the information that surrounds the phenomena. In that sense, what distinguishes innovation management from gambling? Both involve committing resources to something which (unless the game is rigged) have an uncertain outcome (Tidd and Bessant, 2013).

It is widely accepted that the concept of Innovation involves uncertainty, imprecision and imperfect or vague information. The challenges faced then must be addressed by overrunning that level of uncertainty and providing useful tools in the terms of administration models for the analysis and treatment of variables, taking into account endogenous and exogenous elements, qualitative and quantitative information, among other components. When conceptualized as a process, the concept of uncertainty in innovation can be more visual, *the importance of an understanding of innovation as a process is that it shapes the way in which we try and manage it* Tidd (2001). The term innovation means a process as well as its result, Drejer (2002). I Ohme (2002) show an example of all the components involved within an organization. Figure 4 shows CIDEM innovation process model (i Ohme, 2002) which is a highly cited process innovation approaches and it was thought to evaluate and measure the intensity in which a firm conducts its innovative actions.

It is an accepted convention that external factors of the *market* involve uncertainty, Roberts (1998); Rese & Baier (2011); Tidd and Bessant, 2013; Bowers & Khorakian (2014). *The facts of nature are uncertain; the economic, social, financial sphere of business change without ceasing; the acts of man – because he is free and provided with imagination – like relationships between mankind – because these are no robots – are all the fundamental causes of uncertainty*, Gil-Aluja (2004). Economic environment, competitors, suppliers, available workforce, users, highly changing trends, technology, politics and R&D facilities are some of the elements that make the environment uncertain. These elements envelope the scope in which a firm will develop and manage innovation. The procurement and awareness that a firm upholds on external information is base for the success upcoming projects. At an internal level of a firm, uncertainty plays a key role in diverse aspects: *Creating New Concepts, Developing Products, Redesigning the Production Process and Redesigning of the Marketing Process, Managing Knowledge and Technology* all need complex interactions and fast connections in order to generate effective outcome. “Economic life, in all of its possibilities, is submerged in this context and decisions have to be taken within its realm are even more complex as a consequence of the uncertainty in the outcomes of future events”, Gil-Aluja (2001). Table 6 shows the diverse sub-processes, which have been matched to elements that involve uncertainty in CIDEM’s Innovation Process Model.

Figure 4: CIDEM Innovation Process Model



Source: i Ohme (2002).

Fuzzy Logic Models and Innovation

Studies with a fuzzy-oriented standpoint have been increasing since the last century and have proven efficacy while dealing with complex phenomena. As stated by Bellman & Zadeh (1970) “much of the decision making in the real world takes place in an environment in which the goals, the constraints and the consequences of possible actions are not known precisely”. The theory of decision under uncertainty initializes with the appearance of the article *Fuzzy sets. Information and Control,* Zadeh (1965), and has proven efficiency handling incomplete and uncertain knowledge information see Ribeiro (1996). The theory of Fuzzy Sets has been applied in the field of the formal sciences; nonetheless in the past 44 years researchers from all over the world have been publishing diverse research studies with applications in varied fields of knowledge.

As stated by Zadeh (2008) major implications about using Fuzzy Logic into innovation management could be in the machinery of linguistic variables and fuzzy if–then rules, which is unique to fuzzy logic, the concepts of precisiation and cointension that play important roles in nontraditional view of fuzzy logic, the use of Natural Language Computation that opens the door to a wide-ranging enlargement of the role of natural languages in scientific theories, enabling the Possibility theory, which may be viewed as a formalization of perception of possibility a direct relevance to knowledge representation, semantics of natural languages, decision analysis and computation with imprecise probabilities, and Fuzzy logic as a modeling language, which is natural when the objects of modeling are not well defined, e.g., data compression, information compression and summarization. The result of imprecisiation is an object of modeling which is not precisely defined. A fuzzy modeling language comes into play at this point. This is the key idea, which underlies the fuzzy logic gambit. The fuzzy logic gambit is widely used in the design of consumer products – a realm in which cost is an important consideration. Other applications that have successfully conducted the application of Fuzzy Logic in the fields of social sciences can be found in the aggrupation of municipalities under uncertain conditions towards the creation of synergies, Alfaro et al. (2012), aggrupation of stakeholders for a better administration of enterprises see Gil-Lafuente and Barcellos de Paula (2013), a personnel selection model see e.g. Keropyan and Gil-Lafuente (2013). In our research, the adoption and further application of Fuzzy Logic methodologies has multiple significances, at a first instance it introduces the possibility of addressing uncertainty at a different standpoint than traditional methods, also it allows to group, assign, link and relate different variables whether endogenous or exogenous that are present in the process of innovation in certain circumstances of a firm.

Table 6: Elements of Uncertainty in an Innovation Process Model

Process	Sub-Process	Elements on Uncertainty
1. Creating New Concepts	Generating new product concepts Product innovation planning Innovativeness and creativity Exploiting innovation	Evaluating market needs Screening new concept ideas Selection of new or enhanced products Planning product innovation Favoring creativity and inventiveness Evaluating alternatives for developing new business opportunities
2. Developing Products	Product development process Teamwork Transfer to manufacturing and distribution Teamwork and organization Industrial design	Choosing appropriate people for critical innovative roles Managing product development projects Facilitating communication among different groups Establishing role and priority projects Defining states of project managers in the organization Integrating customer needs in product development Establishment of cross-functional teams
3. Redesigning the Production Process	Formulating a manufacturing strategy Implementation of new processes Continuous improvement	Matching process capabilities to the requirements of the marketplace Linking process innovation to process innovation Allocating resources for developing new process technologies Identifying opportunities for improvement in process Benchmark production process performance
4. Redesigning of the Marketing Process	Formulating marketing strategy Product introduction Product promotion Product placement	Grouping affine products for effective market introduction Assigning the best placement of products Link market preferences to image Relating customers characteristics to products or services
5. Managing knowledge and Technology	Managing intellectual property Human Resources Climate for innovation Systems Formulating technology strategy Selection generation and sourcing of technology	Choosing sources of technologies (In house), R&D, licensing, partnering, etc. Identifying emerging technologies Relating technology to business objectives and strategies Use methods to evaluate to evaluate R&D projects Identifying key issues in R&D

Source: Adapted from Chiesa et al. (1996)]

CONCLUDING COMMENTS

The purpose of this study is to review how Fuzzy Logic is currently dealing with subjective complex data in innovation management; the objective is to show the relevance of such methodologies and techniques in innovation measurement approaches. A systematic review within the timespan of January 1986 until September 2014 is proposed; papers from Thomson Reuters database ISI Web of Science were utilized. Results show an increasing interest for assessing innovation management theories under a Fuzzy Logic approach. Decision support making models for innovation management were found to be the most numerous articles in the systematic review. The treatment of information under uncertain conditions with a high level of confidence is considered to be one of the main benefits of utilizing fuzzy logic techniques around innovation management. Although there is no ultimate path for measuring innovation in firms, new frameworks lead the discussion towards a set of key activities that must be covered for a firm to continuously revise their innovative capabilities in order to achieve competitive advantages, however much of the information needed to support those key activities tend to be qualitative or subjective. There are several recognized limitations to our study, firstly, we focused on gathering research and categorizing it, such classification may have omitted relevant topics. Secondly, our review uses only one database; such database may have omitted relevant research. Thirdly, the timespan and filtering methods may have also omitted relevant papers. Further research needs to be conducted, firstly to apply the Fuzzy methodologies on specific conditions, and secondary to keep reconnoitering additional Fuzzy Logic models, which could support decision making under undefined environments. Results motivate the use of Fuzzy Logic methodologies in social studies as key for the development of effective innovative strategies in enterprises towards the creation of competitive advantage.

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