EXPLORING THE RELATIONSHIPS BETWEEN PRODUCT INNOVATION RADICALNESS AND EXTENSIVENESS OF FLEXIBILITY OF SUSTAINABLE MANUFACTURING SYSTEM IN MOST INNOVATIVE COMPANIES FROM USA

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This research aims to verify the relationship between product innovation radicalness and extensiveness of flexibility of sustainable manufacturing system in most innovative companies. Furthermore, this research examines how the flexibility affects the innovative factories performance (Business outcomes). The study was tested in most innovative companies of different sectors from the United States of America (USA) in the period 2011 to 2017. A conceptual framework is drawn up based on the literature and confirmed with specialists. The research involved the intervention of experts, selected according to their technical-scientific criteria (production managers, product innovation managers, others). The data were extracted by means of a matrix of judgement in which experts made their judgments about the variables investigated (a Survey). This study intends to fill an existing gap in literature between the radicalness product innovation and flexibility towards the innovative factories.

Palavras-chave: Radicalness in product innovations, extensiveness of flexibility in manufacturing system, Business Performance
1. Introduction

Recently, relevant changes have made organizational boundaries more fluid and dynamic in response to the rapid pace of knowledge diffusion (Chen and Chen, 2016; Woschke and Haase, 2016; Azaiez, et. al., 2016), innovation and international competition (CHESBROGH and ROSENBOOLOM, 2002). Since the last decades, business environment has been dramatically changed. This helps to reconsider how to succeed with innovation (HAYES and WHEELWRIGHT, 1984). Therefore, the supply of innovative products is presented as a quality standard in the race for pressing demands. It is feasible to offer innovative products as it enables companies to have incremental gains and competitive advantage, in particular industries dealing with radical innovations. Radical innovation is critical for many firms and for society (BAKER and SINKULA, 2002). Although the importance of radical innovations is widely recognized, developing them is still rather poorly understood (SANDBERG, 2007). Greater radicalness hinders the ability of rivals to learn about the innovation.

Radicalness in products innovation requires the combined effort of various innovative activities, a condition of limited resources. In this sense, the manufacturing system should not only produce high-quality products at the lowest possible price; it should also be able to react quickly to market changes, consumers preferences and a higher performance of manufacturing process flexibility (Lafou, et.al., 2016), in an context of sustainability. Today, products are no longer judged by the price but the sustainable initiatives implemented by firms. Efforts to reduce the environmental impacts of manufacturing operations have traditionally been viewed as an obstacle to profitability and efficiency (HAMI, MUHAMAD, and EBRAHIM, 2014). Achieving sustainable manufacturing or in an older perspective, sustainable manufacturing, has become the main part in many companies vision. The economical and environmental benefits obtained as a result of having sustainable processes and products, have put this issue in the centre of attention during recent years. There have been many strategies to achieve this goal and many efforts have been done to increase the sustainability of the products and processes (HAMI, MUHAMAD, and EBRAHIM, 2014).

Deciding on an ideal balance regarding radicalness of product innovation and extensiveness of flexibility in sustainable manufacturing system is a complicated issue. This
research aims to verify the relationship between product innovation radicalness and extensiveness of flexibility of sustainable manufacturing system in most innovative companies. Furthermore, this research examines how the flexibility affects the innovative companies performance (Business outcomes). The study was tested in most innovative companies of different sectors from the United States of America (USA) in the period 2011 to 2017. Advanced or sustainable manufacturing has recently been gaining increasing attention from the academia and industry in major economies (YUAN, QIN, and ZHAO, 2017).

To achieve the research objectives, the remainder of this paper is structured as follows: The next section will provide an overview of the relevant literature and concepts that will provide the theoretical lens through which the research is being viewed. The subsequent section of the paper focuses on the research method, findings and ends with a discussion. The implication significance, the limitations and recommendation for future research are then examined. The last section of this paper presents the conclusions.

2. Theoretical Background

Although the importance of radical innovations is widely recognized, developing them is still rather poorly understood. As such, radical innovation is a priority for some though not all firms, with the hope that radical innovativeness leads them to success (BAKER and SINKULA, 2002). Many factors can be identified as being associated with the product innovation success as flexibility in manufacturing process (BARCLAY and BENSON, 1990; BRIX and PETERS, 2015). Traditionally flexibility is interpreted as the ability of a system to change its behaviour without changing its configuration (WIENDAHL, et. al. 2007). Chryssoulouris defines flexibility of a manufacturing system as its sensitivity to change and states: “The lower the sensitivity, the higher the flexibility” (CHRYSSOLOURIS, 2006). In Chryssoulouris (2006), flexibility is defined as “the sensitivity of a manufacturing system to changes. The more flexible a system, the less sensitive to changes occurring to its environment it is”. Various types of flexibility are introduced in the literature. In Chryssoulouris (2006), summarized the flexibility in three main forms, which are Operation flexibility, Product flexibility and Capacity flexibility (LAFOU, et.al., 2016).

In addition, with the growing global concerns on sustainability issues such as scarcity of natural resources, rapid environmental degradation, unequal balance of social equities and
intense global competitions, sustainable manufacturing (SM) strategies have drawn attention. The concept of sustainability has considerably influenced the nature of business activities. As human beings constantly pursuing higher life quality, manufacturing firms encounter a pressing challenge on producing more products whilst using less resources as well as less pollution emitted and waste generated (CHEN and CHEN, 2016). Pursuing more environmentally friendly products and business operations, and being socially responsible would improve operational efficiency (Woschke and Haase, 2016) and generate competitive advantage (HAMIA, MUHAMADB, and EBRAHIM, 2015). Environmental conscious and socially responsible practices would be source of competitive advantage that leads to increase firm competitiveness and eventually create superior performance (HAMIA, MUHAMADB, and EBRAHIM, 2015). Thus, greater efforts are required to understand the relationship between sustainable manufacturing flexibility and product innovation radicalness, and their effect on business performance.

3. Research Framework

3.1 Conceptual Model: Constructs and hypotheses

On the basis of the above mentioned literature review, a research model is developed to examine the relationship between product innovation radicalness and extensiveness of flexibility of sustainable manufacturing system in smart factories. In addition, this research examines how the flexibility affects the smart factories performance (outcomes). Figure 1 shows the conceptual framework for the current study.

Figure 1: Conceptual model
From the conceptual model, the following independent variable, dependent variable and hypotheses were made:

**Independent Variables:** The independent variables are extracted from the specialized literature and assessed by experts for confirmation. The following independent variables are identified: Radicalness of product innovation in sustainable manufacturing system in plants of USA companies of different sectors.

**Dependent Variables:** The dependent variables are extracted from the specialized literature and assessed by experts for confirmation. The following dependent variables are identified: Extensiveness of flexibility in sustainable manufacturing system of USA companies in different sectors.

**Hypothese H1:** The radicalness of product innovations have effects to a greater or lesser degree on the extensiveness of flexibility in manufacturing system in USA companies of different sectors.

**Hypothese H2:** The extensiveness of flexibility in manufacturing system have effects to a greater or lesser degree on the business performance in USA companies/different sectors; i.e., the effectiveness rate global performance of success (ERGPS) of the product innovations depends on the combination and interaction of the flexibility in manufacturing system of USA companies in different sectors. Next, these procedures are detailed.

### 3.2 Sample and Data Collection

The population of this study was in most innovative companies from the United States of America (USA) in the period 2011 to 2017 - Source: Thomson Reuters). The authors investigate the influence of the radicalness in product innovation on extensiveness of flexibility in sustainable manufacturing system of sectors different: Aerospace & Defense; Biotechnology; Chemicals & Cosmetics; Food, Tobacco & Beverage Fementation; Hardware & Electronics; Household Goods; Insight; Manufacturing & Medical; Oil, Gas, & Energy; Software; and Telecommunications; and Agriculture and Forestry sectors. A questionnaire was used as a main instrument of this study (an assessment matrix).

The questionnaire incorporated sections dealing with: general information of company, innovation information in the company, characteristics of radicalness product innovation of company, flexibility information, assessment of degree of interacting between
the radicalness of product innovation and extensiveness of flexibility of process. The actual
survey was carried out between October, November, and December, 2017 which involved 145
specialists. The samples were selected by random sampling technique. Of the 145 specialists
in our sample, 120 completed questionnaires were retuned. However, five cases had to be
excluded from further analysis due to excessive missing data. Therefore, the present sample
comprised of 115 specialists in manufacturing in USA companies/sectors resulting in a
response rate of 79 percent.

The number of respondents of this study is sufficient to carry out the analysis. The
questionnaire was sent to the respondents through registered mail. The self-administered
questionnaire was chosen as the mode for data collection. Respondents were given one month
to complete the questionnaire. After one month, emails were sent to remind the respondents
that the questionnaire should be sent out to the researchers. Respondents who do not yet
complete the questionnaire were given another additional month to complete it. The experts
were issue their judgments through a scale questionnaire. The specialists have experience and
innovation, production, technology, technical knowledge on product development in
companies investigated, and with the following skills: Director Manufacturing Research &
Advanced Engineering, Senior R&D Engineer, Director Research & Innovation, Director
New Technologies & Innovation, others. Next, these procedures are detailed.

4. Conceptual Model Verification: Results and Underlying Analyses

The results and underlying analyses are structured according to the following phases:
Phase 1: Determination of the Drivers of higher radicalness of products innovations in plants
of manufacturing of USA companies of different sectors. Phase 2: Determination of the
Drivers of extensiveness of products innovations in plants of manufacturing of USA
companies in different sectors. Phase 3: Evaluation of the effect of radicalness product
innovation on the extensiveness of flexibility of manufacturing process in plants in USA
companies in different sectors; and Phase 4: Evaluation of the effect of the (degree) of
extensiveness of flexibility on the Business Performance in context of radicalness of products
innovations using neurofuzzy technology, i.e., evaluation of the effectiveness rate global
performance (ERGP) of the business performance from combination and integration of the
drivers of flexibility in manufacturing process. The procedures are detailed as it follows.
Phase 1: Determination of the Drivers of radicalness (degree) of products innovations in plants of manufacturing of European Companies

This phase has been subdivided as follows: Stage 1 - Identification of radicalness drivers in product innovation; Stage 2 - Radicalness drivers evaluation using the method of Categorical Judgments of Thurstone (1927). The results reflect the experts’ preference probabilities in relation to stimuli (Radicalness drivers - degree). Thus, study was designed, based on the literature and confirmed by the assessment of experts. In this perspective, the data were first extracted from the specialized literature (560 articles). The results can be observed in following: (i) Products with new performance for the enterprise and market; (ii) New feature for company or industry; (iii) complex management; unstructured process; (iv) triggered by new business in the market; (v) Degree of Uncertainty; (vi) Discontinuity creation potential in the market, in technology and organization; and (vii) New set of engineering and scientific principles that open that open new applications and new market segments, which may threaten the competitive position of established companies. After their identification, the radicalness is evaluated in order to establish a ranking by relevance (degree/extensiveness). Here the scale model of categorical judgments designed by Thurstone in 1927 has been adopted. The results show that there is a predominance in radicalness in “Products with new performance for the enterprise and market” and “New feature for company or industry; complex management; unstructured process; triggered by new business in the market” in all sectors: Aerospace & Defense; Biotechnology; Chemicals & Cosmetics; Food, Tobacco & Beverage Fementation; Hardware & Electronics; Household Goods; Insight; Manufacturing & Medical; Oil, Gas, & Energy; Software; and Telecomunications; and Agriculture and Forestry sectors.

Phase 2: Determination of the Drivers of flexibility in manufacturing process in plants in EU companies/sectors

This phase has been subdivided as follows: Stage 1 - Identification of flexibility drivers in manufacturing process; and Stage 2 - Flexibility drivers evaluation using the method of Categorical Judgments of Thurstone (1927.)

After determining the radicalness in product innovation (degree), the determination of the flexibility in manufacturing process ensues. The result has allowed defining ten groups that represent the flexibility (ten groups): Flexible Process, Flexible Market, Flexible

Phase 3: Evaluation of the effect of (degree) radicalness product innovation on the (degree) flexibility of manufacturing process in plants in USA companies (sectors)

This section evaluates the drivers of radicalness of products innovations on the flexibility in manufacturing process in USA companies (sectors). This procedure was developed using the multi-criteria analysis. The methods used are Compromise Programming, Electre III and Promethee II. The results achieved in this phase confirm Hypothesis H1: The radicalness of product innovations have effects to a greater or lesser degree on the extensiveness of flexibility in manufacturing system in USA companies of different sectors. The results produced by the methods demonstrate the effect of radicalness in product innovation on the flexibility in companies / sectors; i.e., the effect of radicalness - “Products with new performance” and “consumer demand” as the most significant ones in the extensiveness of flexibility in manufacturing process in all sectors / company. The results global of preferences/ranking (By way of demonstration, using the Chemicals & Cosmetics sector) is then presented in increasing order of importance/intensity. There is a influence of radicalness “Products with new performance for enterprise and market – PNEP” and “Degree of Uncertainty (UCD) on all agility dimensions in Automotive sector.

Phase 4: Evaluation of the effect of the (degree) flexibility on the Business Performance in context of radicalness of products innovations using neurofuzzy technology

This phase focuses the evaluation of the effect of the extensiveness of flexibility on the business performance in context of radicalness of products innovations, using Neurofuzzy modeling (Figure 2). This model combines the Neural Networks and Fuzzy Logic technology (neurofuzzy technology) (CURY,1999; VON ALTROCK, 1997). Here this model supports the degree (global) of effect of flexibility and agility on the business performance (results), as it allows to evaluate the desirable rate toward the acceptable business performance in the sectors different in manufacturing companies. 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 are extracted from the independent variables (agility and flexibility drivers). The linguistic terms assigned to each IV are: High, Medium and Low: These variables were extracted (10 variables – agility dimensions and
flexibility dimensions) from the independent variables (Phase 2): Flexible Process, Flexible Market, Flexible Program, Flexible Expansion, Flexible Operations, Flexible mix, Flexible delivery, Flexible volume, Flexible New Products, and Flexible Generic. The IVs in the model, which are transformed into linguistic variables with their respective Degrees of Conviction or Certainty (DoC), with the assistance of 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).

**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: Flexible mix Performance, Flexible delivery Performance, Flexible volume Performance, and Flexible new products Performance.

**Determination of Output Variable (OV) – Effectiveness rate global performance of the business performance in the companies/sectors:**

The output variable (OV) of the neurofuzzy model proposed was called Effectiveness Rate Global Performance (ERGP) of business in sectors.

**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, i.e., computing the IF rules part; and (ii) composition, the THEN part of the rules.

**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. The output variable (OV) of the Neurofuzzy model proposed was called Effectiveness Rate Global Performance (ERGP) of business in sectors. By way of demonstration, using assigned IT (average) (Sector Chemicals & Cosmetics) 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=0.50, HIGH=0.30. The rate is 0.8876. With this result (Rate: 0.8876) produced for a better combination and interaction of drivers (variables) of flexibility on business performance in context of radicalness in product innovation, that converged toward a single parameter, it is feasible to assert that this combination of drivers of flexibility in Chemicals & Cosmetics sector at this time, can at least ensure the business performance desired by the Chemicals & Cosmetics sector at that time.

Figure 2: Neurofuzzy Model

It is plausible that the sector maintains at least this value (0.8876), which ensures the desired performance. The results confirm the Hypothesis - H2: The extensiveness of flexibility in manufacturing system have effects to a greater or lesser degree on the business performance in USA companies/sectors different; i.e., the effectiveness rate global performance of success (ERGOPS) of the product innovations depends on the combination and interaction of the flexibility in manufacturing system of USA companies/different sectors; i.e., the effectiveness rate global performance of success (ERGOPS) of the product innovations depends on the combination and interaction of the high flexibility in manufacturing process of USA companies/sectors. To illustrate this, assuming that the study-object sectors demonstrate the following effectiveness rate global performance of the business performance – rates: Chemicals & Cosmetics: 0.91 (91%); Food, Tobacco & Beverage Fmentation: 0.76 (76%); Hardware & Electronics: 0.95 (95%); Household Goods: 0.79 (79%); Manufacturing & Medical: 0.86 (86%); Oil, Gas, & Energy: 0.81 (81%); Pharmaceuticals:0.82 (82%); Telecommunications: 0.89 (89%); and Automotive: 0.85 (89%) (Figure 3).
Figure 3: Effectiveness rate global performance of the business performance – USA

<table>
<thead>
<tr>
<th>Industry</th>
<th>Effectiveness Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automotive</td>
<td>85%</td>
</tr>
<tr>
<td>Telecomunications</td>
<td>89%</td>
</tr>
<tr>
<td>Pharmaceuticals</td>
<td>82%</td>
</tr>
<tr>
<td>Oil, Gas, &amp; Energy</td>
<td>81%</td>
</tr>
<tr>
<td>Manufacturing &amp; Medical</td>
<td>86%</td>
</tr>
<tr>
<td>Household Goods</td>
<td>79%</td>
</tr>
<tr>
<td>Hardware &amp; Electronics</td>
<td>95%</td>
</tr>
<tr>
<td>Food, Tobacco &amp; Beverage Fmentation</td>
<td>76%</td>
</tr>
<tr>
<td>Chemicals &amp; Cosmetics</td>
<td>91%</td>
</tr>
</tbody>
</table>

The results of this study indicate that the respondents generally perceive that flexibility (extensiveness) has a positive impact on business performance of different sectors, but, it is concluded that: Hardware & Electronics (0,95) and Chemicals and Cosmetics Sectors show efficiency in the combination of their of flexibility strategies in context of radicalness in product innovation, based on the performance expectations (Business results). Companies experience an increasing importance for implementing sustainability concerns into their processes and product offerings. The combination of extensiveness of flexibility in sustainable manufacturing system carries a significant potential to foster the environmental sustainability, but that this potential is highly context dependent. On the other hand, the Chemical industry is highly innovative and its new products are important in stimulating innovation and in other industrial sectors. In fact, Rising advancements in manufacturing sectors force manufacturers to rethink and redesign their existing systems in order to cope with the challenges that emerged with globalization and environmental concerns. An increase in customer awareness and pressures from stakeholders shifted manufacturers’ focus; no longer were financial benefits the primary concern in the contemporary business environment (SHANKAR, KANNANAND, and KUMAR, 2017).
5. Final words

This research aims to verify the relationship between product innovation radicalness and extensiveness of flexibility of sustainable manufacturing system in most innovative companies. Furthermore, this research examines how the flexibility affects the smart factories performance (outcomes). The study was tested in most innovative companies of different sectors from the USA in the period 2011 to 2017. Of the results analysed, by far the most important factor is the management style. A clear need here is that management should provide strong support for products radical innovation needs and to be able to create an atmosphere of trust, co-ordination and control. A survey was developed for USA companies (Survey) 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 radicalness 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.

References


