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**SEARCH STRATEGY ON PRODUCT INNOVATION PROCESS:  
 THEORY AND EVIDENCE FROM THE EVOLUTION OF AGROCHEMICAL LEAD DISCOVERY PROCESS**

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**ABSTRACT**

This paper investigates different methods of problem solving strategy – dubbed in this paper as “Search Strategy” – in the process of Product Innovation. It objects the basic assumption of current models of Product Innovation Process (PIP) proposed by previous literature which considers *unrealistically* that the product innovation’s actors – the product innovators – are hyper-rational, homogenous and non choice-restricted actors. In order to take into account the more realistic view of the product innovators – bounded rationale, heterogeneous and choice-restricted actors –, this paper proposes an alternative model of Product Innovation Process based on the Science of Cognitive Psychology. According to this framework, the options of Search Strategy available to each product innovator depend on certain cognitive abilities which the product innovator is able or not to use. To examine the validity of this theoretical framework, this paper investigates the phenomenon of the evolution of discovery methods in the Agrochemical lead discovery process. Data for this investigation is gathered through chronological product innovation survey from agrochemical patents data base and through publications index data base. Result from this investigation seems to confirm the above argument.

**KEYWORDS:** Search Strategy; Product Innovation Process; New Product Development Process; Cognitive Model; Cognitive Ability; Bounded Variation.

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## 1. INTRODUCTION

This paper tries to understand the use of different modes of problem solving strategy – dubbed in this paper as Search Strategy – within the process of Product Innovation. Rather than trying to discover the best practice of Product Innovation Process, this paper tries to accommodate various models of Product Innovation Process – many of which have been proposed by the previous literature – and adds the conditions for their use. By synthesizing these various models of Product Innovation Process, this paper tries to build a theoretical framework of Product Innovation Process which not only it can be further tested but also, most importantly, it can accommodate a more realistic assumption of Product Innovators – the actors in the Product Innovation Process. In this paper, the phenomenon of the evolution of Agrochemical Lead Discovery strategy will be used to assess the validity of this theoretical framework.

The second section of this paper will discuss the previous literature on Product Innovation Process. It argues that the majority of Product Innovation Process literature believes that there is one best way of conducting Product Innovation Process and every Product Innovator is assumed to be able to make use of it. This paper objects this unrealistic assumption of innovators based on the evidences from various case stories on individual product innovation study that clearly indicate the bounded rational, heterogeneous and choice-restricted nature of Product Innovators. It then raises, at the end of the section, the important question that this paper tries to answer: what factors affect and limit Product Innovators search behavior within the process of Product Innovation ? In the third section, this paper will propose a new theoretical framework of Product Innovation Process based on the science of Cognitive Psychology in an attempt to take into account the more realistic view of Product Innovators. Fourth section describes the methodology of research used in this paper to assess the validity of the framework to answer the research question by using the well-known phenomenon of the evolution of Agrochemical Lead Discovery Process while the fifth section unveils the result of this investigation. Finally, sixth section closes this paper with a conclusion.

## **2. PREVIOUS LITERATURE AND CRITICS ON THE ORTHODOX MODELS OF PRODUCT INNOVATION PROCESS**

The way Product Innovators solve their product development problem has been widely discussed on various Product Innovation Process literature or New Product Development Process literature. Several well-known reviews have also been written by various scholars to summarize, categorize or evaluate different models of Product Innovation Process or New Product Innovation Process (see for example Saren (1984), Calantone & Di Benedetto (1990); Forrest (1991); Thomas (1993); for comprehensive review on the different models of Product Innovation Process). In this paper, those literature will be divided into two main categories: literature that emphasizes on the single model of Product Innovation Process (dubbed as Unitarianism Model) and literature that tries to integrate the variety of Product Innovation Process' model into one framework of analysis (dubbed in this paper as Pluralism Model).

### ***2.1. MAIN UNITARIANISM MODELS OF PRODUCT INNOVATION PROCESS***

The Unitarianism literature emphasizes on the single best model of Product Innovation Process. The scholars in this line of literature usually try to develop a model of Product Innovation Process which is destined to be prescriptive, normative and general. The main research question that this line of literature tries to answer is how the model of Product Innovation should look like in order to achieve successful Products. The virtue of this model is to guide product innovators to achieve best result by giving them procedures and references that can be used to warn them against the danger of deviation from the ideal norms of best practice. Methodology of research of these kinds of literature is usually based on the search for best practices from the successful product innovation case studies and the avoidance of mal-practices from the unsuccessful product innovation case studies. The majority of this literature has its origin from Marketing discipline (see for example more recently Crawford & Di Benedetto, 2000) or Engineering discipline (see for example Ulrich & Eppinger, 1995). The main Unitarianism models of Product Innovation Process are presented in the table 1 below, categorized according to their basic structure of the model.

**Table 1: Different Unitarianism Models of Product Innovation Process: Selected Studies**

|            | Category    | Example of Study                            | Main Concept                                | Type of Study/ Methodology  | Samples/ Unit of Observation               | Context   |  |
|------------|-------------|---|---|---|--|---|--|
| Structured | Simple      | Successive                                  | Cooper (1987)                               | Stage Gate  | Empirical Survey and Multiple Case Studies | Hundred of Successful and Unsuccessful New Product Development Projects | Hundred of Canadian Manufacturing Firms              |
|            |             |   | Wheelwright & Clark (1992)                  | Development Funnel  | Multiple Case Studies                      | Hundred of Development Project  | Hundred of Manufacturing Firms in US, Japan & Europe |
|            |             | Iterative (Several Loops)                   | Barnett & Clark (1998)                      | Iteration of Design-Build-Test  | Multiple Case Studies                      | Product Development Projects  | Six US Material Firms                                |
|            |             | Cyclic (Continuous)                         | Padmore, Schuetze & Gibson (1998)           | Continuous Cycle of Activities  | Theory/ Concept                            |   |  |
|            | Concurrence | Interwoven of Successive Phase              | Harvard Auto Study (Clark & Fujimoto, 1991) | Cross Functional Step by Step Integration/ Step by step overlapping phase | Empirical Survey and Multiple Case Studies | 25 Development Projects   | 20 US, Europe and Japan Automobile Firms             |
|            |             |   | Pugh (1991)                                 | Total Design  | Theory/Concept                             |   |  |
|            | Network     | Multiple Connectivity of Flow of Activities | Adler, Mandelbaum, Nguyen, Schwerer (1996)  | PERT in Product Innovation Process  | Case Study                                 | Organization  | One US Electrical Diversified Firm                   |
|            |             |   | Web   | Josty (1990)  | Interrelationship of Many Actors           | Multiple Case Studies   | Product Development Projects                         |
|            |             | Systemic                                    | Ford & Sterman (1998)                       | System Dynamic  | Modeling                                   |   |  |
|            |             | Chaotic                                     | Takeuchi & Nonaka (1996)                    | Rugby Style   | Multiple Case Studies                      | 7 Successful Development Projects                                       | 5 Japanese Firms                                     |
| Chaotic    |             |   |   |   |  |   |  |

The Unitarianism scholars believes that there is one best model of Product Innovation Process for every situation or condition that can guide them to successful Products (Saren, 1984). They hope that every Product Innovator (or Product Developer) is able to apply their “recipe” model whatever Product Innovator’s specific background and whatever conditions that Product Innovator faces during the process of Product Innovation. By hoping so, they indirectly assume that all Product Innovators are all the same, capable to act rationally and capable to have free choice in their Product Innovation Process.

## **2.2. MAIN PLURALISM MODELS OF PRODUCT INNOVATION PROCESS: A CONTINGENCY-BASED REVIEW**

Unlike Unitarianism literature, Pluralism literature believes that there is no single model of Product Innovation Process which is highly effective. The optimal model of Product Innovation Process varies depending on certain contingency factors. The question that this line of research tries to

answer is what contingency can be associated with what model of Product Innovation Process. Rather than trying to build an ideal model, this line of literature tries to identify different variances in the practice of product innovation. The main Pluralism models of Product Innovation Process are presented in the table 2 below.

**Table 2: Different Pluralism Models of Product Innovation Process: Selected References**

| References                      | Variations in Product Innovation Process Model   | Contingencies   |
|---------------------------------|--|---|
| Shrivastava & Souder (1987)     | Stage-Dominant Model, Process-Dominant Model and Task Dominant Model   | Environment (Market & Technological Uncertainties); Organization (Technological Complexity, Structure, Culture and Norms) |
| Miller & Blais (1993)           | Science-based product innovation, Entrepreneurial fast-track experimentation, Global cost leader-type of innovation and Conventional reliance on information technology and process adaptation | Industrial context, Firm's competencies, Business opportunities, Managerial Preferences                                   |
| Rothwell (1994)                 | First, Second, Third, Fourth and Fifth Generation of Innovation Process  | Macro-economic condition  |
| Utterback (1994)                | Process that can nurture the generations and selections of many ideas vs. Process that can improve efficiently and rapidly some initial basic ideas.   | Industry Life Cycle   |
| Shenhar & Dvir (1996)           | Different types of project management for Product Innovation   | Technological Uncertainties and Product System Architecture   |
| Coombs, McMeekin & Pybus (1998) | Type 1, Type 2 and Type 3 of R&D Project   | Technology and Market Uncertainty, Product Impact.  |
| O'Shea & McBain (1999)          | Product Innovation Process based on experimentation and testing vs. Product Innovation Process based on rational plan  | Strategic Choice  |
| MacCormack (2000)               | Stage-Gate Model vs. Flexible Model  | Level of Uncertainty faced by the Development Teams   |

As it can be seen in the table 2, the majority of Pluralism literature focus their attention on the environmental types of contingency. The Pluralism scholars believe that Product Innovation Process should be tailored according to the environment factors that the Product Innovators face during the process of Product Innovations (MacCormack, 2000). Here, the scholars start to realize that heterogeneity amongst the innovators exist and persist and that heterogeneity has its origin from the environment within which the Product Innovation takes place. Hence, they assume indirectly that Product Innovators are different across different environments but facing the same environments, all innovators will behave similarly. In other words, inside the same environment, all Product Innovators are homogeneous. Also, from this assumption, it can be further implied that the Product Innovators are able to choose without problem any environment within which they can have the optimum advantage.

### **2.3. CRITICS ON THE ORTHODOX MODELS OF PRODUCT INNOVATION PROCESS AND THE RESEARCH QUESTION**

The immediate question arising from the above review is whether the Product Innovators are really similar to the ones that the orthodox literature assumes. The closer look into some Product Innovation case stories seems to reveal that the reality is more complex than the orthodox literature assumption. First of all, Product Innovators are different and behave differently even within the same industrial sector. Rolls-Hansen (1997) shows that in the early 20<sup>th</sup> century, Swedish plant breeders differed significantly with British plant breeders on the way they developed the improved plant material. Swedish breeders were ready to apply the Genetic Theory developed by Mendel and approach the problem of plant breeding more rationally while the British breeders refused to accept the “new science” and remained relying on mass screening. Secondly, Product Innovators can not always act rationally. In their article on the evolution of drug development in oncology, Markman and Peereboom (1997) shows that the approach for developing oncology drugs differ significantly from serendipity in the early 40s towards more rational approach nowadays due to the advance on Product Innovators knowledge. In fact, like Simon’s (1957) argument, Product Innovators can only behave rationally within their cognitive limits and therefore until after the knowledge of developing oncology drugs is enough to approach the problem more rationally, the development strategy remains serendipity based on random screening. Finally, Product Innovators do not always have freedom of choice in choosing their Product Development strategy. Mary Tripsas’ (1997) study on the innovation in Typesetter industry shows how certain Product Innovators (in this case Typesetter firms) do not have a freedom in choosing their product development strategy due to their peculiar background. These natures of Product Innovators have been reported by much wider studies on inventors or innovators’ behavior during the process of Product Innovation (see for example previously Jewkes *et . al.*,1969 or more recently Weber & Perkins, 1992)

The examples above confirm that in reality Product Innovators are different amongst each other, have limited horizon of rationality and restricted in their options on solving Product Innovations problems according to their peculiar background. These evidences clearly contradict the belief of the Unitarianism school of Product Innovation and even the Environmental Contingency School of Product Innovation. Product Innovation models developed by both schools, in particular the Unitarianism school, have little theoretical value to be able to be used outside its practical purpose due to this lack of realism. Even though they may be extremely useful for prescriptive purposes, they are very weak in their explanative power.

Taking the example of Nelson and Winter's (1982) effort to consider the realistic assumption of the Economic actors in the Economic analysis, this paper takes the same initiative of considering the realistic assumption on Product Innovators in the discussion of Product Innovation Process. The **Research Question** that this paper want to answer is, **within a Product Innovation Process, what affect and limit the use of certain Search Strategy by Product Innovators.**

### **3. TOWARDS A NEW THEORY OF COGNITIVE-BASED INNOVATION PROCESS**

To answer that question, one should understand the nature of Product Innovation Process. Despite some propositions that consider Product Innovation Process as Decision Making Process (e.g. Ronkainen, 1985); as Communication Process (e.g. Allen, 1977) or as Hermeneutic Process (Piore *et. al.*, 1994), the majority of literature seems to agree that Product Innovation Process is basically a Problem Solving activity (Brown & Eisenhardt, 1995). As Problem Solving activity, Product Innovation Process may include identifying and defining problem, solving problem and implementing solution. If the problem definition is mainly a political process (Prasad & Rubenstein, 1994) while the solution implementation can be considered as a managerial process, this paper argues that Solving Problem is mainly a Cognitive Process and, in this paper, the focus of our attention is on the way the Product Innovation problem is solved by Product Innovators – in the other words: The Product Innovators Search Behavior in the process of Product Innovation.

### ***3.1. COGNITIVE DIVERSITY AMONGST PRODUCT INNOVATORS***

Amongst any other subjects that deal with the issue of Problem Solving, Cognitive Psychology is the subject that concerns most with human problem solving issue. According to many literature in this subject, problem solving has three crucial elements: a goal state, a starting state and a set processes that can transform a starting state into a solution state as required by the goal state (Newell & Simon, 1972). Any of these three elements may be poorly or well specified according to cognitive ability of each individual solver (Garnham & Oakhill, 1994). This differences in cognitive ability affects the solver ability to apply a particular problem solving strategy (Best, 1999).

In Product Innovation Process, the goal state can be associated with the product innovation problem. The starting state can be associated with the prototype of solution and the set of transforming process can be associated with the testing procedures that can transform the prototype of solution into the proper solution. Product Innovators has different ability in specifying each of those three elements. Some innovators can parse or decompose the problem into several independent sub-problems that can be attacked semi-independently while others can not do it. Some innovators are able to design beforehand the starting solution while others are not able to do it. Finally, some innovators are able to devise a transforming process that can be repeated many times in the event of repeated failure while others are not able to do it. These cognitive differences are the origins of heterogeneity amongst Product Innovators facing the problem of Product Innovation.

### ***3.2. BOUNDED VARIATION AND SELECTION OF SEARCH STRATEGY***

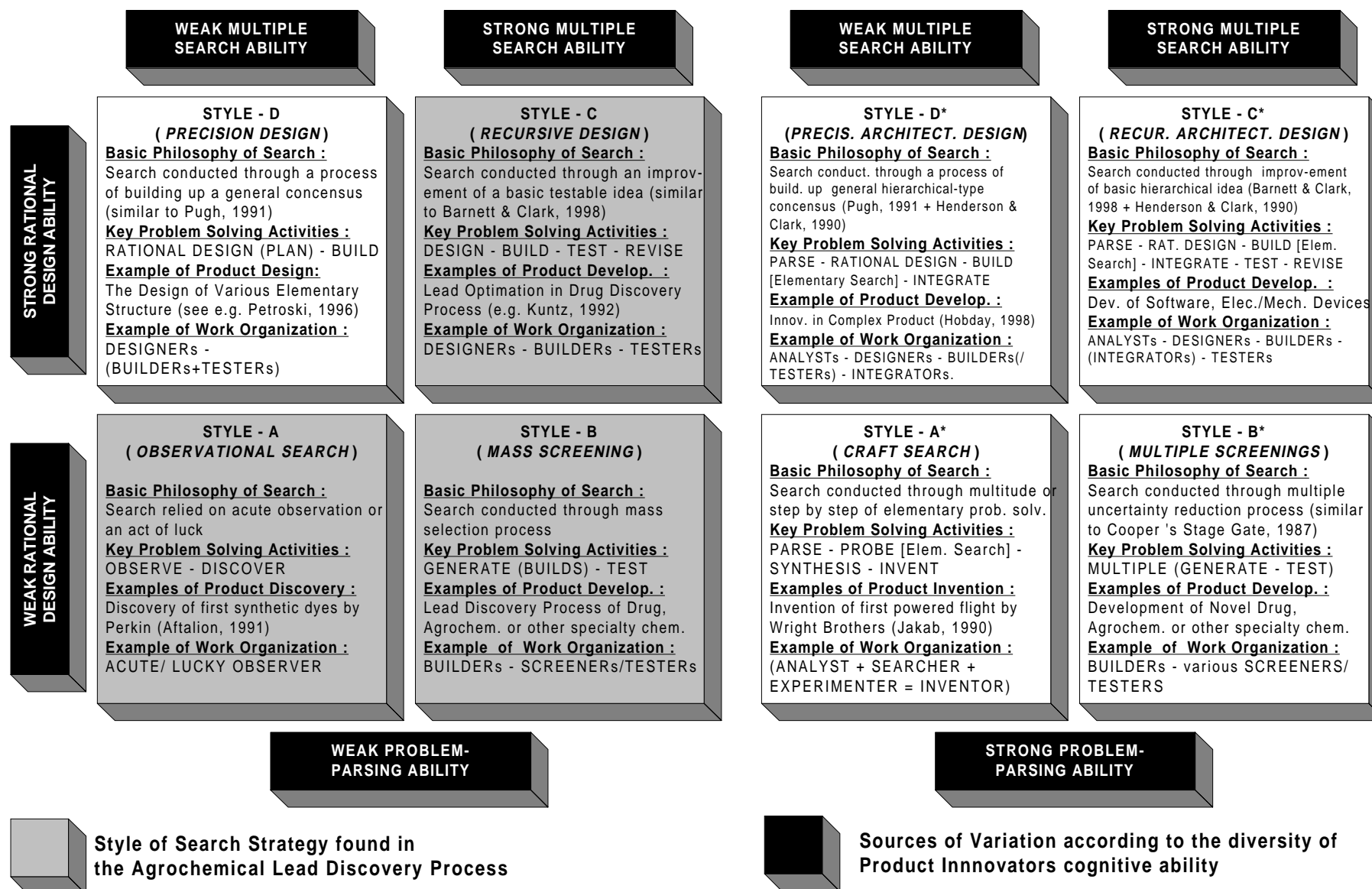
There are varieties of Search Strategy (problem solving strategy) depending on certain cognitive abilities that the Product Innovators are able or not to make use of them. The varieties of Search Strategy that Product Innovators are able to employ increase with the advance of their cognitive abilities. In other words, the varieties of Search Strategy available to Product Innovators are bounded or limited according to the extent of Product Innovators' cognitive abilities.

For example, in a conditions where simultaneously Product Innovators are not able to simplify their product innovation problem into more simple sub-problems that can be attacked independently, are not able to design beforehand a workable prototype of solution as a starting point and are not able to devise a reliable multiple search technique, the best thing they can do is to observe and wait until their luck turns up. Once they are able to devise a reliable multiple search technique, the Search Strategy options available to them increase. They do not only rely on the use of Pure Observation in their search for novel product but also they are now able to use Mass Screening strategy to take advantage of their ability to devise a reliable multiple search technique. If, in addition, they are able to design beforehand a workable prototype of solution as a starting point, besides Pure Observation and Mass Screening strategy, they can use Precision Design strategy – where they plan carefully beforehand their prototype of solution before they build it – or use Recursive Design strategy (if they want to take advantage of their multiple search ability) – where they can apply several iterations of Design-Build-Test-Revise activities.

In a situation where several Search Strategies are possible to be used, the most advantageous search strategy perceived by Product Innovators will be most likely to be chosen. Similarly in a population of innovation, the more advantageous strategy will occur more frequently compared to the less advantageous ones. The advantage of a Search Strategy compared to the others can take form of either its relative advantage in the feasibility of search – the degree to which the search can be pursued within innovators cost and time constraint –; its relative advantage in the effectiveness of search – the degree to which the search can achieve the innovators intended goals – or its relative advantage in the efficiency of search – the degree to which the search achieves its intended goal within (or by using) the least possible resources.

The whole options of Search Strategy, categorized according to the diversity of Product Innovators cognitive abilities, can be seen in the figure 1.

Figure 1: Different Styles of Search Strategy



Two main reservations apply for this kind of analysis. The first one is the issue of oversimplification of the real complex process of Product Innovation. This theoretical framework is certainly a gross oversimplification of what really happen in the process of Product Innovation which consist of infinite gradation of Search Strategy and Human Cognitive abilities. Nevertheless, this oversimplification is somewhat useful and necessary for the purpose of conceptualization for further analytical study.

The second issue is concerning the dynamic nature of the goal state. The goal state that Product Innovators want to achieve is certainly in constant move, Nevertheless, even though goal is always in constant move, the Search Strategy that Product Innovators use to attain the goal state can always be categorized into the styles that have been mentioned previously in the figure 1.

### 3.3. *WORKING HYPOTHESIS*

From the theoretical framework developed above, it is clear that Product Innovators' cognitive abilities affect and limit their choice of Search Strategy during the process of Product Innovations. These cognitive abilities have their origins from the three crucial elements of problem solving activity. Therefore, the testable hypothesis related to the above research questions is that:

**H: The use of certain Search Strategy by Product Innovators depends on the following cognitive abilities:**

1. ***Problem Parsing Ability***: The ability of the Product Innovators to decompose their Product Innovation problem into meaningful sub-problems that can be attacked at least semi independently. The variability of this ability can be associated with the variability of Product Innovator in specifying the goal state, as mentioned by Cognitive Psychology literature. The important of this factor has been suggested by several authors (e.g. Newell & Simon, 1972; Von Hippel, 1990 or Weber & Perkins, 1992).
2. ***Multiple Search Ability***: The ability of the Product Innovators to devise a search technique that can be reliably repeated many times in the event of repeated failure. The

variability of this ability can be associated with the variability of Product Innovators in specifying the set of transforming process that can transform the starting state into the solution state, as mentioned by Cognitive Psychology literature. The important of increasing the throughput of search or experimentation has been suggested by some authors (e.g. Chandler, 1990; Thomke et. al., 1998 or Nightingale, 2000).

3. ***Rational Design Ability***: The ability of Product Innovators to rationally design a prototype of solution as a starting point. Rational Design here means that the Product Innovators have already a certain extent of knowledge about the cause and effect relationship about the problem that can be used to design a prototype of solution as a starting point. This knowledge about the cause and effect relationship is known also as [Rational] Design Knowledge. The variability of this ability can be associated with the variability of Product Innovators in specifying the starting state, as mentioned by Cognitive Psychology literature. The important of Design Knowledge in Product Innovation has been suggested by some authors (e.g. Rosenberg, 1976 or Vincenti, 1990).

For the reason explained later, this paper will try to assess the validity of the last two of the above cognitive abilities.

## **4. METHODOLOGY OF RESEARCH**

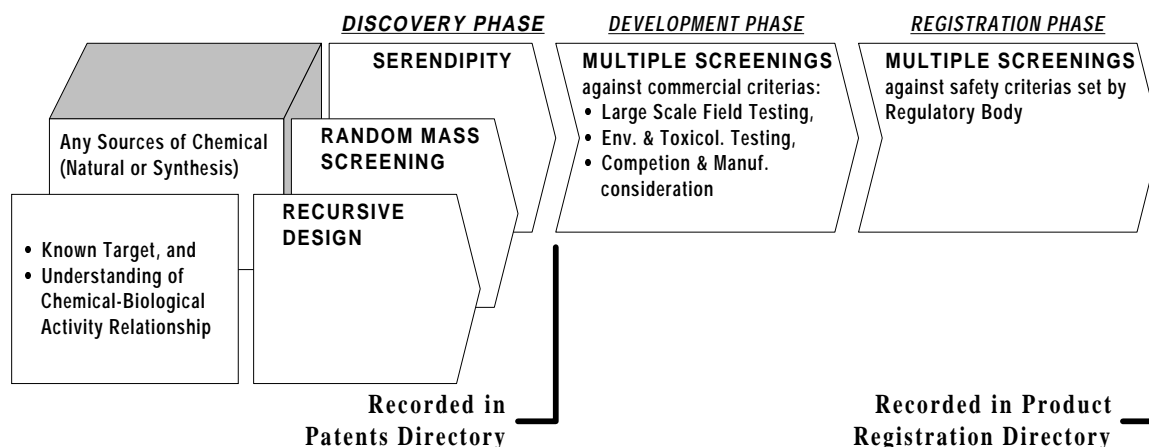
### ***4.1. CHOICE OF STUDY CASE AND AN OVERVIEW OF AGROCHEMICAL DISCOVERY PROCESS***

To assess the validity of the above hypothesis, it is preferable to select, for a study case, one product-field which contains a significant samples of Product Innovation records which, in turn, have been discovered, invented or designed by all Search Strategies mentioned in the theoretical framework. This is certainly a very difficult task. However, if we try to narrow the scope of our assessment by trying to assess the validity of, at least for the beginning, some parts of the above theoretical framework, we can find, with relative easiness, some potential study cases which can be

suitable for this research, like the case of the evolution of discovery process in many Specialty Chemical industries such as Pharmaceutical industry, Advanced Material industry or Agrochemical industry. For the reasons related to the accessibility of the data and the relative uniformity of the sample records, this research chooses the evolution of Agrochemical Lead Discovery Process as the case study to assess the validity of the above arguments.

Although the detailed processes differ greatly from Product Innovation case to Product Innovation case, the process of Agrochemical Discovery tends to follow a common pattern, similar to Multiple Screening strategy where various chemical lead compounds – considered as prototypes of solution – undergo several successive independent screens/tests to cope with the complexity of the final product requirements (Lever, 1990). Basically the whole discovery process can be divided into three phases: Discovery Phase, Development Phase and Registration Phase (ACPA, 1994). In the discovery phase, most efforts are devoted to discover lead compounds that shows certain extent of pesticidal activity while in the development phase most efforts are devoted to select lead compounds that exhibit the optimum commercial advantages and finally in the registration phase, the effort is devoted to select the potential compounds which have the safest properties as required by the regulation. According to Evans & Lawson (1992), in the discovery phase, the lead compounds can be discovered through Random Leads, Analogue Chemistry, Natural Products and Biorational Design. In our framework, the strategies similar to those explained by Evans & Lawson (1992) are Observational Search, Mass Screening and Recursive Design. By concentrating our study case in the early phase of Agrochemical discovery process – the Agrochemical Lead Discovery Process – the scope of theoretical assessment in this paper is narrowed into the problem of two cognitive abilities (see figure 1 above). The Product Innovation Process in the Agrochemical industry can be schematized in the figure 2 below.

**Figure 2: Product Innovation Process in Agrochemical Industry**



The evolution of Search Strategy in the Agrochemical Discovery Process has been reported by various scholar, mainly from scientific community (see for example Stetter, 1993 and more recently Stetter & Lieb, 2000). In this paper, this phenomenon will be investigated in-depth in order to be able to be used for the hypothesis assessment purpose. The investigation itself is based on product innovation survey and the result will be primarily and mainly descriptive with some early effort towards more confirmatorial statistical interpretation.

#### 4.2. DATA SOURCES AND ANALYSIS

##### *Sources of Product Innovation Survey*

The Product Innovation cases used in this study are collected from *Pesticide Manual*, starting from Volume 1 until Volume 12. These Manuals contain the directory of Chemical Compounds that have (or had) been used or marketed as Agrochemical (Pesticide, Herbicide, Fungicide, etc.). More recent cases, in particular about the Pesticide discovery through Design and High Throughput Screening, are collected through *Web of Science*. Information about the Product Innovation cases (as indicated from those Pesticide Manuals) themselves such as the list of inventors, the year of invention etc. is gathered from the earliest patent of the particular chemical compounds as Agrochemical, as recorded in *Chemical Abstracts*<sup>→</sup>. Information about the earliest cases (before

1907) is gathered from the Pesticide Manuals themselves or from various pesticide history literature. The study contains over 1150 Agrochemical Innovation cases ranging from ancient time until the year of 2000.

### *Concept and Categorizations*

#### **DEPENDENT VARIABLE**

**Search Strategy:** The type of Search Strategy that was used to discover a particular Agrochemical compound is deduced from the composition of inventors' expertise written in the inventors list of the earliest patent of that chemical compounds. For example, the existence of Biologists (such as Agriculturists) only in the inventors list of the patent can be interpreted as an indication of the use of Pure Observation during the discovery of Agrochemical. The existence of Organic Chemical Synthesists and Biologists together in the same patent can be interpreted as an indication of the use of Mass Screening while the existence of Molecular Modelers, Organic Chemical Synthesists and Biologists together in the same patent can be used as an indication of the use of Recursive Design during the process of Agrochemical Lead Discovery. The expertise of the inventor is deduced mainly from the pattern of publication of the inventor recorded in the *Chemical Abstracts*<sup>→</sup>. This procedure is confirmed randomly through the interview with various practitioners in the Agrochemical sector.

#### **VARIOUS INDEPENDENT VARIABLES:**

**Type of Applicant (Individual Vs. Corporate/ Institutional):** The type of applicant, written in the first page of patent, is used to guess the types of Search Strategy mainly along the Single-Multiple search dimension. It assumes that corporate has more ability to do multiple search strategy (for example due to its ability to coordinate various expertise) than individual applicant.

**Number of Applicant's Product Innovations (Few Vs. Many Product Innovations):** This variable is used also to guess the types of Search Strategy mainly along the Single-Multiple search dimension. Few number of applicant's product innovations means that, at the moment of certain

Product Discovery, the applicant has less than 5 other product innovations discovered within plus/minus five years of interval. It assumes that single search method produces fewer product innovations than multiple search method.

**Period (within the interval of 5 Years) of the discovery of certain Agrochemical compared with the period of the early adoption of various scientific and technological knowledge relevant to the Agrochemical Lead Discovery Process (Before Vs. After) by the Agrochemical**

**sector:** The idea is that before the adoption of certain scientific and technological knowledge, the innovators are not able to make use of that particular knowledge. In this study, it is assumed that the ability of innovator to use a particular knowledge is not much different than the ability of wider scientific community. This assumption can be considered as sufficiently adequate, since all knowledge-subjects considered in this study are within the area of biology and chemistry which have been recorded extensively as early as the end of nineteenth century. All knowledge-subjects used in this study are determined through various scientific article in the area of Agrochemical Discovery and confirmed by interviews with practitioners. The period of early adoption of a particular knowledge-subject by Agrochemical sector is determined through the earliest use of certain keywords related to that particular subject in the scientific publications published by at least three distinct Agrochemical firms. The pattern of the evolution of those keywords is gathered from *Chemical Abstracts*<sup>→</sup> through its electronic data interface such as HCAPlus<sup>→</sup> and HCAOLD<sup>→</sup> from STN Service. The information concerning this period of emergence of particular science is in turn confirmed by various literature in the subject of History of Science. The list of all knowledge-subjects considered in this study can be seen in the table 3 in the result section.

**SOME CONTROL VARIABLES:**

Since market condition differs greatly amongst different types of Agrochemical such as Fungicides, Herbicides and Insecticides (European Commission, 1997), it is interesting to see whether this

product-market diversity affects or limit the choice of certain Search Strategy in the process of Product Innovation as having been proposed by some Pluralism literature.

Other control variable includes the comparison between the period of certain agrochemical discovery with the period of the emergence of tighter regulations in the mid 1960s (Marco *et. al.*, 1991). It is interesting to see whether the change in the environment within which the innovation takes place can have an effect on the innovator's search behavior.

### *Method of Analysis*

The principle of analysis used in this study is basically to determine which independent variables (estimators) best estimate the occurrence of the dependent variable. The analysis itself is primarily descriptive where the estimators will be determined intuitively through the pattern of co-evolution between the dependent variable and various independent variable. Control variables are used to check whether there is significant departure from the usual pattern of co-evolution at different level of category of the control variable. Statistical methods will be used as the supporting evidence only.

## **5. RESULTS AND DISCUSSION**

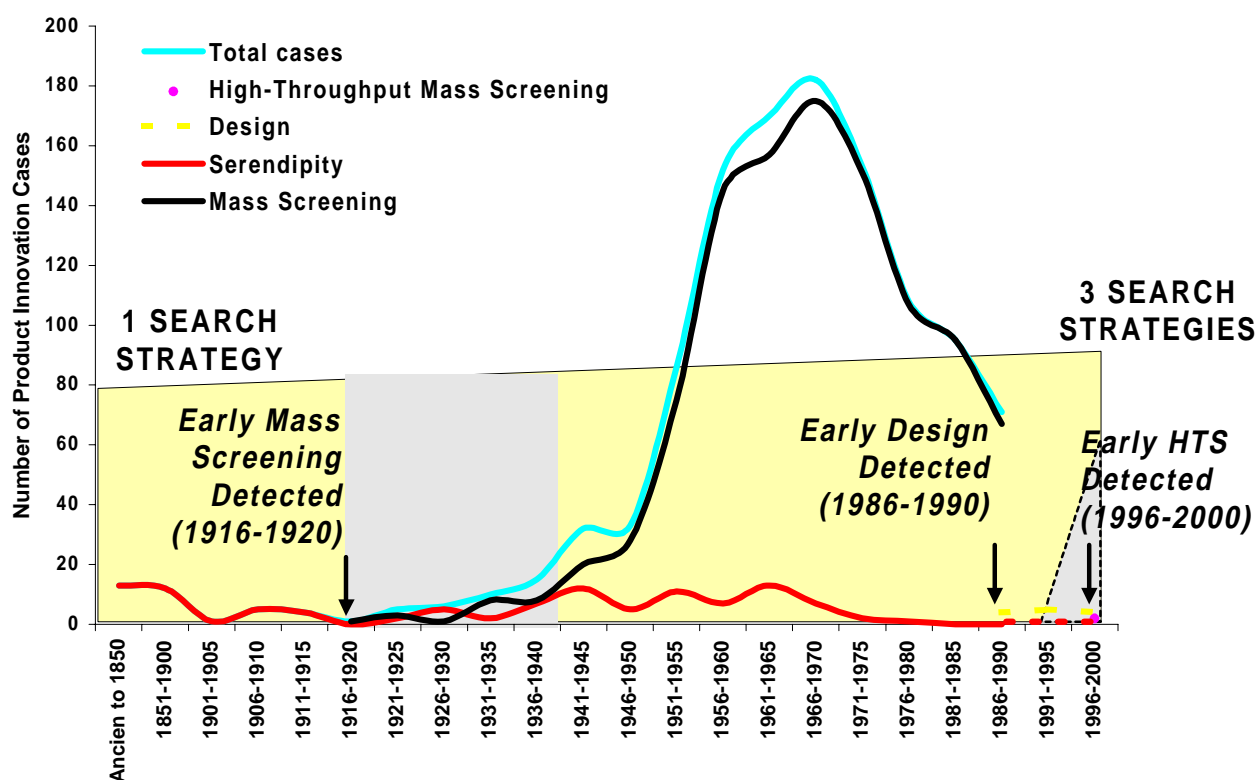
### ***5.1. PRODUCT INNOVATION SURVEY ON THE AGROCHEMICAL LEAD DISCOVERY PROCESS***

Some results emerge from the Product Innovation Survey on the Agrochemical Lead Discovery Process. The cluster analysis on the composition of inventors expertise produces 6 main clusters depending on the existence or the non-existence of Molecular Modeler, Organic Synthesis Chemist or Biologist in the inventor list. The major clusters consist of "No inventor", "Biologist only", "Organic Synthesis Chemist only", "Organic Synthesis Chemist and Biologist" and "Molecular Modeler-Organic Synthesis Chemist and Biologist". From further analysis and confirmation from (mainly e-mail) interview with pesticide scientists and from scientific publications, it is possible to reduce the number of main cluster into 3 main clusters labeled as Pure Observational Search, Mass Screening and Recursive Design. The random checking on the member case of these main clusters

shows a good association with the expected categorization known in the industry by Serendipity, Random Screening and Rational/Bio-rational Design.

The evolution of Search Strategy from the ancient time to the year 2000 can be seen in the figure 3 below. The pattern of the evolution of product innovation (total cases) itself is similar to the one reported by Achilladelis *et. al.* (1987).

**Figure 3: The Evolution of Search Strategy in The Agrochemical Lead Discovery Process**



It can be seen from the figure 3 that even though the product innovation data is gathered until the year 2000, the information about the product discovery itself stops around 1990. This is due to the fact that it requires between 8 to 10 years to develop new marketable Agrochemical after its early discovery and, in this study, the analysis is concentrated at the early phase of Product Innovation. The discovery cases after 1990s are still recorded in various patent database but they more likely have not been marketed yet and therefore have not yet been recorded in Product Innovation directory. After 1990, only discovery cases that use Recursive Design and High

Throughput Screening are reported in this study. Obviously, they have not been marketed yet and there is no guarantee that they can be marketed later. That is why they are presented by dot lines. So, it should be noted that it does not mean that there is no any discovery using Pure Observation and Mass Screening anymore after 1990. Only in this study, their occurrences are not counted for deliberate reason. Therefore, this study fully realizes that the majority of Agrochemical Discovery in this period is still using Random Screening or Mass Screening (among around 300 Agrochemical patents recorded each year after 1990 by *IBM Delphion Patent Database*, only 13 patents – for the whole 90s – are known to be discovered through Rational Design). The reason for not counting the Observational and Mass Screening strategies is for being able to make the effect of Recursive Design sufficiently appear in the statistical calculation. By doing this, this study understand fully that it grossly overestimates the importance of Recursive design in the Agrochemical Discovery Process during 1990s.

From the figure 3, it can be seen that there has been an evolution of Agrochemical Discovery Process, similar to have been reported by various scientific literature (see for example Stetter & Lieb, 2000). The variety of Search strategy has been increased from one to three during all periods of evolution. The Observational search, the most simple of Search Strategy, still continues until nowadays even after the emergence of the other Search Strategies. As having been expected, the occurrences of Observational Search shows a fluctuated pattern which shows the unpredictable nature of this kind of search strategy. Mass Screening strategy started to appear during the period of 1916-1920 and, after the fluctuated period of 25 years, it took off until it reached its peak around 1966-1970 before it dropped continually until nowadays. The early recursive design was recorded much later in the period of 1986-1990 and has never taken off since. Another variant of Mass Screening strategy – High Throughput Screening techniques – started to appear in the period of 1996-2000.

From this result, it can be said that all strategies do not appear simultaneously but in succession. This indicates that before a certain time, innovators can not switch their search behavior into a certain search strategy which does not exist yet. Furthermore, all strategies do not appear in a predictable way. For example, Mass Screening appeared in the period of 1916-1920 when there was no apparent reason to appear. It is true that the observational search can not be controlled but it is not enough to be used as the reason for the emergence of Mass Screening because the Mass Screening itself endured the early fluctuated period for 30 years before taking off in the 50s. Also, the emergence of Rational Design can not be solely attributed to the decreasing effectiveness of Mass Screening strategy. Agrochemical firms have suffered for more than 25 years to be able to see the early result of Rational Design with mixed opinion (Stetter & Lieb, 2000).

The next logical question is what affect this phenomenon. What makes the emergence of certain search strategy ? But before answering these questions, this paper will discuss the evolution of scientific and technological knowledge related to the Agrochemical Discovery Process.

## ***5.2. THE EVOLUTION OF SCIENTIFIC AND TECHNICAL ABILITIES RELATED TO THE AGROCHEMICAL LEAD DISCOVERY PROCESS***

The result of bibliometric-based survey on the emergence of certain knowledge-subjects relevant to the Agrochemical Discovery Process is listed on the table 3 overleaf. There are 23 knowledge-subjects that can be related to one or more activities, important for the search process such as Designing, Building and Testing chemical compounds. The subjects are arranged chronologically according to their diffusion period in the Agrochemical sector – the period (within the interval of 5 years) within which at least three distinct Agrochemical firms start to use keywords related to the subjects. Complemented by the data from various literature on the subject of History of Science, the result of this survey covers practically the whole 20<sup>th</sup> century – the most important century in the History of Agrochemical Discovery.

**Table 3: Evolution of Scientific and Technological Knowledge related to Agrochemical Discovery Process: A Bibliometric-based Survey**

| Subject   | Scope of Keywords  | Period of Early Emergence*** | Period of Early Adoption in the Agrochemical Sector*** |
|---|--|------------------------------|--|
| Organic Synthesis Chemistry   | SYNTHESIS, PREPARATION OF  | 1820s                        | 1851-1900  |
| Study of Insects and Pests  | ENTOMOLOGY, INSECT   | Early 1800s                  | 1916-1920*   |
| Plant and Weed Science  | BOTANY, PLANT SCIENCE, WEED  | 1530                         | 1916-1920*   |
| Phytopathology  | MYCOLOGY, FUNGI, FUNGAL, PLANT PATHOLOGY, PLANT DISEASE, PHYTOPATHOLOGY    | 1850s                        | 1916-1920*   |
| Biological Assay (In Vivo Assay)  | ASSAY + PESTICIDES   | 1850s                        | 1916-1920*   |
| Crystal Structure Determination   | (X-RAY, CRYSTALOGRAPHY, DIFFRACTION) + (STRUCTURE)                         | 1910s                        | 1951-1955*   |
| Study on Molecular Structure  | (ELUCIDATION, DETERMINATION, ANALYSIS) + (MOLECULE, CRYSTAL) + (STRUCTURE) | 1850s                        | 1961-1965*   |
| Study on Molecular Spectroscopy   | (SPECTROSCOPY, IR, NMR, UV, MASS) + MOLECULE                               | 1950s                        | 1961-1965*   |
| Biochemistry Study on Plants, Insects & Microorganisms                              | BIOCHEMISTRY + (PLANTS, INSECTS, MICROORGANISMS)                           | 1900s                        | 1961-1965*   |
| Biochemistry Study on Pesticides  | BIOCHEMISTRY + (PESTICIDES, AGROCHEMICALS, INSECTICIDES, FUNGICIDES, etc.) | 1920s                        | 1966-1970*   |
| Enzymes Study on Plants, Insects & Microorganisms                                   | (ENZYME, BIOSYNTHESIS) + (PLANTS, INSECTS, MICROORGANISMS)                 | 1900s                        | 1966-1970*   |
| Enzymes & Cells Production Techniques (for In Vitro Assay)                          | (ENZYME) + (ISOLATION, PURIFICATION, PRODUCTION)                           | Mid 1940s*                   | 1966-1970*   |
| Biochemistry Mode of Action of Pesticides   | (BIOCHEMISTRY MODE OF ACTION, BIOCHEMICAL PATHWAY) + (PESTICIDES, etc.)    | 1967*                        | 1966-1970*   |
| Targeted Organic Chemical Synthesis Techniques                                      | (TARGET SYNTHESIS, DIRECTED SYNTHESIS, TOTAL SYNTHESIS, RETROSYNTHESIS)    | 1950s                        | 1971-1975*   |
| Structure Activity Relationship   | STRUCTURE ACTIVITY RELATIONSHIP  | 1960s                        | 1971-1975*   |
| Study on Molecular Biology  | MOLECULAR AND CELL BIOLOGY   | 1950s                        | 1981-1985*   |
| Biotechnology   | BIOTECHNOLOGY  | 1970s*                       | 1981-1985*   |
| Molecular Modeling  | COMPUTATIONAL CHEMISTRY, COMPUTER AIDED MOLECULAR DESIGN, MOLECULAR DESIGN | 1970*                        | 1986-1990*   |
| Plants, Insects and Microorganisms Genomic  | (PLANTS, INSECTS, MICROORGANISM) + GENOMIC                                 | 1975*                        | 1986-1990*   |
| Study of Active Sites, Target Sites, Receptors on Weeds, Insects and Microorganisms | (ACTIVE SITE, TARGET SITE, SITE OF ACTION, RECEPTOR) + (PESTICIDES, etc.)  | 1972*                        | 1986-1990*   |
| Bioinformatic   | BIOINFORMATIC  | 1985*                        | 1996-2000*   |
| Mass Synthesis  | COMBINATORIAL CHEMISTRY, COMBINATORIAL SYNTHESIS, COMBINATORIAL LIBRARY    | 1990*                        | 1996-2000*   |
| High Throughput Screening   | HIGH THROUGHPUT SCREEN   | 1991*                        | 1996-2000*   |

\* Deduced from Bibliometric Study in the *Chemical Abstracts* →

\*\*\* Data on the earlier periods is obtained from various literature in the subject of History of Science

**NOTES FOR TABLE 3:** Organic Synthesis Chemistry = The achievement of Friedrich Wohler in synthesizing Urea in 1828; Entomology = The publication of "Introduction to Entomology" by William Kirby and William Spence in the early 1800s; Plant and Weed Science = According to History of Botany by F.G.J Sachs (1890); Phytopathology = Modern Era in the History of Phytopathology according to Whetzel, H.H. (1918): "An outline of the History of Phytopathology", Philadelphia, PA: WB Saunders; Biological Assay = The establishment of Agricultural Experimentation in the USA in the 1850s; Crystal Structure Determination = Invention of X-Ray Crystallography by Bragg in 1912; Study on Molecular Structure = Kekule's proposition on the structure of Benzene in 1858; Study on Molecular Spectroscopy = Introduction of various "atlases" of IR, UV, NMR and Mass Spectra of numerous organic compounds by American Institute of Petroleum Research in 1950s; Biochemistry Study on Plants, Insects and Microorganisms = According to Florkin, M. & Stotz, E.H. (1972): "A History of Biochemistry: From proto-Biochemistry to Biochemistry", in Comprehensive Biochemistry edited by Florkin, Amsterdam: Elsevier; Biochemistry Study on Pesticide = The investigation of plant biochemical inhibition by Otto Warburg in 1920; Enzyme Study on Plants, Animal, Microorganism = Edvard and Hans Buchner experiment that showed dead cell extracts can perform reactions of living cells in 1897; Targeted Organic Chemical Synthesis = Development of the Logic of Chemical Synthesis by Corey in the 1950s; Structure Activity Relationship = The earlier QSAR study by Corwin Hansch in 1960s; Molecular Biology = The early structural study on biological related molecule by Linus Pauling in the 1950s.

Table 3 shows that there is uneven emergence of the knowledge subjects related to the Agrochemical Discovery. The subjects emerged in unpredictable way. Chemistry related subjects and Biology related subjects preceded or followed one another or even fused between each other at random time interval (see column 3 of the table 3). Yet, all are useful for the Agrochemical Discovery Process. This is proven by their adoption sooner or later by the sector.

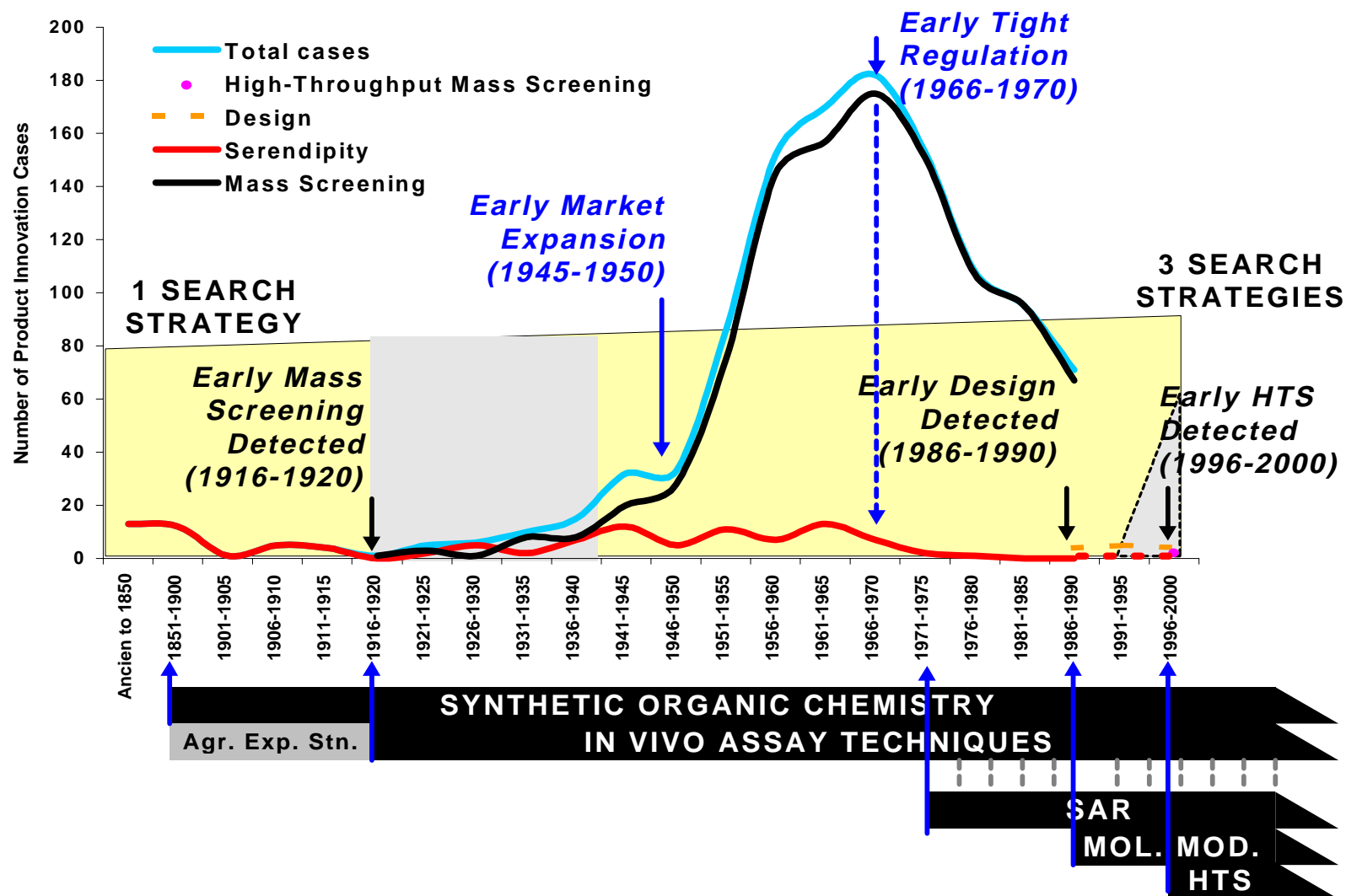
In this table, it can be seen also that the Agrochemical sector is always late in adopting new knowledge subjects (see column 4 of the table 3). There is no apparent logic in the adoption strategy of those subjects. Some subjects such as Mass Synthesis and High Throughput Screening were quickly adopted by the sector around ten year after their emergence. Other subjects such as Enzymes study and Biochemistry Study of Pests were only adopted 60 years after their emergence in the early 1900 and within that 60 years, Agrochemical sector had been adopted much “younger subjects” such as Crystal Structure Determination and the Study on Molecular Spectroscopy.

From this result, it can be concluded that knowledge-subjects relevant to the Agrochemical Discovery process emerged unevenly and adopted at different period of time by the Agrochemical sector. As there is no pattern of emergence as well as no pattern of adoption of technological and scientific knowledge-subjects, this signifies that the emergence of those knowledge-subjects is independent to the adoption policy of the Agrochemical sector. This finding seems to support Vincenti (1990) proposition that Scientific knowledge generating activities is independent to the Engineering knowledge generating activities.

### ***5.3. ASSESSING THE RELATIONSHIP BETWEEN INNOVATORS' COGNITIVE ABILITIES AND THEIR SEARCH BEHAVIOR: THE CASE OF AGROCHEMICAL LEAD DISCOVERY PROCESS***

To assess the relationship between the innovators' cognitive abilities and their search behavior in developing novel products, it requires an investigation into the co-evolution of innovators' cognitive ability and their Search Strategy in the process of Product Innovation. This can be done by juxtaposing or bringing together the result of both surveys. The result of this juxtaposition can be seen in the figure 4 below.

Figure 4: The Co-Evolution of Knowledge Subjects and Search Strategy in The Agrochemical Lead Discovery Process



From the figure 4 above, the phenomenon of co-evolution between the style of Agrochemical Lead Discovery Process as dependent variable and various knowledge subjects as well as environmental conditions becomes clearer. Intuitively, a coherent story can be built from these results. Along the period of evolution, the number of Search Strategy increases from 1 to 3 strategies. As having been understood, the product innovation cases using Observational Search strategy fluctuate along all the period of evolution due to, comprehensively, the uncontrollable nature of this kind of strategy. The Mass Screening strategy starts to be detected in the period of 1916 to 1920 coincided with the early adoption of various Biological (In Vivo) techniques by Agrochemical sector. This strategy endured a period of transition for more than 25 years before taking off in mid 40s and early 50s. The reason of this transition might be due to the lack of confidence from the sector about the advantage that can be offered by this strategy and might be due also to the lack of determining factor that can make the advantage of this new strategy become clear. But for sure, after the start of the expansion of Agrochemical market on the period after the World War II (Lever, 1990), the use of Mass Screening in discovering novel agrochemicals steadily increases. This may be due to the advantage of Mass Screening in delivering novel products comparing to the “accidental” chance of Pure Observational Search. Anyway, the more you increase your capacity of experimentation, the more you have a chance to hit a jackpot (Nightingale, 2000). Nevertheless, this does not mean that the sector abandons the Pure Observational strategy. There are still fluctuation of this strategy at the same time of the pervasive use of Mass Screening in the Agrochemical sector after 1950s. This steady increase of Mass Screening product innovation case stopped around the period of 1966 to 1970 coincided with the start of tighter regulation in the registration regulation of novel Agrochemicals. Tighter regulation means that innovators have to add more screening criteria within their process of Product Innovation. This conditions certainly diminish the effectiveness of Mass Screening strategy and the Agrochemical sector was not able to explore a novel strategy of search until after 1990s. It does not mean that the sector does not want to explore towards the use of novel search strategy that can

design beforehand a prototype of solution. The adoption by Agrochemical sector of several knowledge-subjects related to the ability to design beforehand a biologically active chemical compounds such as Biochemistry Mode of Action of Pesticide or Structure Activity Relationship started as soon as that period of 1966-1970. Nevertheless, not until the adoption of Molecular Modeling at the end of 1980s, the Recursive Design strategy started to appear in the 1990s. Again, other styles of search strategy are still widely used together with the Recursive Design strategy.

This story can be confirmed to certain extent by some statistical analysis. The appropriateness of independent variables (see section 4) in guessing the type of dependent variables for each individual dimension of theoretical framework can be seen in the table 4 overleaf. It can be seen from this table that Type of Applicant (Individual Vs. Corporate) and the Adoption of Biological Assay (Before Vs. After) estimate quite well the type of Search Strategy whether it is single or multiple search. The importance of the Type of Applicant comes with no surprise since Corporate-type of Applicant is more able to conduct multiple search by integrating different kinds of resources than Individual-type of Applicant. In the other hand, the Adoption of Molecular Modeling and High Throughput Screening (Before Vs. After) estimate best, comparing to the other variables, the type of Search Strategy whether it follows Rational Design search or not.

The appropriateness of the combination of any two independent variables in estimating the type of Search Strategy can be seen in the table 5 overleaf. The estimation is done by running Multinomial Logistic Regression of any two independent variables by considering only the main effect of the independent variables. Nagelkerk measure of association (Tabachnick & Fidell, 1996) is used as a measure of appropriateness of the combination of independent variables in estimating the type of search strategy. The best combination of any two independent variables in estimating the type of Search Strategy is achieved by the combination of the Type of Applicant (Individual Vs. Corporate) and the Adoption of Molecular Modeling (Before Vs. After). This result matches perfectly with the one predicted by the theoretical framework in which Corporate is more able to

integrate different kind of resources to conduct multiple type of search such as Mass Screening than individual while Recursive Design search can only be used after the adoption of Molecular Modeling knowledge subject.

**Table 4: The Goodness of Estimation of the type of Search Strategy (Dependent Variable) by Individual Estimator (Independent Variable), Interpreted through Cramer's criteria of the strength of association between two variables**

| ESTIMATOR   | SINGLE SEARCH STRATEGIES (Observational Search) Vs. MULTIPLE SEARCH STRATEGIES (Mass Screening and Recursive Design) | NON RATIONAL DESIGN SEARCH STRATEGIES (Observational Search and Mass Screening) Vs. RATIONAL DESIGN SEARCH STRATEGIES (Recursive Design) |
|---|--|--|
| Type of Patent Applicant (Individual Vs. Corporate)                       | 0.543***   | 0.016 <sup>?</sup>   |
| Applicant's Number of Product Innovations (Few Vs. Many)                  | 0.438  | 0.035 <sup>?</sup>   |
| (Before Vs. After) The Use of Organic Synthetic Chemistry techniques      | 0.316  | 0.060 <sup>?</sup>   |
| (Before Vs. After) The Use of Biological Assay techniques                 | 0.512***   | 0.023 <sup>?</sup>   |
| (Before Vs. After) The Use of Molecular Crystal Determination             | 0.506***   | 0.017 <sup>?</sup>   |
| (Before Vs. After) The Use of Molecular Structure Study                   | 0.336  | 0.061 <sup>?</sup>   |
| (Before Vs. After) The Use of Enzyme Study                                | 0.292  | 0.090  |
| (Before Vs. After) The Use of Structure-Activity Relationship (SAR) Study | 0.247  | 0.122  |
| (Before Vs. After) The Use of Molecular Biology Study                     | 0.137  | 0.229  |
| (Before Vs. After) The Use of Molecular Modeling techniques               | 0.087  | 0.343***   |
| (Before Vs. After) The Use of High-Throughput Screening (HTS) techniques  | 0.013 <sup>?</sup>   | 0.449***   |

\*\*\* Best Estimator

? Non Significant Value

**Table 5: The Goodness of Estimation of the type of Search Strategy (Dependent Variable) by the Combination of Two-Estimators (Independent Variable), Interpreted through Nagelkerke measure of association from Multinomial Logistic Regression (Tabachnick & Fidell, 1996)**

| Applicant Product Innovation Throughput | Organic Synthetic Chemistry | Biological Assay | Crystal Determinat. | Molecular Structure | Enzyme Study | SAR   | Molecular Biology | Molecular Modeling | HTS                |                               |
|---|-----------------------------|------------------|---------------------|---------------------|--------------|-------|-------------------|--------------------|--------------------|-------------------------------|
| 0.327                                   | 0.339                       | 0.372            | 0.378               | 0.388               | 0.383        | 0.387 | 0.379             | 0.396***           | 0.000 <sup>?</sup> | Type of Applicant             |
|   | 0.294                       | 0.351            | 0.369               | 0.343               | 0.356        | 0.355 | 0.333             | 0.339              | 0.000 <sup>?</sup> | Appl. Prod. Innov. Throughput |
|   |                             | 0.233            | 0.309               | 0.249               | 0.251        | 0.234 | 0.193             | 0.193              | 0.018              | Organic Synthetic Chemistry   |
|   |                             |                  | 0.341               | 0.325               | 0.340        | 0.335 | 0.314             | 0.321              | 0.000 <sup>?</sup> | Biological Assay              |
|   |                             |                  |                     | 0.309               | 0.334        | 0.341 | 0.348             | 0.363              | 0.000 <sup>?</sup> | Crystal Determination         |
|   |                             |                  |                     |                     | 0.217        | 0.228 | 0.245             | 0.266              | 0.243              | Molecular Structure           |
|   |                             |                  |                     |                     |              | 0.196 | 0.224             | 0.250              | 0.234              | Enzyme Study                  |
|   |                             |                  |                     |                     |              |       | 0.188             | 0.216              | 0.196              | SAR                           |
|   |                             |                  |                     |                     |              |       |                   | 0.132              | 0.143              | Molecular Biology             |
|   |                             |                  |                     |                     |              |       |                   |                    | 0.133              | Molecular Modeling            |

\*\*\* Best Combination of Estimators

? Singularities in the Hessian Matrix Encountered

Test of Independence between any two independent variable also seems to support the above result, even though it is not fully satisfactory. The values of Chi-square and Cramer's strength of association between any of two variables are listed in the table 6. From this table it can be seen that even though the value of Chi-square of Molecular Modeling and the Type of Applicant indicates that they are not totally independent to each other, this value is still relatively low comparing to the value of the other combinations. At least for this Agrochemical study case, it still can be said that the ability to conduct multiple search is independent to the ability to conduct Rational Design.

**Table 6: The Values of Chi-square and Cramer's Strength of Association of any two independent variables**

| Applicant Product Innovation Throughput | Organic Synthetic Chemistry | Biological Assay   | Crystal Determinat. | Molecular Structure | Enzyme Study       | SAR  | Molecular Biology                          | Molecular Modeling                         | HTS  |                               |
|---|-----------------------------|--------------------|---------------------|---------------------|--------------------|--|--|--|--|-------------------------------|
| 631.221<br>(0.741)                      | 98.130<br>(0.292)           | 293.286<br>(0.505) | 344.695<br>(0.547)  | 133.104<br>(0.340)  | 98.381<br>(0.292)  | 56.797<br>(0.222)                          | 27.836<br>(0.156)                          | 11.512<br>(0.1)                            | 0.808 <sup>?</sup><br>0.026 <sup>?</sup>   | Type of Applicant             |
|   | 53.816<br>(0.216)           | 160.841<br>(0.374) | 194.985<br>(0.412)  | 89.209<br>(0.278)   | 56.070<br>(0.221)  | 26.013<br>(0.150)                          | 6.050 <sup>?</sup><br>(0.073) <sup>?</sup> | 3.219 <sup>?</sup><br>(0.053) <sup>?</sup> | 0.034 <sup>?</sup><br>(0.005) <sup>?</sup> | Appl. Prod. Innov. Throughput |
|   |                             | 385.114<br>(0.578) | 94.951<br>(0.287)   | 26.888<br>(0.153)   | 14.468<br>(0.112)  | 8.471 <sup>?</sup><br>(0.086) <sup>?</sup> | 2.600 <sup>?</sup><br>(0.048) <sup>?</sup> | 1.183 <sup>?</sup><br>(0.032) <sup>?</sup> | 0.069 <sup>?</sup><br>(0.008) <sup>?</sup> | Organic Synthetic Chemistry   |
|   |                             |                    | 283.783<br>(0.497)  | 80.362<br>(0.264)   | 43.241<br>(0.194)  | 25.319<br>(0.148)                          | 7.770 <sup>?</sup><br>(0.082) <sup>?</sup> | 3.535 <sup>?</sup><br>(0.055) <sup>?</sup> | 0.206 <sup>?</sup><br>(0.013) <sup>?</sup> | Biological Assay              |
|   |                             |                    |                     | 325.942<br>(0.532)  | 175.384<br>(0.390) | 102.691<br>(0.299)                         | 31.512<br>(0.165)                          | 14.339<br>(0.112)                          | 0.835 <sup>?</sup><br>(0.027) <sup>?</sup> | Crystal Determination         |
|   |                             |                    |                     |                     | 619.333<br>(0.734) | 362.632<br>(0.561)                         | 111.280<br>(0.311)                         | 50.635<br>(0.210)                          | 2.949 <sup>?</sup><br>(0.051) <sup>?</sup> | Molecular Structure           |
|   |                             |                    |                     |                     |                    | 673.934<br>(0.765)                         | 206.809<br>(0.424)                         | 94.102<br>(0.286)                          | 5.481 <sup>?</sup><br>(0.069) <sup>?</sup> | Enzyme Study                  |
|   |                             |                    |                     |                     |                    |  | 353.205<br>(0.554)                         | 160.715<br>(0.374)                         | 9.361 <sup>?</sup><br>(0.090) <sup>?</sup> | SAR                           |
|   |                             |                    |                     |                     |                    |  |  | 523.727<br>(0.675)                         | 30.506<br>(0.163)                          | Molecular Biology             |
|   |                             |                    |                     |                     |                    |  |  |  | 67.044<br>(0.241)                          | Molecular Modeling            |

() Cramer's Strength of Association

<sup>?</sup> Non Significant

## 6. CONCLUSION

From this investigation, it can be said that the theoretical framework proposed above seems to work at least for the two last dimensions – the ability to conduct multiple search and the ability to conduct Rational Design search – in the Agrochemical Lead Discovery Process.

The emergence of novel Search Strategy seems to happen in a condition where the necessary cognitive abilities exist. Certain environmental factors (such as the change in the size of market and the change in the regulation) do have the influence in changing the fate of certain search strategy. Those kinds of factor may have triggered the quest for novel search strategy in product innovation but they are not enough to cause the emergence of the novel search strategy itself. The emergence of novel search strategy still needs to be supported by the adequate cognitive abilities.

Also from this investigation, it is too early to say anything about the possibility of the taking off of the Rational Design Search Strategy. The reason is that the Rational Design strategy is still in the emergence phase and it still has to endure long transition phase where different innovators may have different kind of opinions about its usefulness. This is not new. Mass Screening had to wait for more than 25 years before taking off in the 50s as the popular search strategy after the big expansion of Agrochemical market. Hence, Rational Design still needs more adequate conditions to be able to be used as an important Search Strategy in the Agrochemical Lead Discovery Process.

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