# The Impact of Applying Open Innovation Practices on Performance of Firms in Nanotechnology Industry

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# ABSTRACT

## The Impact of Applying Open Innovation Practices on Performance of Firms in Nanotechnology Industry

Arman Sadreddin

A distributed innovation process based on purposively managed knowledge flows across organization boundaries, using pecuniary and non-pecuniary mechanism in line with each organization's business model is called Open Innovation according to Chesbrough. This thesis has two main objectives. First is to investigate the application of Open Innovation business model in nanotechnology sector both in Canada and worldwide and to compare it from different aspects. The second objective involves finding a causal relation between applying different Open Innovation practices and having better performance of firms. The thesis' methodology involves an extensive online survey run in several countries whose results were analyzed through descriptive and inferential statistical analyses. Moreover, based on the gathered data a simulation model was created and several scenarios tested. The findings revealed that it is mostly large companies which implement Open Innovation practices, while the level of implementation is much lower among the small and medium enterprises. In Canada, these types of practices are more common in Quebec than in other provinces. European countries are known to be pioneers in Open Innovation business model, the results revealed a higher frequency of applying Open Innovation practices in European firms than Canadian firms mostly in collaborating with universities. The results of inferential statistical analysis suggest that applying both Outside-In, which is opening up company's own innovation to other companies for any kinds of contribution, and Inside-Out, which is unused and unutilized ideas and technologies to be used by other firms and companies for their businesses, pecuniary Open Innovation practices together has a significant effect on the performance of firms in terms of an increase in technological and scientific outcomes (measured by the number of patents and articles). However, if only one type of pecuniary Open Innovation practice (either Outside-In or Inside-Out type) is applied then there is no such positive impact detected. The

simulation model built in Vensim has considered four different scenarios and confirmed these findings as well and predicted the close future of the firms in this industry by applying the proposed scenarios. It is thus suggested to embrace the Open Innovation model in its entirety instead of focusing on the implementation of isolated practices.

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# Chapter 1

## 1. Introduction

Open business model is one type of business model which is used in high-tech industries and could increase the performance of firms. Firms use this pattern to create and obtain value by collaborating with outside partners in a systematic way. There are two main types of collaboration with outside partners which are Inside-Out, which is unused and unutilized ideas and technologies to be used by other firms and companies for their businesses and Outside-In, which is opening up company's own innovation to other companies for any kinds of contribution (H. W. Chesbrough, 2003). Also, based on recent studies the rate of applying open business model in other industries are increasing. There are different practices for applying Open Innovation in a firm.

On the other hand, implementing a model of Open Innovation is naturally associated with a number of risks and challenges, such as revealing intellectual property and losing a firm's competitive advantage and satisfaction level by applying this kind of business model.

Many companies have started opening up their R&D processes and using various Open Innovation practices, but there are still many which are hesitant to embrace the new Open Innovation model in fear that it may hurt their businesses.

University of Montreal, HEC Montreal, Concordia University and UQAM have created a research partnership with industry Canada, the consortium de recherché et d'innovation en aérospatiale au Québec (CRIAQ), the Centre de Collaboration MiQro Innovation (C2MI), Thales Canada and Nano-Québec that seeks to expand and mobilize knowledge of Open Innovation.

The purpose of my thesis is hence to shed some light on this divergence of opinions and to study in depth the behavior of Open Innovation systems. The main objective is to analyze the impact of Open Innovation practices on the performance of firms in nanotechnology industry, measure the frequency of applying Open Innovation practices in nanotechnology industry, compare the frequency of applying Open Innovation practices between Canada and Europe, and within Canadian provinces and predict the future R&D strategies with various degrees of openness.

The first step of this research involves a literature review in the field of business models, Open Innovation and nanotechnology innovation. As the second step, the data has been collected from nanotechnology companies by applying an online survey for the target population of this research.

Working with a real company is the only way to experience all the reality. The information regarding the company's internal and external R&D processes, the practices they use to collect and capture the innovative value and the information on the performance measures and indicators has been gathered. Then by applying a descriptive and inferential statistical analysis the top practices has been identified and finally the relations between outcomes and those practices have been investigated. In the next phase, a System Dynamics model capturing the behavior of the Open Innovation system based on the business model of the case study companies has been built. Moreover, several scenarios operating under various degrees of openness have been simulated and the resulting impact on the system evaluated.

This work is expected to provide valuable insights into the behavior of open versus closed innovation systems. To my knowledge this is going to be the first research using System Dynamics approach to model the behavior of these systems, and a significant contribution to the advancement of the knowledge in the innovation management field is therefore expected. Furthermore, the developed model can be modified for the use of other companies in the industry and thus it can help firms in analyzing the suitability of the intended R&D policies and hence in improving their businesses.

# Chapter 2

## 2. Literature Review

The first step of this research involves literature review in the field of business model, Open Innovation and nanotechnology.

### 2.1. Business Model

A business model is a representation of an organization in different types. The business model could be in a type of conceptual, textual or graphical models (Al-Debei et al. 2008). A business model shows how an organization creates, delivers, and captures value (Osterwalder & Pigneur, 2010).

#### 2.1.1. Business Model Patterns

In this section, business models with similar characteristics and similar behaviours are described; these similarities are called business model patterns.

Unbundling Business Model: The concept of unbundled business model is consist of three types of businesses. The three fundamentally different types of businesses are customer relationship businesses, product innovation businesses and infrastructure businesses. Each of these types has different economic, competitive, and cultural imperatives (Hagel & Singer, 1999). It is possible that the three types co-exist within a single corporation, but ideally they are "unbundled" into separate entities in order to avoid conflicts or undesirable trade-offs (Treacy & Wiersema, 1997). An example for this pattern is private banking industry which has three types of business. The relationship business is custom-tailored wealth management services, product innovation is its financial products and its infrastructure business is transaction business (Osterwalder & Pigneur, 2010).

The Long Tail: The goal of this pattern is about selling less of more. The long tail pattern focuses on offering a large number of niche products, which are not sold frequently. Aggregate sales of niche items can be beneficial. This pattern of business models requires low inventory costs and strong platforms in order to make the niche product available to interested buyers (Anderson, 2006). Examples for this pattern is LEGO which is expanding the scope of its products by giving

its fans a tool for designing and selling their own custom designed product and getting their own commission (Osterwalder & Pigneur, 2010).

Multi Sided Platforms: This pattern shows two or more different but interdependent groups of customers (Eisenmann, et al. 2006). The platform creates value by simplifying interactions between different groups of customers (D. S. Evans et al. 2006). A multi-sided platform grows and attracts more users, this is called network effect (D. Evans, 2003). An example for this pattern is Google because it has three main values which are targeted advertisements, free searching and monetizing contents (Osterwalder & Pigneur, 2010).

Free as a Business Model: In this pattern at least one customer segment is able to endlessly benefit from a free-of-charge offer (Anderson, 2008). The customers who are not paying are financed by another part of the business model or by another customer segment (Anderson, 2009). An example for this pattern is Skype which is offering free internet and video calling on the other hand, it is offering cheap calls to phones (Osterwalder & Pigneur, 2010).

Open Business Model: Firms use this pattern to create and obtain value by collaborating with outside partners in a systematic way. This collaboration could happen in different ways, such as "Outside-In" by exploiting external ideas within the firm, or "Inside-Out" by providing external parties with ideas or assets lying idle within the firm (H. W. Chesbrough, 2006; H. W. Chesbrough, 2003). An example for this pattern is Innocentive website which is connecting a broad network of scientist solvers, connect seekers and solvers and people can have an access to scientific challenges with cash rewards (Osterwalder & Pigneur, 2010).

## 2.2. Open Innovation

Before defining the concept of Open Innovation, the concept of closed innovation will be discussed: If a company has a closed business model, the following would be their characteristics: The smart people in the field work for them in their firm this is in contrast to the Open Innovation concept where smart people are not only inside company but also those outside the company contribute to the research and development of the new products of the company. To profit from R&D, they must discover the product first, develop it and ship it themselves which is in contrast to the Open Innovation concept where discovering, developing and shipping the final product could be done by different companies. If they discover it themselves, they will get it to the market first but in Open Innovation concept companies which are creating the knowledge can transfer it

to other companies for commercialization. If they create the most and the best ideas in the industry, they will win however, in Open Innovation concept there is no need for companies to create the ideas to have the market share. They should control their intellectual property (IP), so that other competitors do not profit from their ideas but in Open Innovation concept companies can share their ideas' to have a revenue from them (Osterwalder & Pigneur, 2010).

The idea that most smart people work for someone else is called Joy's law (Lakhani & Panetta, 2007). Companies use the external knowledge and ideas of other companies in their own business and let the other companies use their internal unused ideas and technologies (H. W. Chesbrough, 2003). Table 1 is showing the min differences between open and closed innovation.

*Table 1 - Open versus Closed (Osterwalder & Pigneur, 2010)*

| | Smart People | | R&D - Ideas | | Knowledge | | Innovation – IP | |
|---|---|---|---|---|---|---|---|---|
| | Inside Firm | Outside Firm | Internal | External | Create | Transfer | Control | Share / Buy |
| Open | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | - | ✓ |
| Closed | ✓ | - | ✓ | - | ✓ | - | ✓ | - |

Innovation and development can either be possible with enormous resources to explore the world state-of the-art components, systems and processes, seeking fundamental discoveries that could fuel forthcoming generations of products and services or by deploying a complete different strategy in the battle for innovation leadership. Any kind of technology the company would require, it could acquire from the outside, usually by collaborating, partnering or investing in promising established institutions and companies or start-ups.

The concept of Open Innovation has been defined by Henry Chesbrough in 2003. By googling the word "Open Innovation" there will be about 483 million links available and there is an increase in books and publication in this area (Figure 1).

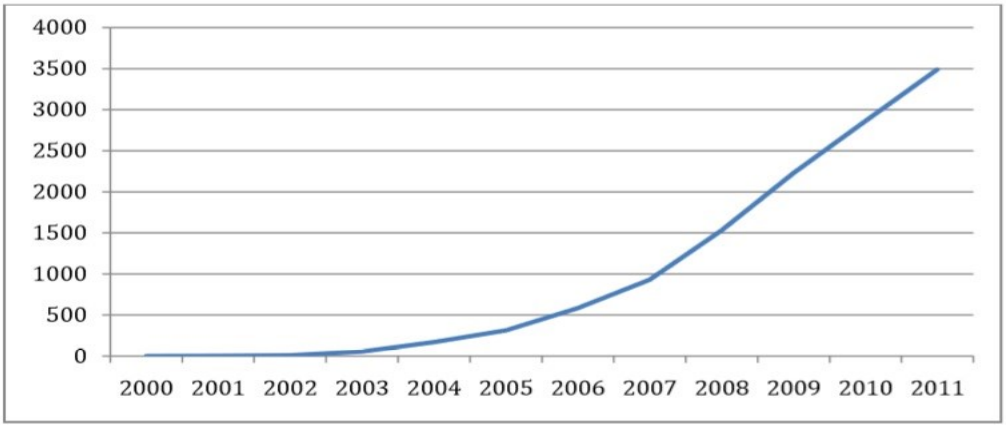


*Figure 1 - Annual citation to Open Innovation in Google Scholar based on search keyword "Open Innovation" (H. Chesbrough & Bogers, 2014)*

Based on H. Chesbrough & Bogers (2014) the definition of Open Innovation is "*a distributed innovation process based on purposively managed knowledge flows across organization boundaries, using pecuniary and non-pecuniary mechanism in line with each organization's business model.*" These flows of knowledge may involve knowledge inflows to the organization, knowledge outflows from an organization or both (coupling external knowledge sources and commercialization activities).

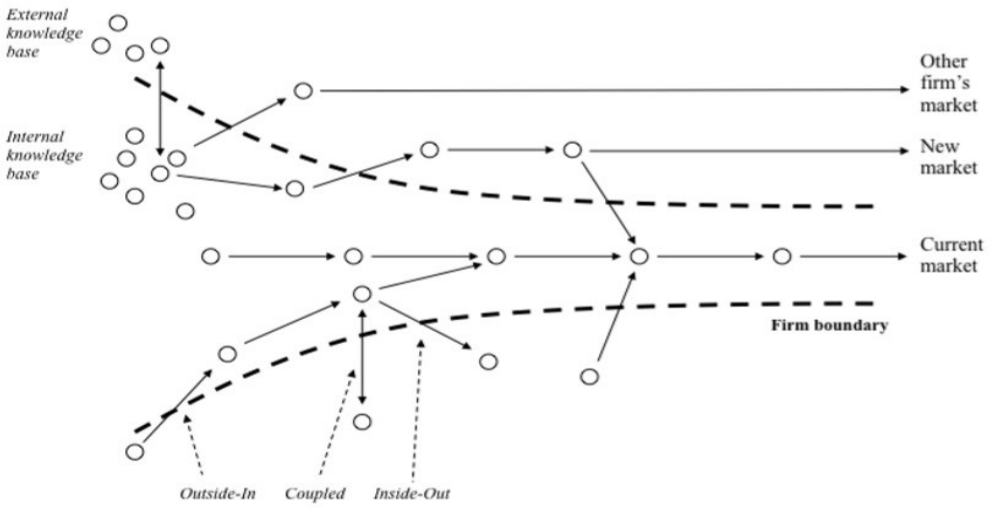


*Figure 2 - Open Innovation Model (H. Chesbrough & Bogers, 2014)*

An organization's "openness" is to the acquisition of new ideas, patents, products, etc. from outside its boundaries, often via licensing protected intellectual property or other practices (H. W. Chesbrough, 2003). Although, Table 1 clearly divides the features into Open Innovation models and closed innovation models, openness is not a binary classification of open versus closed (H. W.

Chesbrough, 2003). In fact, openness is a degree which could be measured to indicate which firm is more open than the others (Michelino et al., 2014).

Chesbrough (2003) proposed so called erosion factors, which are reasons for the firms to change from closed innovation to Open Innovation model. These factors are increase mobility of workers, more capable universities, declining US hegemony, growing access of start-up firms to venture capital and rise of internet (H. Chesbrough & Bogers, 2014).

## 2.3. Types of Open Innovation

In order to apply open business model in a firm there are several Open Innovation practices which can be used. These practices are categorized into three different types. The first type of Open Innovation practices is Inside-Out (Outbound) practices, which allows the firm let unused and unutilized ideas and technologies to be used by other firms and companies for their businesses. The second type is Outside-In (Inbound) practices, which involves opening up company's own innovation to other companies for any kinds of contribution (H. W. Chesbrough, 2003).The last type of practices is combined coupled type which is a combined knowledge inflows and outflows between actors in the innovation process (Gassmann & Enkel, 2004). Also, Dahlander and Gann (2010) categorized them into two different types, which are pecuniary and non-pecuniary.

Based on other researchers analysis most of the academic researches and industry practices are related to Outside-In (Inbound) practices while there is relatively little focus on Inside-Out and coupled types. For example, West & Bogers (2014) reviewed about 165 Open Innovation articles and 118 of them was addressing Outside-In Open Innovation practices, 50 Inside-Out and 70 articles in the sample was addressing the coupled type.

Different scientists categorized practices of Open Innovation through different models (Table 2). Dahlander and Gann (2010) categorized the Outbound practices to "revealing" and "selling".

Revealing means how internal resources are revealed to the external environment such as selling a licence of an innovation to other companies. This type of practices deals with how firms reveal internal resources without immediate financial rewards, and they look for indirect benefits. An example of this type of Open Innovation practices is providing innovation for standardization organization or knowledge transfer to non-profit organizations, such as Wikipedia. Some of the advantages of this kind of practices are transferring the technology to the public in order to gain some collaboration. One of the main disadvantages of this type of practices is that other companies

(competitors) can make use of this revealed information without any financial benefit for the owner of the information.

Selling means how firms commercialize their inventions and technologies by selling or licensing out what they have in their organization. One of the advantages of using this type of practices is to have more investment in R&D part and have more patents and bring inventions to the market for commercializing, selling or licensing them out. Some of the disadvantages of this type of practices are risk of stealing the ideas and difficulty in anticipating the potential values (Dahlander & Gann, 2010).

Acquiring and sourcing are types of Open Innovation practices as an Inbound ones.

Acquiring means how firms acquire and input innovation process and expertise from outside of the firm. An example of this kind of practice is university-industry collaboration. The main advantage of this type of practices is using the experts and the ability to have great network in the field. The main disadvantages of this type is that if the firms are knowledge based in the field they already know, it would be difficult to come up with novel combinations.

Sourcing means that firms use external sources of innovation by searching and scanning the environment before starting the R&D step. One of the advantages of this type is that firms create synergy between their own processes and the ideas which are available outside of the firms. Some of the disadvantages of this type are spending lots of time for searching (over searching) and analyzing the surrounding environment and trying to understand those ideas, technologies or innovations (Dahlander & Gann, 2010).

*Table 2 – Structure of different types of openness based on (Dahlander & Gann, 2010)*

| | **Inbound Innovation** | **Outbound Innovation** |
|---|---|---|
| **Pecuniary** | Acquiring | Selling |
| **Non-pecuniary** | Sourcing | Revealing |

## 2.4. Open Innovation Practices

According to different categories of Open Innovation practices which were discussed in part 2.3, there are several practices which companies are applying in their firms to have a higher degree of openness and better impact on the performance of their companies (H. Chesbrough & Bogers, 2014).

Based on different business plans, firms will use some of the practices of Open Innovation. Practices related to Inbound practices are, scouting, in licensing IP, university research programs,

funding start-up companies in one's industry, or collaborating with intermediaries, suppliers and customers, and utilizing nondisclosure agreements, crowdsourcing, competitions and tournaments, communities and spin-ins or spin-back (H. Chesbrough & Bogers, 2014).

The Outbound practices are such as, out licensing IP and technology, donating IP and technology, spin-outs, corporate venture capital, corporate incubators, joint ventures and alliances.

Practices which are used for coupled openness are such as, joint invention and commercialization activities (Bogers, 2011; Bogers et al. 2012).

## 2.5. Challenges of Open Innovation

West & Gallagher (2006) have identified three fundamental challenges for firms applying the Open Innovation practices which are: finding creative ways to exploit internal innovation, incorporating external innovation into internal development, and motivating outsiders to supply an ongoing stream of external innovations. There is a paradox which is why should firms spend money in their own R&D department and the result would be available to their rival firms? They researched the open source software industry to find out the reasons of this question and they finally reached to four strategies which firms are using in order to address the challenges which was mentioned earlier. These strategies are: pooled R&D / product development, spinouts, which means where firms transform the projects which was done internally to externally visible open source projects, selling complements, and attracting donated complements.

H. Chesbrough and Crowther (2006) identified the not-invented-here (NIH) syndrome and lack of internal commitment as the main challenges of applying Open Innovation in a firm. Some other challenges of applying Open Innovation are lacking resources, free-riding behavior, and problems with contracts (Hoffmann & Schlosser, 2001; Mohr & Spekman, 1994).

Also, stealing the intellectual property (IP) of the innovation of a firm is another challenge of applying Open Innovation. There are several ways to ensure that others cannot assert claims over useful knowledge that the firms seeks to use. Patenting, trade secrecy, copyright, licensing and publications are some of them.

In US, Japan and EU patent system, the first-to-invent criterion shifts to first-to-file; so, publication may become an even more attractive alternative to patenting (H. Chesbrough et al., 2014).

## 2.6. Recent Studies on Open Innovation

There are two reasons for studying Open Innovation at firm level. First, innovation is one of the outcomes of firms, so R&D competition among firms should be analyzed. Second, each firm has its own business model which can value innovations of firms and should be analyzed as well. (H. Chesbrough & Rosenbloom, 2002)

Surveys are one way of expanding experimental evidence on Open Innovation and until 2005 no large scale survey had been designed to analyze the Open Innovation impacts on firms (West et al. 2005). So, the impact of applying Open Innovation business model at firm level should be analyzed.

Laursen and Salter (2004) designed a survey named U.K. Innovation Survey which is based on European Community Innovation Survey (CIS). They sent the survey to 19602 business units in the United Kingdom in two different steps in 2001 and their response rate was 41.7 percent. They used a subsample of 2707 manufacturing firms for this research. Their research findings show that firms who are using greater number of sources will be more open than the firms which are not doing so. Also firms which apply search strategies and invest in their R&D are more likely to collaborate with universities than other firms. Laursen and Salter (2006) in their later work claim that firms which are open to external knowledge and search channels are likely to have a higher level of innovative performance. Searching is curvilinearly related to performance. However, oversearch would result negative effects on innovative performance.

Van der Meer (2007) conducted a survey on Dutch companies named as Dutch National Innovation Survey. They worked on a sample consisting of 814 questionnaire responses and 28 interviews. They found that principal of Open Innovation (its culture and importing mechanisms) is successfully accepted in innovative Dutch companies. By analysing the result of the survey, they mentioned the factors which are hamper of innovation in Dutch companies. About 74% of Dutch companies are using Outside-In type of Open Innovation practices in their companies and 54% of them are using Inside-Out type of practices. The main challenge they found in Dutch companies was about handling their business model.

Since until 2009 most of the studies were focused on high-tech, multinational enterprises. Van de Vrande et al., (2009) decided to investigate the implementation of Open Innovation practices in small- and medium sizes enterprises (SMEs). Their sample comprised of 605 innovative firms in Netherlands which shows 27% response rate. They used a computer-assisted telephone

interviewing. They found that SMEs have been involved in applying many Open Innovation practices during the last seven years. The main reasons for their involvement were to meet customer demands or keep up with competitors. They did not find any major differences between manufacturing and service industries, but they did find the implementation differences among the various firm sizes. Medium sized firms are more involved in applying Open Innovation practices than small sized firms. The main challenge of these firms in applying Open Innovation is organizational and cultural issue which is a result of having connection with more external contacts.

Carlsson et al., (2011) examined the impact of Outside-In Open Innovation on innovation performance of firms. They designed a questionnaire which they sent to stock-listed companies in Germany, Switzerland and Austria. They gathered the data from 141 R&D managers for the period of 2004 to 2008. They found that the openness of Outside-In Open Innovation process is very important for having better innovation output. Openness with customers, suppliers and universities has a significant positive impact on innovation performance of firms. Also, they found that for cross-sector companies, openness has a negative impact on the innovation performance of firms.

Parida, et al., (2012) designed a survey targeting Swedish technology-based SMEs in IT sector. 252 high-tech SMEs participated in this survey. Based on their studies Open Innovation practices are positively influence on innovation outcomes in large firms. They found that different Inbound Open Innovation activities lead to different innovation outcomes in SMEs.

H. Chesbrough and Brunswicker (2013) designed a survey and asked about the main practices, challenges, outcomes, partners, etc. of large firms in United States. H. Chesbrough and Brunswicker (2013) studied how SMEs are involved in external knowledge sourcing (type of Inbound Open Innovation practices). Their research was based on a database with more number of responses than CIS on SMEs in Europe in different industry groups. They gathered 1411 samples for the analysis. They found 82% of the participants mentioned that Open Innovation is practiced more intensively compared to three years ago. Customer co-creation, informal networking and university grants are three leading Inbound practices in 2011 and crowdsourcing and Open Innovation intermediary services are rated the lowest importance in the results. Joint ventures, selling market-ready product and standardization are the three leading Outbound practices. Donations to non-profit organizations and spin-offs are the least important ones. The three leading Open Innovation partners are customers, universities and suppliers. The firms'

biggest challenge in managing Open Innovation is the change process from closed to Open Innovation.

Khan et al. (2015) studied the Open Innovation practices in SMEs of part of Pakistan. They focused only on jewelers and beauty industry with a questionnaire on a sample of 15 business shops who are working in this area. They found that most of the SMEs in this industry apply Open Innovation practices and use different external resources.

H. Chesbrough and Crowther (2006) in another study focused on high-tech industries, which were applying Open Innovation in their industries by conducting a qualitative interview. They used search engines to find the names of companies which are on the web and used some key words related to the concept of Open Innovation in order to select companies for their qualitative analysis. They reached to final 40 companies and they had 12 qualitative interviews with mostly large enterprises. They found that Open Innovation is most suitable for high-technology industries while the concept is in an early stage in other industries. Also, based on the participants' opinion Open Innovation is not primarily applied in their companies to reduce cost or outsourcing of the R&D functions.

As a summary, Table 3, describes the research carried out on Open Innovation by using questionnaire design and survey analysis.

*Table 3 – Recent studies on Open Innovation with survey analysis*

| Authors | Year | Research Target | Sample Size |
|---|---|---|---|
| Laursen, Salter | 2004, 2006 | U.K. | 2707 |
| Chesbrough et al. | 2006 | High-Tech Industries | 12 |
| Han van der Meer | 2007 | Dutch Firms | 842 |
| Van de Vrande et al. | 2009 | Netherlands | 605 |
| Carlsson et al. | 2011 | Germany, Switzerland and Austria | 141 |
| Parida et al. | 2012 | Sweden | 252 |
| Chesbrough and Brunswicker | 2013 | U.S. | 125 |
| Khan et al. | 2015 | Pakistan | 15 |

Based on the most recent studies in this area, European countries are the pioneers of applying Open Innovation in their firms. The reason could be because of huge amount of studies and surveys which were done in European countries during the last ten years.

In general, sample of these works are mostly for some specific countries or some specific firm's size and companies cannot generalize these works for their industries. Current work will analyze the impact of applying Open Innovation practices on technological and scientific outcome which was not analyzed before both by statistical analysis and simulation.

## 2.7. Nanotechnology

Nanotechnology involves the manipulation of matter at the molecular scale and has the potential to fundamentally alter the way people live, by providing new drug delivery systems, faster and cheaper manufacturing processes, cleaner and more efficient energy generation, new materials, clean water and the next generation of computing devices (Buzea et al., 2007; Drexler, 1992).

Nanotechnology is not an industry – it is an enabling technology. Considering the evolution of products based on nanotechnology, there are 3 horizons:

Horizon 1 is the incorporation of a form of nanotechnology in a product such as a powder in a cosmetic, as an additive to a surface coating to provide an enhanced product.

Horizon 2 is where nanotechnology is by design an integral element such as a drug delivery particle designed for targeted slow delivery in a particular part of the body.

Horizon 3 is complex (by today's standards) highly functionalized products, designed from the ground up around nano science principles, at the present predominantly the area of visionaries and science fiction. This area will include bio mimicry i.e.; simulating or copying Mother Nature (Victoria, 2005).

Based on (Roco, 2011) nanotechnology has a great economic benefits for society. Until 2020, nanotechnology will create about 6,000,000 potential jobs and projected to account about US $1 trillion dollar (Roco et al., 2011).

## 2.8. Nanotechnology in Canada

Nanotechnology can address key Canadian economic and social challenges relating to health and medicine; energy and environment; advanced materials and manufacturing; electronics; and information and communication technologies (Nador & Gray, 2005).

This study will focus on nanotechnology in Canada because will have 10% of the market share of this industry by 2020 and will create about 600,000 jobs and a revenue of $1 million dollar (Roco et al., 2011). So, it has a great impact on the economic growth of Canada.

According to the report which was published in 2013; the global governmental nanotechnology spending for top ten countries is shown in Figure 3. Canada is among the top ten countries (Sargent Jr, 2013). This shows that Canada is one of those top ten countries that its government is supporting it and there is a good opportunity for developing nanotechnology in this country.

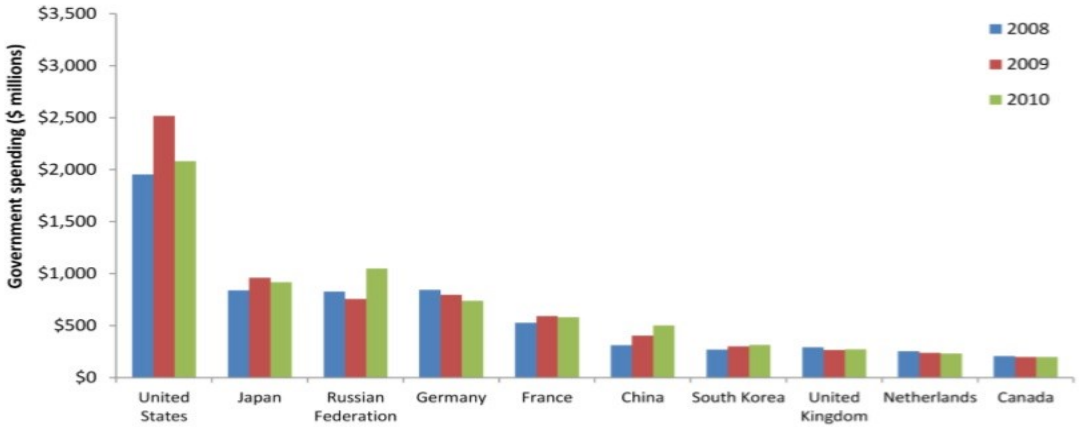


*Figure 3 - Global Government nanotechnology spending for top ten countries, 2008-2010 based on (Xue, 2011)*

Canada is not in the list of the corporate nanotechnology spending for top ten countries. (Figure 4). This shows that this field is too new in this country and still companies have to invest more in order to improve their knowledge.

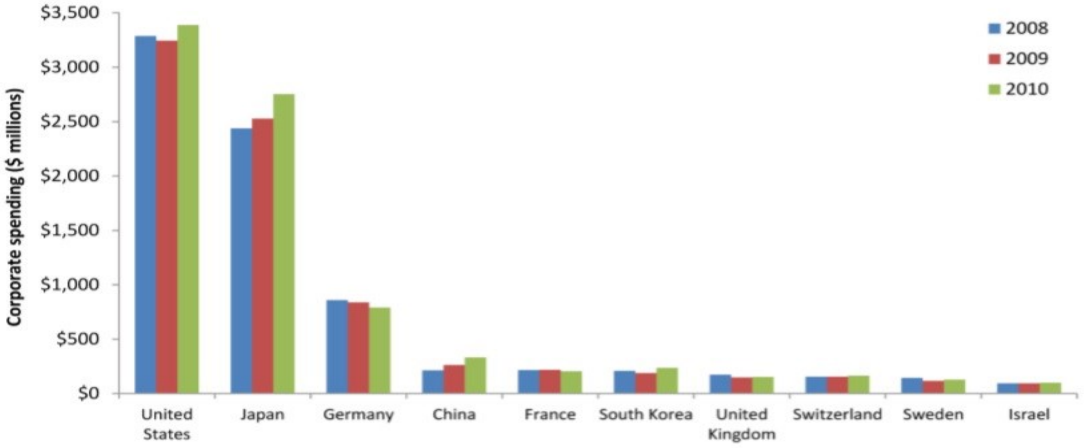


*Figure 4 - Corporate nanotechnology spending for top ten countries, 2008-2010 based on (Xue, 2011)*

Canada is within the list of top five countries that venture capital spending in nanotechnology (Figure 5). This is showing the high number of start-ups in Canada which are supported by venture capitals.

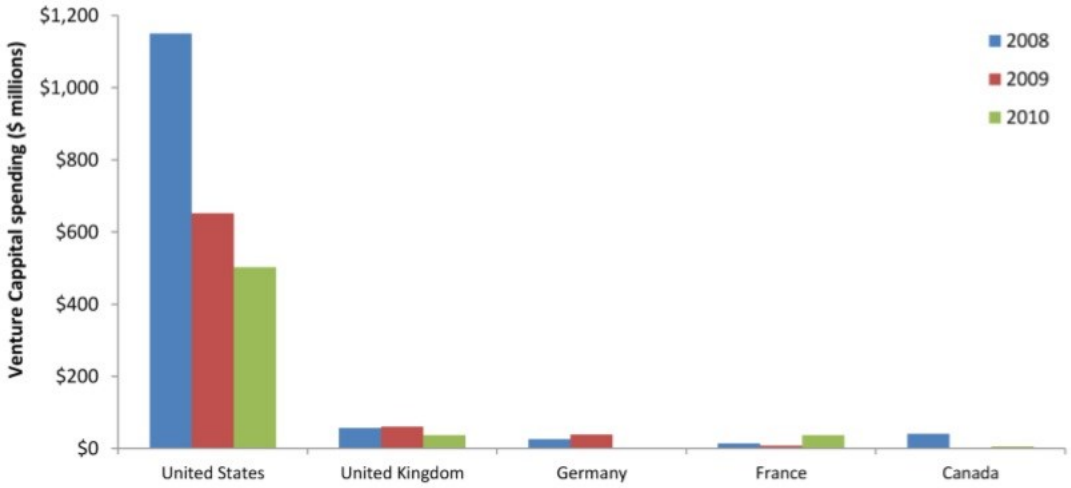


*Figure 5 - Venture capital spending for top five countries, 2008-2010 based on (Xue, 2011)*

Based on Figures 3, 4 and 5, government of Canada and venture capitals are mostly spending in nanotechnology industry in Canada which is showing that there are more start-up companies in Canada. When countries reach to specific level of knowledge and technology the corporate nanotechnology spending would be increase. This is the case of United States as there is a decrease in spending of venture capitals and government support and an increase in corporate spending. The future of Canada could be like the current situation of United States.

Also, according to the Australian Academy of Science (Warris, 2004), percentage of nanotech publications compared to all science publications from 1990 until 2003 is as described in Figure 6. Japan and Netherlands have higher percentage than Canada. Canada is below the world average percentage and almost similar to Australia.

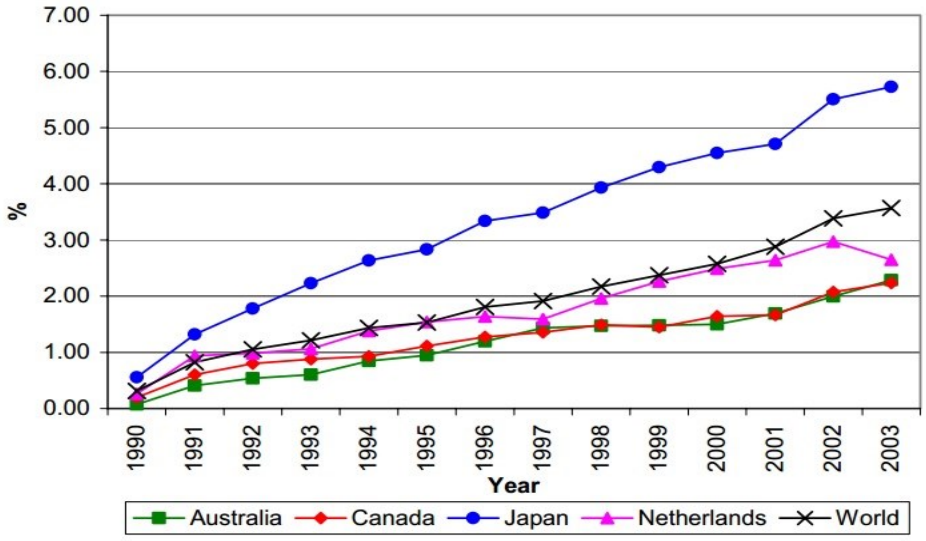


*Figure 6 - Percentage of nanotech publications compared to all science publications, 1990-2003 (Warris, 2004)*

Moreover, Figure 7 shows the percentage of science publications that are nanotech. According to this Figure Canada is below the world average percentage of science publications that are nanotech. Netherlands, France, Germany and United States are within the top ranked countries in this Figure.

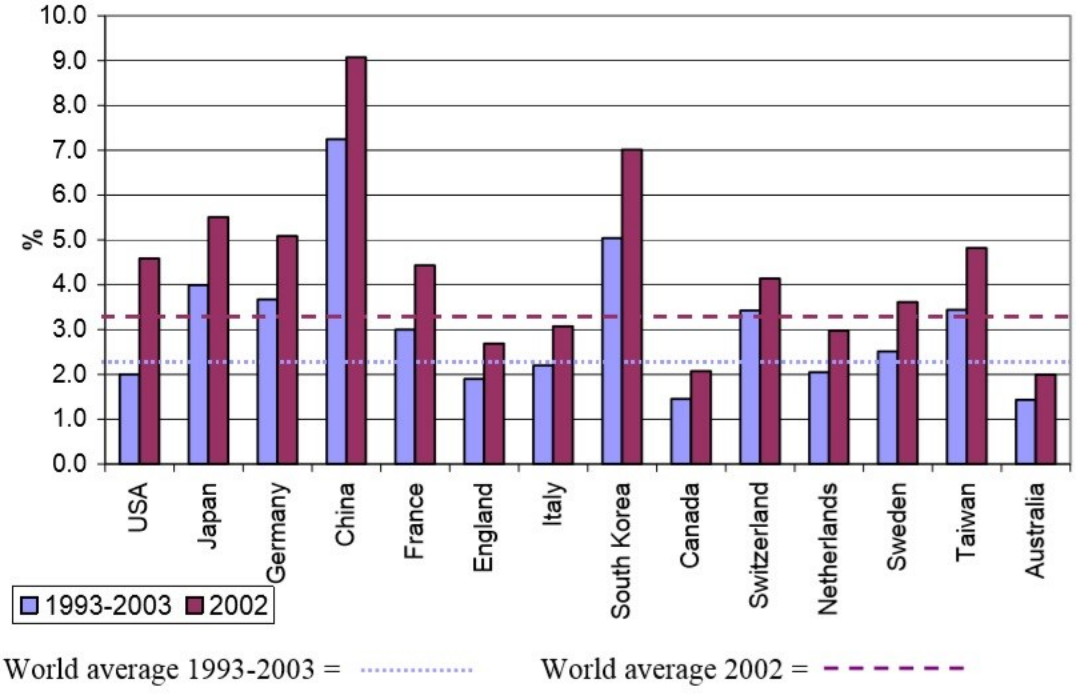


*Figure 7 - Percentage of science publications that are nanotech for selected countries, 1993-2003 (Warris, 2004)*

## 2.9. Country Case Study Selection

Since nanotechnology is really useful and helpful for the economy of the country, the focus of this study is on Canada. By applying benchmarking and analyzing how the countries who are pioneers of nanotechnology in world doing it, Canadian nanotechnology system will be compared with them. Based on the presented information, in this research scientists who are working in nanotechnology industry from Canada, United States, Netherlands, France, Australia, United Kingdom, Germany and Belgium was contacted and the analysis conducted on the data gathered from these high-tech countries in nanotechnology.

Based on Figure 8, the mentioned countries are those who have most citation in the publications related to nanotechnology.

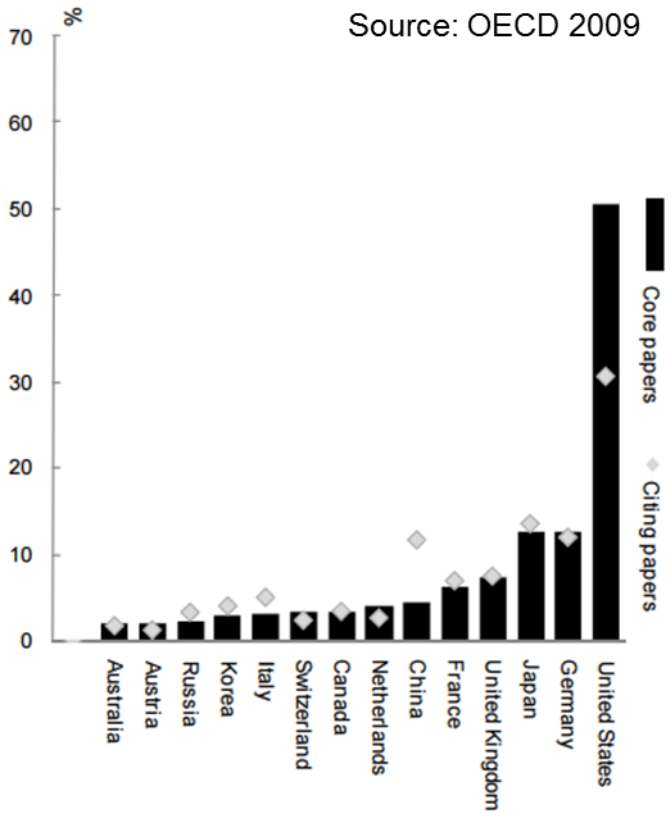


*Figure 8 - Share of core and citing nanotechnology-related publications by country, 1995-2004 (Palmberg et al., 2009)*

## 2.10. Research Questions

There are two main objectives in this research. First is investigating the application of Open Innovation business model in Canadian nanotechnology industry and comparing it from different aspects. The second objective involves finding a causal relation between applying different Open Innovation practices and having better productivity in firms. Below you will find the objectives outlined in detail:

- Examine the implementation of Open Innovation business model in Canada and other countries and generalize it
    - Examine and compare the implementation of Inbound and Outbound practices
    - Examine and compare the implementation of various practices between Canada and European countries
    - Examine and compare the implementation of various practices between French and English speaking Canadian provinces
- Investigate the impact of Open Innovation practices on the performance of firms
    - Determine the impact of implementation of Inbound practices on the performance of firms
    - Determine the impact of implementation of Outbound practices on the performance of firms
    - Determine the impact of concurrent implementation of both kinds of practices on the performance of firms
    - Create a causal diagram and system dynamics model to model the Open Innovation system of nanotechnology industry from technological and scientific aspects

# Chapter 3

## 3. Methodology

The methodology applied in this research has six main steps which are described in Figure 9.

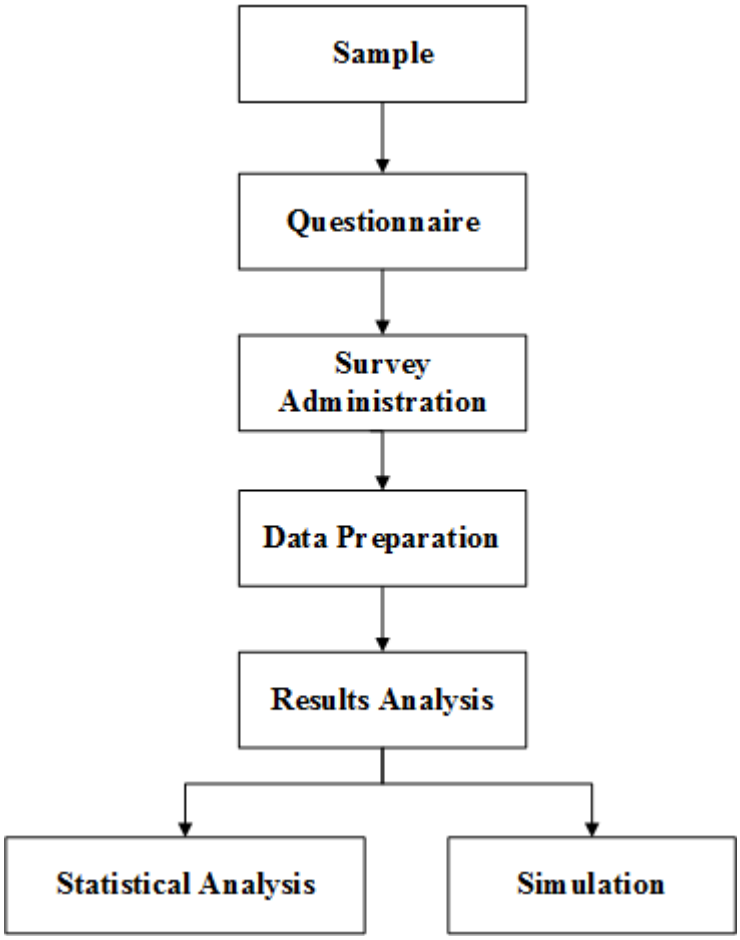


*Figure 9 - Research methodology*

## 3.1. Sample

Since, the main purpose of this research is to examine the use of Open Innovation practices and to analyze their on the performance of firms in nanotechnology industry it was decided that the best source of the data are the firms themselves. The data then should be gathered from these type of firms.

In order to identify the nanotechnology companies we looked into the database built by Moazami et al., (2015). It contains the information on all the nanotechnology scientific articles published until 2012 which was extracted from Scopus database. In order to distinguish nanotechnology related articles (Moazami et al., 2015) studied several possible keywords search strategies and created their own combined collection based on seven different sources (Alencar, Porter, & Antunes, 2007; Fitzgibbons & McNiven, 2006; Mogoutov & Kahane, 2007; Noyons et al., 2003; Porter, Youtie, Shapira, & Schoeneck, 2008; Zitt & Bassecoulard, 2006; Zucker & Darby, 2005). Their current database contains the names and affiliations of the scientists from all the world working (and publishing) in nanotechnology field.

Based on the data provided in Chapter 2, only certain countries were selected to take part in the survey. E-mails addresses for randomly selected scientists from these countries were searched on the Internet in order to be able to create my own database which is the subset of the original database but it contains also the contact information. The next step was to determine the sample size.

In this research, the sample size was calculated in order to be able to generalize the result and make an acceptable conclusion with 90% confidence level. The resulted sample size is 267 firms, and it was calculated with the following formula.

$$Sample\ Size = \frac{X^2\ NP(1-P)}{d^2(N-1) + X^2\ P(1-P)}$$

$X^2$ : The Table value of chi-square for one degree of freedom at the 90% confidence level: (2.71)

$N$: The population size (20,000)

$P$: The population proportion (0.5)

$d$: The degree of accuracy expressed as a proportion (0.05)

Based on Figure 10, when the population is not clear it could be considered to be 20,000, because the sample size for the population of more than 20,000 is almost constant (Krejcie & Morgan, 1970).

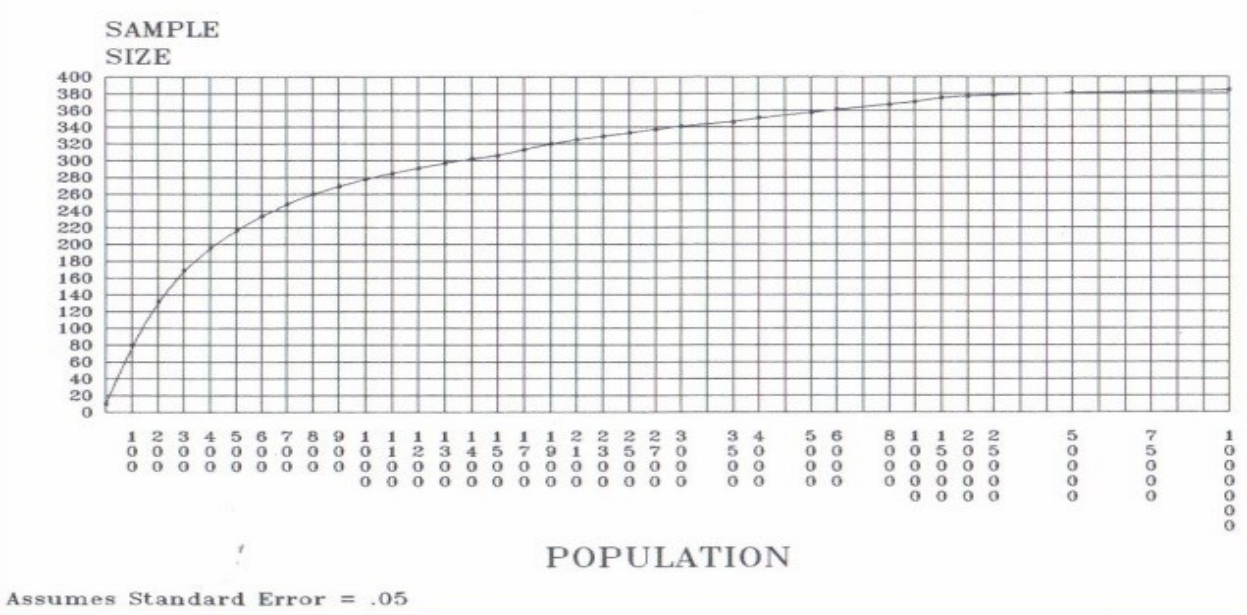


*Figure 10 - Population vs sample size (Krejcie & Morgan, 1970)*

The type of sampling used in this survey is stratified sampling, which is when subpopulation with a population is vary, it is possible to sample each subpopulation independently and create the sample. Among the data which was related to scientists of different countries such as, Australia, Belgium, Canada, France, Germany, Netherlands, United Kingdom and Unites States. There were two main proportion of companies, SMEs and LEs, based on the number of employees in each firm. There were almost equal number of companies in our population.

## 3.2. Questionnaire

The research team designed a questionnaire that contains the following parts: the questionnaire starts with some demographic questions about the size of the firms, these are followed by the questions about the frequency of applying different types of Open Innovation (OI) practices in a Likert scale (always, sometimes and rarely), and the final section of the questionnaire evaluates the outcomes of firms after implementing the OI practices. The questions in this section are in a Likert scale (increased, remained the same and decreased) as well. The structure of the questionnaire is presented in Figure 11.

The questionnaire is attached in the Appendix 1 of this thesis.

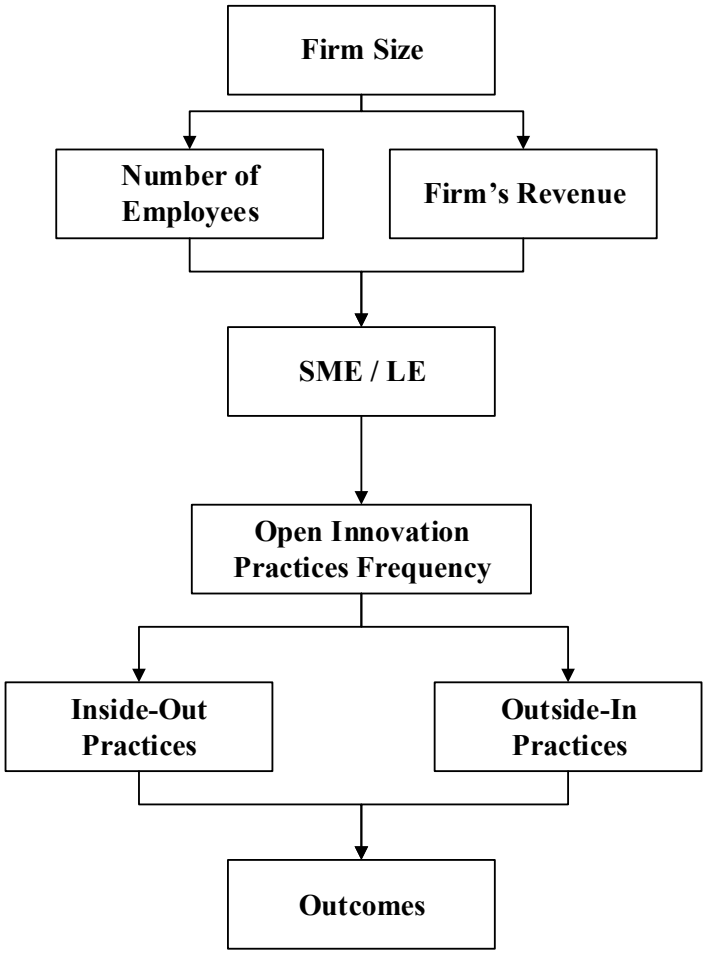


*Figure 11 - Questionnaire structure*

In this questionnaire, the sequence of asking about different OI practices are based on the categories which was mentioned in the literature review of this research. The main reason that practices related to one type are close to each other's is because if the participants are not familiar with Open Innovation practices, they could have better idea of what we are asking them and what is Open Innovation in practice.

In order to ensure the validity and reliability of the questionnaire, the research team had some meetings with experts in statistical analysis at Ecole Polytechnique. Moreover, to check the results the survey was first implemented on a small sample (65 answers). In order to validate the reliability of the questionnaire method called Cronbach's Alpha was used based on De Vaus (2002) for all 27 questions of the questionnaire. Cronbach's Alpha for the small sample of 65 participants was 0.93 which means the internal consistency of the questionnaire is excellent.

*Table 4 – Cronbach's Alpha*

| Reliability Statistics | |
|---|---|
| Cronbach's Alpha | N of Items |
| .934 | 27 |

## 3.3. Survey Administration

Furthermore, the research team had a Skype interview with the Co-founder of Neverfrost[1] company in Waterloo, Mr. Chong Shen, in order to check the questionnaire and the duration time for answering it. The feedback was very positive. The questionnaire was found to be well constructed, the respondent understood well the questions and felt comfortable about providing all the information.

The questionnaire was fully administered online. The infrastructure used to implement the survey was SurveyMonkey[2] website which could send the survey to targeted scientists and gather the data about each respondent while still keeping his/her confidentiality.

In order to increase the response rate, it was decided to promise 5 gift cards, each with the value of $50 for the randomly selected participants of the survey. The email with the link leading to the survey which was sent to the participants is attached in Appendix 2.

About 15,000 emails were sent to the targeted population at three different times. Initially, it was only several thousands, but due to a very low response rates in some countries (sometimes around 1%), new contacts had to be searched for and new e-mails had to be sent in order to finally reach the required sample size. Nine MEng students were involved in this research as their 5-credit projects. They were helping mainly with searching for the contacts of the companies. Finally, when around 15,000 e-mails have been sent, the surveys from 315 scientists who agreed to participate in the research were received. The significance level for this survey is 0.1. Among these responses, 302 were valid and the statistical analysis was conducted on them.

## 3.4. Results Analysis

In this step, the raw data which was gathered from the survey will be prepared for the final analysis and then the final analysis will be applied on them.

[1] http://www.neverfrost.com/
[2] http://www.surveymonkey.com

### 3.4.1. Data Preparation

The result of the survey was coded into SPSS software. Number of employees was coded from 1 to 6 and "I do not know" as (7), annual revenue was coded from 1 to 3 and "I do not know" as (4), frequency of applying Open Innovation practices was coded based on a Likert scale from "always" (3), "sometimes" (2), "rarely" (1) and "N/A" as (0) and the outcomes of the firms from different aspects was coded based on a Likert scale from "Increased" (3), "Remained the same" (2) "Decreased" (1) and "N/A" as (0).

In a categorical data, there is a sample mode approach which is the mode where each sample could be replaced with a missing value (Batista & Monard, 2003). Also, some responses which have lots of missing data could be deleted from the sample. This approach has been applied in the gathered data in order to prepare it for the statistical analysis.

Based on Dahlander and Gann (2010) section of this research, there are 4 types of Open Innovation practices, Outside-In Pecuniary (OIP) practices, Outside-In Non Pecuniary (OINP) Practices, Inside-Out Pecuniary (IOP) Practices and Inside-Out Non Pecuniary (IONP) Practices. Since eleven of the practices which were mentioned in the survey are from pecuniary practices, this research will be focusing on these practices mostly. Table 5 shows the 4 types of practices:

The new sophisticated and useful variables of the mentioned 4 types of practices are developed in order to apply more analysis on them. These four new variables are created based on the available practices of the questionnaire. The four new variables are:

OIP = P1 + P2 + P3 + P5 + P6 + P7

OINP = P4

IOP = P8 + P9 + P10 + P11 + P12

IONP = P13 + P14

*Table 5 – Open Innovation practices based on their type*

| OIP | OINP | IOP | IONP |
|---|---|---|---|
| Buying a License (P1) | Crowdsourcing (P4) | Joint Venture Agreement (P8) | Providing your innovation for standardization organization (P13) |
| Contract with other companies for R&D services (P2) | | Sell New Knowledge developed in your R&D to another company (P9) | Donating your innovation / knowledge to any non-profit organization (P14) |
| Buying any innovative ideas from start-up companies (P3) | | Participating in a business incubator programs (P10) | |
| Consulting with any specialized Open Innovation companies (P5) | | Selling your R&D market ready by-product (P11) | |
| Collaborating with students in a research agreement with a university (P6) | | Selling license of your innovations (P12) | |
| Assigning a research fund to an academic institute (P7) | | | |

Since the data has been gathered from the questionnaire, it should be validated that the respondents of this research are categorizing the Open Innovation practices based on the literature, two main analysis have been conducted: Kaiser Meyer Olkin (KMO) which ranges from 0 to 1. If this statistic is above 0.5, then the correlations are high to make factor analysis suitable (De Vaus, 2002).

For OIP type, there are six variables in this category. The result of KMO test shown in Table 6 is 0.766 (and it is significant), which means that the data is justifiable in this category.

For OINP type, there is only one practice in this category.

For IOP type, there are five variables in this category. The result of KMO test shown in Table 6 is 0.8 (and it is significant), which means that the data is justifiable in this category.

For IONP type, there are two variables in this category. The result of KMO test shown in Table 6 is 0.5 (and it is significant), which means that the data is justifiable in this category.

*Table 6 – KMO measure of sampling adequacy*

| KMO Measure of Sampling Adequacy | |
|---|---|
| OIP – KMO | 0.766 |
| Sig. | 0.000 |
| IOP – KMO | 0.802 |
| Sig. | 0.000 |
| IONP – KMO | 0.5 |
| Sig. | 0.000 |

By performing the Spearman correlation among these four types of practices, the raw data are validated in order to start the statistical analysis.

Table 7 shows the correlation between different variables. Since, the correlation is not high, it could be concluded that there is no relation among the four categories.

*Table 7 – Correlation Table on four types of practices*

| Correlations | | | | | | |
|---|---|---|---|---|---|---|
| | | | OIP | OINP | IOP | IONP |
| Spearman's rho | OIP | Correlation Coefficient | 1.000 | .387** | .497** | .472** |
| | | Sig. (2-tailed) | . | .000 | .000 | .000 |
| | | N | 302 | 302 | 302 | 302 |
| | OINP | Correlation Coefficient | .387** | 1.000 | .363** | .470** |
| | | Sig. (2-tailed) | .000 | . | .000 | .000 |
| | | N | 302 | 302 | 302 | 302 |
| | IOP | Correlation Coefficient | .497** | .363** | 1.000 | .589** |
| | | Sig. (2-tailed) | .000 | .000 | . | .000 |
| | | N | 302 | 302 | 302 | 302 |
| | IONP | Correlation Coefficient | .472** | .470** | .589** | 1.000 |
| | | Sig. (2-tailed) | .000 | .000 | .000 | . |
| | | N | 302 | 302 | 302 | 302 |
| **. Correlation is significant at the 0.01 level (2-tailed). | | | | | | |

By applying principal components analysis, the weights of each variable in each category will be identified (normalized) (De Vaus, 2002).

*Table 8 – Weight of each variable*

| OIP | | OINP | | IOP | | IONP | |
|---|---|---|---|---|---|---|---|
| P1 | 0.141 | P4 | 1 | P8 | 0.168 | P13 | 0.5 |
| P2 | 0.181 | | | P9 | 0.218 | P14 | 0.5 |
| P3 | 0.179 | | | P10 | 0.183 | | |
| P5 | 0.157 | | | P11 | 0.204 | | |
| P6 | 0.164 | | | P12 | 0.227 | | |
| P7 | 0.178 | | | | | | |

Then, the new score for each firm in each category will be calculated based on the following formula (De Vaus, 2002):

$$\text{Old Score} = \sum_{i=1}^{k} (Survey\ Score_{\ i} \times Weight_{\ i})$$

$$\text{New Score} = \left(\left(\frac{Old\ Score - Min\ Score}{\text{Range}}\right) \times \text{n}\right)$$

i: Open Innovation Practices in each category [1,2, …, k]

Survey Score: Likert score from survey [0, 1, 2, 3]

Weight: Weight of each variable based on PCA

Min Score: Lowest observed value on old scale [0]

Range: Range of observed score on survey score [3]

N: Upper limit for new scale [100]

Since the result of this formula is a continues data, the data will be transferred into discrete type from 0 to 3 based on the Table 9 criteria. The inferential statistical analysis will be conducted on the new transformed data.

*Table 9 – Continuous to desecrate data*

| Continues Data | Desecrate Data |
|---|---|
| 0 | 0 |
| (0, 33.33] | 1 |
| (33.33, 66.66] | 2 |
| (66.66, 100] | 3 |

### 3.4.2. Statistical Analysis

In this section, two approaches which were used to analyze the data that was gathered from the survey will be introduced.

By applying a descriptive statistical analysis on the data, the most frequent Open Innovation practices according to their firm size and most increased outcomes in the whole sample are identified. Also, the most frequent Open Innovation practices within Canadian provinces are identified. In addition, most frequent practices of Canadian firms and European firms and English and French provinces of Canada were compared.

In this part, a relations between the practices and the outcomes have been identified. By applying Kruskal-Wallis test and correlations, it could be determined which practices caused each outcomes (Van de Vrande et al., 2009). In this section, the focus of the research is on pecuniary practices because most of the Open Innovation practices are pecuniary and it could be identified whether by applying Inside-Out pecuniary practices, Outside-In pecuniary practices, both or none of them the outcome would be significantly different or not.

If firms answered that OIP and IOP are applied in their firms “sometimes” (2) or “always” (3), this is coded as 4, if only OIP is applied “sometimes” or “always” it is coded as 3, if only IOP is applied “sometimes” or “always” it is coded 2 and if none of them are applied “sometimes” or “always” it is coded as 1.

### 3.4.3 Simulation

Based on the result of the inferential statistical analysis, a causal diagram can be created to show the relations between each variable and which variables in this system will influence which variables and showing the available feedback loops in this complex system.

System Dynamics approach is a methodology for studying and managing feedback loops in complex systems, systems such as systems in business, economic, population and other complex systems. This approach is very suitable to be used for modeling of the specific feedback systems, because the future behaviors of this system can be predicted by analyzing the feedbacks. The System Dynamics will be adopted in order to analyze and better understand the behavior of this complex system (Forrester, 1994; Sterman, 2000).

Based on the available causal diagram, a stock and flow diagram will be created. In this step, all the variables of the system will be categorized into: level, rate, axillary and constant. The input of the system will be the equations of this variables and constants.

In this research, Table functions were used to show the behaviour of each variable. Based on the result of the survey analysis and literature review of the work, Table functions were created and inserted into the model.

The stock & flow diagram could be found in section 4.4. The Table functions of each variable could be found in Appendix 3.

The model has been simulated with Vensim software which is a simulation program for system dynamics modeling. This approach is for predicting the close future (Forrester, 1994; Sterman, 2000). This simulation was performed for two periods of 3 years.

Based on Sterman (2000), there are twelve methods of validating a systems dynamic model. The following three methods are applied in this research to validate the proposed model. The three mentioned methods are: checking the extreme points, checking the historical behaviour of the system and comparing the result of the simulation with them and changing the initials of the simulation in order to check the behaviour of variables.

There are four different scenarios for applying Open Innovation practices in firms. Each scenario was simulated and the result was compared to the statistical analysis result to make the final decision and proposing the final policy for the firms in nanotechnology industry.

# Chapter 4

# 4. Results

In this chapter the result of this research will be presented in details:

## 4.1. Descriptive Statistical Analysis

### 4.1.1. Sample

In this survey about 315 firms participated, after cleaning the data, statistical analysis was conducted on 302 firms. 54% of the respondents were from SMEs[3] and 45% from LEs[4]. The remaining 1% of the participants did not mention the size of their firms. The detail of frequencies and percentages of the participants could be found in Table 10.

*Table 10 – Participant's firm size*

| | | Frequency | Percent | Valid Percent |
|---|---|---|---|---|
| Valid | SME | 163 | 54.0 | 54.5 |
| | LE | 136 | 45.0 | 45.5 |
| | Total | 299 | 99.0 | 100.0 |
| Missing | System | 3 | 1.0 | |
| Total | | 302 | 100.0 | |

Table 11 and Figure 12 show the distribution of the countries which participated in this online survey.

*Table 11 - Participated countries in the online survey*

| | | Frequency | Percent |
|---|---|---|---|
| | Australia | 89 | 29.5 |
| | Belgium | 4 | 1.3 |
| | Canada | 95 | 31.5 |
| | France | 55 | 18.2 |
| | Germany | 13 | 4.3 |
| | Netherlands | 16 | 5.3 |
| | UK | 8 | 2.6 |
| | USA | 22 | 7.3 |
| | Total | 302 | 100.0 |

[3] Small, Medium Enterprises (Number of employees <100) – North America
[4] Large Enterprises (Number of employees >100) - North America

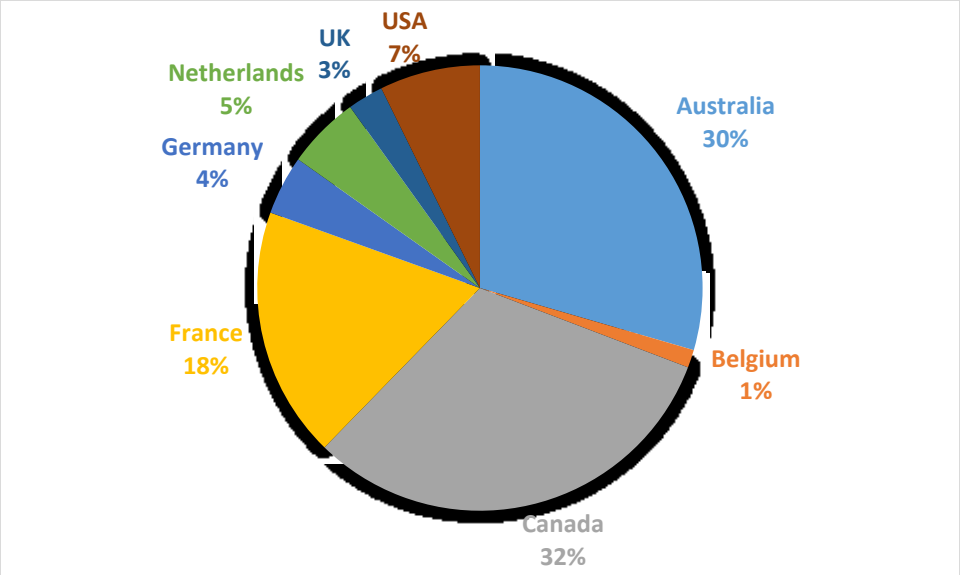


*Figure 12 - Participated countries in the online survey*

Table 12 is showing the number of employees in the sample which participated in the online survey.

*Table 12 - Number of employees*

| What is the total number of employees of your company? | | | | | |
|---|---|---|---|---|---|
| | | Frequency | Percent | Valid Percent | Cumulative Percent |
| Valid | 0-10 | 60 | 19.9 | 19.9 | 19.9 |
| | 11-50 | 47 | 15.6 | 15.6 | 35.5 |
| | 51-100 | 21 | 7.0 | 7.0 | 42.5 |
| | 101-250 | 28 | 9.3 | 9.3 | 51.8 |
| | 251-500 | 20 | 6.6 | 6.6 | 58.5 |
| | 501 or More | 122 | 40.4 | 40.5 | 99.0 |
| | I do not know | 3 | 1.0 | 1.0 | 100.0 |
| | Total | 301 | 99.7 | 100.0 | |
| Missing | System | 1 | .3 | | |
| Total | | 302 | 100.0 | | |

Also, based on the annual revenue of these companies, the proportion of companies which participated in the sample is about 47% SMEs, 39.7% LEs and 13.3% not mentioned. (Table 13).

*Table 13 - Annual revenue range*

| What is the company's annual revenue range? ($M) | | | | | |
|---|---|---|---|---|---|
| | | Frequency | Percent | Valid Percent | Cumulative Percent |
| Valid | 0 - 5 | 101 | 33.4 | 33.7 | 33.7 |
| | 5 - 25 | 40 | 13.2 | 13.3 | 47.0 |
| | 25 or More | 119 | 39.4 | 39.7 | 86.7 |
| | I do not know | 40 | 13.2 | 13.3 | 100.0 |
| | Total | 300 | 99.3 | 100.0 | |
| Missing | System | 2 | .7 | | |
| Total | | 302 | 100.0 | | |

Since the annual revenue of firms is confidential and it is not easy to gather, the number of employees was considered as the base for distinguishing whether the firm is SMEs or LEs.

### 4.1.2. Open Innovation Practices

Based on the following scale from the Likert type questionnaire (Table 14), the frequency of applying Open Innovation practices are described:

*Table 14 - Likert scale values (Practices)*

| Value | Frequency |
|---|---|
| 0 | N/A |
| 1 | Rarely |
| 2 | Sometimes |
| 3 | Always |

Table 15 and Figure 13 show the frequency of applying practice 1 (Buying a license) in the sample. The result shows that the frequency of applying this practice in majority of firms in nanotechnology industry is “rarely”.

*Table 15 - Frequency of applying practice 1*

| | | Frequency | Percent |
|---|---|---|---|
| Valid | N/A | 50 | 16.6 |
| | Rarely | 131 | 43.4 |
| | Sometimes | 63 | 20.9 |
| | Always | 58 | 19.2 |
| | Total | 302 | 100.0 |

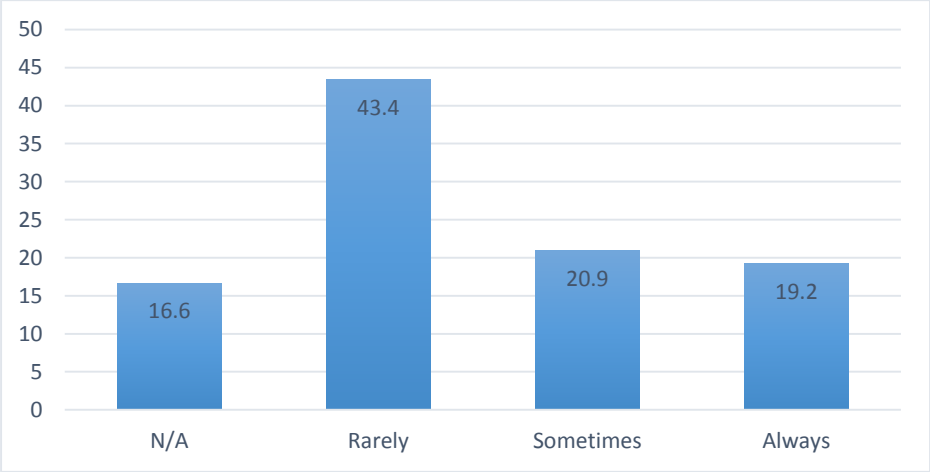


*Figure 13 - Bar chart for frequency of applying practice 1*

Table 16 and Figure 14 show the frequency of applying practice 2 (Contracting with other companies for R&D services) in the sample. The result shows that the frequency of applying this practice in majority of firms in nanotechnology industry is “always”.

*Table 16 - Frequency of applying practice 2*

| | | Frequency | Percent |
|---|---|---|---|
| Valid | N/A | 24 | 7.9 |
| | Rarely | 60 | 19.9 |
| | Sometimes | 75 | 24.8 |
| | Always | 143 | 47.4 |
| | Total | 302 | 100.0 |

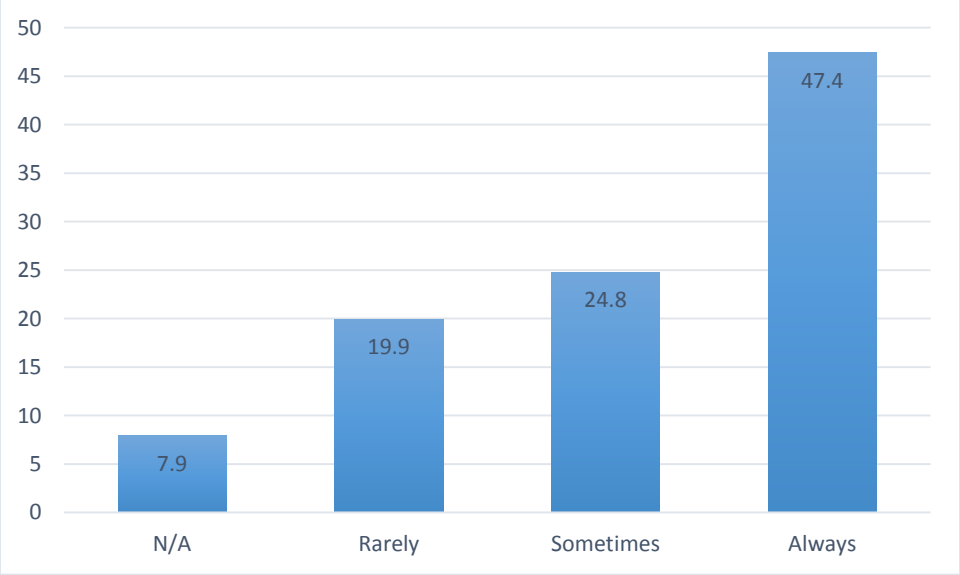


*Figure 14 - Bar chart for frequency of applying practice 2*

Table 17 and Figure 15 show the frequency of applying practice 3 (Buying any innovative ideas from start-up companies) in the sample. The result shows that the frequency of applying this practice in majority of firms in nanotechnology industry is “rarely”.

*Table 17 - Frequency of applying practice 3*

| | | Frequency | Percent |
|---|---|---|---|
| Valid | N/A | 61 | 20.2 |
| | Rarely | 179 | 59.3 |
| | Sometimes | 39 | 12.9 |
| | Always | 23 | 7.6 |
| | Total | 302 | 100.0 |

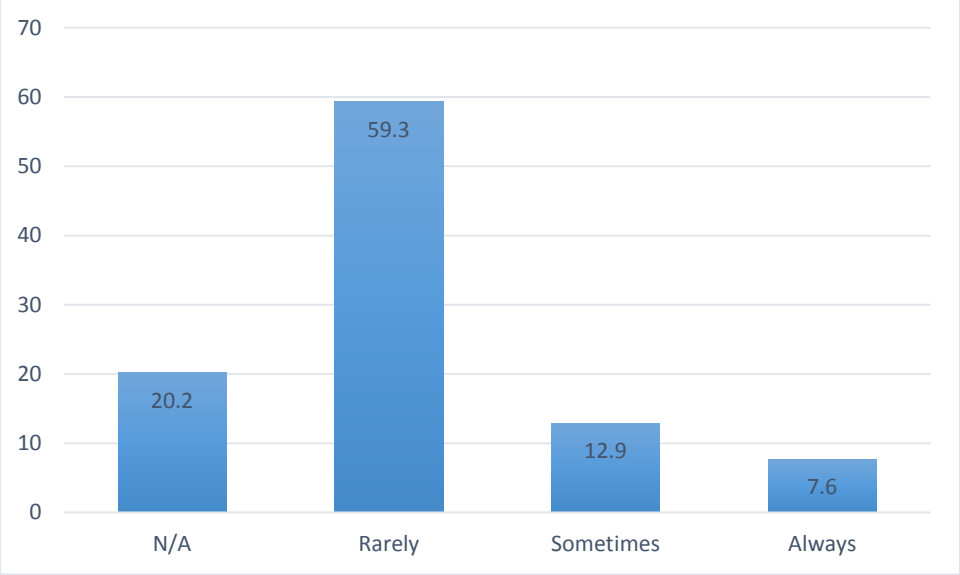


*Figure 15 - Bar chart for frequency of applying practice 3*

Table 18 and Figure 16 show the frequency of applying practice 4 (Obtaining innovative ideas from a large group of people - Crowdsourcing) in the sample. The result shows that the frequency of applying this practice in majority of firms in nanotechnology industry is “rarely”.

*Table 18 - Frequency of applying practice 4*

| | | Frequency | Percent |
|---|---|---|---|
| Valid | N/A | 36 | 11.9 |
| | Rarely | 131 | 43.4 |
| | Sometimes | 68 | 22.5 |
| | Always | 67 | 22.2 |
| | Total | 302 | 100.0 |

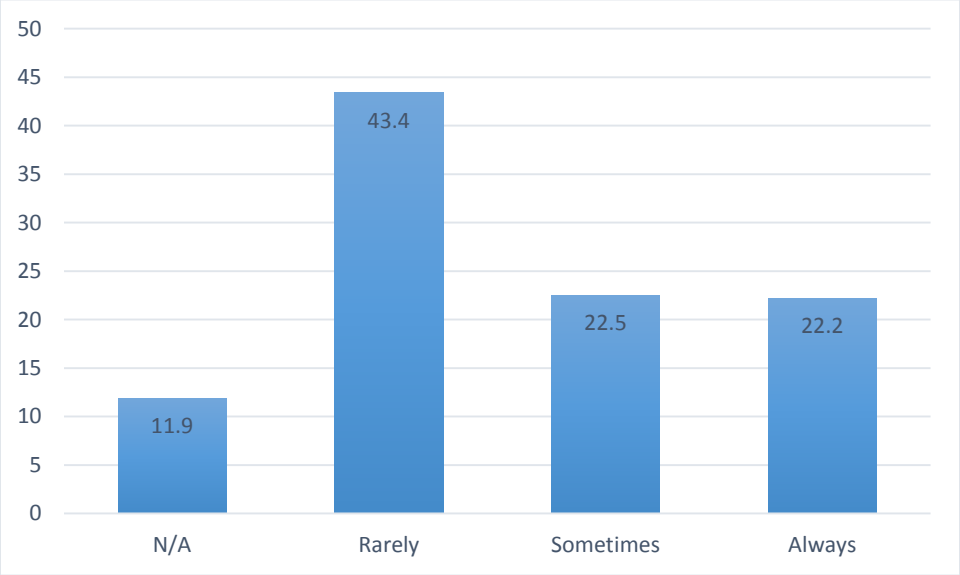


*Figure 16 - Bar chart for frequency of applying practice 4*

Table 19 and Figure 17 show the frequency of applying practice 5 (Consulting with any specialized Open Innovation companies) in the sample. The result shows that the frequency of applying this practice in majority of firms in nanotechnology industry is “rarely”.

*Table 19 - Frequency of applying practice 5*

| | | Frequency | Percent |
|---|---|---|---|
| Valid | N/A | 51 | 16.9 |
| | Rarely | 159 | 52.6 |
| | Sometimes | 50 | 16.6 |
| | Always | 42 | 13.9 |
| | Total | 302 | 100.0 |

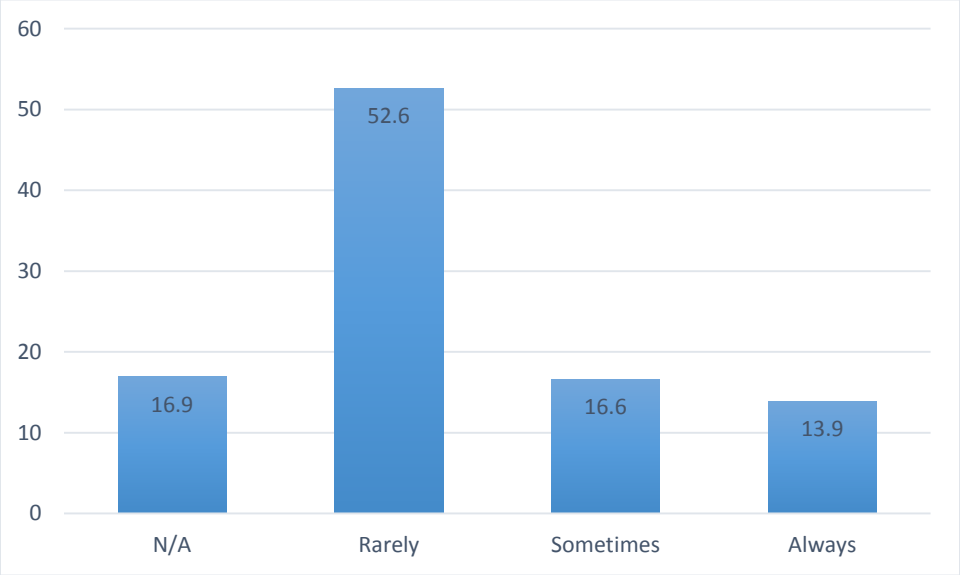


*Figure 17 - Bar chart for frequency of applying practice 5*

Table 20 and Figure18 show the frequency of applying practice 6 (Collaborating with students in a research agreement with a university) in the sample. The result shows that the frequency of applying this practice in majority of firms in nanotechnology industry is “always”.

*Table 20 - Frequency of applying practice 6*

| | | Frequency | Percent |
|---|---|---|---|
| Valid | N/A | 10 | 3.3 |
| | Rarely | 37 | 12.3 |
| | Sometimes | 64 | 21.2 |
| | Always | 191 | 63.2 |
| | Total | 302 | 100.0 |

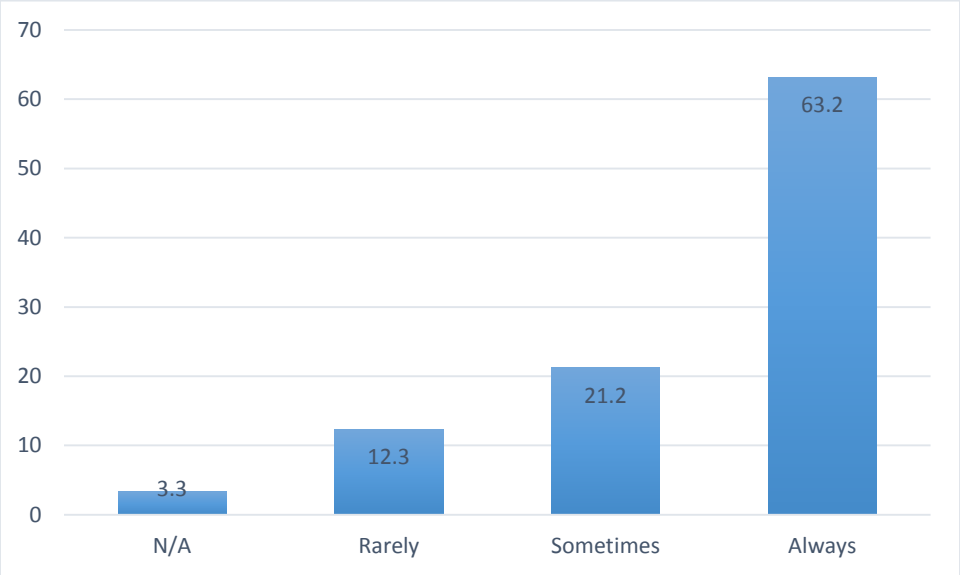


*Figure 18 - Bar chart for frequency of applying practice 6*

Table 21 and Figure 19 show the frequency of applying practice 7 (Assigning a research fund to an academic institute) in the sample. The result shows that the frequency of applying this practice in majority of firms in nanotechnology industry is “always”.

*Table 21 - Frequency of applying practice 7*

| | | Frequency | Percent |
|---|---|---|---|
| Valid | N/A | 33 | 10.9 |
| | Rarely | 82 | 27.2 |
| | Sometimes | 61 | 20.2 |
| | Always | 126 | 41.7 |
| | Total | 302 | 100.0 |

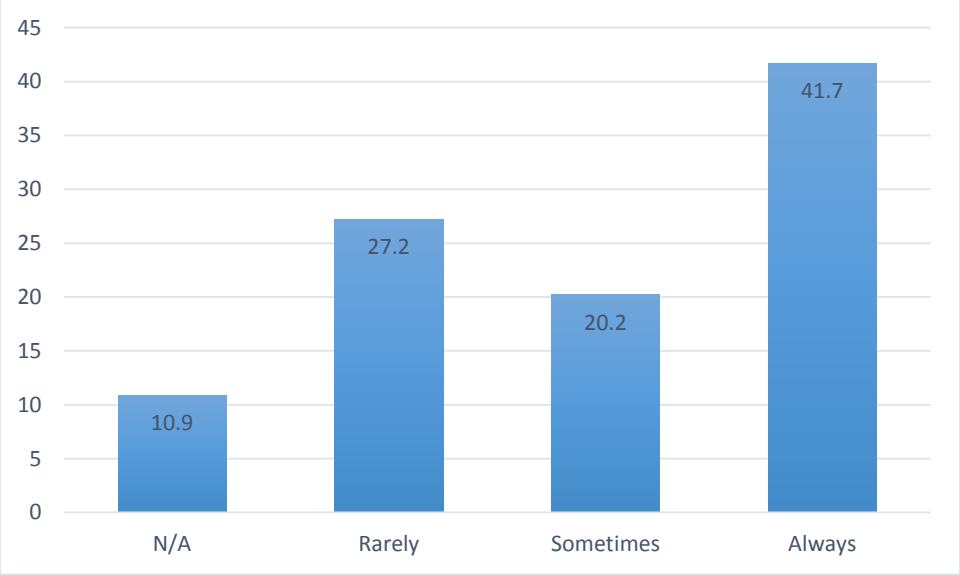


*Figure 19 - Bar chart for frequency of applying practice 7*

Table 22 and Figure 20 show the frequency of applying practice 8 (Joint Venture Agreement) in the sample. The result shows that the frequency of applying this practice in majority of firms in nanotechnology industry is “sometimes”.

*Table 22 - Frequency of applying practice 8*

| | | Frequency | Percent |
|---|---|---|---|
| Valid | N/A | 40 | 13.2 |
| | Rarely | 91 | 30.1 |
| | Sometimes | 100 | 33.1 |
| | Always | 71 | 23.5 |
| | Total | 302 | 100.0 |

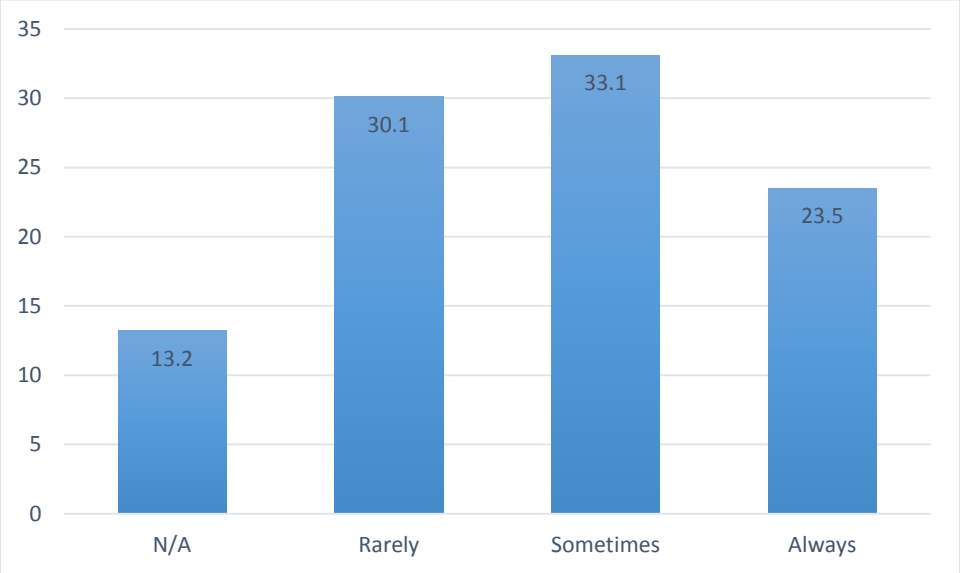


*Figure 20 - Bar chart for frequency of applying practice 8*

Table 23 and Figure 21 show the frequency of applying practice 9 (Sell new knowledge developed in R&D to another company) in the sample. The result shows that the frequency of applying this practice in majority of firms in nanotechnology industry is mostly “rarely”.

*Table 23 - Frequency of applying practice 9*

| | | Frequency | Percent |
|---|---|---|---|
| Valid | N/A | 27 | 8.9 |
| | Rarely | 100 | 33.1 |
| | Sometimes | 92 | 30.5 |
| | Always | 83 | 27.5 |
| | Total | 302 | 100.0 |

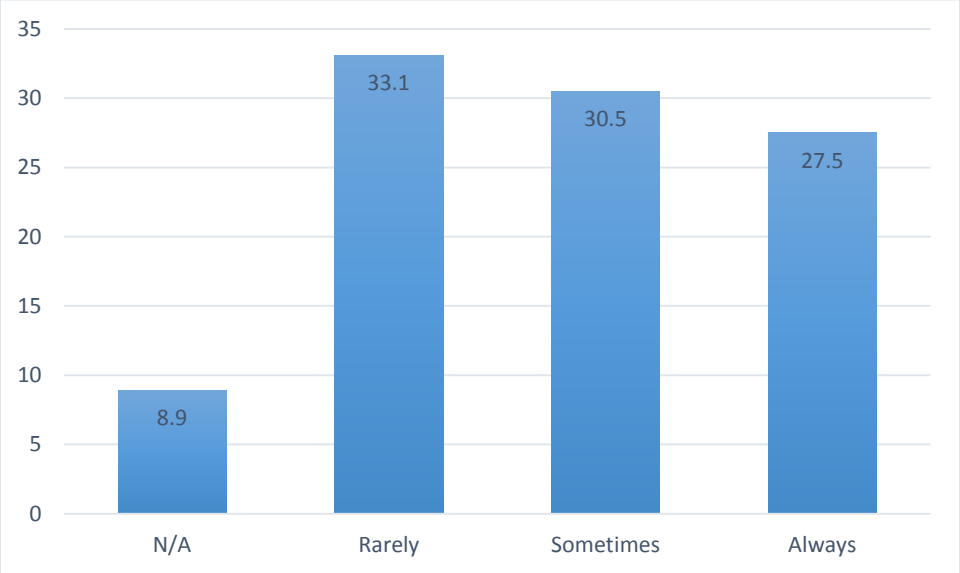


*Figure 21 - Bar chart for frequency of applying practice 9*

Table 24 and Figure 22 show the frequency of applying practice 10 (Participating in a business incubator program) in the sample. The result shows that the frequency of applying this practice in majority of firms in nanotechnology industry is mostly “rarely”.

*Table 24 - Frequency of applying practice 10*

| | | Frequency | Percent |
|---|---|---|---|
| Valid | N/A | 37 | 12.3 |
| | Rarely | 135 | 44.7 |
| | Sometimes | 74 | 24.5 |
| | Always | 56 | 18.5 |
| | Total | 302 | 100.0 |

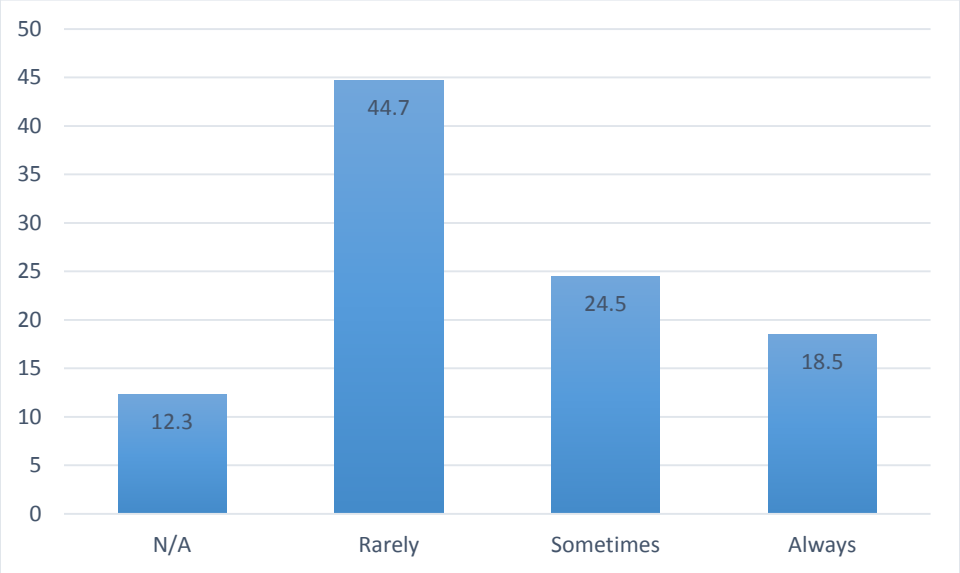


*Figure 22 - Bar char for frequency of applying practice 10*

Table 25 and Figure 23 show the frequency of applying practice 11 (Selling R&D market ready by-product) in the sample. The result shows that the frequency of applying this practice in majority of firms in nanotechnology industry is mostly “rarely”.

*Table 25 - Frequency of applying practice 11*

| | | Frequency | Percent |
|---|---|---|---|
| Valid | N/A | 45 | 14.9 |
| | Rarely | 129 | 42.7 |
| | Sometimes | 60 | 19.9 |
| | Always | 68 | 22.5 |
| | Total | 302 | 100.0 |

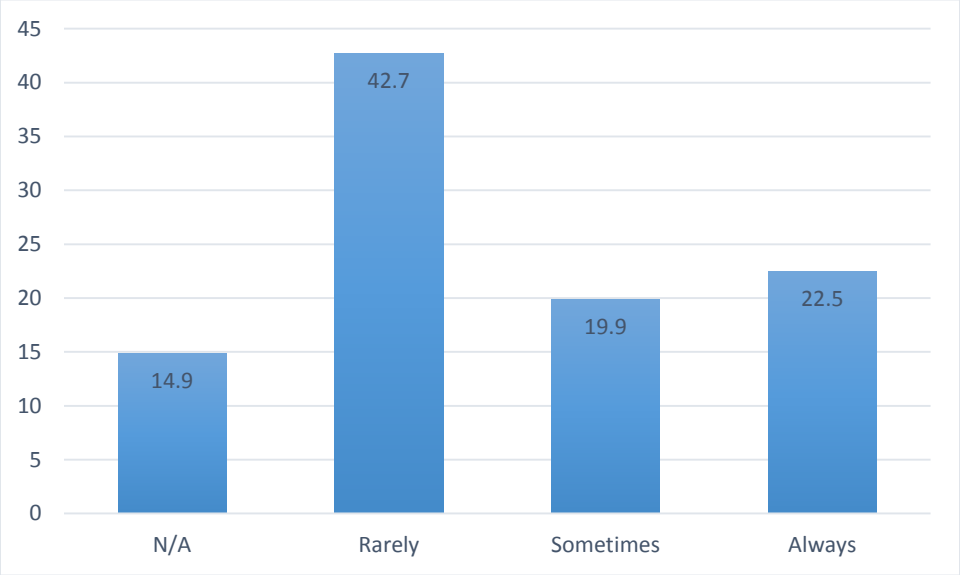


*Figure 23 - Bar chart for frequency of applying practice 11*

Table 26 and Figure 24 show the frequency of applying practice 12 (Selling license of innovations) in the sample. The result shows that the frequency of applying this practice in majority of firms in nanotechnology industry is mostly “rarely”.

*Table 26 - Frequency of applying practice 12*

| | | Frequency | Percent |
|---|---|---|---|
| Valid | N/A | 33 | 10.9 |
| | Rarely | 121 | 40.1 |
| | Sometimes | 70 | 23.2 |
| | Always | 78 | 25.8 |
| | Total | 302 | 100.0 |

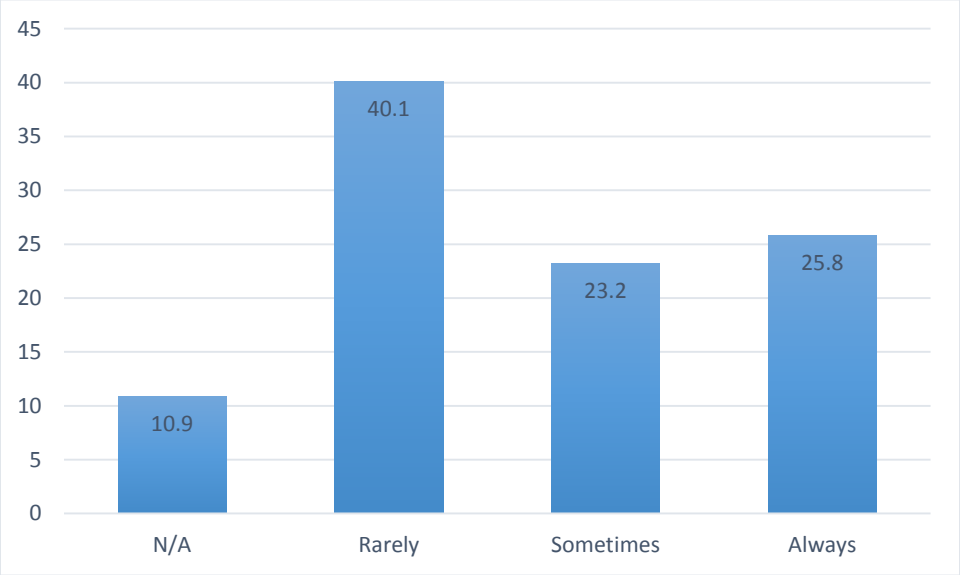


*Figure 24 - Bar chart for frequency of applying practice 12*

Table 27 and Figure 25 show the frequency of applying practice 13 (Providing innovation for standardization organization) in the sample. The result shows that the frequency of applying this practice in majority of firms in nanotechnology industry is mostly “rarely”.

*Table 27 - Frequency of applying practice 13*

| | | Frequency | Percent |
|---|---|---|---|
| Valid | N/A | 49 | 16.2 |
| | Rarely | 141 | 46.7 |
| | Sometimes | 58 | 19.2 |
| | Always | 54 | 17.9 |
| | Total | 302 | 100.0 |

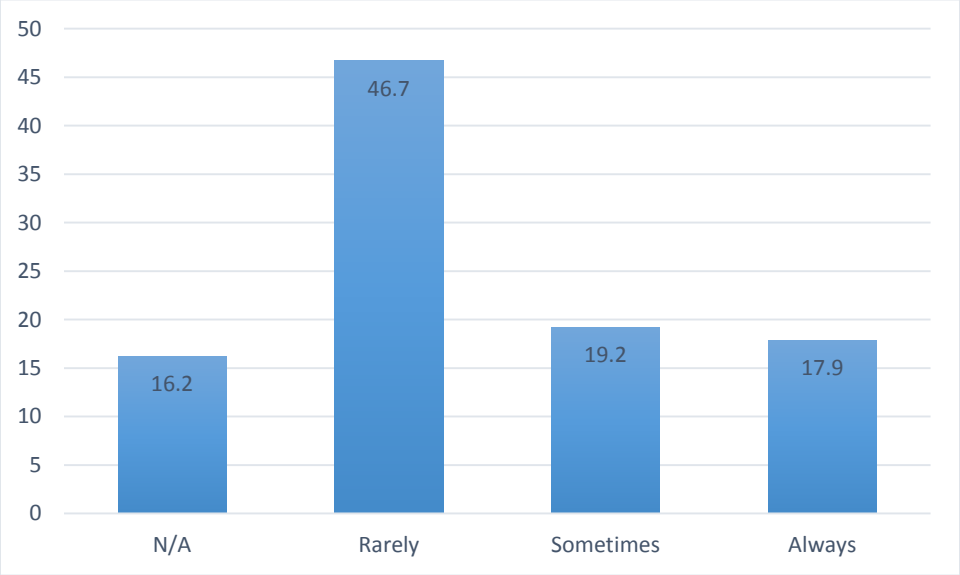


*Figure 25 - Bar chart for frequency of applying practice 13*

Table 28 and Figure 26 show the frequency of applying practice 14 (Donating innovation/knowledge to any non-profit organization) in the sample. The result shows that the frequency of applying this practice in majority of firms in nanotechnology industry is mostly "rarely".

*Table 28 - Frequency of applying practice 14*

| | | Frequency | Percent |
|---|---|---|---|
| Valid | N/A | 56 | 18.5 |
| | Rarely | 157 | 52.0 |
| | Sometimes | 48 | 15.9 |
| | Always | 41 | 13.6 |
| | Total | 302 | 100.0 |

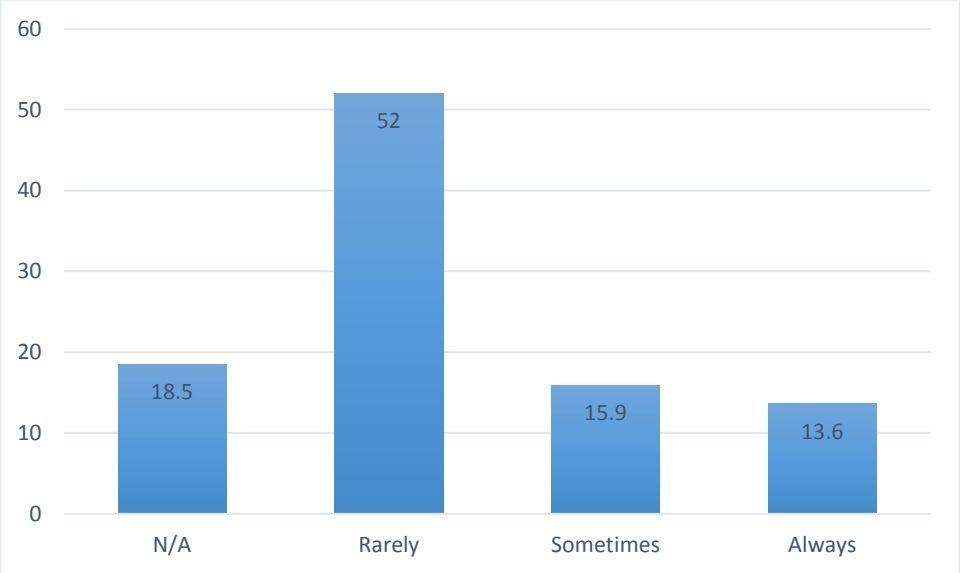


*Figure 26 - Bar chart for frequency of applying practice 14*

In summary, based on the survey results, most frequent practices among all outside – in Open Innovation practices are mentioned in Table 29 and Figure 27:

*Table 29 - Outside – In Open Innovation Practices Frequency*

| Statistics | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Buying a license | Contract with other companies for R&D services | Buying any innovative ideas from start-up companies | Obtaining innovative ideas from a large group of people (Crowd Sourcing) | Consulting with any specialized Open Innovation companies | Collaborating with students in a research agreement with a university | Assigning a research fund to an academic institute |
| N | Valid | 302 | 302 | 302 | 302 | 302 | 302 | 302 |
| Median | | 1.0000 | 2.0000 | 1.0000 | 1.0000 | 1.0000 | 3.0000 | 2.0000 |
| Mode | | 1.00 | 3.00 | 1.00 | 1.00 | 1.00 | 3.00 | 3.00 |

Practice 6 (Collaborating with students in a research agreement with a university), Practice 2 (Contracting with other companies for R&D services) and practice 7 (Assigning a research fund to an academic institute) are the most frequent practices in Outside-In type of Open Innovation practices.

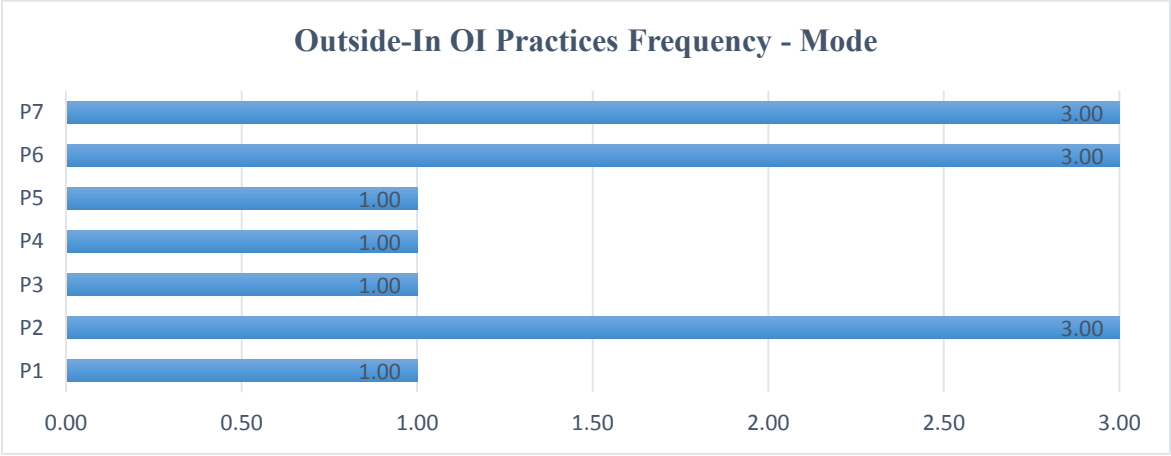


*Figure 27 - Outside – In Open Innovation Practices Frequency*

In summary, based on the survey results, most frequent practices among all Inside-Out Open Innovation practices are mentioned in Table 30 and Figure 28:

*Table 30 - Inside – Out Open Innovation Practices Frequency*

| Statistics | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Joint Venture agreement | Sell new knowledge developed in R&D to another company | Participating in a business incubator program | Selling R&D market ready by-product | Selling license of innovations | Providing innovation for standardization organization | Donating innovation/knowledge to any non-profit organization |
| N | Valid | 302 | 302 | 302 | 302 | 302 | 302 | 302 |
| Median | | 2.0000 | 2.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| Mode | | 2.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |

Practice 8 (Joint Venture Agreement) is the most frequent practices in Inside-Out type of Open Innovation practices.

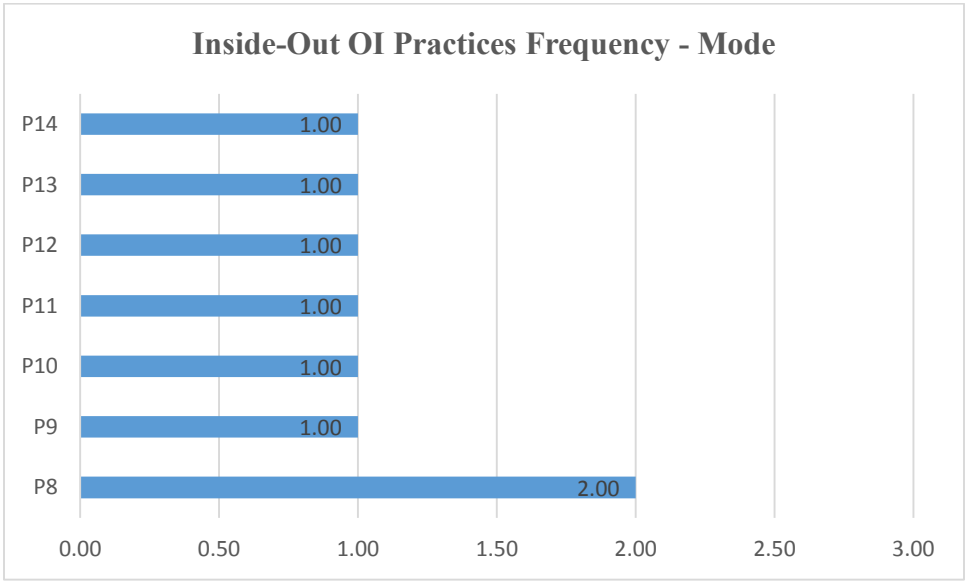


*Figure 28 - Inside – Out Open Innovation Practices Frequen*

Since, none of median and mode of the Inside – Out Open Innovation practices are not more than 2 (average level in Likert scale) which means they are not applying these practices with a high frequency, the remainder of this study will only focus on Outside-In Open Innovation practices which are frequently used in nanotechnology firms. Practice 6 (Collaborating with students in a research agreement with a university), Practice 2 (Contracting with other companies for R&D services) and Practice 7 (Assigning a research fund to an academic institute) are the most frequent practices based on this survey results. As it is expected there is a lot of collaboration between academia and industry. Based on the result of this survey two of the three most frequent practices are related to this type of collaboration.

Based on the survey result, companies are more interested to use Outside-In practices than Inside-Out practices. This result is in line with the findings of Henry Chesbrough (2013), Laursen and Salter (2004) and Van der Meer (2007). University grants and joint venture agreements are the most two frequent practices of Open Innovation based on Chesbrough's survey in 2013 which is similar to the frequent practices in nanotechnology industry.

### 4.1.3. Outcomes

Based on the descriptive statistics analysis among all types of outcomes, Table 32 and Figure 29 show the distribution of answers for the impact of Open Innovation practices on the performance of the companies. The top three outcomes with the highest performance increase in firms are "number of innovation partners", "percentage of funded ideas" and "number of papers".

Table 31 shows Likert scale values for this question in the questionnaire.

*Table 31 - Likert scale values (Outcomes)*

| Value | Frequency |
|---|---|
| 0 | N/A |
| 1 | Decreased |
| 2 | Remained the same |
| 3 | Increased |

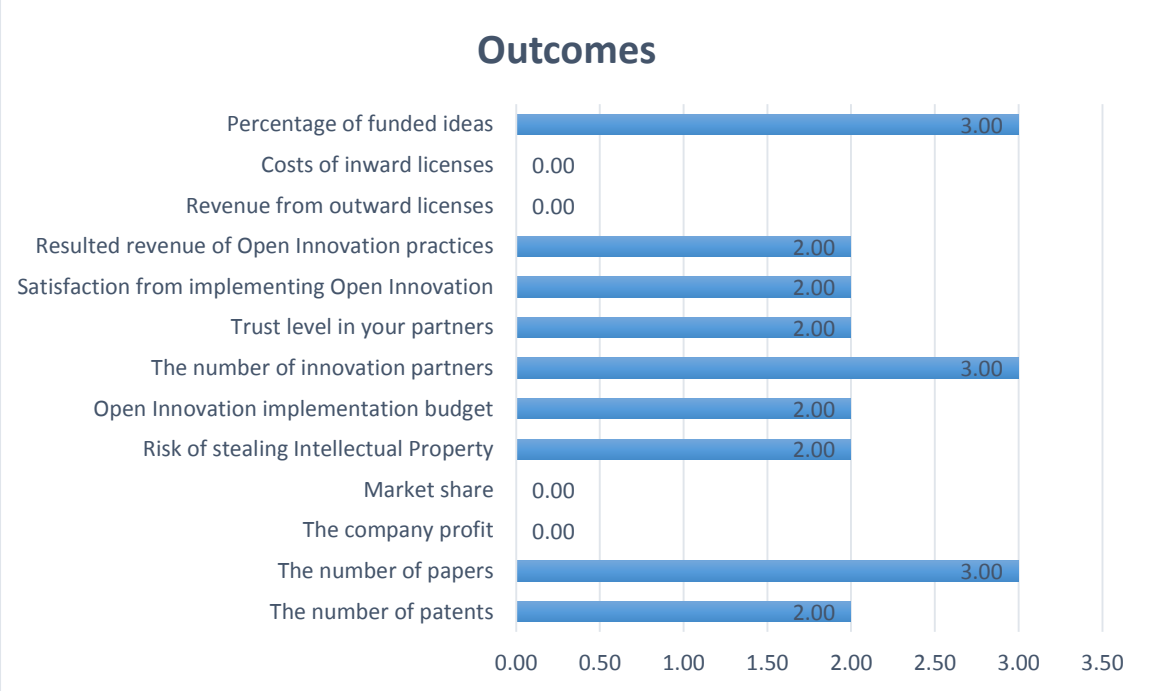


*Figure 29 - Firm's outcome*

*Table 32 - Firm's Outcomes*

| Statistics | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | The number of patents | The number of papers | The company profit | Market share | Risk of stealing Intellectual Property | Open Innovation implementation budget | The number of innovation partners | Trust level in your partners | Satisfaction from implementing Open Innovation | Resulted revenue of Open Innovation practices | Revenue from outward licenses | Costs of inward licenses | Percentage of funded ideas |
| N | Valid | 302 | 302 | 302 | 302 | 302 | 302 | 302 | 302 | 302 | 302 | 302 | 302 | 302 |
| Median | | 2.0000 | 3.0000 | 2.0000 | 2.0000 | 2.0000 | 2.0000 | 3.0000 | 2.0000 | 2.0000 | 2.0000 | 1.0000 | .0000 | 2.0000 |
| Mode | | 2.00 | 3.00 | .00 | .00 | 2.00 | 2.00 | 3.00 | 2.00 | 2.00 | 2.00 | .00 | .00 | 3.00 |

### 4.1.4. Top Open Innovation Practices and Size of the Firms

The frequency of applying the most frequent Open Innovation practices in firms, based on the size of the firms is mentioned below:

75% of LEs and 54% of SMEs are applying "collaborating with students in a research agreement with a university" with a high frequency. This shows that this practice is popular in LEs. (Table 33)

*Table 33 - Firm Size * Collaborating with students in a research agreement with a university Cross tabulation*

| **SIZE * Collaborating with students in a research agreement with a university Cross tabulation** | | | | | | |
|---|---|---|---|---|---|---|
| % within SIZE | | | | | | |
| | | Collaborating with students in a research agreement with a university | | | | Total |
| | | N/A | Rarely | Sometimes | Always | |
| SIZE | SME | 5.5% | 17.8% | 22.7% | 54.0% | 100.0% |
| | LE | 0.7% | 5.1% | 19.1% | 75.0% | 100.0% |
| Total | | 3.3% | 12.0% | 21.1% | 63.5% | 100.0% |

Based on the result of the survey, about 70.8% of LEs are applying this practice with a high frequency. (Figure 30)

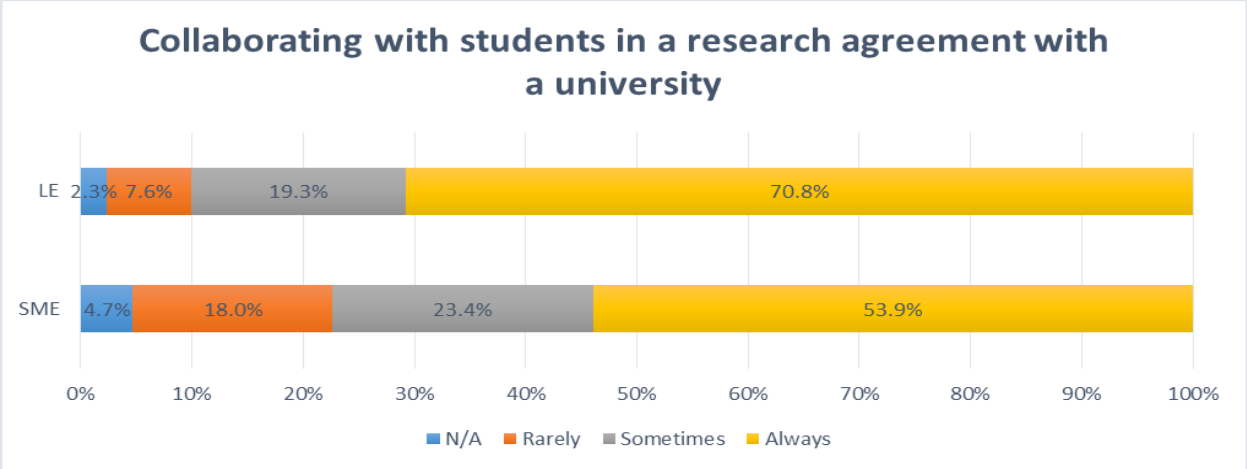


*Figure 30 - Firm Size * Collaborating with students in a research agreement with a university*

53.7% of LEs are applying "contract with other companies for R&D services" with a high frequency. However, only 42.3% of SMEs are applying this practice with a high frequency. (Table 34)

*Table 34 - Firm Size * Contract with other companies for R&D services Cross tabulation*

| **SIZE * Contract with other companies for R&D services Cross tabulation** | | | | | | |
|---|---|---|---|---|---|---|
| % within SIZE | | | | | | |
| | | Contract with other companies for R&D services | | | | Total |
| | | N/A | Rarely | Sometimes | Always | |
| SIZE | SME | 6.7% | 22.7% | 28.2% | 42.3% | 100.0% |
| | LE | 9.6% | 16.9% | 19.9% | 53.7% | 100.0% |
| Total | | 8.0% | 20.1% | 24.4% | 47.5% | 100.0% |

Based on the result of the survey, about 51.5% of LEs are applying this practice with a high frequency. (Figure 31)

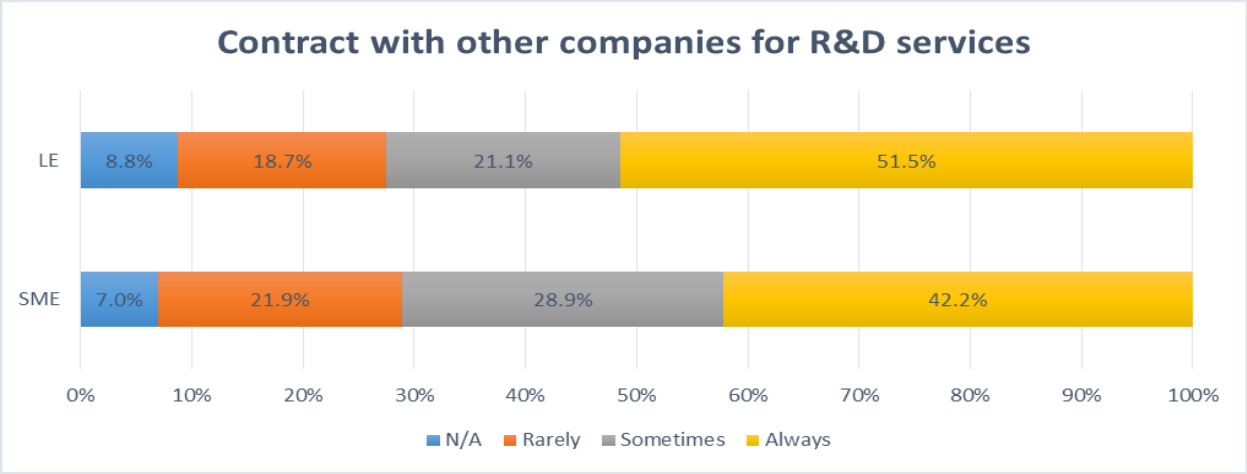


*Figure 31 - Firm Size * Contract with other companies for R&D services*

49.3% of LEs and 35.6% of SMEs are applying "assigning a research fund to an academic institute" with a high frequency. (Table 35)

*Table 35 - Firm Size * Assigning a research fund to an academic institute Cross tabulation*

| SIZE * Assigning a research fund to an academic institute Cross tabulation | | | | | | |
|---|---|---|---|---|---|---|
| % within SIZE | | | | | | |
| | | Assigning a research fund to an academic institute | | | | Total |
| | | N/A | Rarely | Sometimes | Always | |
| SIZE | SME | 12.3% | 36.2% | 16.0% | 35.6% | 100.0% |
| | LE | 9.6% | 16.2% | 25.0% | 49.3% | 100.0% |
| Total | | 11.0% | 27.1% | 20.1% | 41.8% | 100.0% |

Based on the result of the survey, about 34.4% of SMEs are applying this practice with a low frequency. (Figure 32)

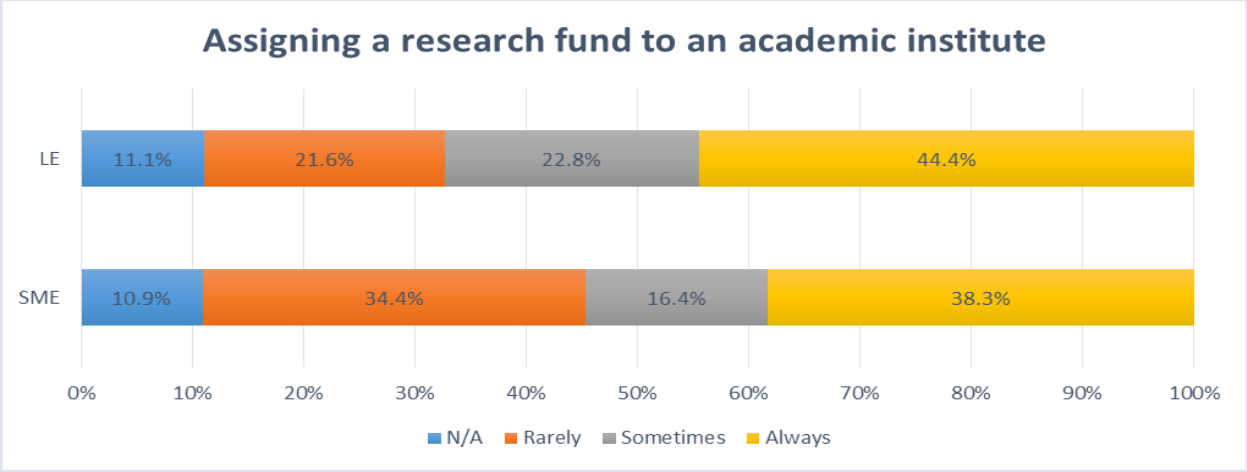


*Figure 32 - Firm Size * Assigning a research fund to an academic institute*

Based on the results of the survey, the frequency of applying Open Innovation top practices in LEs is higher than SMEs. This conclusion is similar to what Van de Vrande et al., (2009) found about the different frequency of applying Open Innovation practices based on firm's size and Parida et al., (2012) mentioned that large firms are applying Open Innovation practices with a higher frequency. This might be because LEs have more resources, equipment and expertise than SMEs.

## 4.1.5. Frequency of Applying Top Open Innovation Practices in Canadian Provinces

### 4.1.5.1. Sample size of Canadian participants

Among the firms which participated in this survey 95 were from Canada. After cleaning the data, Table 36 shows the distribution of these participants based on their provinces in Canada.

*Table 36 - Canadian participants' provinces*

| | | Frequency | Percent |
|---|---|---|---|
| Valid | AB | 7 | 7.6 |
| | BC | 13 | 14.1 |
| | ON | 26 | 28.3 |
| | QC | 46 | 50.0 |
| | Total | 92 | 100.0 |

In this section the frequency of applying OI practices in English and French speaking provinces of Canada will be compared. In Canadian sample, there are 64 SMEs and 27 LEs. (Table 37)

*Table 37 - Firms' size of Canadian participants*

| | | Frequency | Percent | Valid Percent |
|---|---|---|---|---|
| Valid | SME | 64 | 69.6 | 70.3 |
| | LE | 27 | 29.3 | 29.7 |
| | Total | 91 | 98.9 | 100.0 |
| Missing | System | 1 | 1.1 | |
| Total | | 92 | 100.0 | |

### 4.1.5.2. Frequency of Applying OI Practices in English and French Canadian Provinces

Figure 33, shows mode of applying different Open Innovation practices in English and French provinces. Based on this result all the practices are applied with the same frequency except practice 7 (assigning a research fund to an academic institute) which is more frequent in French province than others.

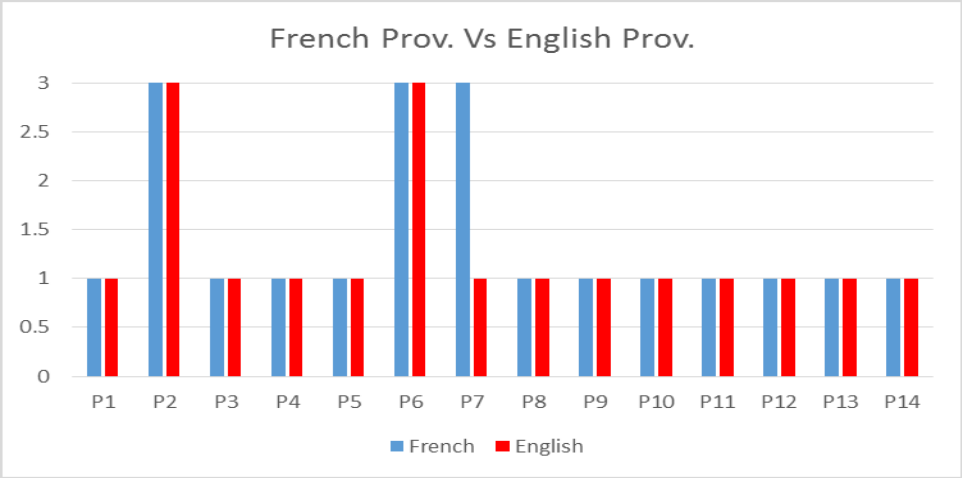


*Figure 33 – Quebec and Rest of Canada OI practices frequency*

Within firms in both French and English provinces, "collaborating with students in a research agreement with a university", is applied with a high frequency, although French firms are using this practice more than English ones. (Table 38)

*Table 38 – Quebec Vs Others, practice 6*

| | | Collaborating with students in a research agreement with a university | | | | Total |
|---|---|---|---|---|---|---|
| | | N/A | Rarely | Sometimes | Always | |
| Province | Quebec | 33.3% | 43.8% | 42.1% | 55.6% | 50.0% |
| | Others | 66.7% | 56.2% | 57.9% | 44.4% | 50.0% |
| Total | | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |

65.2% of firms in Quebec are applying this practices with a high frequency. (Figure 34)

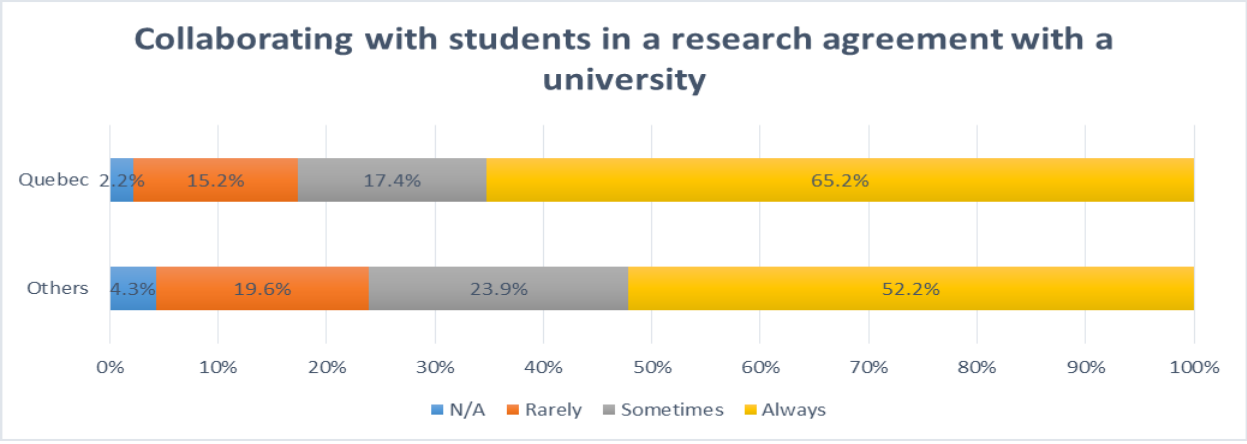


*Figure 34 - Quebec Vs. Others, Practice 6*

Within firms in both French and English provinces, "contract with other companies for R&D services", is applied with a high frequency, although French firms are using this practice much more than English ones. (Table 39)

*Table 39 – Quebec Vs Others, practice 2*

| | | Contract with other companies for R&D services | | | | Total |
|---|---|---|---|---|---|---|
| | | N/A | Rarely | Sometimes | Always | |
| Province | Quebec | 50.0% | 36.8% | 27.8% | 63.3% | 50.0% |
| | Others | 50.0% | 63.2% | 72.2% | 36.7% | 50.0% |
| Total | | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |

67.4% of firms in Quebec are applying this practices with a high frequency. (Figure 35)

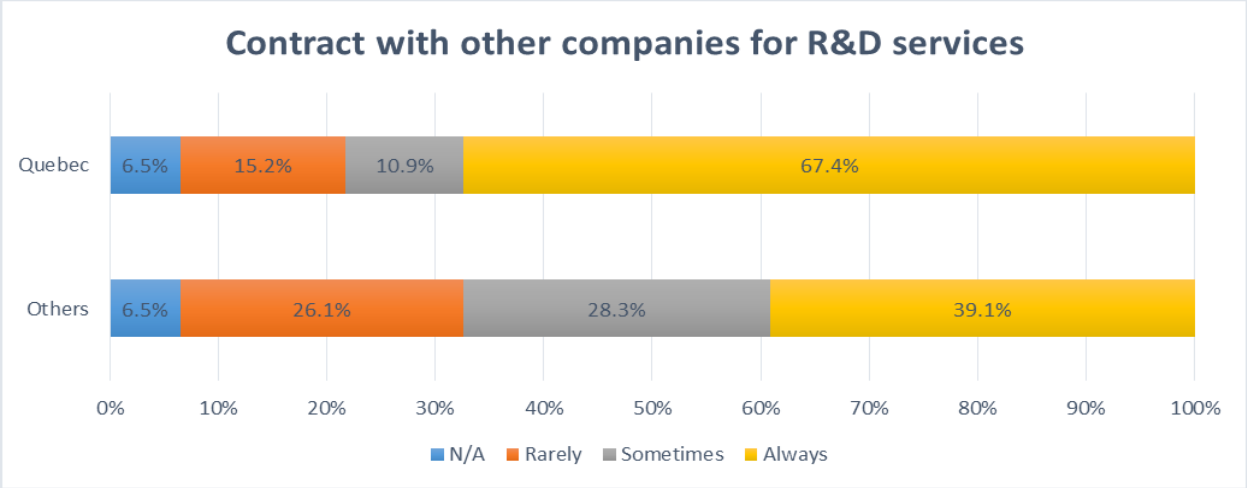


*Figure 35 - Quebec Vs Others, practice 2*

Within firms in French province of Quebec, "assigning a research fund to an academic institute", is applied with a high frequency. However, in English provinces of Canada this practice is applied rarely.

*Table 40 – Quebec Vs Others, practice 7*

| | | Assigning a research fund to an academic institute | | | | Total |
|---|---|---|---|---|---|---|
| | | N/A | Rarely | Sometimes | Always | |
| Province | Quebec | 50.0% | 38.7% | 40.0% | 62.5% | 50.0% |
| | Others | 50.0% | 61.3% | 60.0% | 37.5% | 50.0% |
| Total | | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |

54.3% of firms in Quebec are applying this practices with a high frequency in compare with 41.3% of firms from rest of Canada which are applying this practice with a low frequency. (Figure 36)

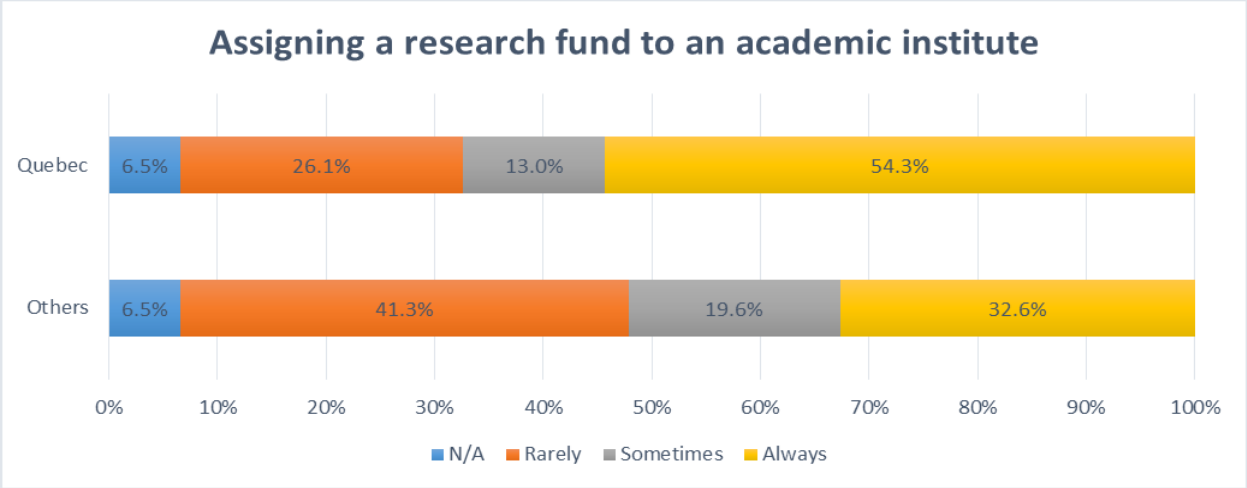


*Figure 36 - Quebec Vs Others, practice 7*

So, applying OI most frequent practices are more frequent in Quebec than other Canadian provinces. One of the possible reasons of this different frequency could be because of level of funding for Quebec universities than other universities in Canada. Since Quebec universities are living in a small community of French researchers; more collaboration in tightly groups can increase the chance of having more funding (Ebadi & Schiffauerova, 2015).

### 4.1.6. Open Innovation Practices - Canada vs. Europe

Since Europe has been engaged in Open Innovation for some time already it would be interesting to compare the results of the survey in Europe with Canada to see the differences.

#### 4.1.6.1. Sample Size of Canadian and European Participants

In this survey, 95 Canadian and 96 European firms participated, which is almost the same proportion of participants in this sample (Table 41). In this part the top Open Innovation practices of Canadian and European firms will be presented.

*Table 41 - Canadian & European sample size*

| | | Frequency | Percent |
|---|---|---|---|
| Valid | Canada | 95 | 49.7 |
| | Europe | 96 | 50.3 |
| | Total | 191 | 100.0 |

50% of the European firms in this sample are SMEs and 50% of them are LEs (Table 42).

*Table 42 - Firms' size of European participants*

| | | Frequency | Percent | Valid Percent |
|---|---|---|---|---|
| Valid | SME | 48 | 50.0 | 50.0 |
| | LE | 48 | 50.0 | 50.0 |
| | Total | 96 | 100.0 | 100.0 |

70.3% of the Canadian firms in this sample are SMEs and 29.7% of them are LEs (Table 43).

*Table 43 - Firms' size of Canadian participants*

| | | Frequency | Percent | Valid Percent |
|---|---|---|---|---|
| Valid | SME | 64 | 69.6 | 70.3 |
| | LE | 27 | 29.3 | 29.7 |
| | Total | 91 | 98.9 | 100.0 |
| Missing | System | 1 | 1.1 | |
| Total | | 92 | 100.0 | |

### 4.1.6.2. Canada

Table 44 shows mode and median of each Outside-In Open Innovation practices in Canada. "Contract with other companies for R&D services" and "collaborating with students in a research agreement with a university" are those two practices that majority of the firms are applying in Canada and "assigning a research fund to an academic institute" is in the next order.

*Table 44 - Outside – In Open Innovation Practices Frequency in Canada*

| Statistics | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Buying a license | Contract with other companies for R&D services | Buying any innovative ideas from start-up companies | Obtaining innovative ideas from a large group of people (ex. online community) | Consulting with any specialized Open Innovation companies | Collaborating with students in a research agreement with a university | Assigning a research fund to an academic institute |
| N | Valid | 92 | 92 | 92 | 92 | 92 | 92 | 92 |
| Median | | 1.0000 | 3.0000 | 1.0000 | 1.0000 | 1.0000 | 3.0000 | 2.0000 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Mode | 1.00 | 3.00 | 1.00 | 1.00 | 1.00 | 3.00 | 3.00 |

Table 45 shows mode and median of each Inside-Out Open Innovation practices in Canada. None of these practices is frequently applied in Canadian firms.

*Table 45 - Inside-Out Open Innovation Practices Frequency in Canada*

| Statistics | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Joint Venture agreement | Sell new knowledge developed in R&D to another company | Participating in a business incubator program | Selling R&D market ready by-product | Selling license of innovations | Providing innovation for standardization organization | Donating innovation/knowledge to any non-profit organization |
| N | Valid | 92 | 92 | 92 | 92 | 92 | 92 | 92 |
| Median | | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| Mode | | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |

### 4.1.6.3. Europe

Table 46 shows mode and median of each Outside-In Open Innovation practices in Europe. "Collaborating with students in a research agreement with a university" is the only practice which most of the firms are applying in Canada and "assigning a research fund to an academic institute" and "contract with other companies for R&D services" are in the next order.

*Table 46 - Outside – In Open Innovation Practices Frequency in Europe*

| Statistics | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Buying a license | Contract with other companies for R&D services | Buying any innovative ideas from start-up* companies | Obtaining innovative ideas from a large group of people (Crowd Sourcing) | Consulting with any specialized Open Innovation companies | Collaborating with students in a research agreement with a university | Assigning a research fund to an academic institute |
| N | Valid | 96 | 96 | 96 | 96 | 96 | 96 | 96 |
| Median | | 1.0000 | 2.0000 | 1.0000 | 1.0000 | 1.0000 | 3.0000 | 2.0000 |
| Mode | | 1.00 | 3.00 | 1.00 | 1.00 | 1.00 | 3.00 | 3.00 |

Table 47 shows mode and median of each Inside-Out Open Innovation practices in Europe. None of these practices is frequently applied in European firms. However, "sell new knowledge developed in R&D to another company" is one of the Inside-Out practices which is applied in firms more than the other types of Inside-Out practices.

*Table 47 - Inside-Out Open Innovation Practices Frequency in Europe*

| Statistics | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Joint Venture agreement | Sell new knowledge developed in R&D to another company | Participating in a business incubator program | Selling R&D market ready by-product | Selling license of innovations | Providing innovation for standardization organization | Donating innovation/knowledge to any non-profit organization |
| N | Valid | 96 | 96 | 96 | 96 | 96 | 96 | 96 |
| Median | | 1.0000 | 2.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| Mode | | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |

### 4.1.6.4. Frequency of Applying OI Practices in Canada Vs Europe

Figure 37 shows the mode of the Open Innovation practices within Canada and Europe. Majority of the participants are applying practice 2, 6 and 7 more frequently than the others in both regions. These practices are the same as the ones which are frequent for the whole sample.

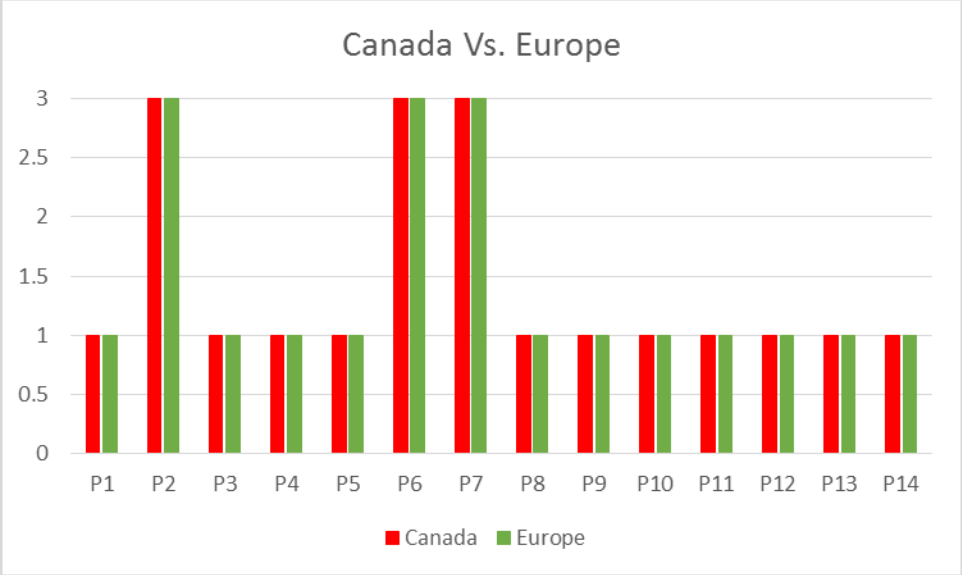


*Figure 37 - Canada and Europe OI practices frequency*

The frequency of applying "contract with other companies for R&D services" is almost similar in both regions (Table 48, Figure 38).

*Table 48 - Country * Contract with other companies for R&D services Cross tabulation*

| Country * Contract with other companies for R&D services Cross tabulation | | | | | | |
|---|---|---|---|---|---|---|
| % within Contract with other companies for R&D services | | | | | | |
| | | Contract with other companies for R&D services | | | | Total |
| | | N/A | Rarely | Sometimes | Always | |
| Country | Canada | 50.0% | 50.0% | 43.2% | 52.6% | 49.7% |
| | Europe | 50.0% | 50.0% | 56.8% | 47.4% | 50.3% |
| Total | | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |

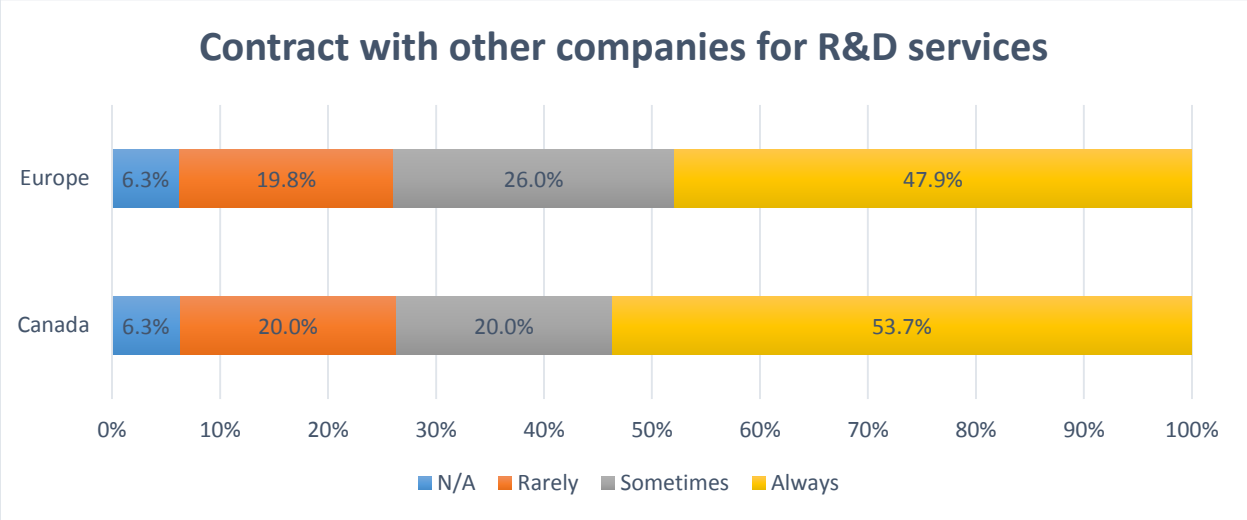


*Figure 38 - Country * Contract with other companies for R&D services*

The frequency of applying "collaborating with students in a research agreement with a university" is higher in European firms than in Canadian ones (Table 49, Figure 39).

*Table 49 - Country * Collaborating with students in a research agreement with a university Cross tabulation*

| Country * Collaborating with students in a research agreement with a university Cross tabulation | | | | | | |
|---|---|---|---|---|---|---|
| % within Collaborating with students in a research agreement with a university | | | | | | |
| | | Collaborating with students in a research agreement with a university | | | | Total |
| | | N/A | Rarely | Sometimes | Always | |
| Country | Canada | 50.0% | 58.6% | 48.8% | 47.8% | 49.7% |
| | Europe | 50.0% | 41.4% | 51.2% | 52.2% | 50.3% |
| Total | | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |

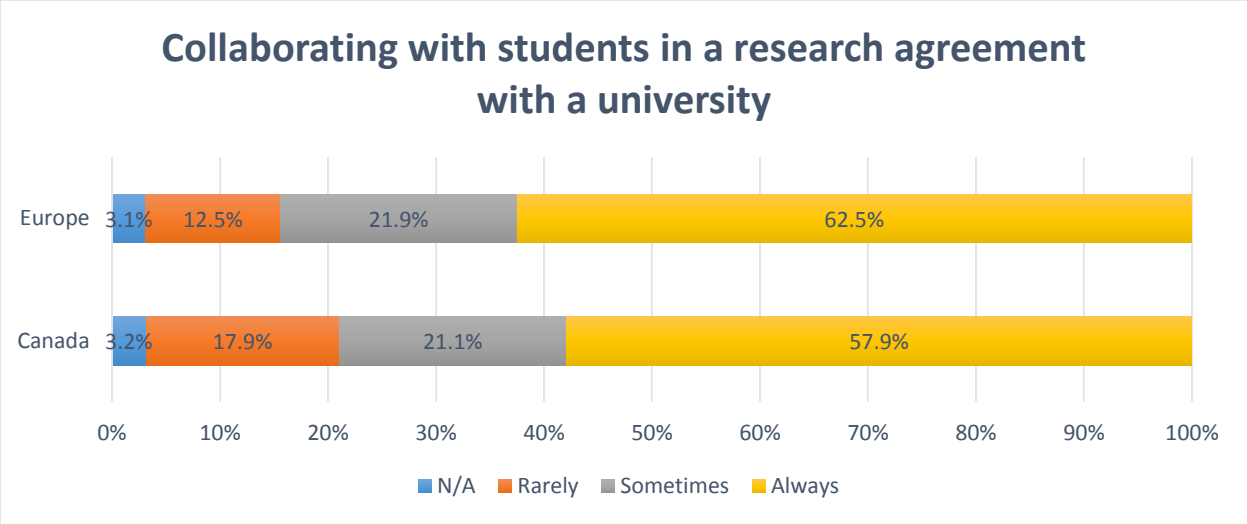


*Figure 39 - Country * Collaborating with students in a research agreement with a university*

The frequency of applying "Assigning a research fund to an academic institute" is higher in European firms than in Canadian ones. 33.7% of Canadian firms are applying this practice with a lower frequency than European countries (Table 50, Figure 40).

*Table 50 - Country * Assigning a research fund to an academic institute Cross tabulation*

| Country * Assigning a research fund to an academic institute Cross tabulation | | | | | | |
|---|---|---|---|---|---|---|
| % within Assigning a research fund to an academic institute | | | | | | |
| | | Assigning a research fund to an academic institute | | | | Total |
| | | N/A | Rarely | Sometimes | Always | |
| Country | Canada | 31.6% | 56.1% | 45.7% | 51.2% | 49.7% |
| | Europe | 68.4% | 43.9% | 54.3% | 48.8% | 50.3% |
| Total | | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |

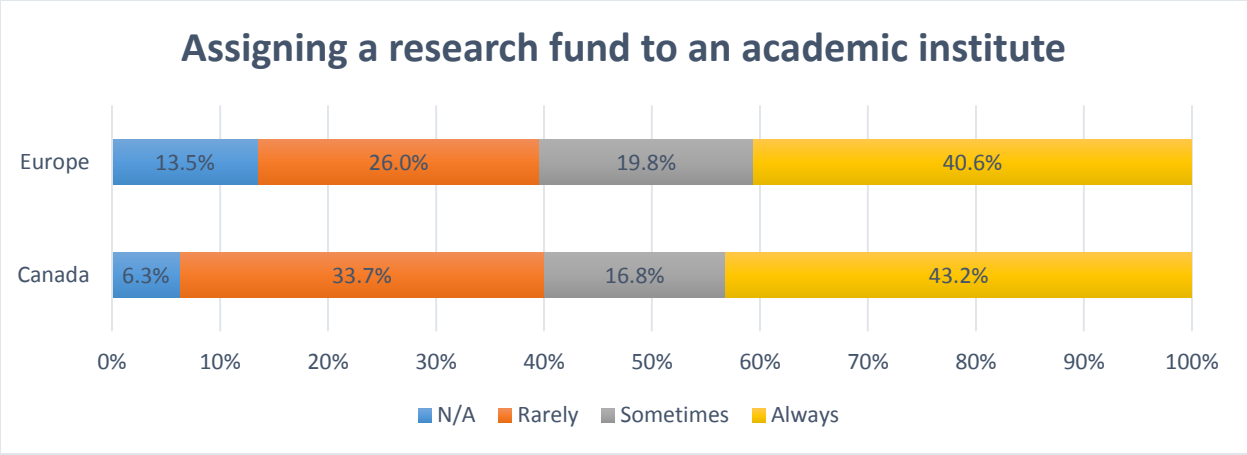


*Figure 40 - Country * Assigning a research fund to an academic institute*

So, the frequency of applying Open Innovation practices which are related to university collaboration in Europe is higher than Canada. This could be similar to the information obtained from Figures 3, 4, 5 and 6 regarding academic productivity and available funding of firms in European countries which is more than Canada.

### 4.1.7. Outside-In Pecuniary vs. Inside-Out Pecuniary OI Practices

Based on the Dahlander and Gann (2010), there are four main categories of Open Innovation practices: Outside-In Pecuniary, Outside-In Non-Pecuniary, Inside-Out Pecuniary and Inside-Out Non-Pecuniary. In this section the focus is only on the pecuniary side of the practices to see which one are more frequent than the other.

Based on the survey result (Table 51), about 87.4% of the firms are applying Outside-In pecuniary type of practice "sometimes" or "always" and in 0.7% of firms applying these practices are not applicable.

*Table 51 - Outside – In Pecuniary Open Innovation Practices*

| Outside – In Pecuniary Open Innovation Practices | | | | |
|---|---|---|---|---|
| | | Frequency | Percent | Cumulative Percent |
| Valid | N/A | 2 | .7 | .7 |
| | Rarely | 36 | 11.9 | 12.6 |
| | Sometimes | 151 | 50.0 | 62.6 |
| | Always | 113 | 37.4 | 100.0 |
| | Total | 302 | 100.0 | |

Based on the survey result (Table 52), about 77.2% of the firms are applying Inside-Out pecuniary type of practice "sometimes" or "always", and in 4.6% of firms applying this practices is not applicable.

*Table 52 - Inside-Out Pecuniary Open Innovation Practices*

| Inside - Out Pecuniary Open Innovation Practices | | | | |
|---|---|---|---|---|
| | | Frequency | Percent | Cumulative Percent |
| Valid | N/A | 14 | 4.6 | 4.6 |
| | Rarely | 55 | 18.2 | 22.8 |
| | Sometimes | 134 | 44.4 | 67.2 |
| | Always | 99 | 32.8 | 100.0 |
| | Total | 302 | 100.0 | |

## 4.2. Inferential Statistics

The focus of this section is on Outside-In Pecuniary and Inside-Out Pecuniary practices. After combing the practices which are grouped into these two categories, those firms which answered "sometimes" and "always" are considered as those who are applying this type of practices and those who answered "rarely" or "not applicable" are considered as those firms which are not applying these practices.

The objective of this section is to find out whether there is a causal relation between applying these two types of practices either separately or simultaneously and achieving an increase or a decrease in the technological and scientific performance of nanotechnology firms. These two types of outcomes are considered to be a metric for showing the level of knowledge in each firm (Eslami, Ebadi, & Schiffauerova, 2013). One of them is a technological outcome measured here by the number of patents the firm registered and the second one is a scientific outcome measured here by the number of papers the firm published in scholarly journals.

The main reason that these two outcomes were focused for this research is because increasing a knowledge in each society can cause an economic growth in that society. The reason that profit and market share were not analyzed in this section is because they are not that much accurate to apply inferential statistical analysis on them but they were used in the simulation part of this study in order to show the relation between variables.

Since the data that is used in this research is a categorical data and it is not following a normal distribution, nonparametric tests are appropriate for this type of data. Kruskal-Wallis Test is similar to Anova and U Mann Whitney is similar to t-test in normal distribution sample and could test whether there is a difference in the outcome of a process by applying different types of practices or not (Van de Vrande et al., 2009).

If firms answered that OIP and IOP are applied in their firms "sometimes" or "always", this is coded as 4, if only OIP is applied "sometimes" or "always" it is coded as 3, if only IOP is applied "sometimes" or "always" it is coded 2 and if none of them are applied "sometimes" or "always" it is coded as 1 (Table 53).

*Table 53 - OI practices coding style*

| OIP&IOP (4) | OIP (3) | IOP (2) | None (1) |
|---|---|---|---|
| 33 | 31 | 13 | 11 |
| 32 | 30 | 12 | 10 |
| 23 | 21 | 03 | 01 |
| 22 | 20 | 02 | 00 |

The hypothesis test which is going to be tested is described below:

$H_0$: There is no difference in the number of patents after the firm started applying this practice

$H_1$: There is a significant difference in the number of patents after the firms started applying this practice

Applying both OIP and IOP practices, only OIP, only IOP and none of them are four main hypotheses to be tested on the data set to see if there is a difference in Outcome 1 (Number of Patents) and Outcome 2 (Number of Papers) of the survey.

Since the p-value of the Kruskal-Wallis test is less than 0.1, the null hypothesis is rejected (Table 55). This shows that there is a significant difference in the number of patents when different types of practices are applied individually or simultaneously.

*Table 54 - Ranks Table for Outcome 1 on all types of practices*

| **Ranks** | | | |
|---|---|---|---|
| | Practices | N | Mean Rank |
| The number of patents | 1.00 | 27 | 96.33 |
| | 2.00 | 11 | 123.73 |
| | 3.00 | 42 | 103.50 |
| | 4.00 | 222 | 168.67 |
| | Total | 302 | |

*Table 55 - Kruskal-Wallis test for Outcome 1 on all types of practices*

| **Test Statistics** | |
|---|---|
| | The number of patents |
| Chi-Square | 37.594 |
| df | 3 |
| Asymp. Sig. | .000 |

When applying the same approach on Outcome 2, number of papers, similarly, we can see that since the p-value of the Kruskal-Wallis test is less than 0.1, the null hypothesis is rejected. This also shows that there is a significant difference in the number of papers when different types of practices are applied individually or simultaneously (Table 57).

*Table 56 - Ranks Table for Outcome 2 on all types of practices*

| Ranks | | | |
|---|---|---|---|
| | Practices | N | Mean Rank |
| The number of papers | 1.00 | 27 | 88.06 |
| | 2.00 | 11 | 104.23 |
| | 3.00 | 42 | 114.55 |
| | 4.00 | 222 | 168.55 |
| | Total | 302 | |

*Table 57 - Kruskal-Wallis test for Outcome 2 on all types of practices*

| Test Statistics | |
|---|---|
| | The number of papers |
| Chi-Square | 41.330 |
| df | 3 |
| Asymp. Sig. | .000 |

### 4.2.1. Number of Patents

In this section, there is a comparison between applying each type of practice and the other practices.

At first, there is a comparison between the number of patents of those who applied Outside-In pecuniary practices with those who did not apply any type of practices.

H0: There is no significant difference in the number of patents between those who applied OIP and those who did not apply any practices.

H1: There is a significant difference in the number of patents between those who applied OIP and those who did not apply any practices.

Since the p-value of the U Mann Whitney test is greater than 0.1, the null hypothesis could not be rejected (Table 59). This shows that based on the current sample there is no significant difference

in the number of patents when firms are applying OIP practices compared to when they are applying no practices.

*Table 58 - Ranks Table for outcome 1 – OIP Vs None*

| Ranks | | | | |
|---|---|---|---|---|
| | OIP - None | N | Mean Rank | Sum of Ranks |
| Number of Patents | 1.00 | 27 | 34.11 | 921.00 |
| | 3.00 | 42 | 35.57 | 1494.00 |
| | Total | 69 | | |

*Table 59 – U Mann Whitney test for outcome 1 – OIP Vs None*

| Test Statistics | |
|---|---|
| | Number of Patents |
| Mann-Whitney U | 543.000 |
| Wilcoxon W | 921.000 |
| Z | -.340 |
| Asymp. Sig. (2-tailed) | .734 |

Second, there is a comparison between the number of patents of those who applied Inside-Out pecuniary practices with those who did not apply any practices.

H0: There is no significant difference in the number of patents between those who applied IOP and those who did not apply any practices.

H1: There is a significant difference in the number of patents between those who applied IOP and those who did not apply any practices.

Since the p-value of the U Mann Whitney test is greater than 0.1, the null hypothesis could not be rejected (Table 61). This shows that based on the current sample there is no significant difference in the number of patents when firms are applying IOP practices in comparison to when they are applying no practices.

*Table 60 - Ranks Table for outcome 1 – IOP Vs None*

| Ranks | | | | |
|---|---|---|---|---|
| | IOP - None | N | Mean Rank | Sum of Ranks |
| Number of Patents | 1.00 | 27 | 18.24 | 492.50 |
| | 2.00 | 11 | 22.59 | 248.50 |
| | Total | 38 | | |

*Table 61 - U Mann Whitney test for outcome 1 – IOP Vs None*

| Test Statistics | |
|---|---|
| | Number of Patents |
| Mann-Whitney U | 114.500 |
| Wilcoxon W | 492.500 |
| Z | -1.231 |
| Asymp. Sig. (2-tailed) | .218 |
| Exact Sig. [2*(1-tailed Sig.)] | .278[b] |

Third, there is a comparison between the number of patents of those who applied both Inside-Out pecuniary practices and Outside-In pecuniary practices with those who did not apply any practices.

H0: There is no significant difference in the number of patents between those who applied OIP and IOP, and those who did not apply any practices.

H1: There is a significant difference in the number of patents between those who applied OIP and IOP, and those who did not apply any practices.

Since the p-value of the U Mann Whitney test is less than 0.1, the null hypothesis could be rejected (Table 63). This shows that there is a significant difference in the number of patents when firms are applying both OIP and IOP practices at the same time in comparison to the firm which are not applying any practices.

*Table 62 - Ranks Table for outcome 1 – Both Vs None*

| Ranks | | | | |
|---|---|---|---|---|
| | Both - None | N | Mean Rank | Sum of Ranks |
| Number of Patents | 1.00 | 27 | 71.98 | 1943.50 |
| | 4.00 | 222 | 131.45 | 29181.50 |
| | Total | 249 | | |

*Table 63 - U Mann Whitney test for outcome 1 – Both Vs None*

| Test Statistics | |
|---|---|
| | Number of Patents |
| Mann-Whitney U | 1565.500 |
| Wilcoxon W | 1943.500 |
| Z | -4.335 |
| Asymp. Sig. (2-tailed) | .000 |

Fourth, there is a comparison between the number of patents of those who applied both Inside-Out pecuniary practices and Outside-In pecuniary practices with those who applied only Outside-In Pecuniary practices.

H0: There is no significant difference in the number of patents between those who applied OIP and IOP, and those who applied only OIP practices.

H1: There is a significant difference in the number of patents between those who applied OIP and IOP, and those who applied only OIP practices.

Since the p-value of the U Mann Whitney test is less than 0.1, the null hypothesis could be rejected (Table 65). This shows that there is a significant difference in the number of patents when firms are applying OIP and IOP practices when compared to firms applying only OIP practices.

*Table 64 - Ranks Table for outcome 1 – Both Vs OIP*

| Ranks | | | | |
|---|---|---|---|---|
| | OIP - Both | N | Mean Rank | Sum of Ranks |
| Number of Patents | 3.00 | 42 | 84.90 | 3566.00 |
| | 4.00 | 222 | 141.50 | 31414.00 |
| | Total | 264 | | |

*Table 65 - U Mann Whitney test for outcome 1 – Both Vs OIP*

| Test Statistics | |
|---|---|
| | Number of Patents |
| Mann-Whitney U | 2663.000 |
| Wilcoxon W | 3566.000 |
| Z | -4.702 |
| Asymp. Sig. (2-tailed) | .000 |

Fifth, there is a comparison between the number of patents of those who applied both Inside-Out pecuniary practices and Outside-In pecuniary practices with those who applied only Inside-Out Pecuniary practices.

H0: There is no significant difference in the number of patents between those who applied OIP and IOP, and those who applied only IOP practices.

H1: There is a significant difference in the number of patents between those who applied OIP and IOP, and those who applied only IOP practices.

Since the p-value of the U Mann Whitney test is less than 0.1, the null hypothesis could be rejected (Table 67). This shows that there is a significant difference in the number of patents when firms are applying OIP and IOP practices in comparison to firms which are applying only IOP practices.

*Table 66 - Ranks Table for outcome 1 – Both Vs IOP*

| Ranks | | | | |
|---|---|---|---|---|
| | IOP - Both | N | Mean Rank | Sum of Ranks |
| Number of Patents | 2.00 | 11 | 82.41 | 906.50 |
| | 4.00 | 222 | 118.71 | 26354.50 |
| | Total | 233 | | |

*Table 67 - U Mann Whitney test for outcome 1 – Both Vs IOP*

| Test Statistics | |
|---|---|
| | Number of Patents |
| Mann-Whitney U | 840.500 |
| Wilcoxon W | 906.500 |
| Z | -1.881 |
| Asymp. Sig. (2-tailed) | .060 |

Finally, there is a comparison between the number of patents of those who applied only Outside-In pecuniary practices with those who applied only Inside-Out pecuniary practices.

H0: There is no significant difference in the number of patents between those who applied only OIP and those who applied only IOP practices.

H1: There is a significant difference in the number of patents between those who applied only OIP and those who applied only IOP practices.

Since the p-value of the U Mann Whitney test is greater than 0.1, the null hypothesis could not be rejected (Table 69). This shows that based on the current sample there is no significant difference in the number of patents when firms are applying OIP practices in comparison to the firms applying only IOP practices.

*Table 68 - Ranks Table for outcome 1 – OIP Vs IOP*

| Ranks | | | | |
|---|---|---|---|---|
| | OIP - IOP | N | Mean Rank | Sum of Ranks |
| Number of Patents | 2.00 | 11 | 30.73 | 338.00 |
| | 3.00 | 42 | 26.02 | 1093.00 |
| | Total | 53 | | |

*Table 69 - U Mann Whitney test for outcome 1 – OIP Vs IOP*

| Test Statistics | |
|---|---|
| | Number of Patents |
| Mann-Whitney U | 190.000 |
| Wilcoxon W | 1093.000 |
| Z | -1.005 |
| Asymp. Sig. (2-tailed) | .315 |

Based on the correlation Table below, when a firm is applying both types of practices the number of patents are increasing. The correlation is medium and has a positive sign and is significant (Table 70).

*Table 70 - Correlation for O1 – Both Vs None*

| Correlations | | | | |
|---|---|---|---|---|
| | | | Both - None | Number of Patent |
| Spearman's rho | Both - None | Correlation Coefficient | 1.000 | .275** |
| | | Sig. (2-tailed) | . | .000 |
| | | N | 249 | 249 |
| | Number of Patent | Correlation Coefficient | .275** | 1.000 |
| | | Sig. (2-tailed) | .000 | . |
| | | N | 249 | 249 |
| **. Correlation is significant at the 0.01 level (2-tailed). | | | | |

In conclusion, there is a similar result among the result of this research and Parida et al., (2012) and Carlsson et al., (2011). All of these researches are concluding that there is an increase in the innovation output by applying OI practices. But this research is the first research which is showing the relation of number of patents and when applying both Inside-Out and Outside-In OI practices. Base on this research when firms are applying both types of practices at the same time there is an increase in their number of patents.

### 4.2.2. Number of Papers

In this section, there is a comparison between applying each type of practice and the other and its impact on the number of papers.

First, there is a comparison among the number of papers of those who applied Outside-In pecuniary practices with those who did not apply any practices.

H0: There is no significant difference in the number of papers between those who applied OIP and those who did not apply any practices.

H1: There is a significant difference in the number of papers between those who applied OIP and those who did not apply any practices.

Since the p-value of the U Mann Whitney test is greater than 0.1, the null hypothesis could not be rejected (Table 72). This shows that based on the current sample there is no significant difference in the number of papers when firms are applying OIP practices in compare to applying no practices.

*Table 71 - Ranks Table for outcome 2 – OIP Vs None*

| Ranks | | | | |
|---|---|---|---|---|
| | OIP - None | N | Mean Rank | Sum of Ranks |
| Number of Papers | 1.00 | 27 | 31.28 | 844.50 |
| | 3.00 | 42 | 37.39 | 1570.50 |
| | Total | 69 | | |

*Table 72 - U Mann Whitney test for outcome 2 – OIP Vs None*

| Test Statistics | |
|---|---|
| | Number of Papers |
| Mann-Whitney U | 466.500 |
| Wilcoxon W | 844.500 |
| Z | -1.333 |
| Asymp. Sig. (2-tailed) | .183 |

Second, there is a comparison among the number of papers of those who applied Inside-Out pecuniary practices with those who did not apply any practices.

H0: There is no significant difference in the number of papers between those who applied IOP and those who did not apply any practices.

H1: There is a significant difference in the number of papers between those who applied IOP and those who did not apply any practices.

Since the p-value of the U Mann Whitney test is greater than 0.1, the null hypothesis could not be rejected (Table 74). This shows that based on the current sample there is no significant difference

in the number of papers when firms are applying IOP practices in compare to applying no practices.

*Table 73 - Ranks Table for outcome 2 – IOP Vs None*

| Ranks | | | | |
|---|---|---|---|---|
| | IOP - None | N | Mean Rank | Sum of Ranks |
| Number of Papers | 1.00 | 27 | 18.67 | 504.00 |
| | 2.00 | 11 | 21.55 | 237.00 |
| | Total | 38 | | |

*Table 74 - U Mann Whitney test for outcome 2 – IOP Vs None*

| Test Statistics | |
|---|---|
| | Number of Papers |
| Mann-Whitney U | 126.000 |
| Wilcoxon W | 504.000 |
| Z | -.786 |
| Asymp. Sig. (2-tailed) | .432 |
| Exact Sig. [2*(1-tailed Sig.)] | .485[b] |

Third, there is a comparison between the number of papers of those who applied both Inside-Out pecuniary practices and Outside-In pecuniary practices with those who did not apply any practices.
H0: There is no significant difference in the number of papers between those who applied OIP and IOP than those who did not apply any practices.
H1: There is a significant difference in the number of papers among those who applied OIP and IOP than those who did not apply any practices.
Since the p-value of the U Mann Whitney test is less than 0.1, the null hypothesis could be rejected (Table 76). This shows that there is a significant difference in the number of papers when firms are applying both OIP and IOP practices in compare at the same time in comparison to the firm which are not applying any practices.

*Table 75 - Ranks Table for outcome 2 – Both Vs None*

| Ranks | | | | |
|---|---|---|---|---|
| | Both - None | N | Mean Rank | Sum of Ranks |
| Number of Papers | 1.00 | 27 | 66.11 | 1785.00 |
| | 4.00 | 222 | 132.16 | 29340.00 |
| | Total | 249 | | |

*Table 76 - U Mann Whitney test for outcome 2 – Both Vs None*

| Test Statistics | |
|---|---|
| | Number of Papers |
| Mann-Whitney U | 1407.000 |
| Wilcoxon W | 1785.000 |
| Z | -5.135 |
| Asymp. Sig. (2-tailed) | .000 |

Fourth, there is a comparison between the number of papers of those who applied both Inside-Out pecuniary practices and Outside-In pecuniary practices with those who applied only Outside-In pecuniary practices.

H0: There is no significant difference in the number of papers between those who applied OIP and IOP and those who applied only OIP practices.

H1: There is a significant difference in the number of papers between those who applied OIP and IOP and those who applied only OIP practices.

Since the p-value of the U Mann Whitney test is less than 0.1, the null hypothesis could be rejected (Table 78). This shows that there is a significant difference in the number of papers when firms are applying OIP and IOP practices when compared to firms applying only OIP practices.

*Table 77 - Ranks Table for outcome 2 – Both Vs OIP*

| Ranks | | | | |
|---|---|---|---|---|
| | OIP - Both | N | Mean Rank | Sum of Ranks |
| Number of Papers | 3.00 | 42 | 92.90 | 3902.00 |
| | 4.00 | 222 | 139.99 | 31078.00 |
| | Total | 264 | | |

*Table 78 - U Mann Whitney test for outcome 2 – Both Vs OIP*

| Test Statistics | |
|---|---|
| | Number of Papers |
| Mann-Whitney U | 2999.000 |
| Wilcoxon W | 3902.000 |
| Z | -4.183 |
| Asymp. Sig. (2-tailed) | .000 |

Fifth, there is a comparison between the number of papers of those who applied both Inside-Out pecuniary practices and Outside-In pecuniary practices with those who applied only Inside-Out pecuniary practices.

H0: There is no significant difference in the number of papers between those who applied OIP and IOP and those who applied only IOP practices.

H1: There is a significant difference in the number of papers between those who applied OIP and IOP and those who applied only IOP practices.

Since the p-value of the U Mann Whitney test is less than 0.1, the null hypothesis could be rejected (Table 80). This shows that there is a difference in the number of papers when firms are applying OIP and IOP practices in comparision to firms which are applying only IOP practices.

*Table 79 - Ranks Table for outcome 2 – Both Vs IOP*

| Ranks | | | | |
|---|---|---|---|---|
| | IOP - Both | N | Mean Rank | Sum of Ranks |
| Number of Papers | 2.00 | 11 | 68.64 | 755.00 |
| | 4.00 | 222 | 119.40 | 26506.00 |
| | Total | 233 | | |

*Table 80 - U Mann Whitney test for outcome 2 – Both Vs IOP*

| Test Statistics | |
|---|---|
| | Number of Papers |
| Mann-Whitney U | 689.000 |
| Wilcoxon W | 755.000 |
| Z | -2.839 |
| Asymp. Sig. (2-tailed) | .005 |

Finally, there is a comparison between the number of papers of those who applied only Outside-In pecuniary practices with those who applied only Inside-Out pecuniary practices.

H0: There is no significant difference in the number of papers between those who applied only OIP and those who applied only IOP practices.

H1: There is a significant difference in the number of papers between those who applied only OIP and those who applied only IOP practices.

Since the p-value of the U Mann Whitney test is greater than 0.1, the null hypothesis could not be rejected (Table 82). This shows that based on the current sample there is no significant difference

in the number of papers when firms are applying OIP practices in comparison to the firms applying only IOP practices.

*Table 81 - Ranks Table for outcome 2 – OIP Vs IOP*

| Ranks | | | | |
|---|---|---|---|---|
| | IOP - OIP | N | Mean Rank | Sum of Ranks |
| Number of Papers | 2.00 | 11 | 26.05 | 286.50 |
| | 3.00 | 42 | 27.25 | 1144.50 |
| | Total | 53 | | |

*Table 82 - U Mann Whitney test for outcome 2 – OIP Vs IOP*

| Test Statistics | |
|---|---|
| | Number of Papers |
| Mann-Whitney U | 220.500 |
| Wilcoxon W | 286.500 |
| Z | -.245 |
| Asymp. Sig. (2-tailed) | .807 |

Based on the correlation Table below, when a firm is applying both types of practices the number of papers are increasing. The correlation is medium and has a positive sign and is significant (Table 83).

*Table 83 - Correlation for O2 – Both Vs None*

| Correlations | | | | |
|---|---|---|---|---|
| | | | Both - None | Number of Papers |
| Spearman's rho | Both - None | Correlation Coefficient | 1.000 | .326** |
| | | Sig. (2-tailed) | . | .000 |
| | | N | 249 | 249 |
| | Number of Papers | Correlation Coefficient | .326** | 1.000 |
| | | Sig. (2-tailed) | .000 | . |
| | | N | 249 | 249 |
| **. Correlation is significant at the 0.01 level (2-tailed). | | | | |

In conclusion, there is a similar result among the result of this research and Parida et al., (2012) and Carlsson et al., (2011). All of these researches are concluding that there is an increase in the innovation output by applying OI practices. But this research is the first research which is showing

the relation of number of papers and when applying both Inside-Out and Outside-In OI practices. Base on this research when firms are applying both types of practices at the same time there is an increase in their number of papers.

## 4.3. Causal Diagram

Based on the statistical analysis, Figure 41 shows the causal diagram of the desired variables.

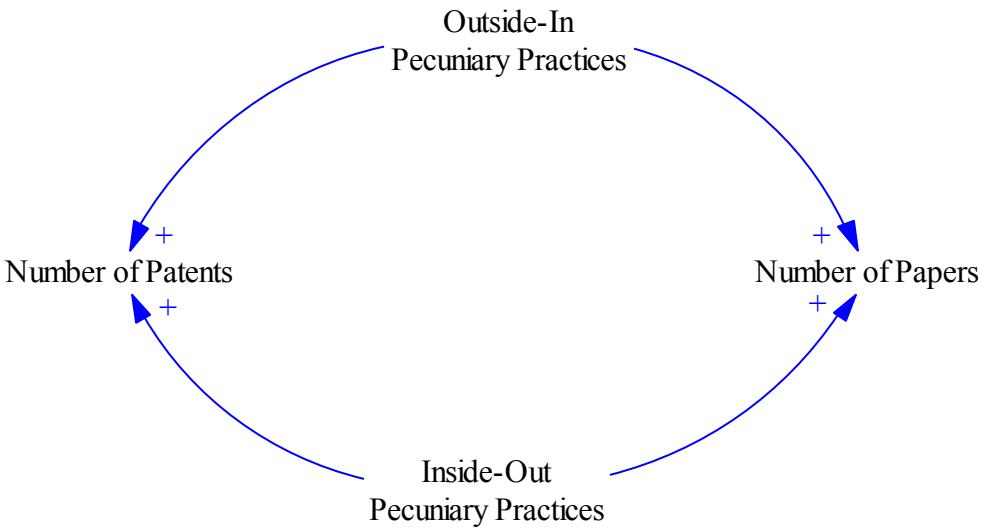


*Figure 41 - Open Innovation causal diagram*

Based on the knowledge acquisition and knowledge creation loop (Tayaran, 2011; Tayaran & Schiffauerova, 2012), national innovation systems model (Samara, Georgiadis, & Bakouros, 2012; Yuna et al., ) and effect of IP on the openness (Carlsson et al., 2011) the following causal diagram has been created (Figure 42):

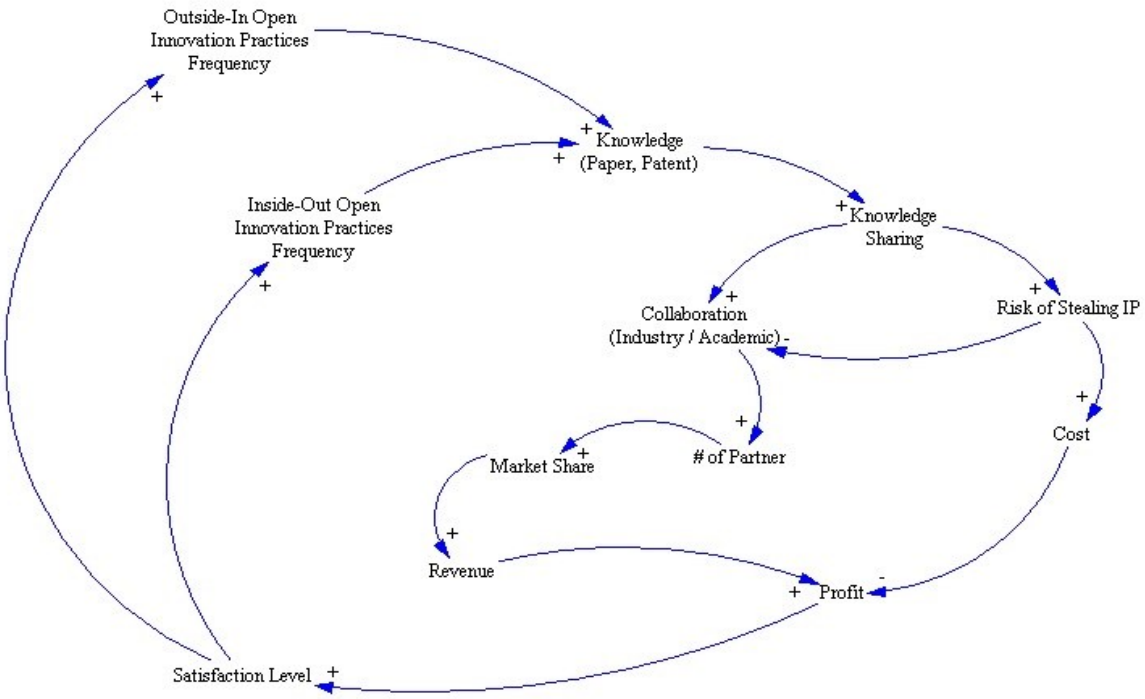


*Figure 42 - Proposed causal diagram of the Open Innovation model*

There are four balancing loops and two reinforcing loops as follows:

### 4.3.1. Balancing Loops:

A balancing loop attempts to change the current state to a desired state. It is called a goal seeking approach (Sterman, 2000). In this model (Figure 43) there are two balancing loops. One of them is showing that if the frequency of applying Outside-In / Inside-Out OI practices are increasing, the level of knowledge will be increased, then when there is more knowledge, there is more knowledge sharing in the system. This could increase the risk of stealing IP of the innovation and could cause lots of cost and decrease the profit and satisfaction level of applying OI practices inside the firm. Therefore, firms will not apply the same frequency of OI practices in their firms and will decrease its frequency. So, the goal in this system is to control the risk of stealing IP of the innovations and control the satisfaction level of the management.

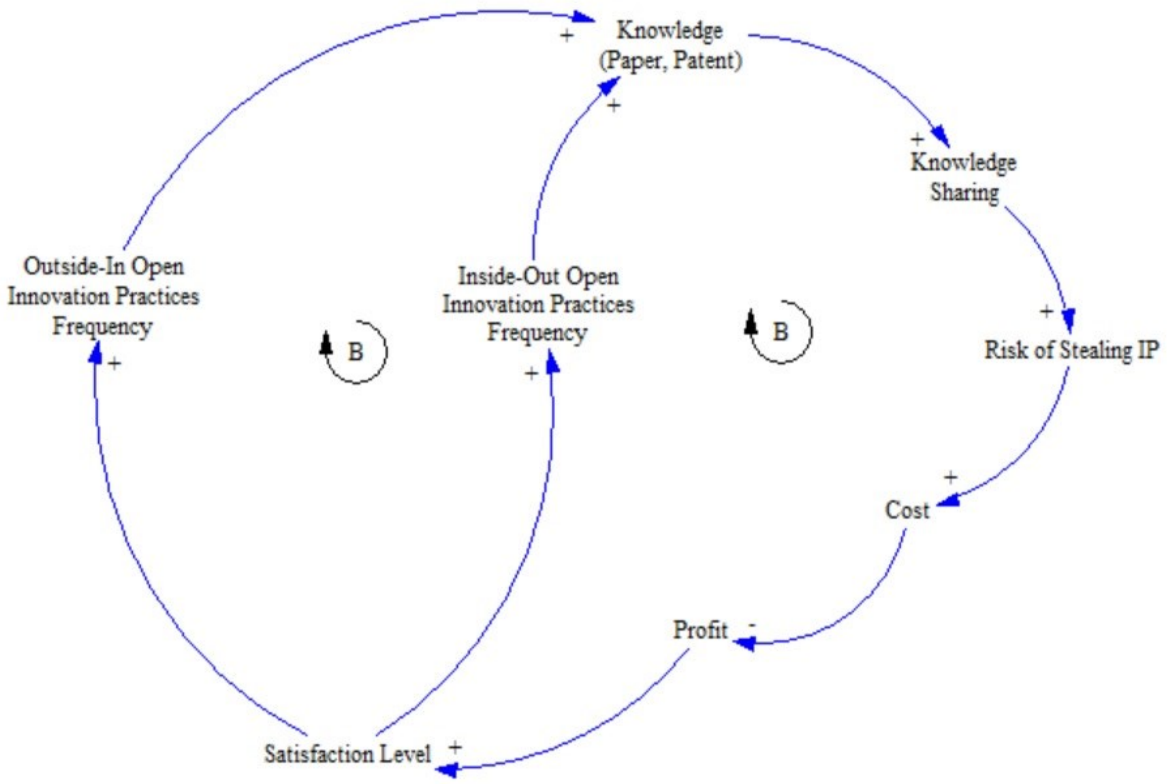


*Figure 43 - Balancing loops of the causal model (1)*

In this model (Figure 44) there are two balancing loops. One of them is showing that if the frequency of applying Outside-In / Inside-Out OI practices are increasing, the level of knowledge will be increased, then when there is more knowledge, there is more knowledge sharing in the system. This could increase the risk of stealing IP of the innovation and could cause lack of trust to the firm and decrease the rate of collaboration and number of partners of the firm. Decrease in the number of partners could cause a lost in controlling the market share and having less revenue and profit in the firm which will decrease the satisfaction level of applying OI practices inside the firm. Therefore, firms will not apply the same frequency of OI practices in their firms and will decrease its frequency.

Therefore, the goal of this model is to control the risk of stealing IP, having more collaboration, control the number of partners and produce more knowledge at the same time.

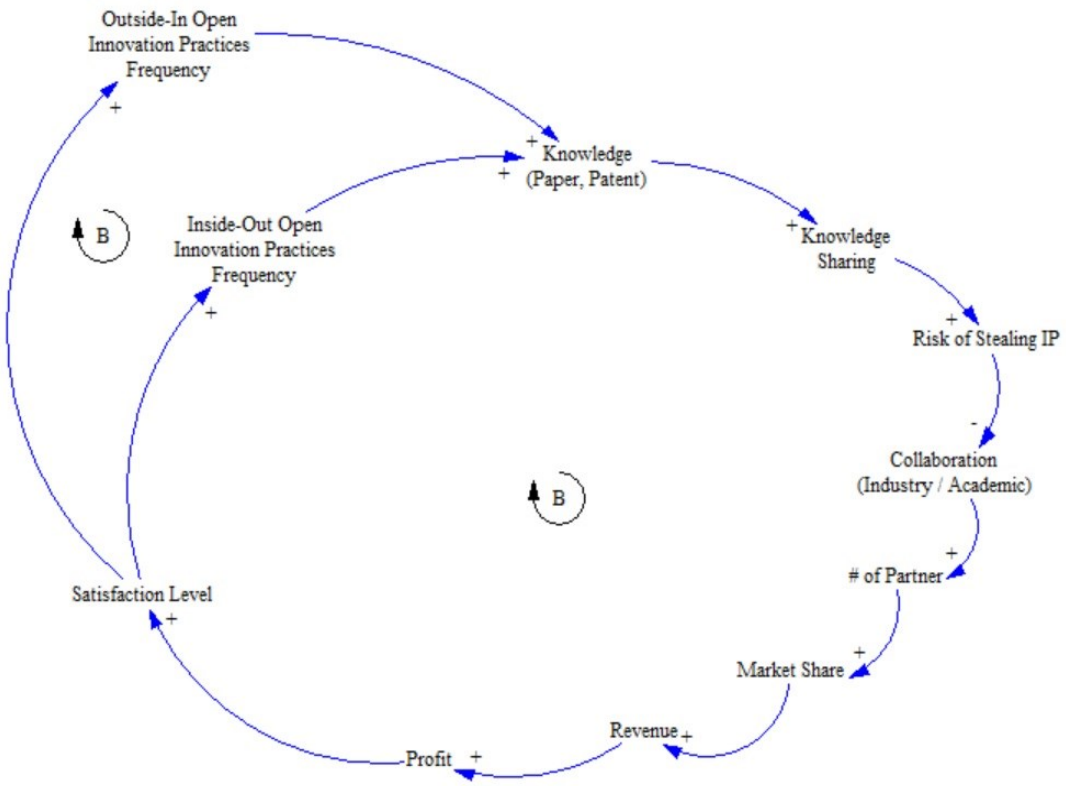


*Figure 44 - Balancing loops of the causal model (2)*

### 4.3.2. Reinforcing Loops:

A reinforcing loop is an action producing more of the same action, which could result in exponential growth or decline of the variable (Sterman, 2000).

In this model (Figure 45) there are two reinforcing loops. One of them is showing that if the frequency of applying Outside-In / Inside-Out OI practices are increasing, the level of knowledge will be increased, then when there is more knowledge, there is more knowledge sharing in the system. This could increase the rate of collaboration and number of partners of the firm. This increase could increase the revenue and profit of the firm and this could cause the high satisfaction of the management and applying Open Innovation practices with a higher frequency.

The model in Figure 45 says by having more collaboration more knowledge will be created.

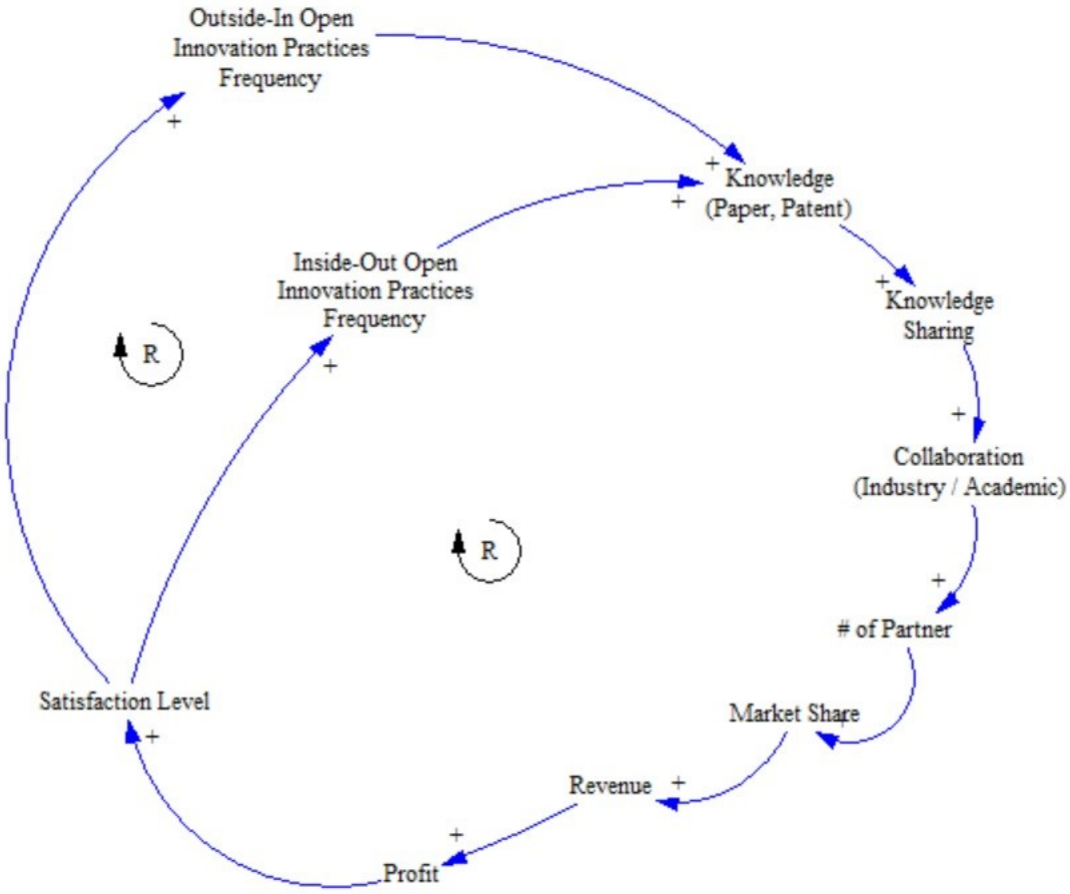


*Figure 45 - Reinforcing loops of the causal model*

## 4.4. Stock & Flow Diagram

According to the causal model of this system, Figure 46 shows the stock and flow diagram of the model. In this model there are two level variables (knowledge and partner) which are showing the level of knowledge and number of partner at a certain time, four rate variables (collaboration rate, spin-off rate, frequency of applying Inside-Out and Outside-In OI practices) which are showing th rate of change in the level variables between two tie intervals, some other auxiliary variables and two constants (OIP and IOP) which are showing the proportion of applying each of these two types of practices.

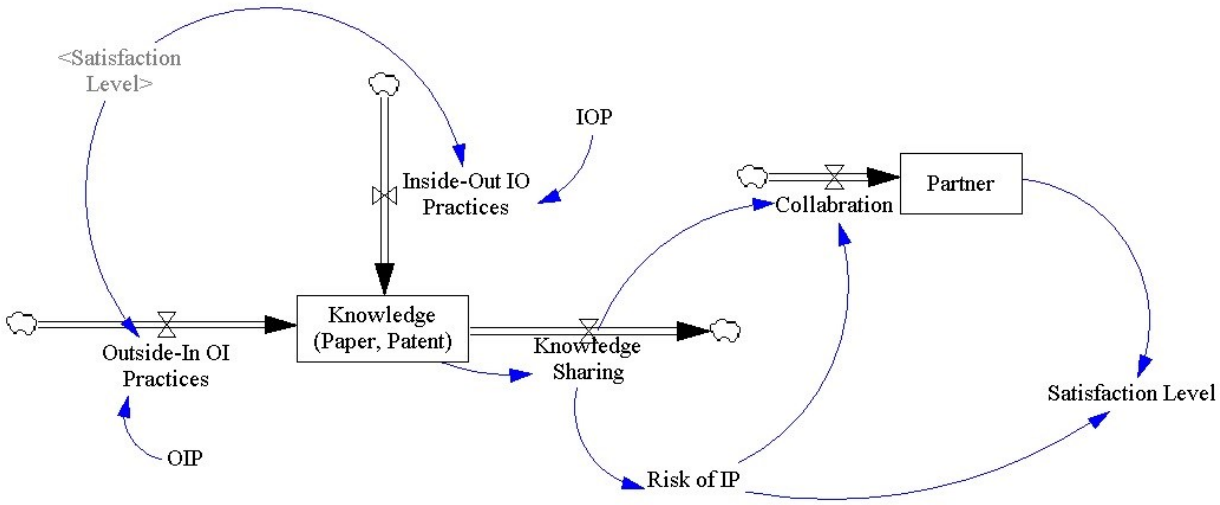


*Figure 46 - Stock & Flow diagram*

## 4.5. Simulation Results

After running the simulation in Vensim software and comparing the four scenarios:

Scenario 1: the situation when firms apply none of the practices

Scenario 2: the situation when firms apply only IOP practices

Scenario 3: the situation when firms apply only OIP practices

Scenario 4: the situation when firms apply both OIP and IOP practices

The result of applying these four scenarios will be presented separately. In each scenario the behaviour of variables of the model during a time horizon will be presented. By changing the frequency of applying OI practices the impact of applying OI practices on different variables will be presented. Based on the results of the simulation the final policy has been made[5].

[5] Note: In this simulation the equation of each variable is a function table of other related variables. The numbers in each table do not have any meaning by themselves. Only the trend of the numbers during a time horizon are important. Since, the input of the function table is from the Likert scale of 3, the difference in the numbers are in their decimals and it is not tangible.

### 4.5.1. Knowledge Trend

Table 84 shows the result of testing the four different scenarios, and their impact on the level of scientific and technological outcomes of the firms named as knowledge (measured by the number of papers and patents, respectively). The results show that if both types of practices are applied the performance of the firm in terms of technological and scientific outcomes is greater than if only one type of practice is applied. This result is in agreement with the statistical analysis results presented in the previous section. Just compare the numbers in Table 84 to see the trend of each scenario.

*Table 84 - Knowledge trend*

| | Knowledge (Patent, Paper) | | | |
|---|---|---|---|---|
| **Time (Year)** | **None** | **Both** | **OIP** | **IOP** |
| **0** | **0** | **0** | **0** | **0** |
| **1** | **0** | **4.98** | **2.49** | **2.49** |
| **2** | **0** | **4.57** | **1.44** | **1.44** |
| **3** | **0** | **5.37** | **0.98** | **0.98** |
| **4** | **0** | **6.76** | **0.78** | **0.79** |
| **5** | **0** | **8.73** | **1.36** | **1.35** |
| **6** | **0** | **11.32** | **1.75** | **1.74** |
| **7** | **0** | **14.44** | **2.49** | **2.48** |

Figure 47 shows the trend of knowledge when the four mentioned scenarios were simulated. Here we can clearly see that Scenario #4 (applying both OIP and IOP) leads to significantly better performance in terms of the number of patents and articles.

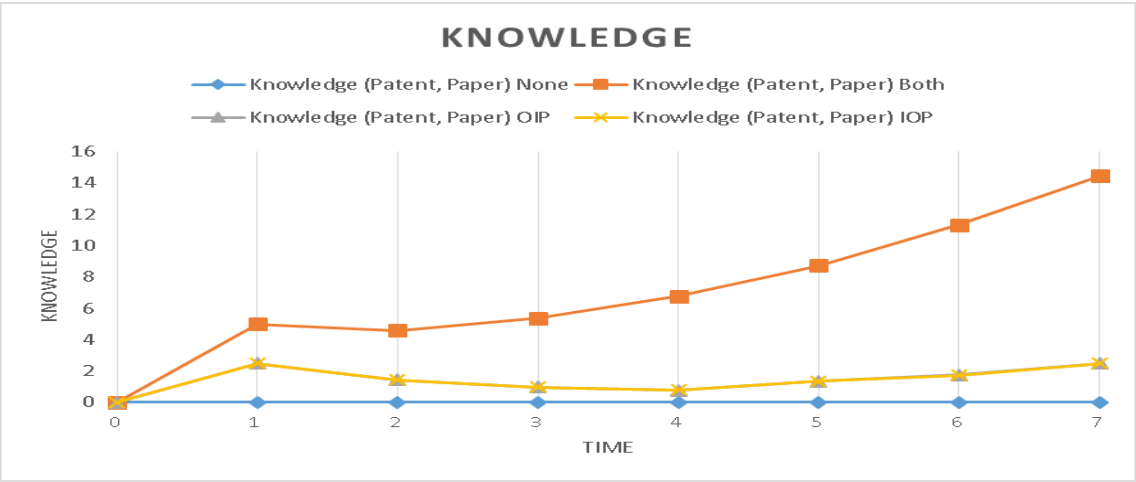


*Figure 47 - Knowledge trend*

### 4.5.2. Collaboration

Table 85 shows the result of testing the four different scenarios, and their impact on the rate of collaboration of the firms. The results show that if both types of practices or each type are applied the rate of collaboration is almost the same.

*Table 85 - Collaboration rate*

| | Collaboration | | | |
|---|---|---|---|---|
| **Time (Year)** | **None** | **Both** | **OIP** | **IOP** |
| **0** | **0** | **0** | **0** | **0** |
| **1** | **0** | **0.84** | **0.84** | **0.84** |
| **2** | **0** | **0.84** | **0.84** | **0.84** |
| **3** | **0** | **0.84** | **0.84** | **0.84** |
| **4** | **0** | **0.84** | **0.74** | **0.74** |
| **5** | **0** | **0.84** | **0.84** | **0.84** |
| **6** | **0** | **0.84** | **0.84** | **0.84** |
| **7** | **0** | **0.84** | **0.84** | **0.84** |

Figure 48 shows the rate of collaboration when the four mentioned scenarios were simulated.

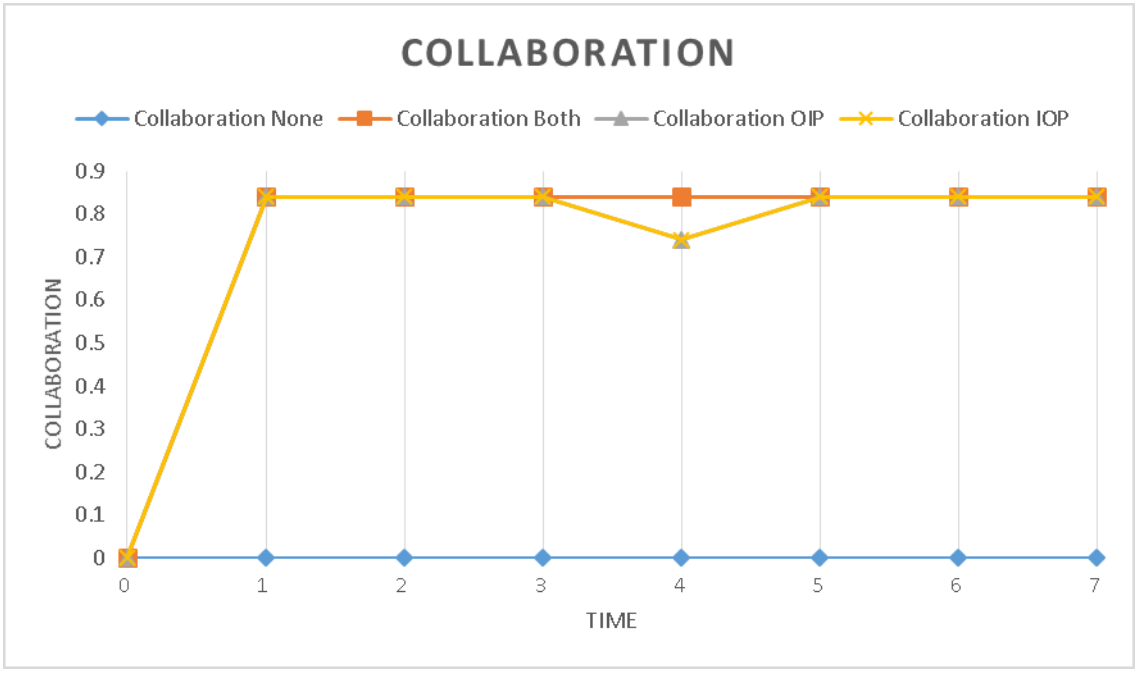


*Figure 48 - Collaboration rate*

### 4.5.3. Risk of Stealing IP

Table 86 shows the result of testing the four different scenarios, and their impact on the risk of stealing firm's intellectual property. Since applying Open Innovation practices can increase the chance of stealing IP of the firm's innovation; controlling the risk of IP in firms is very important and should be analyze I order to apply which type of practices.

The results show that if both types of practices are applied the risk of stealing IP is greater than if only one type of practice is applied. Although the numbers of the Table are so close to each other the only important factor for interpreting the graphs is the difference between numbers.

*Table 86 - Risk of stealing Intellectual Property*

| | Risk | | | |
|---|---|---|---|---|
| **Time (Year)** | **None** | **Both** | **OIP** | **IOP** |
| **0** | **0** | **0** | **0** | **0** |
| **1** | **0** | **1.71** | **1.68** | **1.68** |
| **2** | **0** | **1.71** | **1.66** | **1.66** |
| **3** | **0** | **1.71** | **1.7** | **1.69** |
| **4** | **0** | **1.71** | **1.55** | **1.56** |
| **5** | **0** | **1.71** | **1.69** | **1.69** |
| **6** | **0** | **1.71** | **1.67** | **1.67** |
| **7** | **0** | **1.71** | **1.68** | **1.68** |

Figure 49 shows the risk of stealing IP when the four mentioned scenarios were simulated.

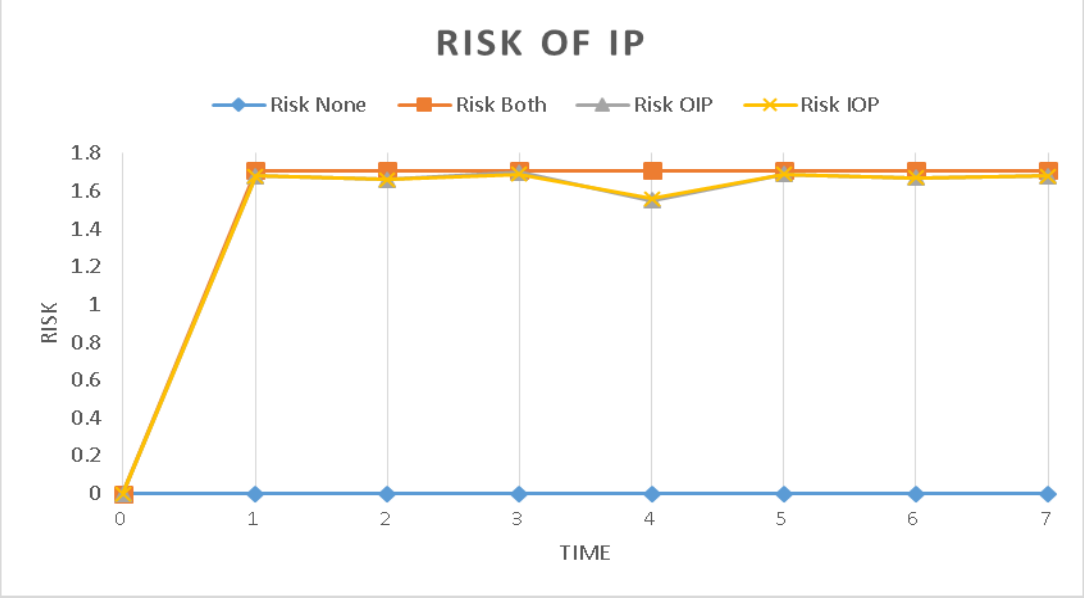


*Figure 49 - Risk of stealing Intellectual Property*

### 4.5.4. Partners

Table 87 shows the result of testing the four different scenarios, and their impact on number of partners. Applying Open Innovation practices can increase the number of partners. In this case the initial number of partners for starting the simulation was assumed to be one.

The results show that if both types of practices are applied the number of partners is greater than if only one type of practice is applied. Although the numbers of the Table are so close to each other the only important factor for interpreting the graphs is the difference between numbers.

*Table 87 - Number of partners*

| | Partner | | | |
|---|---|---|---|---|
| **Time (Year)** | **None** | **Both** | **OIP** | **IOP** |
| **0** | **1** | **1** | **1** | **1** |
| **1** | **1** | **1** | **1** | **1** |
| **2** | **1** | **1.84** | **1.84** | **1.84** |
| **3** | **1** | **2.69** | **2.68** | **2.68** |
| **4** | **1** | **3.53** | **3.52** | **3.52** |
| **5** | **1** | **4.38** | **4.27** | **4.27** |
| **6** | **1** | **5.22** | **5.11** | **5.11** |
| **7** | **1** | **6.07** | **5.94** | **5.95** |

Figure 50 shows the number of partners when the four mentioned scenarios were simulated.

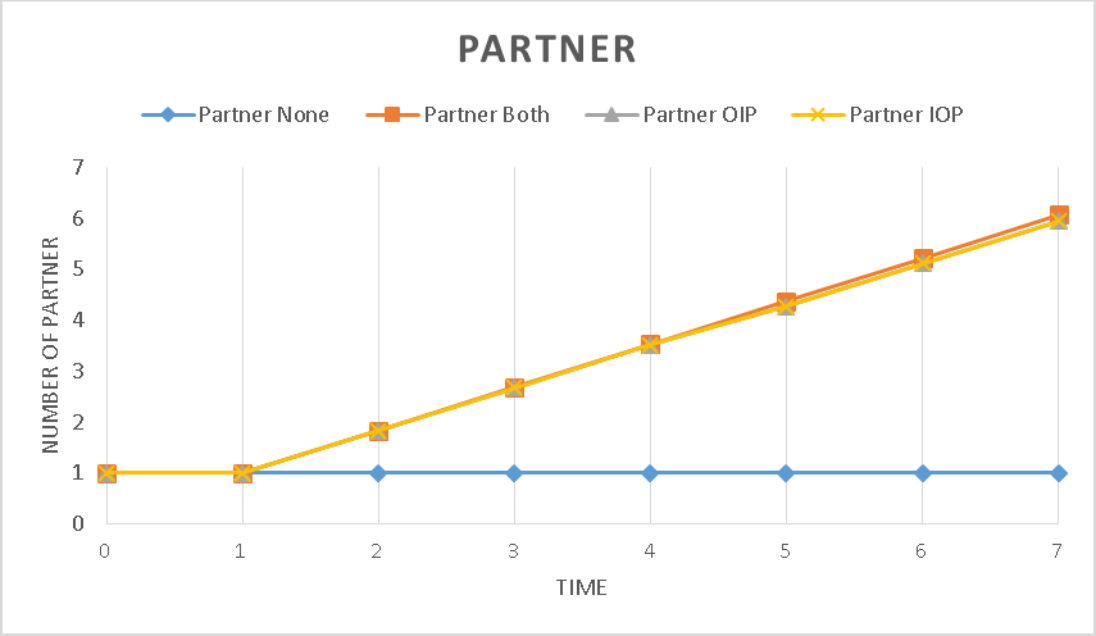


*Figure 50 - Number of partners*

### 4.5.5. Satisfaction Level

Table 88 shows the result of testing the four different scenarios, and their impact on satisfaction of managers.

The results show that if both types of practices are applied the level of satisfaction of managers is lower than applying each type separately. For sure applying none of the practices does not create any concern for the managers and their satisfactory level is higher than the other scenarios.

*Table 88 - Satisfaction level*

| | Satisfaction Level | | | |
|---|---|---|---|---|
| **Time (Year)** | **None** | **Both** | **OIP** | **IOP** |
| **0** | **1.05** | **1.05** | **1.05** | **1.05** |
| **1** | **1.05** | **0.29** | **0.3** | **0.3** |
| **2** | **1.05** | **0.53** | **0.54** | **0.54** |
| **3** | **1.05** | **0.65** | **0.65** | **0.65** |
| **4** | **1.05** | **0.77** | **0.82** | **0.81** |
| **5** | **1.05** | **0.89** | **0.88** | **0.88** |
| **6** | **1.05** | **1.02** | **1.02** | **1.02** |
| **7** | **1.05** | **1.05** | **1.05** | **1.05** |

Figure 51 shows the managers satisfaction level when the four mentioned scenarios were simulated.


*Figure 51 - Satisfaction level*

### 4.5.6. Knowledge Sharing

Table 89 shows the result of testing the four different scenarios, and their impact on rate of spin-off.

The results show that if both types of practices are applied the rate of spin-off is greater than if only one type of practice is applied. Although the numbers of the Table are so close to each other the only important factor for interpreting the graphs is the difference between numbers.

*Table 89 - Spin off*

| | Knowledge Sharing | | | |
|---|---|---|---|---|
| **Time (Year)** | **None** | **Both** | **OIP** | **IOP** |
| **0** | **0** | **0** | **0** | **0** |
| **1** | **0** | **1.87** | **1.79** | **1.79** |
| **2** | **0** | **1.87** | **1.8** | **1.8** |
| **3** | **0** | **1.87** | **1.83** | **1.83** |
| **4** | **0** | **1.87** | **1.46** | **1.47** |
| **5** | **0** | **1.87** | **1.82** | **1.82** |
| **6** | **0** | **1.87** | **1.76** | **1.76** |
| **7** | **0** | **1.87** | **1.79** | **1.79** |

Figure 52 shows the rate of spin-off when the four mentioned scenarios were simulated.

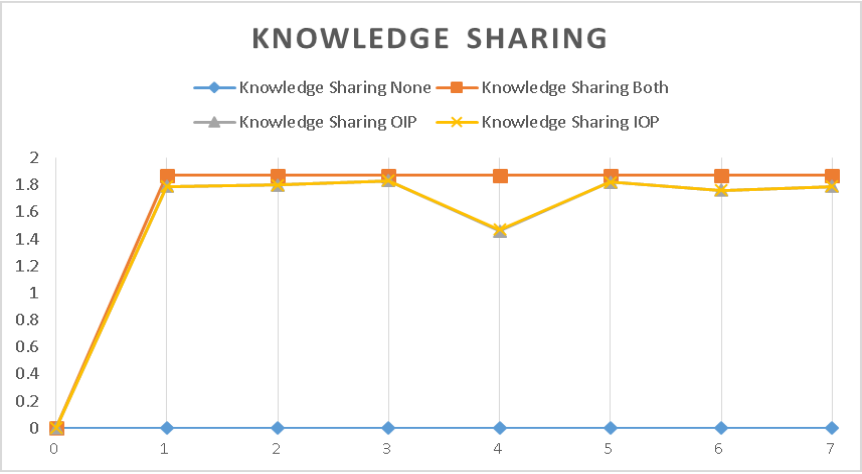


*Figure 52 – Knowledge Sharing*

## 4.6. Model Validation:

There are couple of methods for validating a system dynamics model. Because of having a historical data the following three methods have been selected for validating the mode.

### 4.6.1. Checking the Extreme Points

According to the proposed model. The extreme points for the proposed model are when both types of practices are applied at the same time or none of them are applied. For the mentioned extreme cases which are scenario 1 and 4 the model should be simulated. If the result for each scenario is logical and reasonable, this is showing that the model is working perfectly. For the proposed model, the system is behaving normally and all the trends are acceptable (scenario 1 and 4). So, it is concluded that the model is valid.

### 4.6.2. Historical Data

Since the questionnaire asks the respondents about the experience of the last three years of the firm, in order to validate the model the data of the survey will be compared with the result of the simulation for year 1 to 3.

The technological and scientific outcomes of the firms by applying Outside-In practices and Inside-Out practices has the following trends which is similar to what the result of simulation showing in this research:

Based on the simulation result from year 1 to year 3 the rate of applying Open Innovation practices is increasing (Figure 53).

The average of outcome (Knowledge) in the first three years based on the survey analysis (Likert scale) was increasing which is presented in Table 90. So, the result from the simulation corresponds to the historical data and this could validate the model.

*Table 90 - Knowledge average for the first three years (Likert scale)*

| | Mean | Mode |
|---|---|---|
| Patent (Out of 3) | 2.34 | 2 |
| Paper (Out of 3) | 2.66 | 3 |

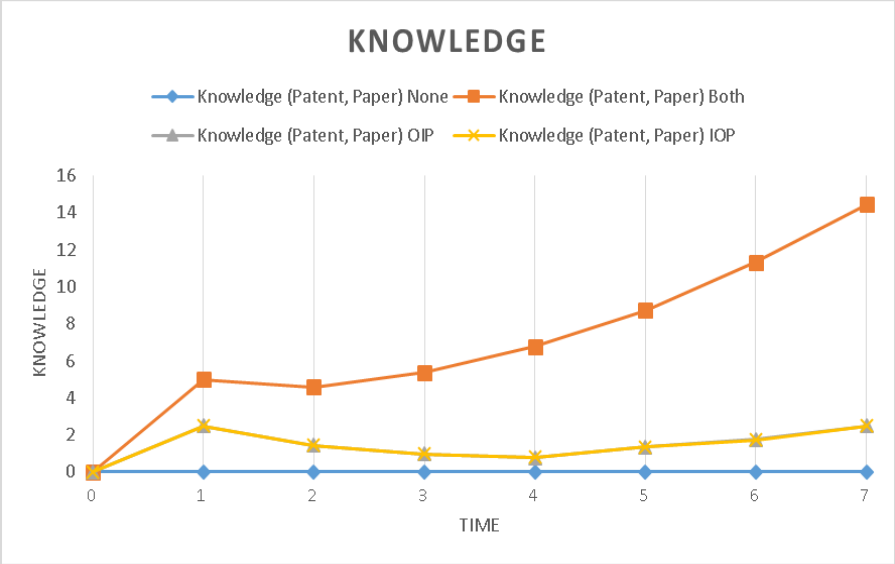


*Figure 53 – Level of Knowledge*

### 4.6.3. Check the Trend

By changing the initial numbers for the number of patents or papers, the trend is not changing and it is logical (Figure 54).

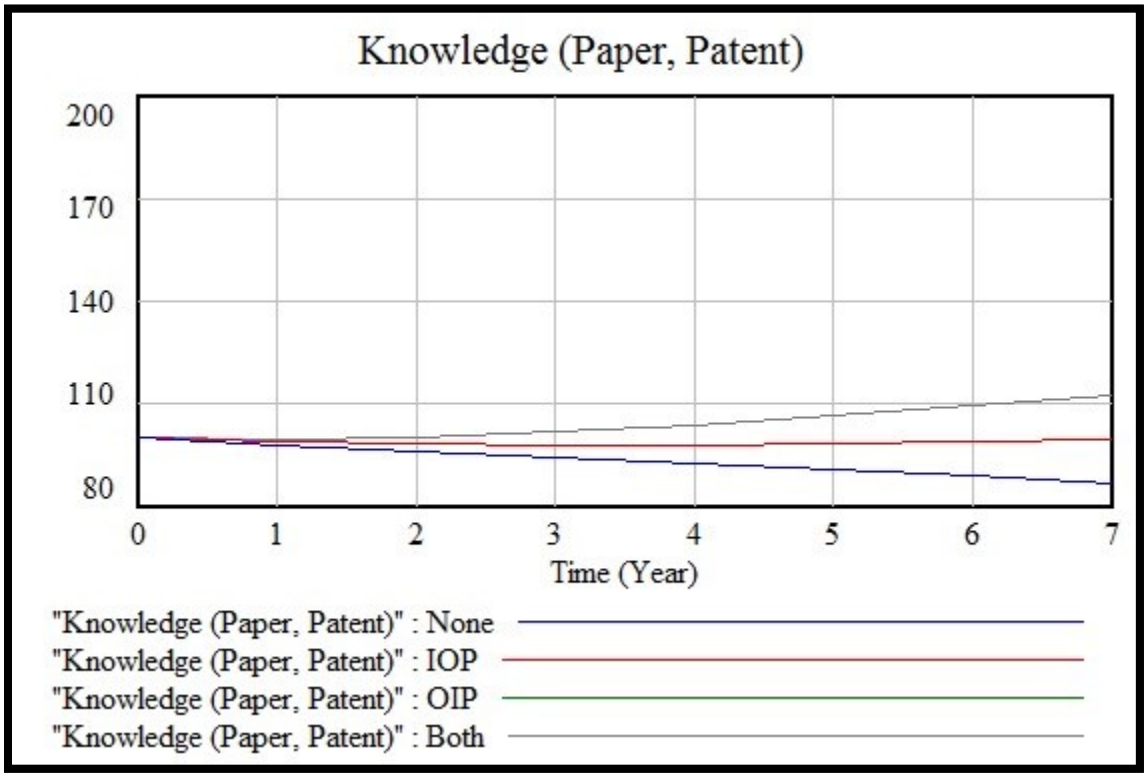


*Figure 54 - Knowledge trend with different initial*

# Chapter 5

# 5. Conclusion

This thesis has two main objectives. First is investigating the application of Open Innovation business model in nanotechnology sector worldwide and comparing it from different aspects. The second objective involves finding a causal relation between applying different Open Innovation practices and having better performance of firms.

The thesis' methodology involves an extensive online survey run in several countries whose results were analyzed through descriptive and inferential statistical analyses. Moreover, based on the gathered data a simulation model was created and several scenarios tested.

The findings revealed that the most frequent Outside-In types of Open Innovation practices are related to the collaboration of the firms with universities, either through a firm having a research agreement with a university or through assigning a research funding to an academic institute. Contracting with other companies for R&D services was also among the most frequently implemented Outside-In practices. As for the Inside-Out type of Open Innovation practices, it was joint venture agreement which gained the highest score among the companies responding to the survey.

The companies were also asked about the outcomes of the implementation of such practices, and the most commonly mentioned outcomes were related to the number of innovation partners, to the percentage of funded ideas and to the number of published papers. In general, the outcome of applying these practices seem to be positive.

The thesis also examined the impact of the size of the company on the use of these practices in. The results show that it is mostly large companies which implement Open Innovation practices, while the level of implementation was much lower among the small and medium enterprises.

Also, the frequency of applying Open Innovation practices in Canadian English and French provinces was analyzed. The results show that these types of practices are more common in French provinces than in the English ones. Furthermore, the collaboration among French companies and universities was much more frequent.

In addition, since European countries are known to be pioneers in Open Innovation business model a comparative analysis between Europe and Canada has been conducted. The results revealed a

close similarity in the implementation pattern of Open Innovation practices in these two regions but collaboration with universities is mostly applied in European countries and they are more frequently applying this practice rather Canadians.

In the inferential statistical section the focus of the analysis was on pecuniary type of Open Innovation practices. Based on the result of inferential statistical analysis applying both Outside-In pecuniary Open Innovation practices and Inside-Out pecuniary Open Innovation practices together has a significant effect on the performance of firms in terms of an increase in technological and scientific outcomes. Applying these practices together is suggested to cause an increase in the number of patents and number of papers of firms. However, if only one type of pecuniary Open Innovation practice (either Outside-In or Inside-Out) is applied then there is no such impact detected. It is thus suggested to embrace the Open Innovation model in its entirety.

The simulation results have confirmed the findings coming from the inferential statistical analysis. Also, in the simulation part, it was predicted that by applying this policy, there would be more knowledge in firms within the next four years as well. It was shown that applying both Outside-In pecuniary Open Innovation practices and Inside-Out pecuniary Open Innovation practices together can increase the technological and scientific performance of the firms (in terms of the number of registered patents or published papers). Moreover, there were some positive effects detected on the collaboration rate and the number of partners and knowledge sharing when any of the type of the Open Innovation practices was applied.

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# Appendix

## Appendix 1

If your company is part of an enterprise group: Please answer all further questions in relation to the branch in which you are working.

Your co-operation will be appreciated in the acknowledgement of the survey report.

1- What is the total number of employees of your company?

0-10 11-50 51-100

101-250 251-500 501 or More I do not know

2- What is the company's annual revenue range? ($M)

0 – 5 5 – 25 25 or More I do not know

3- How often did your company use the following Open Innovation practices during the last three years (2011 to 2013)?
(Tick "N/A" if the practice has not been used in your company)

| | Always | Sometimes | Rarely | N/A |
|---|---|---|---|---|
| Buying a license | | | | |
| Contract with other companies for R&D services | | | | |
| Buying any innovative ideas from start-up* companies | | | | |
| Obtaining innovative ideas from a large group of people (ex. online community) | | | | |
| Consulting with any specialized Open Innovation companies | | | | |
| Collaborating with students in a research agreement with a university | | | | |
| Assigning a research fund to an academic institute | | | | |

*Startup companies are generally newly created companies, which are in a phase of development and research for markets.

4- How often did your company use the following Open Innovation practices during the last three years (2011 to 2013)?
(Tick "N/A" if the practice has not been used in your company)

| | Always | Sometimes | Rarely | N/A |
|---|---|---|---|---|
| Joint Venture agreement | | | | |
| Sell new knowledge developed in R&D to another company | | | | |

| | | | | |
|---|---|---|---|---|
| Participating in a business incubator program* | | | | |
| Selling R&D market ready by-product | | | | |
| selling license of your innovations | | | | |
| Providing your innovation for standardization organization | | | | |
| Donating your innovation/knowledge to any non-profit organization | | | | |

*Business incubators are programs designed to support the successful development of entrepreneurial companies through an array of business support resources and services.

5- When you used Open Innovation practices you may have noticed some impact on your business. Evaluate the outcomes of applying Open Innovation practices in your company:

| | Increased | Remained the Same | Decreased | N/A |
|---|---|---|---|---|
| The number of patents | | | | |
| The number of papers | | | | |
| The company profit | | | | |
| Market share | | | | |
| Risk of stealing Intellectual Property | | | | |
| Open Innovation implementation budget | | | | |
| The number of innovation partners | | | | |
| Trust level in your partners | | | | |
| Satisfaction from implementing Open Innovation | | | | |
| Resulted revenue of Open Innovation practices | | | | |
| Revenue from outwards licenses* | | | | |
| Costs of inward licenses** | | | | |
| Percentage of funded ideas | | | | |

* Revenue from outwards licenses: Revenue you earn by selling the license of your product to another company.

** Costs for inward licenses: Costs of the company because of buying a product license of another company.

## Appendix 2

My name is Arman Sadreddin, a Master of Applied Science student at Concordia University doing research on Open Innovation practices in Europe. I belong to a research team led by Dr. Schiffauerova.

Based on our analysis of recent research activities of the European researchers, we identified you as active in scientific research and having research collaborations. We would like to invite you to fill out our SHORT electronic survey designed to help us understand the impact of Open Innovation practices on the performance of your organization.

The survey should take you no longer than 3-4 minutes to complete. Your participation is greatly appreciated. We will be very glad to provide you with the summary of the research findings if you are interested. Moreover, by participating in the survey, you will have a chance to be entered into a random draw to win one of the FIVE $50 gift cards.

Here is the link to the survey:

https://www.surveymonkey.com/s.aspx

Note: please do not forward this message to others because participation in this survey is limited to specific organizations identified in our database.

Thank you,

Arman Sadreddin,
Research Assistant
Concordia Institute for Information Systems Engineering (CIISE),
Concordia University, Office: EV8.225,
1515 Ste-Catherine O, Montreal, Quebec, H3G 2W1, Canada
Telephone: + (514) 848 2424 #5069

INFORMATION FOR RESPONDENT

You have been asked to participate in a program of research being conducted by Dr. Andrea Schiffauerova of Concordia Institute for Information Systems Engineering of Concordia University. It is completely up to you whether to participate or not. You are free to discontinue your participation at any time without negative consequences.

CONFIDENTIALITY

Your participation in this study is confidential. The data obtained through this survey will be collected and kept in MS Excel file. Concordia University is prohibited from publishing any information that may divulge

statistics obtained from this survey and that relates to any identifiable institution, individual or business. Please, rest assured that this data is treated in strict confidence; it is used only for statistical purposes and published only in aggregate form. The data will be kept at Concordia University for a period of 10 years and during this time it is only the principal investigator and graduate students working on the project who will have access to this data.

ASSISTANCE

If at any time you have questions about this research or require assistance, please contact the studys principal investigator, Dr. Andrea Schiffauerova, Concordia Institute for Information Systems Engineering of Concordia University, andrea@ciise.concordia.ca, (514) 848 2424 #3307.

If you want to remove your email from our database please click on the following link: https://www.surveymonkey.com/optout.aspx

## Appendix 3

**SD Model Equations:**

(01) Collaboration = WITH LOOKUP (Spin Off/(Risk of IP+0.1),
([(0,0)-(3,3)],(0,0),(1,0.84),(2,0.97),(3,1.08) ))

(02) FINAL TIME = 7

Units: Year

The final time for the simulation.

(03) INITIAL TIME = 0

Units: Year

The initial time for the simulation.

(04) "Inside-Out IO Practices" = WITH LOOKUP (Satisfaction Level*IOP,([(0,0)-(3,3)],(0,0),(1,2.5),(2,2.21),(3,2.25) ))

(05) IOP= 1

(06) "Knowledge (Paper, Patent)"= INTEG ("Inside-Out IO Practices "+"Outside-In OI Practices"-Spin Off, 0)

(07) OIP= 1

(08) "Outside-In OI Practices" = WITH LOOKUP (Satisfaction Level*OIP, ([(0,0)-(3,3)],(0,0),(1,2.5),(2,2.29),(3,2.47) ))

(09) Partner= INTEG (Collaboration, 10)

(10) Risk of IP = WITH LOOKUP (Spin Off, ([(0,0)-(3,3)],(0,0),(1,1.38),(2,1.76),(3,2.06) ))

(11) Satisfaction Level = WITH LOOKUP (Partner/(Risk of IP+0.1),([(0,0)-(3,2)],(0,0),(1,0.53),(2,0.78),(3,1.05) ))

(12) Spin Off = WITH LOOKUP ("Knowledge (Paper, Patent)", ([(0,0)-(3,3)],(0,0),(1,1.87),(2,1.72),(3,1.87) ))

(13) TIME STEP = 1

Units: Year [0,7]

The time step for the simulation.