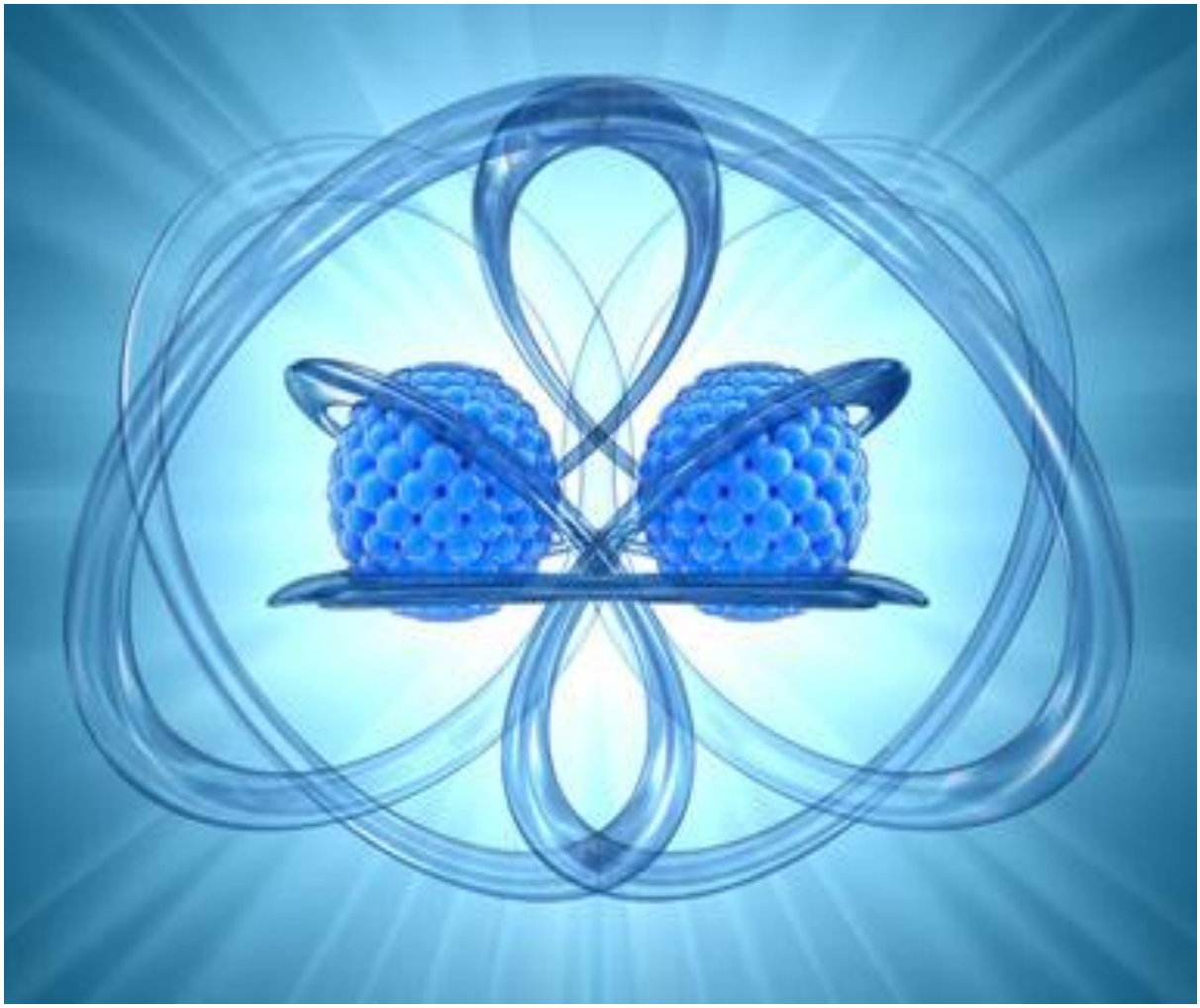
Barriers to commercialize nanotechnology product innovation and strategies to overcome the barriers

An exploratory study



Master of Science thesis

TU Delft
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Barriers to commercialize nanotechnology product innovation and strategies to overcome the barriers

Master of Science Thesis
Faculty of Technology, Policy and Management
Program: Management of Technology

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Executive Summary

Nanotechnology has drawn a substantial amount of attention from policy makers and companies all across the globe. This research-intensive field is relatively in its early stages of commercialization. A plethora of large corporations and small-medium enterprises (SMEs) exists in different industries which harness nanotechnology to develop innovative products. A vast sum of money continues to be invested by governments all across the globe to accelerate the commercialization efforts for bringing innovative nanotechnology products to the market. However, the commercialization of such products is hindered by a variety of barriers. This research takes a closer look at product innovation springing from the SMEs in the field of nanotechnology. In this research, following central questions have been investigated:

1. What barriers are faced by SMEs during the commercialization of nanotechnology product innovation?
2. And, how do SMEs overcome the barriers?

Qualitative research is adopted to answer these questions. Multiple case study method is used to investigate the topic. Literature study on barriers to innovation, desk research on the cases and semi-structured interviews have been conducted to fully answer the questions. The research contributes to the existing body of literature in barriers by finding out new barriers in the cases. Further, empirical based strategies devised in the research holds managerial implications both for the companies and policy makers. A new framework is built for the categorisation of barriers based on a simplified market model of a firm. Four broad categories of barriers namely technology-related, firm-related, environmental and market characteristics have been defined. These categories are further sub-divided into several ones. The framework is further used to categorise the barriers found in the cases. This categorisation further helped in formulating strategies to deal with these barriers.

Concerning the barriers, the research reveals that the cases are heavily hit by firm-related barriers. It is followed by technology related-barriers, environmental barriers and market-characteristic barriers. The strategies adopted by the companies to overcome the barriers were influenced by the context in which the product innovation was commercialised. Generic strategies that came out of the research can be broadly seen as that of either improving or circumventing the barrier, or leaving the barrier unaddressed.

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Jolly Sharma
Delft, August 2012

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1. Introduction

This research is undertaken after being a part of the research study conducted by PwC, Netherlands. The study is commissioned by the European Commission. It aims to uncover the factors that better facilitate the transition of enabling technologies – nanotechnology, microelectronics, photonics and production processes from research to the market. The factors are further translated to recommendations to the policy makers to assist companies in commercializing innovative technologies associated with the key areas addressed in the study. The data collection for the thesis is largely performed in PwC.

Innovation is crucial for companies and, in turn, countries to progress economically and socially. Commercialization of innovation, however, is challenging due to the uncertainty and various other factors. Companies across the globe experience diverse barriers in commercializing innovative products in the market. Sometimes, these barriers vary with the type of technology behind the products.

Nanotechnology is perceived as an enabling technology cutting across various technologies, industries, regions and countries. It is comparatively a new technology when compared to other technologies such as microelectronics, automotive etc. Its current market size and growth potential is recognized as tremendous by nations and companies. In 2009, the market size of products underpinned by nanotechnology was US$ 254 billion (Cunningham, 2011). Its market size for 2015 is expected to reach almost the tenfold level of 2009 with US$ 2.5 trillion. It ranks high on the national agenda of the US, Europe and Japan due to the perception of possible economic and social gains and international competitiveness that could be achieved through this technology. It is considered to be a research-intensive field(Nikulainen, 2010). Currently, a lot of investments are flowing into the field to develop innovative products and processes which have the capability to revolutionize other sectors. European Commission and national government organisations have reported that there has been an increase of about nine times in the worldwide investment in nanotechnology research and development between the years 1997 ($432 million) and 2005 ($4,100 million) (Roco, 2005). The number of companies introducing innovative nanotechnology in the market is growing at a very rapid pace.

A whole array of large corporations, small medium size enterprises and start-ups are acting as a springboard to research and commercialize nanotechnology products. Small-Medium Enterprises (SMEs), in particular, are active in bringing innovative nanotechnology products to the market. It has been recognised that the small firms innovate differently than the large firms (Tödtling, 2002). They usually experience financial and other resource constraints for R&D (Madrid-Guijjaro, 2009). Moreover, it has also been recognised that small firms do relatively less market research. Although, it is also found that the small companies have a much more adaptability and flexibility,

but the road to market is marred by various challenges attributed to numerous factors such as sheer nature of technology, markets being addressed, cost constraints, institutional hurdles, corporate-level difficulties etc. These challenges or barriers occur at different phases of the product development and commercialization. A typical nanotechnology product development process starts with a basic research, followed by Intellectual Property Rights (IPR) filing and commercialization including identifying markets, manufacturing, distribution and after-sale service.

It becomes essential for the companies to know the road to commercialization of nanotechnology products well ahead of the time when they actually traverse it. One of the key to planning commercialization is to recognize barriers that could inflict the product introduction in the market. And, to devise strategies that could either mitigate or lift those barriers. It would possibly better assist companies in facilitating smooth transition of the product to the market. Companies know what can be expected in the commercialization path, to a large extent, and how to overcome the hurdles. Identifying barriers and formulating strategies to overcome those is also of interest to the policy makers. Given the policy focus on nanotechnology in developed as well as developing nations, it becomes necessary for them to know the kind of bottlenecks that are faced by nanotechnology companies and how well the public institutions can either reduce or help the companies in getting rid of those.

In the following sub-sections, first the key terms that have been widely used throughout the report have been explained. Definitions are followed by the research problem, objective and research questions central to the research. Further, scientific and managerial relevance of the research have been detailed. Subsequently, the structure of the remaining report has been explained.

1.1 Technical Terms

In this sub-section, the basic definitions of the technical terms that will be used throughout the report are given.

Nanotechnology - Nanotechnology is the study, design, creation, synthesis, manipulation, and application of functional materials, devices, and systems through control of matter at the nanometre scale (1–100 nanometres, one nanometre being equal to 1×10^{-9} of a meter), that is, at the atomic and molecular levels, and the exploitation of novel phenomena and properties of matter at that scale (Salamanca-Buentello, 2005).

Nanotechnology products – Nanotechnology value-chain spans across three constituents – Nanomaterials, Nano-intermediates and Nano-enabled products. All three constituents are created through the application of nanotechnology. Nanomaterial forms the basic raw material such as carbon nanotubes which when further processed transforms to nano-intermediates such as nanosensors. Nano-intermediates are further

processed to form final product such as toothpaste. Following figure demonstrates the typical value chain of nanotechnology:

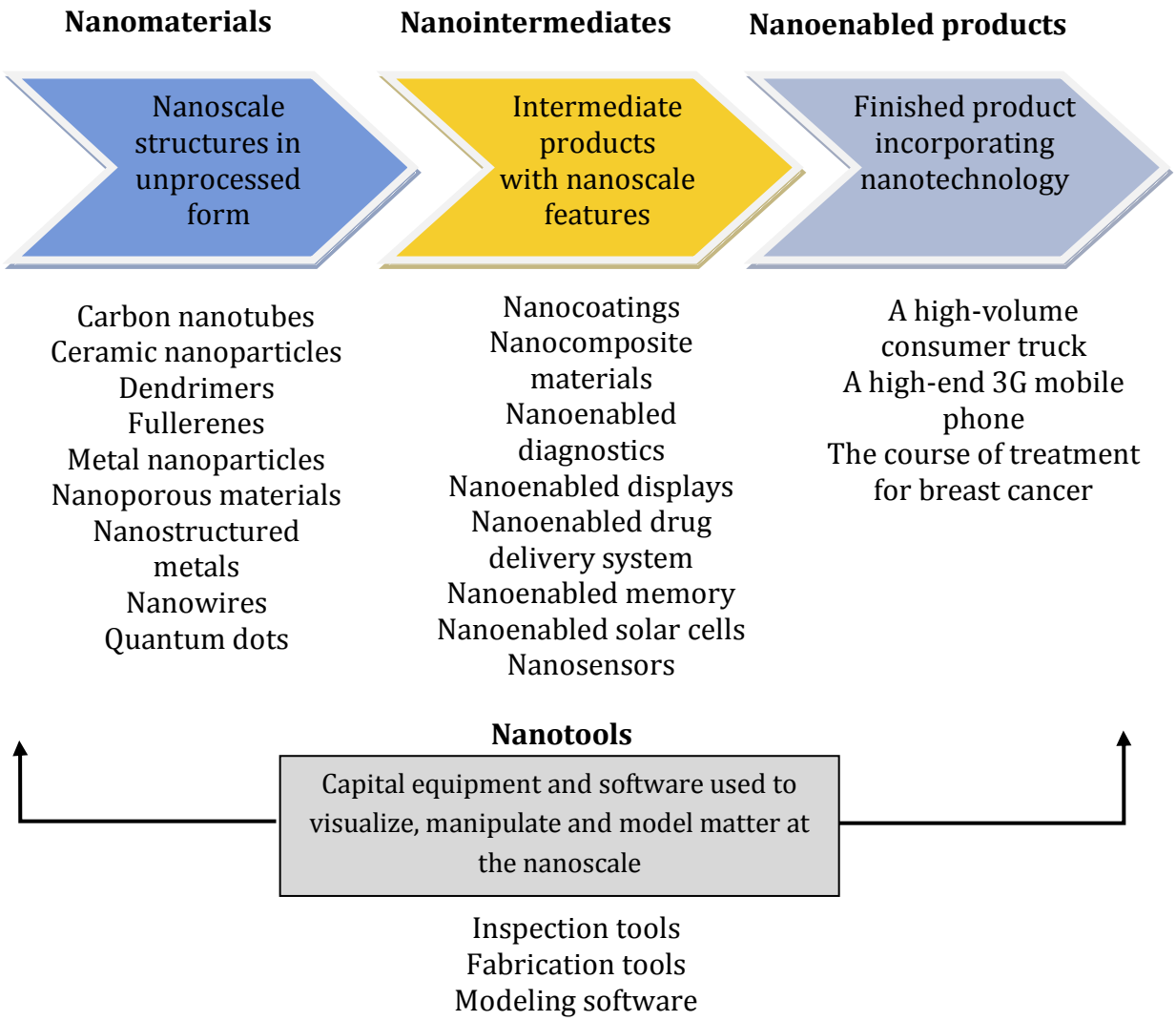

Figure 1: Nanotechnology value-chain, Source: adapted from Lux research (2006)

1.2 Research Problem

A considerable amount of literature exists which probes into barriers to innovation. Most of the literature emerges from the field of technology management. A fair proportion of it also belongs to environmental and sustainable technologies management. However, there is no such literature which puts light on the innovative nanotechnology products. Nanotechnology has drawn attention of policy makers and researchers worldwide. The industry is moving from fundamental research to applied research. Thus, it becomes more crucial to gain the better understanding of the commercialisation path of such products. The introduction gives a fair indication of states the research problem investigated in the research.

1.3 Research Objective

The key objective of this research is to contribute to the existing body of knowledge on the barriers that hinder the commercialization path of innovative products, in particular, nanotechnology product. Empirical evidence of the barriers and the solutions applied to lift those has been gathered in the realm of nanotechnology from SMEs commercializing nanotechnology products. Built on the insights from the practice, general strategies have been formulated which could help in assisting companies and policy makers in facilitating the transition of such products from the laboratory to the market.

1.4 Research Questions

The central questions that have been investigated in the research are:

1. **What barriers are faced by SMEs during the commercialization of nanotechnology product innovation?**
2. **And, how do SMEs overcome the barriers?**

To answer these key questions, following sub-questions will be addressed:

What barriers are faced by SMEs during the commercialization of nanotechnology product innovation?

Sub-questions:

- According to the literature, what are the barriers to innovation?
- What types of barriers are encountered while commercialising innovative products?
- What barriers, across the value chain, are faced by SMEs in commercializing innovative nanotechnology products?

And, how do SMEs overcome those barriers?

Sub-questions:

- What solutions (if any) are typically applied by the nanotechnology SMEs to overcome different types of barriers?
- What are the general strategies deployed to overcome different types of barriers?

The first research question is aimed to explore a list of barriers seen in the commercialisation of nanotechnology product innovation. To answer this key-question, further sub-questions are formulated. In the first sub-question, the barriers mentioned in the literature of innovation are searched. Next, a suitable categorization of barriers is

formulated. The categorisation of barriers also helps in answering a part of the second research question. It is followed by a sub-question focussing specifically on nanotechnology products to identify any new barriers.

The second research questions focuses on the solutions and strategies to overcome the barriers. It is further answered through two sub-questions. Answer to the first sub-question results in solutions applied by companies for different type of barriers. Through the last sub-question, general strategies are attempted to be drawn through answer to the first sub-question.

1.5 Scientific and Managerial Relevance

This research contributes to the existing body of knowledge on barriers that hinder the commercialization of innovative nanotechnology products. It could also be extrapolated to the barriers faced during the commercialization of innovative products, in general. Based on the insights from empirical data in the field of nanotechnology on barriers and the strategies followed to overcome those, a set of general strategies are formulated. These strategies may act like a tool for the SMEs active in the same field. It would have two-fold benefits for such companies: they would be well-informed in advance about the barriers that they may experience in the commercialization path and also, they may use the strategies presented for avoiding the barriers or mitigating their effects. Thus, this research offers significant relevance to science and practice.

1.6 Report Structure

In this sub-section, the structure of the remaining of the report is explained. In the second chapter, research methodology that is planned to be followed for the thesis is elaborated. The chapter includes research strategy and material. In the third chapter, scientific background of the topic including the existing study on barriers is explained. In the following chapter, the new framework for the categorisation of barriers is explained. In the fifth chapter, data gathered in the form of case description is described. Subsequently, data analysis is made. It consists of sub-sections including within case analysis and cross-case analysis. Next, key conclusions of the research are drawn. In the last chapter discussion on scientific contributions, contributions to practice, perspectives on barriers, limitations, future research and validity of research are described.

2. Research Methodology

In this chapter, the methodology followed for conducting the research is explained. In the first sub-section, the research strategy, including various research methods that were used at different stages of the research are explained in detail. In the second sub-section, the research material that was used for carrying out research is detailed.

2.1 Research Strategy

As mentioned earlier, it has been recognized that there is a considerable amount of literature available on the barriers experienced by companies in commercializing innovative nanotechnology products. However, it could also be noticed that the previous work in this field is specific in nature, focusing on either elements of nanotechnology value chain or scoping the study to a specific country etc. After carefully taking these factors into account, the research strategy followed for this thesis is a combination of desk research and case study. The research is qualitative in nature aimed at deep understanding of the underpinnings of the barriers faced by SMEs in commercializing the nanotechnology products in the market. Fig.2 is a pictorial representation of the research strategy.

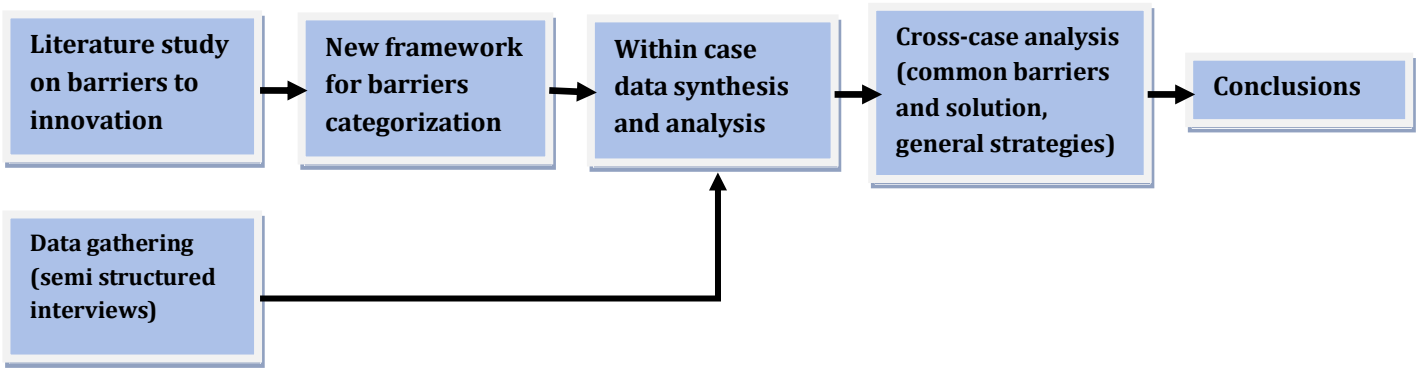

Figure 2: Pictorial representation of the research process followed

During the first stage of the research, desk research in the form of literature study was conducted. A comprehensive literature study helped in understanding the work carried out in the field of barriers to innovation. It helped in devising a framework that could be used to categorize barriers and further for devising strategies. Reliable, relevant and significant sources such as journal articles, government reports on nanotechnology etc. have been studied. Desk research offers an advantage over other methods. By harnessing this technique, fairly large amount of data can be collected in shorter time without using rigorous data collection tool. Although, it may lead to a bias while selecting relevant material for desk research (Verschuren, 2010).

Furthermore, the desk research was supplemented with case study. Case study helped in gathering empirical evidence of the barriers taken into account and the solutions implemented to lift those in practice. The case composition for the study is relatively

heterogeneous in nature. The cases vary along several dimensions, country, sector of origin, sector of application. Maximum variant cases have been selected for the case study. This case selection is motivated by a number of reasons. These reasons include:

- Taking products from different industries would help in identifying diverse scenarios ranging in barriers and the strategies. The product development process in the selected industries varies widely. It is more likely to lead to a rich inventory of barriers, the topic that lies at the centre of the research;
- Differences in the country of origination would lead to the understanding of the diverse regulatory and institutional factors that may act as impediments to the progress of innovation;
- Nanotechnology is being explored in a wide range of industries from semiconductors to cosmetics. The innovation efforts are relatively high in the industries taken into account in this research, photonics, pharmaceutical and chemicals.

All the cases were first examined independently as a single case. Subsequently, the results from each case consisting of barriers and the strategies were integrated to form a comprehensive set.

Following nanotechnology cases were studied for the research:

#	Product	Industry	Country	Applications
1	Pulse laser	Photonics	Japan	R&D applications
2	Laser diode	Photonics	Germany	Gas pipelines, power plants, medical systems, airborne and satellite applications
3	Toothpaste	FMCG/Pharmaceutical	Japan	Anti-caries/re-mineralizing, Whitening toothpaste
4	Surgical dressings	Pharmaceutical	North America	Surgical care , wound dressing
5	Ship coatings	Chemicals	Norway	Ship coatings
6	Fuel additive	Chemicals	United Kingdom	Transport vehicles, automotive

Table 1: Overview of nanotechnology product cases

Case study based research strategy provides flexibility to change course during the research. Also it helps in obtaining significant result without use of training (Verschuren, 2010) and (Yin, 2003). However, major disadvantage is that it is difficult to make generalization to larger population as fewer cases will be investigated (Yin, 2003).

Following table represents the specific methods that will be used to answer each sub-question:

Research questions	Research process	Chapters and sub-sections
According to the literature, what are the barriers to innovation?	Review of the existing literature mainly through reliable journal articles	3.1, 3.2
What types of barriers are encountered while commercialising innovative products?	Based on the literature search, a new framework is derived for the categorisation of barriers	3.2,4
What barriers, across the value chain, are faced by SMEs in commercializing innovative nanotechnology products?	Interviews with the company management and company publications and other websites are referred. Also, the framework is validated through other researchers	5,6.1
What solutions (if any) are typically applied by the nanotechnology SMEs to overcome different types of barriers?	Within case analysis is performed to identify solution	6.1
What are the general strategies deployed to overcome different types of barriers?	Based on cross-case analysis, common themes are derived for formulating general strategies	6.2.1

Table 2: Overview of process to answer research questions

2.2 Research Material

Various research sources were used for conducting the research at different stages of the research. For conducting literature study, secondary sources such as scientific journal articles, reports on nanotechnology, web materials etc. were used. Tools such as *Google scholar, Scopus* were used for searching relevant literature. The advantage of using secondary sources is that deep insights into the subject can be gained at a relatively rapid pace. In addition, it eliminates the need of collecting relevant information, all on our own (Verschuren, 2010). Though the downside of this technique is that one develops a bias and have a confidence on existing literature sometimes losing sight of own ideas (Verschuren, 2010).

For developing the case description, mainly interviews were conducted to gather data. The information further was supplemented with company publications and relevant news articles. Interviews were used to gather relevant information from the companies.

The interviews were semi-structured consisting of questions formulated on the basis of desk research and also few probing questions. The interviews were conducted over telephone and took about three-quarters of an hour to an hour. In order to get a holistic view of the case, actors across the whole value chain were interviewed. The interviewees were people from Upper management such as CEO, Founder, R&D head etc., sales and distribution people, research partners, customers, investors. This helped in sketching a reasonable picture of the whole commercialization cycle since different barriers may occur at different stage of the commercialization. This led to progressive insights into the case in terms of the subject addressed. The interview questions can be found in Appendix A.

3. Scientific Background

In this chapter, an overview of academic literature associated with the barriers to innovation is presented. This chapter is sub-divided into two sub-sections. In the first sub-section, the literature search methodology is explained. In the following sub-section, work of different authors in the field of barriers to innovation is presented in a structured manner. The literature search is mainly done on barriers to innovation, in general. This generic approach is followed at the initial stage in order to build a foundation for the more narrowed subject research in point. Finally, the literature study is scoped down to the overview of the barriers that are experienced during commercialization of innovative nanotechnology products. The insights from the academic literature aid the basic understanding of the subject. Furthermore, it helped in the formation of an inventory of the barriers cited in the existing body of literature on barriers. At the later stage, the barriers found in the cases are compared these barriers to find any new ones.

3.1 Literature Search Methodology

The literature search was conducted on barriers to innovation and barriers to commercialise innovation. Several databases were used to search for articles on the barriers. Both general databases such as Google scholar and specific databases such as science direct were mined for the relevant information. The search was made by keying in relevant terms.

Following table represents the keywords used to search articles in the Google scholar:

Keywords	Articles retrieved (as on 24/05/2012)
Barriers to innovation	770, 000
In title:"barriers to innovation "	229
Barriers to commercialize innovation	16,300
In title:"barriers to commercialization of innovation "	0
In title:"barriers to commercialization"	29
In title:" commercialization barriers"	11

Table 3: Keywords and the query used for literature search in Google

A funnelled approach was followed to gather relevant articles for the research. As the table shows, searching only 'barriers to innovation' term resulted in thousands of articles. Thus, a keyword 'in title' was used to narrow down the search. Mainly the articles retrieved from the search with the search word 'In title' were included in the

literature research. Further to this step, following process was used to skim the articles retrieved through the database search:

1. Read abstract to get a brief summary of articles. Articles narrating relevant content on barriers, specifically explicitly mentioning barriers and the categories of barriers were included.
2. References that appear in many articles indicated that the corresponding work is important in the field. This helped in identifying distinguished articles in the subject.
3. Forward and backward search was made on the distinguished articles to increase the exhaustiveness of the search.

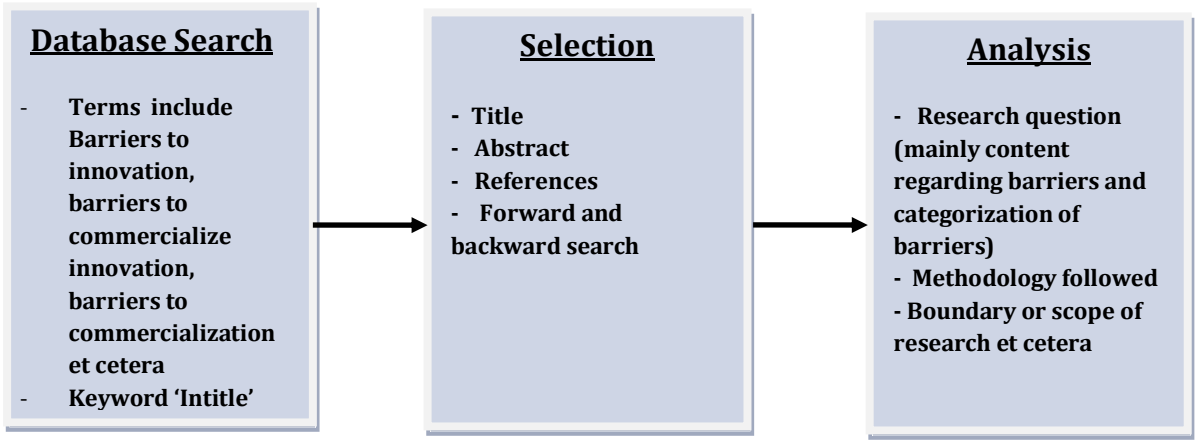

Figure 3: Pictorial representation of literature research process

It was found that there were several articles which just mentioned the word barrier but did not contain any substantial value-adding information. Such articles were ruled out of the study. Further, a substantial overlap was observed during the database searches with the keywords mentioned in the table presented above. This overlap was kept in mind while progressing in the literature research process. It must also be noted that synonyms of the word 'barrier' were not specifically searched to limit the scope of the study.

After following the structure of research described above, a total of about thirty articles and papers were identified that provided a substantial amount of information on barriers. These articles originate from diverse disciplines such as strategic management, environmental management, Economics, technology management and marketing strategy. They have been published in reputed journals such as Technovation, Research Policy, Journal of Economic Behaviour and Organisation et cetera.

3.2 Literature Search: Barriers to Commercialize Innovation

Appendix B provides an overview of a few articles that were referred for carrying out the literature study. The articles mention barriers and categorize them into several categories. Most of the authors banked on the usual categories devised in earlier studies. Nevertheless, a few authors devised their own categorization based in the research question investigated in the article. A few authors took a resource-based view, explaining the differences between innovation activities due to the differences in the resources(Madrid-Guijjaro, 2009). However, no core theory is applied for the categorisation of barriers.

The papers vary in their focus along different dimensions such as technology, country, kind of barrier studies etc. A wide variation is also observed in the methodology followed for the research. A vast proportion of the literature found follows the scheme of quantitative research to explore the realm of barriers. Instruments such as surveys, questionnaires et cetera were deployed to unfold the answers to research questions around barriers. A very few articles also provide a literature review of the existing literature on barriers. A number of authors have highlighted the fragmented nature of the literature on barriers. Literature reviews also do not present the exhaustive list of all the barriers mention in the literature so far. Interestingly, sparse literature is available in which the question of barriers is investigated qualitatively. A few authors followed the case study method to investigate the topic of barriers. However, the number of these kinds of studies is far less than the quantitative studies.

There are studies available which investigated barriers in innovative firms located in Poland (Balcerowicz, 2010). The author streamlined the study by categorizing barriers into financial barriers, knowledge barriers and market barriers. Similar study was conducted in Sweden in which author studied barrier related to the customer. A few papers were also found that discussed institutional barriers such as national innovation policy, infrastructure etc (Oyelaran-Oyeyinka, 2006). In another paper, institutional barriers were investigated in the context of sustainable technologies (Kemp, 1998). It included government policy and regulatory framework. One of the papers discussed barriers to innovation faced by SMEs in a small less developed country. The author explains exogenous or external and endogenous or internal barriers. Exogenous barriers were further divided into supply, demand and environment related barriers (Hadjimanolis, 1999). To summarize, barriers in commercializing innovation have been studied through different lenses by various authors. Moreover, the categorization of the barrier varied widely.

In the majority of articles, the categorization of the barriers used by the authors is derived from Piater study which was carried out for the Commission of European communities(Piatier, 1984). It distinguishes barriers into two categories namely internal and external. However, there is no concrete theory that has been used by the

authors to derive such categorisations. A few authors tried to categorise barriers at a deeper level with several categorisations. A few studies take a step ahead by finding the perceived importance of the barriers by the companies. However, the epicentre of those articles was not solely the barrier but other dimensions such as a particular strategy like external partnering as an answer to such barriers. It can be argued that no comprehensive assessment has been made of the subject of barriers and strategies in a single study.

The literature search on the barriers to innovation also led to the retrieval of articles focusing solely on nanotechnology. It was found that a plethora of literature is available regarding barriers or challenges faced by companies associated with nanotechnology. However, the literature focuses on certain key boundary conditions such as country, a part of value chain of nanotechnology or a particular industry influencing nanotechnology. Various national governments such as those of the US, the UK and rest of Europe have been commissioning studies in order to delve deep into nanotechnology (Nikulainen, 2010). A number of such reports are available on the web that details the barriers or challenges that are experienced in progressing nanotechnology products(Tom, 2007).

Cost or lack of financial resources is the most frequent factors that arose in most of the articles. It is recognised as the most significant barrier to innovation(Madrid-Guijjaro, 2009). Another significant barrier cited is the lack of highly skilled labour. This barrier hampers the innovation process specially, in the hi-tech industry(Frenkel, 2003). Lack of market information too was recognised as a barrier. An inventory of the barriers found in the literature search is presented in the below table.

Barriers	Author
Availability of materials/reagents; Public acceptance of biotechnology; Lack of skilled researchers; Availability of marketing personnel; Availability of production personnel; Management expertise; Fiscal expertise; R&D technical expertise; Business strategy experience; Lack of external funds including venture capitals, public funds etc.; Food and drug administration; Environmental Protection Agency; Government fiscal and regulatory framework; Patent decisions including both home and foreign territories	(Greis, 1995)
Competitors are actively hindering the innovation; Alternatives or competitors are less expensive; It is difficult to explain the benefit to the customer; The customer experienced a tentative risk in changing technology; Permits and planning processes are hindering market; Introduction; Costly to demonstrate the innovation and its benefits;	(Englund, 2010)

Supply infrastructure limitations; Lack of external funds including venture capitals, public funds etc.; Government fiscal and regulatory framework;	(Hirst, 1990)
Incumbent's defensive response ; Multiple market applications; Custom design and development; Pilot scale-up; Government fiscal and regulatory framework	(Maine, 2006)
Technology ; Infrastructure and Maintenance; Lack of manufacturing facilities; Cultural and Psychological Factors of the firm; Government fiscal and regulatory framework; Infrastructure and Maintenance;	(Kemp, 1998)
Lack of Regional Infrastructure; Codes and standards	(Scozzi, 2005)
Lack of skilled managers ; Lack of research facilities/assets; Lack of manufacturing facilities; Lack of external funds including venture capitals, public funds etc.; Patent decisions including both home and foreign territories; Lack of mktg./distr. Channels	(Hall, 2002)
Sources of knowledge exchange; Learning efficiency;	(Oyelaran-Oyeyinka, 2006)
Lack of intellectual property rights; Lack of external partners and networking possibilities; Limited internal know-how to manage the innovation process; Bureaucratic hurdles - long administrative procedures - restrictive laws and regulations ;	(Lukjanska, 2009)
Lack of intellectual property rights;	(J. R. G. Baldwin, G., 2004)
Lack of external partners and networking possibilities	(Hewitt-Dundas, 2006); (Mohnen, 2005); (Freel, 2000)
IPR Disputes ; High cost of product; Lack of external funds including venture capitals, public funds etc.; Lack of funds within an enterprise or group	(Shapiraa, 2008)
Lack of external partners and networking possibilities; Lack of funds within an enterprise or group; Market dominated by established enterprises and uncertain demand for innovative goods; Lack of information on markets; Lack of demand for innovations	(Balcerowicz, 2010)
High cost of product	(Frenkel, 2003); (J. L. Baldwin, Z., 2002)

Limited internal know-how to manage the innovation process	(Rammer, 2006),
Transfer technology to buyer	(David J. Teece, 1986)
Lack of funds within an enterprise or group	(Madrid-Guijjaro, 2009)
Bureaucratic hurdles - long administrative procedures - restrictive laws and regulations	(Acs, 1990)
Economic Turbulence , Lack of information on markets	(Frenkel, 2003);

Table 4: List of barriers identified in the literature

4. Framework for Categorization of Barriers

After a thorough analysis of the existing literature, a new framework is drawn which attempts to include and articulate a majority of the barriers mentioned in the literature. This framework is further deployed at the data analysis phase to categorise barriers identified in all the cases. The framework serves two-fold purpose – it helps in elucidating and structuring barriers, and it assists in devising strategies to overcome barriers.

As described in the previous chapter on scientific background, different categorisation has been followed by authors such as internal/external, endogenous/exogenous, and institutional, firm-related/environment related et cetera. The barriers identified and categorisation by NP Gries(Greis, 1995) provides an exhaustive and a concrete basis for the barrier framework. However, the framework presented here is derived keeping the strategies in mind. Hence, the existing categorisation of barriers is tailored to a new framework. The new framework, broadly speaking, represents a simplified market model of the firm. A typical firm usually functions in a web of other firms, making alliances both horizontally and vertically along the value chain. It is represented in the following figure.

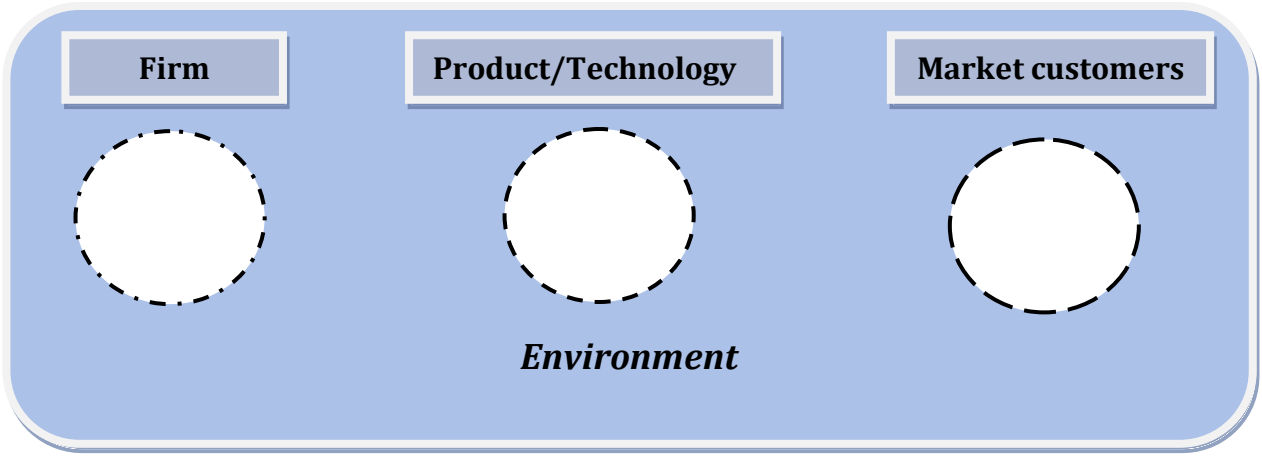

Figure 4: Simplified market model of a firm

For the purpose of this research barriers are being broadly categorise into four categories namely technology-related, firm-related, environmental, and market characteristics. These categorises are further sub-divided as shown below in the new framework chosen for the research.

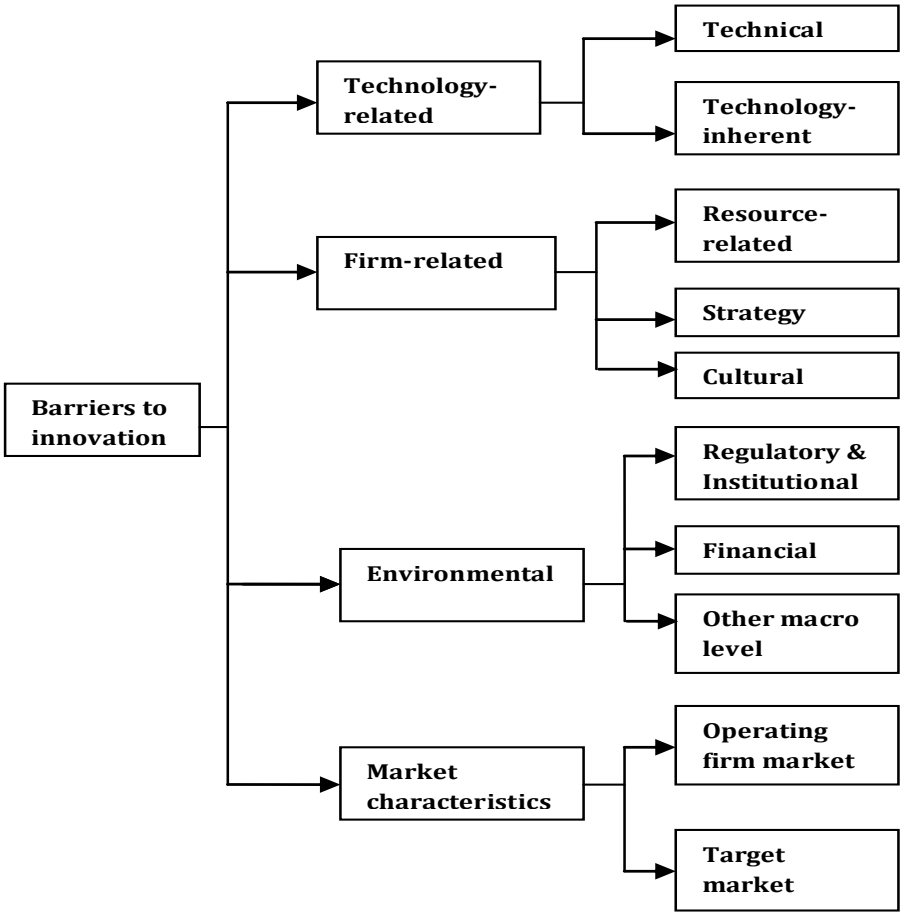

Figure 5: New framework for the categorization of barriers to innovation

The definitions of a barrier and different categories of barriers as represented in the above figure are given below:

Barrier – In the dictionary, a barrier is defined as any condition that makes it difficult to make progress or to achieve an objective. In this research, the definition also encompasses mistakes or factors that may potentially impede the commercialisation of the product innovation.

Barriers to innovation are divided into four main categories namely, technology-related, firm-related, environmental and market characteristics.

Technology-related – These barriers include the barriers which are associated with the technology deployed by the firm. These barriers are further sub-divided into two categories – technical and technology-inherent. Technical barriers refer to the technical bottlenecks that are encountered by the firms while developing and commercialising a product. For instance, technical difficulties in the paint formulation et cetera. Technology-inherent barriers are the non-technical barriers which are stimulated by the technology itself. For example, the necessity of undergoing field trials of chemicals.

Firm-related – Firm-related barriers refer to those barriers which are internal to the firm. These barriers are sub-categorized into three barriers namely, resource-related, strategy and cultural. Resource-related barriers are those that related to lack of sufficient resources such as lack of sufficient internal capital, experts et cetera. Strategy barriers are those barriers that associate with the strategy chosen by the firm. For instance, ineffective marketing strategies et cetera. Cultural barriers relate to the internal culture of the firm that may hinder the progress of the product such as risk-aversion attitude of the management.

Environmental – Environmental barriers are those barriers which are triggered at a macro-level. These barriers are sub-categorized into regulatory and institutional, financial and other macro-level barriers. Regulatory and institutional barriers refer to policy implications, standards and various government regulations such as FDA standards, issues in patent filing et cetera. Financial barriers refer to lack of external funding to the firm. Other macro-level barriers refer to natural disasters, economic downturn et cetera that may act as a barrier to the progression of the innovation.

Market characteristics – These barriers relate to the market characteristics of the firm in which it is operating as well as the customers targeted by the firm. These barriers are sub-divided into the barriers associated with the operating-firm market and the target market. Barriers associated with the operating-firm market include barriers such as competition from a large number of players. Barriers associated with the target market include the characteristics of the customer such as hesitance to adopt the product.

5. Case Description

In this chapter, the data gathered through interviews and company publications is presented for all the cases in the form of case descriptions.

5.1 Product A

<Section left blank due to confidentiality reasons>

5.2 Product B

<Section left blank due to confidentiality reasons>

5.3 Product C

<Section left blank due to confidentiality reasons>

5.4 Product D

<Section left blank due to confidentiality reasons>

5.5 Product E

<Section left blank due to confidentiality reasons>

5.6 Product F

<Section left blank due to confidentiality reasons>

6. Data Analysis

In the previous chapter, the data collected through desk research and interviews was presented. In this chapter, the gathered data is analysed through the lens of the framework presented in the beginning of the research. The chapter is sub-divided into two sub-sections broadly detailing within case analysis and cross-case analysis. In the sub-section 6.1, the framework is applied to the individual cases considering the context of product innovation to identify barriers, types of barriers encountered, and the solutions adopted while commercialising the products in the cases. In the sub-section 6.2, the analysis is taken to a next level of cross-case analysis. Barriers and corresponding solutions are reconciled from different cases. Furthermore, the barriers identified in the cases are validated with the barriers that have already been highlighted in the existing literature. Any additions (if any) to the existing list of barriers highlighted in the literature are reported in this sub-section. The findings from the cross-case analysis are further translated to general strategies. These strategies could potentially be adopted by companies immersed in similar contexts.

6.1 Application of Barriers Framework to the Cases

In this sub-section, the barriers framework is applied to the individual cases to identify barriers and solutions for those cases. Attention is paid to the contextual information as well. For all the cases, firstly, a brief context is provided in which the barriers occurred. It is further succeeded by a short description of barriers and the solutions adopted by the company. It must be noted that some barriers may be intertwined which other making it difficult to sort the barrier into a suitable category. In such cases, the underlying cause of the barrier is identified and accordingly, a suitable category is chosen for placing the barrier.

Product A

The company producing product A is a small-medium sized company diversified in other types of lasers and optical systems. The innovation steps for producing the laser broadly followed a traditional route of research, testing and manufacturing. The company used its own patented technology to develop Product A. The test results were perceived as universal in terms of its applicability to different customers. Since the laser was complex in nature, it became imperative for the sales team to communicate the laser's functioning and benefits in a very discernible manner. Initially, the product was meant for business-to-business market, specifically for universities and corporate research labs. The competitors were mainly producers of conventional lasers.

The progress of the product was hindered by all the four broad-level barriers explained in the framework. The company responded to these barriers in any of the three ways – solved the barrier, no action since the barrier is uncontrollable by the company, no

action due to strategic reasons. The following table gives an overview of the barriers and the corresponding solutions.

Barriers	Solutions
Technology inherent	
Restricted supply of good quality carbon nano-tube	Left it unaddressed; solved with time
Difficulty in explaining the product to the potential customers	Provided customers with a complete set of do's and don'ts with the laser
Resource related	
Limited number of expert resources	Still unaddressed
High price	Set up a small production procedure and now they have a better cost control structure; efficient production process
Sluggish marketing due to lack of resources	More aggressive efforts in marketing; Sales team increased from one to five
Strategy	
Lack of participation in the exhibitions	The company has started going to the same exhibition every year to gain trust of the people
Positioning through name of the product	Still unaddressed
Regulatory and institutional	
Patent issue difficulties in the foreign territory	Did not file the patent in the foreign territory; selling the product through distributors in the foreign territory
Other macro level	
Economic crisis and natural disasters	Left it unaddressed
Target market	
Discontinuation of the system incorporating the product by a major customer	The company decided to make the system on their own

Table 5: Barriers and corresponding solutions identified for product A

Unsurprisingly, many of the barriers encountered in the progression of product A are firm-related. The company faced resource-related barriers, lack of both technical experts and sales peoples. The company responded to the barrier by hiring more sales people. However, since the company is diversified into other types of laser and is of small-size, it could not afford to create a dedicated team for the product. Moreover, the demand for the product is not sufficient enough to engage experts in the production of only one product. Another barrier faced by the company is that the product is costly in the market. This is due to the fact that there is no large demand for the laser which means that the company could not achieve economies of scale and offer the product at a relatively cheaper price. On the other hand, it could be argued that since the product is costly, the demand for it is less. As noted, it has formed a vicious circle. The company attempted to create a small production procedure which has led to a better cost-control.

Although the company faced strategy barriers, interestingly no financial barriers were reported. Since the company was mainly run by technology enthusiasts, marketing was indeed its weak spot. It did not participate in exhibitions regularly and hence failed to establish credibility in the market place. However, the company was quick to realise this and rectified its strategy by intensive participation in industry exhibitions. The company reported that unlike its competitors, they did not position themselves as laser-only company which had an impact on the degree of credibility of the laser. The company recognised this but it also reported to have benefitted from its diversified business, specially, at the times of economic downturn impacting the product's demand. Hence, due to the overall strategic reasons the company decided not to take any action for this point.

The company did not face any technical barriers. It could potentially be due to the fact that the company invented the laser itself. Moreover, the inventor was an expert in lasers. However, there were a few barriers under the category of technology inherent that affected the progression of the product. One of the constraints was on the availability of the raw material, carbon nano-tubes. It was not available commercially. Moreover, the CNT available was of sub-quality. It was beyond the company's strength to fix the barrier. However, as the time passed, CNT was available commercially and of good quality. Another barrier was of explaining the product to the potential customers. Due to the complexity of the product, sales people found it difficult to communicate the characteristics of the product. The company solved the barrier by providing customers with a complete set of both do's and don'ts.

The company experienced difficulties in getting the patent issued in the foreign territory. The procedural challenges were far beyond the company's capacity. Hence, the company did not file the patent. However, it started selling its product via distributors in the foreign territory. Economic crisis and natural disasters also affected the overall business of the company. Since, these barriers were beyond the company's reach, they remained intact. However, with time the things appeared to improve.

Within the market characteristics barriers, the company was hit by a major customer that discontinued the purchase of the product, which was used in customer's system. The company then decided to produce the system on its own.

Product B

Product B is produced by a small-medium sized company in Japan. It belongs to the product category of pharmaceuticals. The market for the product is business-to-customer. The company acquired a patent from a public body in the foreign territory to use the element mentioned in the patent. Although the founder did not have a much of technical expertise, he had a good network through which he was introduced to universities. The universities performed the task of research and field trials. The

company was originally into other business before committing itself to the production of the toothpaste. It had accumulated substantial funds to carry out the production of toothpaste.

Due to the small size of the company, the product commercialisation was mainly spearheaded by the founder. It was a long-haul for getting the government approval to stamp the medical claims of the product. The company adopted a quick strategy to introduce the product under the 'cosmetics category'. Later, once approved, it launched it under medically approved stamp. Though at first sight the product seems to have faced plenty of competition but in reality, the product adopted a differentiation strategy. It was positioned as a highly-priced product.

The company faced all types of barriers. However, most of the barriers could be seen as firm-related. The company faced a few technical barriers which it resolved by resorting to help from universities or a manufacturing partner who had enough expertise. Another barrier was the justification of the high price of the toothpaste. After collecting the feedback from early customers, the company found which characteristics does the customers like the most. The company then positioned its product centring on those characteristics at a large scale. Aggressive marketing helped in selling a differentiated product.

Due to the small size and limited experience, the company encountered several resource-related barriers such as insufficient production capacity, lack of marketing expertise and high-attrition rate. The company learnt to deal with this with time. The company also encountered a few strategy related-barriers such as inefficient supply-chain planning and competing distribution channel. The company solved this barrier with time by learning-by-doing. One of the strategy barriers that company faced was diversification of business. The company diversified in many directions such as brand extension, applications et cetera. It eventually consolidated its business.

A regulatory and institutional barrier encountered by the company was a long wait-time for getting government approval on the medical claims of the product. It was uncontrollable by the company. But it adopted a quick strategy of introducing the product under other category to maintain cash flow. Tsunami also had an impact on the business. One of the target-market barriers was the difficulty in conducting field trial due to the decision made by the organisation in which trials were taking place. The company could not influence the decision and hence, it remained intact. The following table gives an overview of the barriers and the corresponding solutions.

Barriers	Solutions
Technical	
Technical difficulties associated with product development	Resort to help from the university or manufacturing partner
Technology inherent	
Justify high price of the toothpaste	Company collected feedback from first customers and positioned the product as per the feedback. Company did excellent marketing by airing advertisements which were a national hit
Resource related	
Insufficient production capacity	Postponed the airing of the next TV commercial
High attrition rate at the management level	Unaddressed
Lack of expertise in marketing	Learned by doing the retailing
Strategy	
Inefficient supply-chain planning	Learned with time
Diversification of business	Company eventually consolidated the business
Competing distribution channels	Learned with time
Regulatory and institutional	
Long wait-time for getting government approval	Company launched the product under the cosmetics category
Other macro level	
Natural disaster	Due to Tsunami in Japan, initial export shipments had to be postponed due to the fear of radiation
Target market	
Difficulty in conducting trial due to decisions by the organization in which trials had been taking place	Unaddressed

Table 6: Barriers and corresponding solutions identified for product B

Product C

The product is produced by a small-medium sized company in the United Kingdom. The product is meant for the business-to-business market. The company adopted a niche strategy of first establishing a foothold in one segment. The company licensed a patent from other company and further developed it to produce a feasible product. The company's strength lies in its unmatchable expertise in nano-materials and its excellent customer-service. The company used internal funds from other businesses to fund the production of the fuel-additive. The company proactively participates in target-market industrial gatherings and collaborates with various universities to conduct regulatory tests for the additive. The innovation path of the product consists of R&D, testing and trialling and sales development.

Mainly firm-related barriers occurred in a relatively large number, followed by technology-related, target-market, technology-related and environmental barriers. The company had limited financial resources to scale-up production; hence it outsourced production to other company. It encountered a few strategy barriers such as

intellectual property rights issue with the licensor; ensure quality at an industrial scale and early diversification in many dimensions. The company was able to solve these barriers primarily by re-adjusting its strategy. IPR dispute was settled in the court.

The company did not face many technical barriers. The one which was there was lifted using the technical expertise. Field trials were reported as a time-consuming step. The company mitigated it by keeping the option only for those customers who requested for it. The target market of the company also posed a few barriers; the companies were sceptical of using earlier results for other customers and were sceptical of using the product. The company solved these by providing documentation, conducting separate field test and working proactively with the hands-on people at the customer site.

The company faced a regulator barrier in the foreign territory. It was discouraged by challenging procedural requirements for using its product in the foreign territory for a particular use. The company circumvented the barrier by selling the product for some other usage. The following table gives an overview of the barriers and the corresponding solutions.

Barriers	Solutions
Technical	
Instability of the product	The company was ultimately able to solve the problem through its technical expertise
Technology inherent	
Time consuming field trials	The company has been conducting field trials on request by potential customers
Resource related	
Insufficient financial resources to scale-up production	The company outsourced the production to other company
Strategy	
Intellectual Property Rights issue with the licensor	Finally, the case was settled in the court
Ensure quality at an industrial scale	It did regular quality checks at its end and transferred the knowledge to the outsourced company
Dependence on a single customer	Restructuring of the strategy
Early diversification in many dimensions	The company then re-configured its strategy to focus on one segment and gain credibility in that industry
Regulatory and institutional	
Regulatory reasons discouraging highway usage of the additive in the foreign territory	The company introduced the product in the foreign for off-highway usage
Target market	
The customers demanded field trial specially designed for them. They are not open to trust the earlier field trial results.	The company had to conduct separate field trials for different customers
Sceptical attitude of bus industry	The company provides technical documentation

Hesitance of operating companies of customer in using the additive	The company worked closely with the operators and ensured that the operating companies use the additive in the vehicles. The customer management ordered operating companies to use the product

Table 7: Barriers and corresponding solutions identified for product C

Product D

Product D is produced by a small company in Norway. Marine coatings belong to the category of chemical, broadly. The innovation path, hence, is marked by research, laboratory testing, field trialling and sales development. The company licensed a patent from another company in Europe. The company subsequently polished the concept further and developed a technically feasible product. Both private and public funding was secured to ensure the progression of the product. Although the team is small, it has a rich cumulative experience in the field of coatings.

The product is target at the business-to-business market in the Nordic region. The company collaborated with various universities and research institutes during the commercialisation for different purposes such as research or special testing et cetera.

The company encountered mainly firm-related, technology-related and environmental barriers. There were no market characteristics barriers were reported. This could potentially be due to the fact that the one of the major customer is currently the marine arm of the venture capital firm which had invested in the product. The company encountered a few technical barriers such as difficulty in maintaining product consistency, and technical challenges during research and field trials. The company mainly leveraged its decades of experience in the coatings industry to lift those barriers.

One of the key resource barriers reported by the company was about attracting skilled work-force. Other resource-related barriers were reported to be lack of funds and high-price offering since they have not reached the stage of economies of scale. It takes a lot of time and effort to gain trust of the customers. The company did face institutional barriers in terms of the legal and procedural challenges encountered for the transportation of the coatings. Since, it is beyond the reach of the company these barriers remain as it is. Other macro-level barrier that hindered the progression of the product was the harsh weather conditions of Norway. It limited the period of field trialling to almost half-a-year. The company sorted it out by partnering with university in other part of the world where the weather conditions were favourable throughout the year. The following table gives an overview of the barriers and the corresponding solutions.

Barriers	Solutions
Technical	
Maintain consistency of the product with every delivery	The company leveraged its technical capability to ensure product consistency
Technical challenges in conducting field trials	During field trials, the company has continuously discovered elements for improvement in the product. It continues to solve it through its technical expertise before every following trial.
Technical difficulties during research	The company faced a few technical bottlenecks in understanding the effect of using carbon nanotubes in the coating. However, those were overcome by the team. The company creates a proof-of-concept with every improvement made to the coatings.
Technology inherent	
Time consuming field testing	Left it unaddressed
Resource related	
Attract skilled workforce	Solved with time. It took some time to attract skilled staff
Lack of funding	Resort to investment from a venture capitalist firm. It infused a vast sum of money into the company, which resolved the funding problem
High price offering Strategy Building confidence about the product with the prospective customer	The company is working on reducing the prices to bring it to a competitive level. It takes enormous amount of effort and time to demonstrate the benefits of using the product;
Regulatory and institutional	
Legal and procedural challenges that apply to the transportation of paints Other macro level Dependency of field-testing on weather	Left it unaddressed The company expanded its reach to Singapore. The testing could be conducted in Singapore for all twelve months per year due to the country's favourable weather conditions

Table 8: Barriers and corresponding solutions identified for product D

Product E

Product E is a surgical dressing produced by a small-medium size company in the US. It belongs to the category of pharmaceutical. The product was targeted at the business-to-business market. The company has a strong linkage with the university as reflected in the fact that it was co-founded by a university researcher. The company used internal funds to commercialise the product. The innovation path of the product was characterised by clinical validation, regulatory validation, manufacturing development, and sales development. The company's market was flooded with big players.

Most of the barriers encountered during the progression of the product were firm-related, followed by environmental, technology-related and market-characteristics. Unsurprisingly, barriers such as lack of financial resources and marketing people were encountered by the company. The company faced difficulties in the tasks that required interfacing with the public authorities. It took a long time to obtain the standard mark. The product is still not included in the insurance program. Since, these impediments were beyond the strength of the company, they were left intact.

Due to the nature of the product, it was obligatory to conduct trials of the product. The trials were costly and time-consuming. The company also encountered a barrier related to the market in which the firm was operating. As it was mentioned earlier, the operating-firm's market has quite a presence of big players. The competitors attempted to disseminate misinformation about their products. The company tackled it by publishing results of the product compared to competitors' products. It helped offset the competition. The following table gives an overview of the barriers and the corresponding solutions.

Barriers	Solutions
Technology inherent	
High cost and long time for conducting trials	Company succeeded by finding researchers and institutions who were genuinely interested in the science rather than the fees they charged for the work
Resource related	
Lack of financial resources Lack of marketing people	Solved with time Solved with time
Regulatory and institutional	
Long time to obtain CE mark for the product	Left unaddressed
Exclusion of the product in Insurance program	Left unaddressed
Operating-firm market	
Misinformation about similar product disseminated by competitors	Published results of the product compared to competitors products helped offset the competition

Table 9: Barriers and corresponding solutions identified for product E

Product F

Product F belongs to the product category of lasers. Most of the barriers faced by the companies are resource-related, followed by regulatory and institutional, and target market barriers.

Due to the small size of the company, the company faced a shortage of resources for the production activities. As a response to the shortage, it automated a large amount of production activities thereby eliminating the need for having more peoples. Another resource-related barrier encountered by the company regards to the burgeoning size of

the company. The company maintains the effectiveness of the management by introducing thorough processes in the organisation.

The company may face legislative barrier on the semiconductor due to the legislation in the home continent. The company reported that it will probably resolve it by relocating its production facility to some other continent. Another barrier concerns the language and cultural barriers characterising the target market of the product in the foreign territories. The company resolved it by appointing regional distributors.

Barriers	Solutions
Resource related	
Limited number of personnel for production In-effective management of growing organisation structure	It solved the barrier by automating the work The company tackled this through the introduction of organizational processes in the company
Regulatory and institutional	
Legislative barriers in the home continent	Relocation of the production facility to other continent
Target market	
Linguistic and cultural barriers for direct marketing	The company appointed distributors in the country to sell the laser

Table 10: Barriers and corresponding solutions identified for product F

6.2 Cross-Case Analysis of Barriers and Solutions

The cases have been analysed individually in their own context in the previous chapter. The next step chosen for the data analysis is to make cross-case comparison. In this sub-section, cross-case analysis is performed of all the cases selected for the research. Broadly speaking, the analysis is made to uncover new barriers (if any), and to find out commonalities and differences in the barriers encountered and the corresponding solutions adopted by the companies. General strategies are drawn from the analysis to address the barriers identified in the cases.

All the cases are representative of a certain degree of technology innovativeness, mostly in terms of using a new material in the product. A couple of associated companies used their own patented technology to develop the product. However, others developed the product themselves but licensed a patent that could be deployed for the development work. On an average, the products are in the market now for almost a decade with one exception, the toothpaste case which is on the market for almost two decades now. The associated companies are all private-owned and have a total size of less than 100 employees. Most of the associated companies have technical expertise in the area of the product. Surprisingly, only a couple of companies used public funding to progress the product. Rest of the companies had substantial financial strength to fund the product development and commercialisation itself.

Interestingly, all the associated companies had linkages or collaborations with the universities for different purposes such as development, testing, purchase of raw material and even as a customer of the product. The innovation path of the photonics products such as laser followed a straight path of research, laboratory prototyping, marketing, sales et cetera. These products were immediately introduced to the market without laborious outside testing. On the other hand, cases belonging to product categories, chemicals and pharmaceutical had to undergo rigorous field testing phase. This phase was reported as both time-consuming and costly for most of the cases. The companies associated with all the cases, initially, adopted a niche strategy of establishing their foothold in one market segment. For all the cases except one, the market was business-to-business. For the toothpaste case, mass-market was chosen.

The following table gives an overview of all the cases along different dimensions.

Product Name	A	B	C	D	E	F
Product	Femtosecond laser	Toothpaste	Fuel additive	Advanced Marine coatings	Surgical dressings	Laser diode
Industry of origin	Photonics	FMCG/Pharmaceutical	Chemicals	Chemicals	Pharmaceutical	Photonics
Applications	R&D applications	Anti-caries/re-mineralizing, Whitening toothpaste	Transport vehicles, automotive	Ship coatings	Surgical care , wound dressing	Gas pipelines, power plants, medical systems, airborne and satellite applications
Type of targeted market	B2B business, Niche (Initially to universities, research labs, and later on to companies in Japan)	B2C business, Mass-market (Public in general)	B2B business, Niche (Bus companies in the UK)	B2B business, Niche (Shipping companies in Nordic regions)	B2B business, Niche (Hospitals)	B2B business, Niche (Small companies for their analyzers)
Product innovativeness	Novel use of Carbon Nanotube (CNT) in laser offering various benefits over conventional lasers	World's first re-mineralizing toothpaste containing nanoparticle hydroxyapatite	Novel use of a compound in a fuel additive offering improvements in fuel consumption and targeting a different marketplace	Novel use of Carbon Nanotube (CNT) in marine coatings	Nano-based dressing providing advantages such as significant pain-reduction, reduced scarring and cost-reduction	The technology is functionally new
Intellectual Property	Based on own patent	Licensed a patent and further worked on it to develop the product	Licensed a patent and further worked on it to develop the product	Licensed a patent and further worked on it to develop the product	Based on own patent	Licensed a patent
Company location	Japan	Japan	United Kingdom	Norway	United States of America	Germany

Number of employees	About 25	About 70	Less than 25	About 5	Less than 25	60
Company Background	Spin-out of a SME company; founders were technology enthusiasts; A few employees were PhD scholars ; the company was established to work on a different technology	Private-owned company, had set up as a trading company but later ventured toothpaste business; founder had no rich technical expertise in the toothpaste formulation; founder convinced of the product	Originally developed by a company specialized in nano-materials; located in university's science park; Once the original company was listed on AIM butt later de-listed; finally the business was sold to other company	Private-owned company; founders had rich expertise in coatings sector;	Company co-founded by a university researcher; he had a rich expertise in the technology and held the patent to the technology	University spin-off; formed to convert fundamental research to applied research
Year of product launch	2003	1980 (under 'cosmetics' category and 1993 under 'quasi-drug')	2003-2004	2007	2001	1999
Funding of the product	Internal funds	Internal funds	Internal funds	Private and public funds; use of venture capital and funds from the state government	Internal funds	Public funding
Innovation trajectory	Basic Research, Patent Filing, Prototype development, Marketing, Sales and distribution	Basic research, Production of toothpaste, Market entry through outsourced marketing, Distribution and sales under the 'cosmetics' category, Research and field trials, Protecting	Licensing the patent, Research and Development, Testing and field trialling, Sales development.	Conceiving the basic idea of using CNT in coatings, followed by preliminary research, Acquiring the relevant patent from a Finnish company, Research	Clinical validation, Regulatory validation, Manufacturing development, Product positioning	fundamental research at a university; licensing a patent; laboratory prototype; industrialization; Marketing, Sales and distribution

		and managing intellectual property, In-house marketing, Distribution and sales under the 'quasi-drug' category.		and laboratory testing, Field trials in vessels, Sales development.		
Networks and collaborations	Strong linkages with universities and research labs due to the founders' networks	Networks with universities and collaboration with marketing and production companies	Target market industry associations, nanotechnology associations and low carbon associations. Collaboration with universities from various parts of the world for tests on toxic gases, collaboration with production companies	Collaboration with university and research institutes	Linkage with universities and military as a customer; collaboration with a production company	Strong linkages with university

Table 11: Overview of all the cases describing the aspects of context

The following table summarizes the barriers encountered in all the products.

	Technology-related		Firm-related			Environmental			Market Characteristics	
	Technical	**Technology-inherent**	**Resource-related**	**Strategy**	**Cultural**	**Regulatory and Institutional**	**Financial**	**Other macro level**	**Operating-firm market**	**Target market**
Product A		Restricted supply of good-quality carbon nanotubes (CNT)	Limited number of expert resources	Lack of participation in the exhibitions		Patent issue difficulties in foreign territory		Economic crisis and natural disasters		Discontinuation of the system incorporating the product by a major customer
		Difficulty in explaining the product to the potential customers	High price	Positioning through name of the product						
			Sluggish marketing due to lack of Resources							
Product B	Technical difficulties associated with product development	Justify high price of the toothpaste	Insufficient production capacity	Inefficient supply-chain planning		Long wait-time for getting government approval		Natural disaster		Difficulty in conducting trial due to decisions by the organization in which trials had been taking place
			High attrition rate at the management level	Diversification of business						
			Lack of expertise in marketing	Competing distribution channels						

Product C	Instability of the product	Time consuming field trials	Insufficient financial resources to scale-up production	Intellectual Property Rights issue with the licensor	Regulatory reasons discouraging highway usage of the additive in the foreign territory		The customers demanded field trial specially designed for them. They are not open to trust the earlier field trial results.
				Ensure quality at an industrial scale			Sceptical attitude of bus industry
				Dependence on a single customer			Hesitance of operating companies of customer in using the additive
				Early diversification in many dimensions			
Product D	Maintain consistency of the product with every delivery	Time consuming field testing	Attract skilled workforce	Building confidence about the product with the prospective customer	Legal and procedural challenges that apply to the transportation of paints	Dependency of field-testing on weather	
	Technical challenges in conducting field trials		Lack of funding				
	Technical difficulties during research		High price offering				

Product E		High cost and long time for conducting trials	Lack of financial resources	Long time to obtain CE mark for the product	Misinformation about similar product disseminated by competitors	
			Lack of marketing people	Exclusion of the product in Insurance program		
Product F			Limited number of personnel for production	Legislative barriers in the home continent		Linguistic and cultural barriers for direct marketing
			In-effective management of growing organisation structure			

Table 12: Barriers identified in all the cases along different categories

All the four broad categories of barriers were observed in all the cases. A large concentration of barriers is observed in the firm-related barriers category. It is closely followed by technology related-barriers, environmental barriers and market-characteristic barriers.

Despite of the heterogeneous dataset, a number of commonalities could be drawn from the empirical data on barriers and corresponding solutions. In the firm-related barrier category, most of the barriers were related to the resource and the strategy. Irrespective of the differences in the cases, almost all the cases were hit by lack of sufficient resources such as marketing peoples, technology experts, marketing expertise, production capacity, internal financial capital et cetera. Apparently, contrary to one's expectations, financial blockades were observed in a relatively small number. Lack of marketing people was cited as one of the frequent barrier. The small companies in the initial phases are more likely to face human resource crunch. In most of the cases, the existing employees have to juggle different projects and sometimes juggle diverse roles. A few companies also reported barriers pertaining to attrition of existing workforce, and attracting skilled labours. There could be a number of factors resulting in this barrier depending on the industry, technology, environment et cetera. This could also be likely due to less perks and demanding work at small-sized companies. Another resource-related barriers observed in a couple of cases is the high-price offering of the product. If the companies do not produce a product at a large-scale, they could not achieve economies of scale. This in turn results in high price. It could be argued that due to the high price, there is no substantial demand for the product in the market. Hence, there is no need to go for industrialisation of the product. It forms a vicious circle. However, high price offering sometimes attributed to the innovation offered by the product. The cost of development could be high in the beginning of the technology life cycle.

In the strategy barriers, diversification barrier occurred frequently in the cases. The companies attempted to diversify their business along different dimensions – brand extension, application et cetera, disproportionate to their capacity. This had severe consequences in terms of financial resources for the company. Financial instability of the company, in turn, hindered the progression of the products in the market. Other barriers reported by companies in this category were related to supply-chain management, marketing, relying on a single customer et cetera.

No cultural barriers were encountered in the progression of any product. This could be attributed to the small size and knowledge-intensive nature of the companies. Smaller companies do not have a rigid culture and well-established processes. Moreover, most of the cases are outcome of a technology push to a larger extent. This demonstrates that the companies were very well-committed to develop the product.

A number of technology-related barriers were also observed in most of the cases. Most of the barriers under this category belong to a sub-category of technology inherent. Interestingly, most of the companies reported that no substantial technical barrier blocked the progression of the products. Moreover, the technical barriers were not perceived as a major hindrance to the product. This could be potentially due to the fact that the nanotechnology sector is a knowledge-intensive sector. However, companies did observe a few technical barriers such as instability of the product, maintain product consistency et cetera. It is worthwhile noticing that the technical barriers reported for different cases occurred at different phases of product development and commercialisation such as research, field trialling, scaling- up et cetera. A common technology inherent barrier, pertaining to field trials, was observed in the cases belonging to the categories of chemicals and pharmaceuticals. Due to the nature of the technology, it becomes imperative in such industry to take the product in the outfield for testing. However, the field trialling is reported to be a time-consuming and expensive process, marring the path to commercialisation. Another technology-inherent barrier relates to the complicated nature of the technology. It made it quite difficult for the company to elucidate the technology to the customer.

Barriers under the category environmental were also reported in majority of the cases. Irrespective of the heterogeneity of the cases in terms of geographies represented, a common regulatory and institutional barrier was pertaining to patents and standard mark prevailed in most of the cases. Most of the companies faced issues in getting the patent or standard granted, specifically in the foreign territory. For chemicals and pharmaceutical cases, the respondents reported that it takes long time to get approval from public authorities. It could be due to the legal and procedural requirements specified by the government for granting such approvals. Strikingly, external funding or financial barriers was not cited as an impediment to the commercialisation of the product. It could potentially be because the propagators of the products were convinced of the technology or it was cheaper to produce the products. Moreover, many of the associated companies were diversified into other products before commencing the development of the selected cases. Hence, they already had substantial funds to work on the products. Cases from Japan reported that other macro-level barriers such as natural disasters (Tsunami) and economic crisis did impact the commercialisation of their products in terms of internationalisation.

Market characteristics of the operating firm and its target market both posed several barriers for the companies. A relatively high number of factors were reported that pertain to market targeted by the company. Chemical companies, in particular, encountered barriers during the field trialling. Customers did not trust field trial results for earlier customers. They demanded separate field trials. The scepticism, hesitance and interference from the customer or the targeted market often impeded the smooth progress of the products. However, only in one case an operating-firm market related

barrier was reported. In which case, the competitors misinformed public about a similar product. The market for this product is characterised by the presence of big players. A lower number of barriers under operating-firm market could be explained by the product innovativeness of the product, and number and size of competitors. Most of the products are not threatened by direct competition.

The barriers identified in the cases are compared with the barriers searched from the literature in the scientific background chapter of the research. Majority of the barriers found in practice were already covered by literature in a certain way. However, the comparison also led to the discovery of a few new barriers identified in the nanotechnology cases. The following table lists the new barriers:

S. No.	New barriers identified
1	In-effective management of growing organisation structure
2	Positioning through name of the product
3	High attrition rate at the management level
4	Inefficient supply-chain planning
5	Ensure quality at an industrial scale
6	The customers demanded field trial specially designed for them. They are not open to trust the earlier field trial results.
7	Linguistic and cultural barriers for direct marketing in other territories
8	Natural disaster

Table 13: New barriers identified in the cases

Interestingly, almost none of the new barriers identified characterises specifically the aspects of nanotechnology. However, a few of them do reflect the industry in which they occurred such as the one related to field trials. Most of them concern firm-related barriers. Majority of the barriers reflect the small size of the companies which are hit by the insufficiency of the resources. In one of the cases, it was mentioned that the company faced managerial barrier in dealing with the growing size of the organisation. Linguistic barriers were noted while reaching out to the market speaking foreign language. Apart from these barriers, natural disaster has been cited as an environmental barrier deterring the progression of innovation. Although economic turbulence is mentioned in the barriers literature, this barrier adds to the existing inventory of barriers.

6.2.1 General Strategies to Overcome Barriers

This sub-section takes a step forward by drawing general strategies adopted in the cases for tackling different types of barriers as defined in the framework.

For formulating the general strategies, mainly three elements in the cases were considered namely, barriers, solutions and the context. Apparently, the strategies adopted in practice are dependent on the context in which the barriers appeared.

Hence, while analysing the solutions to seek general strategies due attention is paid to the context. Following figure summarises the interplay of the three elements:

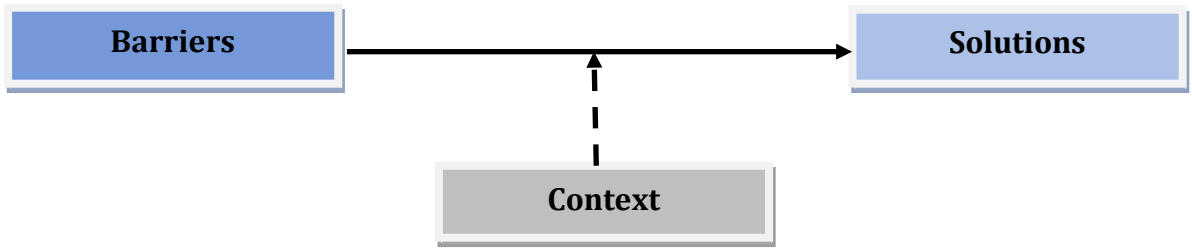

Figure 6: Elements for formulating strategies

In the following paragraphs, first the solutions are listed per barrier type and subsequently the strategies are described per barrier type to overcome the barriers.

Technical barriers, identified in all the cases, were addressed by the companies. Regardless of the case type, most of the companies lifted the technical barriers by leveraging its own technical expertise. For all the cases, except one, the development team or founders possessed a competency in the technology. In the case where the founder did not himself had a rich technical expertise, the technical bottlenecks were resolved by external partnering with either knowledge sources such as universities or expert companies depending on the phase when the barrier appeared. The below table provides a consolidated view of technical barriers and solutions adopted in the cases.

Technical	
Barriers	**Solutions**
Technical difficulties associated with product development	Resort to help from the university or manufacturing partner
Instability of the product	The company was ultimately able to solve the problem through its technical expertise
Maintain consistency of the product with every delivery	The company leveraged its technical capability to ensure product consistency
Technical challenges in conducting field trials	During field trials, the company has continuously discovered elements for improvement in the product. It continues to solve it through its technical expertise before every following trial.
Technical difficulties during research	The company faced a few technical bottlenecks in understanding the effect of using carbon nano tubes in the coating. However, those were overcome by the team. The company creates a proof-of-concept with every improvement made to the coatings.

Table 14: Consolidated overview of the technical barriers and solutions observed in the cases

In small companies, due to the lack of resources, employees especially founder assume several roles. In most of the nanotechnology cases, founders possess technical competency. For technical barriers, if the company possesses technical expertise as its

core competency i.e., technical manager is proficient in the technology, then hiring technical resources could be one of the strategies to resolve technical barriers. Otherwise, external partnering such as contract research, collaboration et cetera could be resorted. External partnering is primarily helpful in the cases where the partner has a rich expertise in a certain area. Furthermore, external partnering could be adopted in case the company has insufficient funds to undertake all the research itself. External partners could then provide equipment, technical resources et cetera at a cost lower than that of hiring own employees.

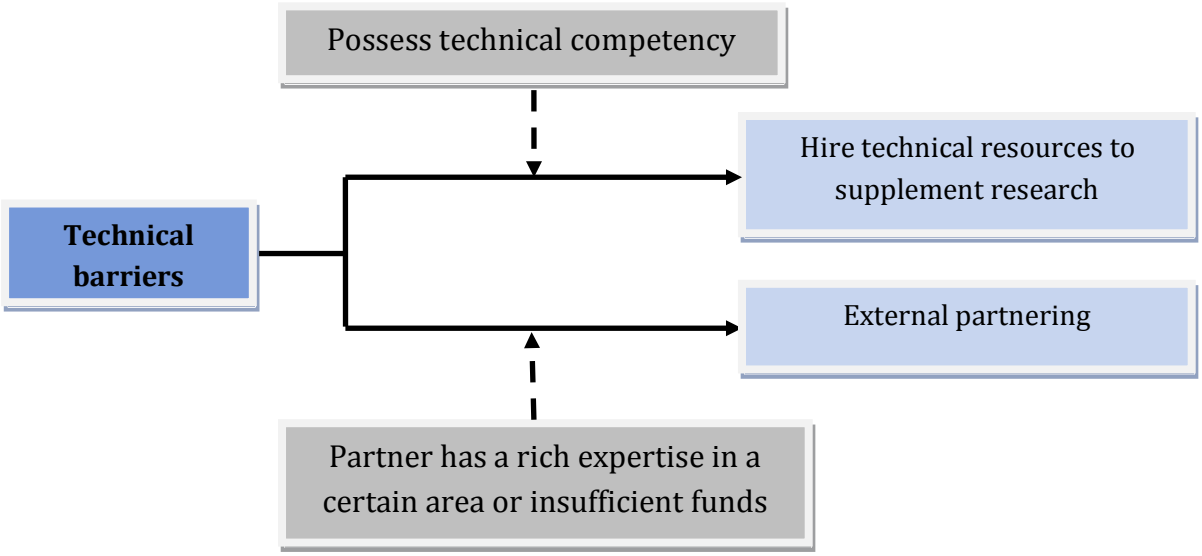

Figure 7: General strategies to tackle technical barriers

Apparently, companies could not totally address the technology-inherent barriers. The most common barrier, time consuming field trials, could not be lifted for any of the chemical cases. However, the company tried to mitigate it by offering field trials to only those customers who request for it. The barriers that pertain to the existence of steps such as field trialling in the process of commercialising product are difficult to address. However, the barriers that pertain to the technology itself but its consequences are on the customer side such as difficulty in explaining product or justifying high price were duly addressed by the companies. The companies devise strategies to deal with these barriers by liaising with the customers in an effective way such as providing enough information or extensive marketing. The below table provides a consolidated view of technology-inherent barriers and solutions adopted in the cases.

Technology inherent	
Barriers	**Solutions**
Restricted supply of good quality carbon nano-tube	Left it unaddressed; solved with time
Difficulty in explaining the product to the potential customers	Provided customers with a complete set of do's and don'ts with the laser
Justify high price of the toothpaste	Company collected feedback from the first customers and positioned the product as per the feedback. Company did excellent marketing by airing advertisements which were a national hit
Time consuming field trials	The company has been conducting field trials on request by potential customers
Time consuming field testing	Left it unaddressed
High cost and long time for conducting trials	Company succeeded by finding researchers and institutions who were genuinely interested in the science rather than the fees they charged for the work but the time issue is still not resolved

Table 15: Consolidated overview of the technology-inherent barriers and solutions observed in the cases

It must be noted that all the cases studied in the research possess a certain degree of innovation, mainly in terms of the technology used. There are non-technical barriers that exist due to the sheer usage of a particular technology. For technology inherent-barriers that are related to the development methodology of a product in the sector, the companies either leave it unaddressed or mitigate it such as field trial on request by a customer. However, the barriers that pertain to the technology itself but its consequences are on the customer side such as difficulty in explaining product or justifying high price were duly addressed by the companies. The companies devise strategies to deal with these barriers by liaising with the customers in an effective way such as providing enough information or extensive marketing. A third kind of barrier observed in the cases are those that are beyond the strength of the company since they relate to the overall technology state in the country or the world. In this case, these barriers are resolved with time as seen in the barrier regarding the restricted supply of good quality carbon nano tube.

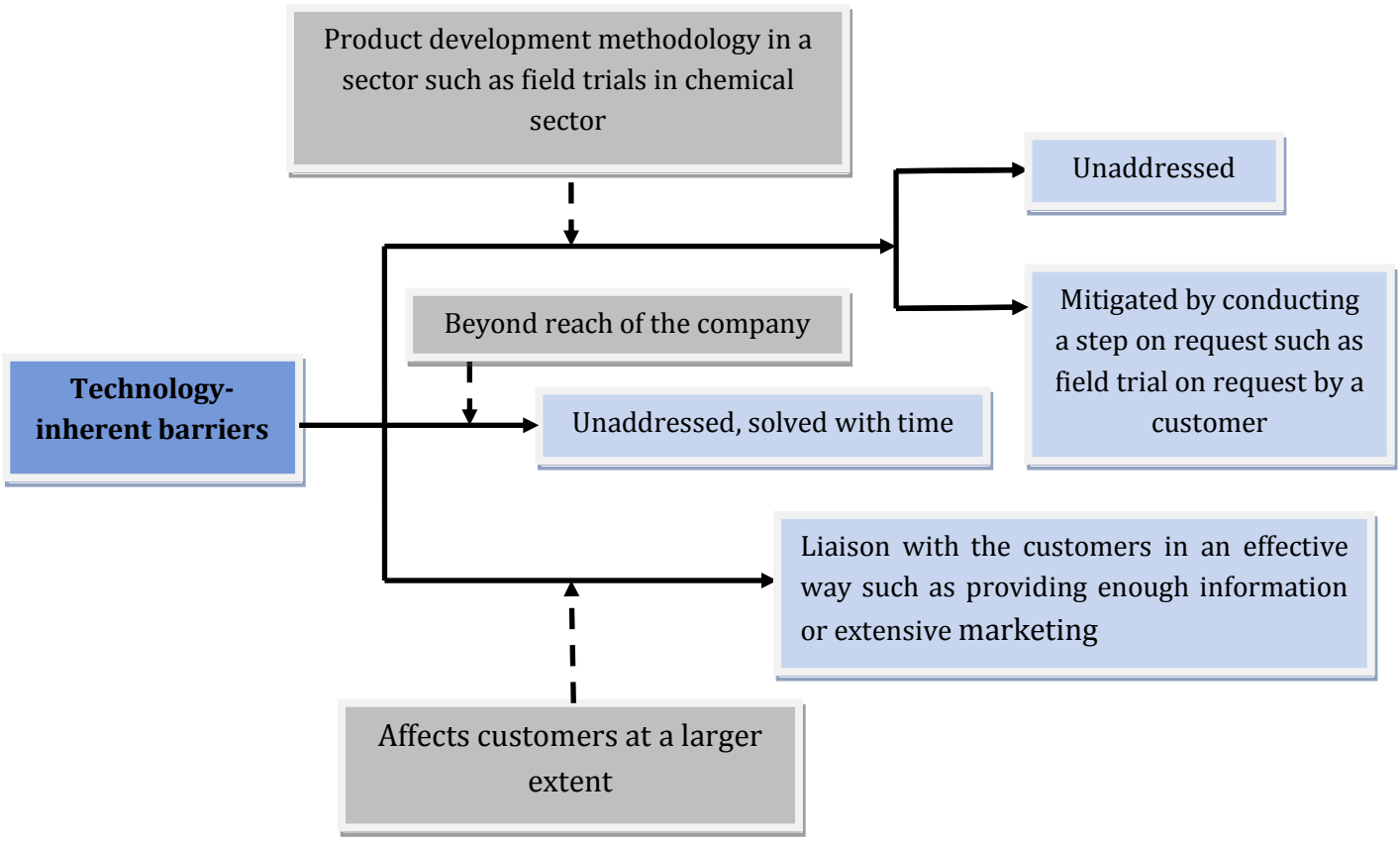

Figure 8: General strategies to tackle the technology-inherent barriers

The companies in the cases attempted to address the barriers related to insufficient resources such as financial, and marketing expertise by either hiring resources , external partnering and learning-by-doing. However, in some of the cases such barriers were left unaddressed due to the overall policy of the overall strategy of the company such as the limited number of expert resources cited in one of the cases. The barrier of high-price was addressed by optimizing internal management such as supply-chain to get a better cost-structure. The below table provides a consolidated view of resource-related barriers and solutions adopted in the cases.

Resource related	
Barriers	**Solutions**
Limited number of expert resources	Still unaddressed
High price	Set up a small production procedure and now they have a better cost control structure; efficient production process
Sluggish marketing due to lack of resources	More aggressive efforts in marketing; Sales team increased from one to five
Insufficient production capacity	Postponed the airing of the next TV commercial
High attrition rate at the management level	Unaddressed
Lack of expertise in marketing	Learned by doing the retailing
Insufficient financial resources to scale-up production	The company outsourced the production to other company
Attract skilled workforce	Solved with time. It took some time to attract skilled staff
Lack of funding	Resort to investment from a venture capitalist firm. It infused a vast sum of money into the company, which resolved the funding problem
High price offering	The company is working on reducing the prices to bring it to a competitive level.
Lack of marketing peoples	Solved with time
Lack of financial resources	Solved with time
Limited number of personnel for production	Solved the barrier by automating the work
In-effective management of growing organisation structure	The company tackled this through the introduction of organizational processes in the company

Table 16: Consolidated overview of the resource-related barriers and solutions observed in the cases

For the resource-related barriers, it is vital for the company to understand the urgency of encountering the barriers. If the barrier is a major stumbling block i.e., without overcoming that barrier, the commercialisation cannot take place than companies access external partnering. Else they try to lower the barriers by increasing efficiency of internal management. A few other barriers are left unaddressed such as those which are tied to the overall strategy of the company.

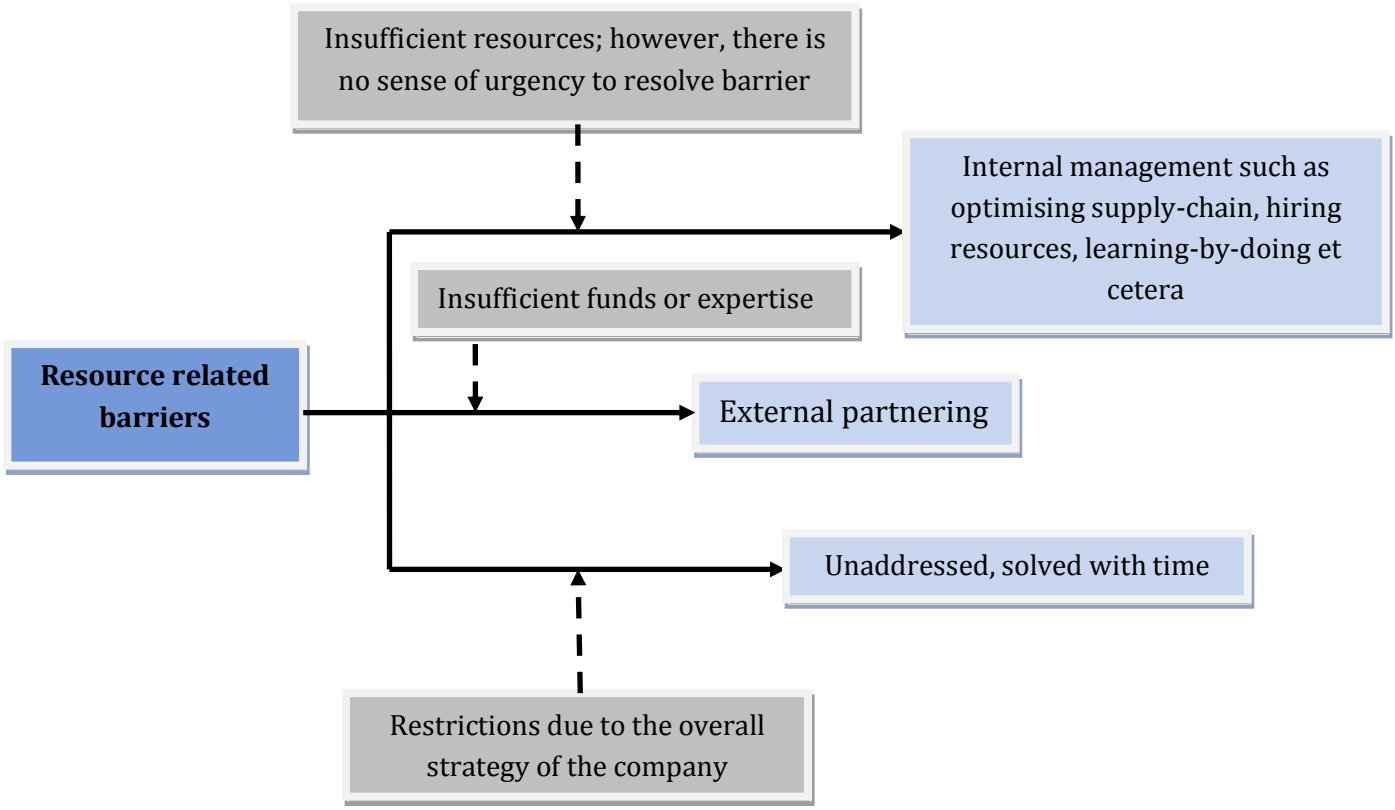

Figure 9: General strategies to tackle the resource-related barriers

Most of the strategy barriers were addressed by re-adjusting the strategy with time. Barriers that are associated with the competency of the companies were addressed by learning-by-doing or in other words, sharpening the capability with time. Diversification of business in almost all the cases was resolved by consolidating the business later in time. For other barriers, the company leveraged its agility, time and effort, and proactively approached the barrier. A few barrier were left unaddressed since the solution would have imbalanced the overall strategy of the company. The below table provides a consolidated view of strategy barriers and solutions adopted in the cases.

Strategy	
Barriers	**Solutions**
Lack of participation in the exhibitions	The company has started going to the same exhibition every year to gain trust of the people
Positioning through name of the product	Still unaddressed
Inefficient supply-chain planning	Learned with time
Diversification of business	Company eventually consolidated the business
Competing distribution channels	Learned with time
Intellectual Property Rights issue with the licensor	Finally, the case was settled in the court

Ensure quality at an industrial scale	It did regular quality checks at its end and transferred the knowledge to the outsourced company
Dependence on a single customer	Restructuring of the strategy
Early diversification in many dimensions	The company then re-configured its strategy to focus on one segment and gain credibility in that industry
Building confidence about the product with the prospective customer	It takes enormous amount of effort and time to demonstrate the benefits of using the product

Table 17: Consolidated overview of the strategy barriers and solutions observed in the cases

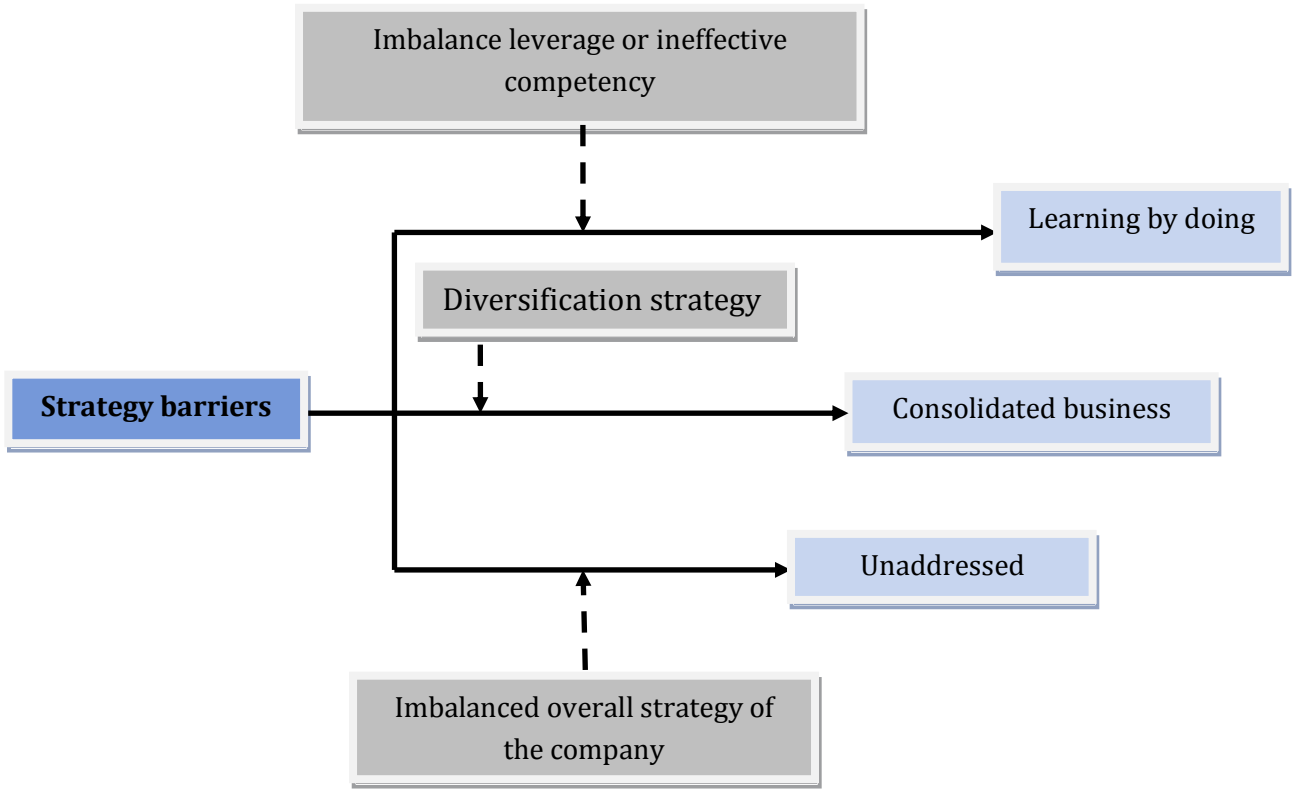

Figure 10: General strategies to tackle the strategy barriers

SMEs are not likely to possess very influential position in the market place. At the first glance, it seems that it is beyond the strength of companies, especially SMEs, to address regulatory barriers. It is right to a certain extent. However, in many of these cases, companies were able to circumvent regulatory and institutional barriers by devising a 'smart' strategy of identifying alternatives. If due to some reasons it was prohibited or would have taken a long time to use a product for a particular category, the company sought the possibility of using it for other category. It was observed in the cases which were diverse in terms of geographies represented. Many of the companies left regulatory and institutional issues related to procedural and legal challenges

unaddressed since they were beyond the control of the companies. The below table provides a consolidated view of regulatory and institutional barriers and solutions adopted in the cases.

Regulatory and institutional	
Barriers	**Solutions**
Patent issue difficulties in the foreign territory	Did not file the patent in the foreign territory; selling the product through distributors in the foreign territory
Long wait-time for getting government approval	company launched the product under the cosmetics category
Regulatory reasons discouraging highway usage of the additive in the foreign territory	The company introduced the product in the foreign for off-highway usage
Legal and procedural challenges that apply to the transportation of paints	Left it unaddressed
Long time to obtain CE mark for the product	Left unaddressed
Exclusion of the product in Insurance program	Left unaddressed
Legislative barriers in the home continent	Relocation of the production facility to other continent

Table 18: Consolidated overview of the regulatory and institutional barriers and solutions observed in the cases

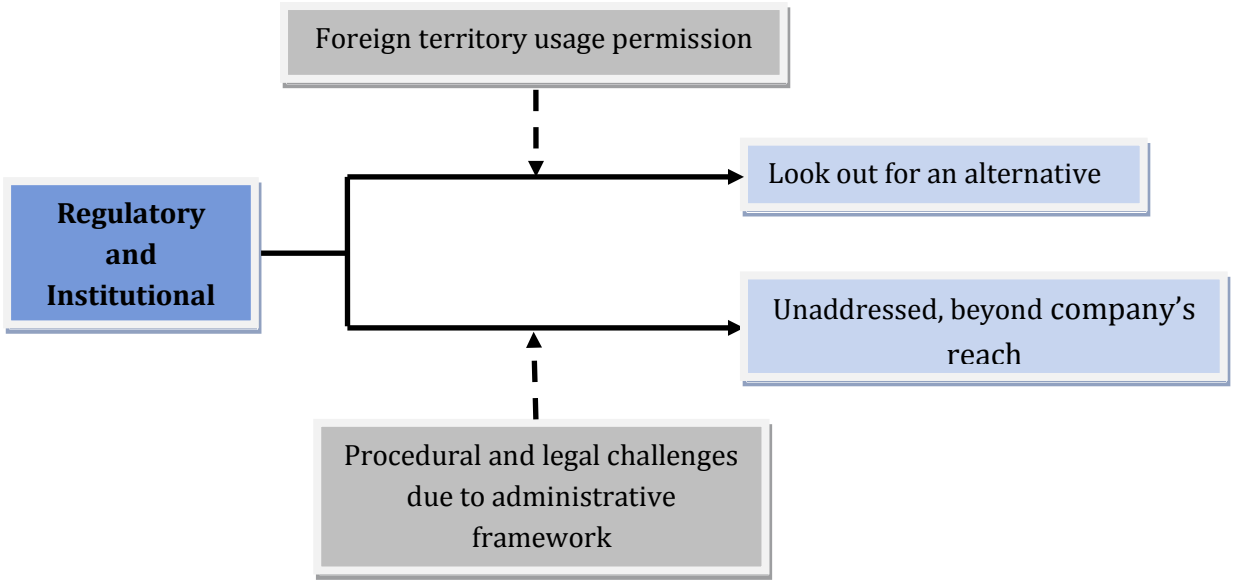

Figure 11: General strategies to tackle the regulatory and institutional barriers

Other macro-level barriers such as disasters, economic downturns, Tsunami were beyond the control of the companies. Although companies did not address these, they

were eroded with time. In one of the cases, the company circumvented the barrier of harsh weather conditions by international partnering with the institutes in other part of the world where testing could be conducted all over the year. The below table provides a consolidated view of other macro-level barriers and solutions adopted in the cases.

Other macro level	
Barriers	**Solutions**
Economic crisis and natural disasters	Left it unaddressed
Natural disaster	Due to Tsunami in Japan, initial export shipments had to be postponed due to the fear of radiation. Left it unaddressed.
Dependency of field-testing on weather	The company expanded its reach to Singapore. The testing could be conducted in Singapore for all twelve months per year due to the country's favourable weather conditions

Table 19: Consolidated overview of the other macro-level barriers and solutions observed in the cases

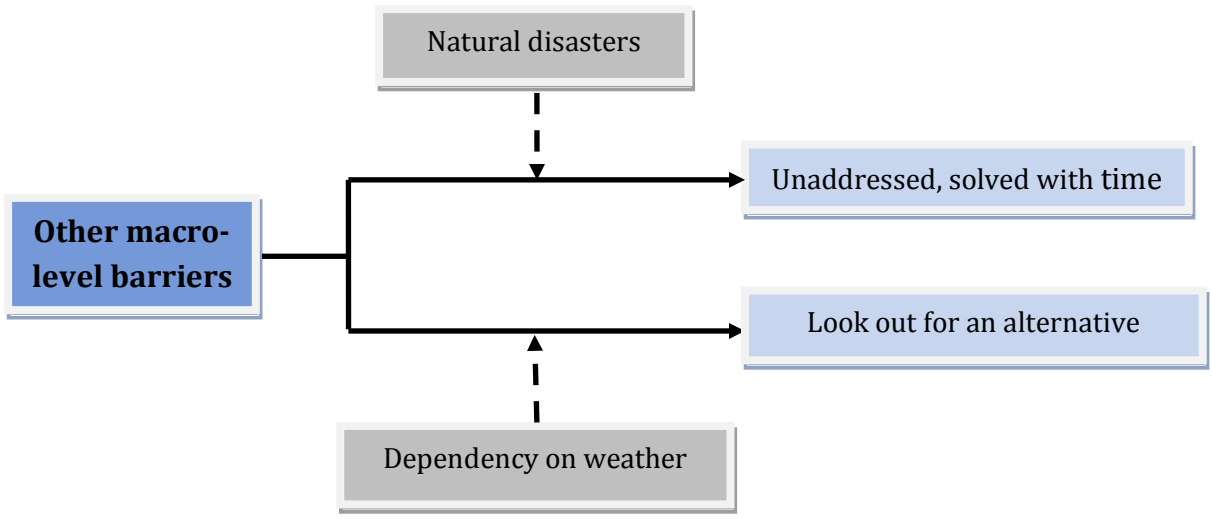

Figure 12: General strategies to tackle the other macro-level barriers

The barrier regarding misinformation by competitors was addressed by publishing results of the product compared to competitors products helped offset the competition. The below table provides a consolidated view of operating firm-market barriers and solutions adopted in the cases.

Operating-firm market	
Barriers	**Solutions**
Misinformation about similar product disseminated by competitors	Published results of the product compared to competitors products helped offset the competition

Table 20: Consolidated overview of the operating-firm market barriers and solutions observed in the cases

Most of the target-market barriers are observed in one case from the chemicals sector. The company addressed most of the barriers related to scepticism and hesitance by following a 'customer-centric' approach providing customers with what they needed technical documentation and separate field trials. It also did hands-on work with the customer following a pro-active approach. There were a few barriers such as discontinuation of product purchase or interference by the organisation where field trials were being conducted. These barriers were accepted as it is and further strategy was devised. The below table provides a consolidated view of other target barriers and solutions adopted in the cases.

Target market	
Barriers	**Solutions**
Discontinuation of the system incorporating the product by a major customer	The company decided to make the system on their own
Difficulty in conducting trial due to decisions by the organization in which trials had been taking place	Unaddressed
The customers demanded field trial specially designed for them. They are not open to trust the earlier field trial results.	The company had to conduct separate field trials for different customers
Sceptical attitude of bus industry	The company provides technical documentation
Hesitance of operating companies of customer in using the additive	The company worked closely with the operators and ensured that the operating companies use the additive in the vehicles. The customer management ordered operating companies to use the product
Linguistic and cultural barriers for direct marketing	The company appointed distributors in the country to sell the laser

Table 21: Consolidated overview of the target market barriers and solutions observed in the cases

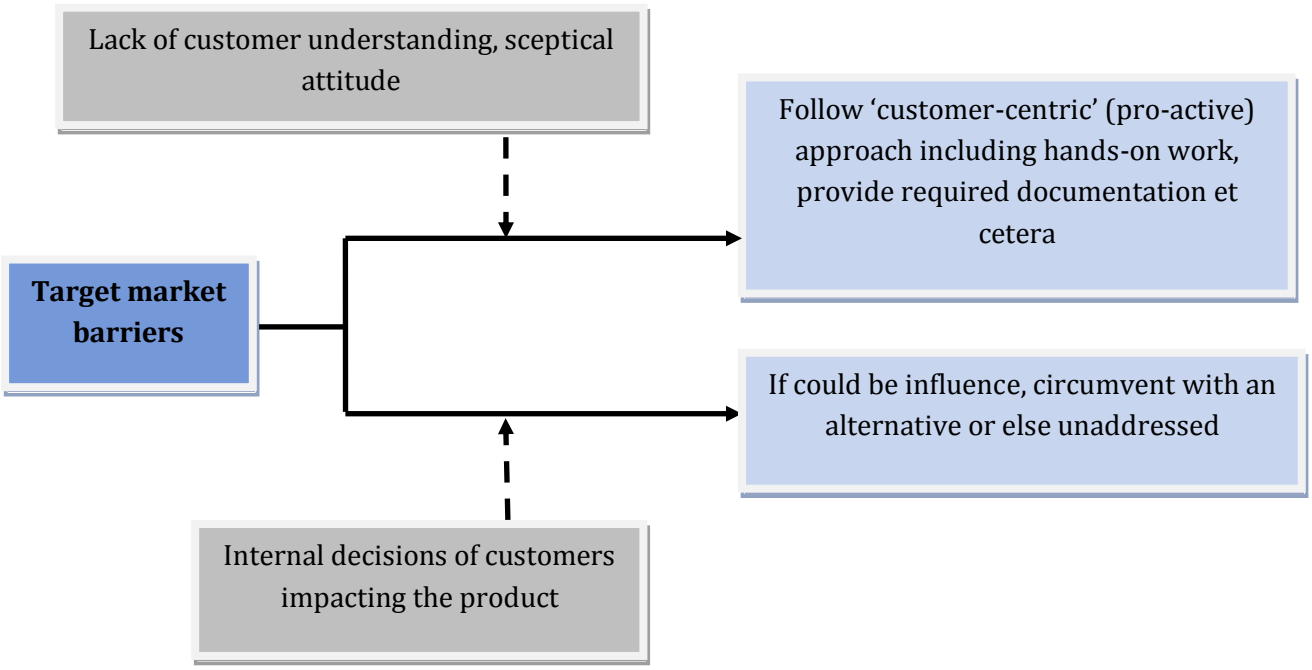

Figure 13: General strategies to tackle the target market barriers

The context in which the barriers appeared is presented for all the categories in the above paragraphs. A number of contextual variables played a role in defining the strategies. These variables include technical competency, funds, type of product, market success, technology complexity, expertise, management competency, multiple business applications, possible alternatives, product application, customer attitude, company network et cetera. From further analysis, it was found that the most frequently appearing contextual variables are the type of product or product category, availability of funds, expertise and customer characteristics.

The following table provides a consolidated overview of the categories of barriers and the general strategies adopted to deal with the barriers.

Categories of barriers	Strategies
Technical barriers	Hire technical resources to supplement research
	External partnering
Technology inherent barriers	Unaddressed
	Unaddressed, solved with time
	Mitigated by conducting a step on request such as field trial on request by a customer
	Liaise with the customer in a n effective way such as providing enough information or extensive marketing

Resource related barriers	Internal management such as optimising supply-chain, hiring resources, learning-by-doing et cetera
	External partnering
	Unaddressed, solved with time
Strategy barriers	Learning by doing
	Consolidated business
	Unaddressed
Regulatory and institutional barriers	Look out for an alternative
	Unaddressed
Other macro level	Unaddressed, solved with time
	Look out for an alternative
Operating-firm market barriers	Provide information to customers
Target-market barriers	Follow 'customer-centric' (pro-active) approach including hands-on work, provide required documentation et cetera
	Circumvent with an alternative
	Unaddressed

Table 22: Consolidated overview of the general strategies adopted in the cases

Upon closer inspection of the above table, it could be observed that the general strategies adopted vary widely among different categories. However, the strategy of leaving the barrier unaddressed appeared for all the categories except the technical one. It is more likely due to the reason that developing a technically feasible product tops the highest priority of the companies. The cause of applying unaddressed strategy varied among the barrier categories. For strategy barriers, for an instance, such strategy was applied when a solution to the barrier was misbalancing the overall corporate strategy. For institutional and regulatory barriers, if lifting the barrier is beyond the company's strength it leaves it unaddressed. Many a times this strategy led to lifting of the barrier with time. In other cases, the barrier remained intact. It could be possibly stated that the perceived importance of such barriers lies lower in the priority chart of the companies.

Another strategy called external partnering occurred in two categories namely technical and resource related. The companies gained access to complementary resources to address the barriers. The strategy of looking for alternatives appeared for two of the environmental barriers namely regulatory and institutional, and other macro-level. At a first look it might be thought that these kinds of barriers may be mostly treated unaddressed by the companies. But it was found that the companies address these barriers by actively searching for other options. The companies circumvent such

barriers whenever possible. A strategy of learning-by-doing is also applied by the companies to deal with two of the sub-categories of firm-related barriers namely, resource-related barriers and strategy barriers. Companies improved their expertise with time.

It could be said that the key generic strategies can be broadly seen as that of either improving or circumventing or leaving the barrier unaddressed. These generic strategies are derived from the work on reverse salient by (Ortt, 2010). The concept of reverse salient was first introduced by (Hughes, 1983). A technological system consists of various sub-systems which in turn consist of further sub-systems and so on. Reverse salient refers to the parts in the technological system, which hampers the progress of the whole system. (Ortt, 2010) in his paper investigated the kind of such factors, timing of their appearance in the technology lifecycle, how these factors affect the system and at last, the strategies to deal with these factors. The strategies devised in the paper were preventing the reverse salient, improving the reverse salient and circumventing the reverse salient.

Since the study looks into the cases in retrospect, the strategy of preventing barrier does not apply to the cases. However the strategies of improving i.e., mitigate or remove the barrier and circumventing i.e., switching to alternatives does apply to the cases. It is also noted that a new broader level strategy, leaving the barrier unaddressed was observed on the cases.

7. Conclusions and Recommendations

In this chapter, conclusions are drawn from the previous chapter on data analysis. The answers to the key research questions that were set out in the beginning of the research for investigation are presented in the following sub-sections. Further, policy implications are described.

7.1 Barriers and the type of barriers

The first research question pertained to the barriers.

1. What barriers are faced by SMEs during the commercialization of nanotechnology product innovation?

The answer to this research question was found by investigating its sub-questions.

1.1 According to the literature, what are the barriers to innovation?

A comprehensive literature search was carried out to explore the barriers to innovation literature. Mainly journal articles were referred to find out the barriers. The literature study culminated in an exhaustive list of barriers. This repository served two purposes. First, it strengthened the knowledge of the key topic i.e., barriers and second, it formed a reference point for comparing the barriers that were subsequently found in the real-life cases. The whole list of barriers found in literature is presented in the scientific background chapter.

1.2 What types of barriers are encountered while commercialising innovative products?

Parallel to developing a repository of the barriers, attentions was paid to the categorisation of barriers. During the literature search, a plethora of articles were found that based their research on a certain way of categorising barriers. A majority of the articles drew the categorisation from a previous study by Commission of European communities dividing barriers into internal and external barriers. A few other articles developed their own categorisation but mainly looked at the subset of the barriers such as knowledge barriers catering to the purpose of the need of the research. Another set of articles were a few articles that sounded quite extensive and elaborated. However, they were concentrated on specific industry such as biotechnology. Hence, new categorisation was made drawn from the insights from literature. It is broadly based on a simplified model of a firm. The categories developed are technology-related including both technical and technology-inherent barriers, firm-related including resource-related, strategy, cultural barriers, environmental including regulatory and institutional, financial and other macro-level barriers, and market characteristics including operating-firm market and target market barriers. These categories subsequently helped in forming strategies.

1.3 What barriers, across the value chain, are faced by SMEs in commercializing innovative nanotechnology products?

Based on the data gathered and, further, analysed for the cases, it was found that all the four broad categories of barriers were present in most of the cases. Most of the barriers concern firm-related barriers. The small-size of the companies associated with the cases has far-reaching consequences in terms of insufficient resources such as workforce, expertise et cetera. Interestingly, shortage of financial capital did not explicitly come up in many of the cases. Another set of barriers that appeared are technology-related barriers. As compared to the technical barriers, a substantial number of barriers appeared in the category of technology inherent barriers i.e., the non-technical barriers which are inherent to the use of a particular technology. These barriers were followed by environmental and market characteristic barriers. The barriers that were well-cemented due to the administrative and legislative procedures stood tall on the way of the firm. Most of the barriers in the category of market characteristics concerned the target market chosen by the companies specifically originating from the customer side. A consolidated list of all the barriers found in the cases can be found in the cross-case analysis chapter. This list was compared with the list found in the literature to identify new barriers. The outcome of the comparison was a few barriers that are still not listed in the literature. It is interesting to know that the new barriers found did not specifically concerned nanotechnology. Rather the new barriers reflect the size of the companies associated with the cases. The list of new barriers can be found in the cross-case analysis chapter.

Surprisingly, public acceptance of nanotechnology was not cited as a barrier in any of the cases. Although scepticism of customers was identified as a barrier, it stems from the industry of the customer. Also, lack of finance was not explicitly seem to hinder the innovation progress.

7.2 Strategies to overcome barriers

2. And, how do SMEs overcome those barriers?

Subsequent to the questions centring on barriers, a question investigated was on the solutions and the general strategies adopted by the companies to overcome the barriers. The answer to this question was derived by answering the following two sub-questions.

2.1 What solutions (if any) are typically applied by the nanotechnology SMEs to overcome different types of barriers?

The data gathered provided insights into the solutions adopted by the companies to solve the barriers. Within-case analysis provides an overview and further elaboration of the solutions adopted in the cases for solving corresponding barriers.

2.2 What are the general strategies deployed to overcome different types of barriers?

The strategies adopted by the companies to solve a barrier depend on the context in which the barrier has appeared. Hence, carefully analysis the three elements namely, barriers, solutions and context helped in formulating different strategies per barrier type to solve corresponding barriers. The companies responded to the barriers either by lifting those i.e., solving it or improving it or circumventing it by finding an alternative or left it unaddressed. A few barriers were solved with time. The strategies adopted by the companies to tackle different types of barriers are presented in the cross-case analysis chapter.

7.3 Policy Implications

The analysis of the cases in the previous chapter has helped in gaining better insights into the barriers experienced during the commercialisation of the cases. These insights direct to policy implications that could help in dealing with the barriers.

The largest proportion of barriers identified was firm-related. Interestingly, lack of financial resources never obstructed the technical development of the product in almost all the cases. The companies had enough financial capital to fund R&D of the cases. However, second order barriers of lack of financial capital such as lack of marketing peoples, insufficient production capacity et cetera were observed after the market introduction of the products. This has implications for the public policy. Apparently, nanotechnology has reached a point where funding instruments are required for the commercialisation of the innovation. Instead of awarding R&D grants for carrying out basic research in nanotechnology, financial instruments may be used by the governments in assisting the companies in diffusing the product innovation in the market.

Another barrier observed frequently is the lack of expertise by the companies especially in business areas such as marketing, distribution and sales. This is more likely due to the nature of technology under investigation. It is a knowledge-intensive field. The origination of most of the cases is by the technologists. The technologists in majority of the cases are weak in the area of business functions or in other words effectively commercialising the technology. A government policy may be devised in which trainings and programs regarding business functions such as marketing, sales et cetera could be imparted to such companies. Another measure could be a one concerning the networking in the field of nanotechnology. Government could also organise networking events for the industry which could facilitate the exchange of technical and business know-how. Further, it could also assist companies in finding experts.

In the environmental barriers, issues in filing patents in foreign territories and long time in getting approvals for standard mark from government agency has been cited as

an impediment to the progress of innovation. Government can help the companies by speeding up the administrative procedure for such small sized innovative companies.

The policy measures recommended for the firm-related barriers are broadly on the supply side i.e., the companies. For the barriers related to the target market, however, demand side measures may be taken to support the commercialisation of product innovation. One of the often cited barriers in this category is the scepticism of the customers about the success of technology in their case. For instance, field trials for each customer et cetera. Government measure can be taken in the form of subsidies in testing the products for their agency. It could then publish the results of the testing for the public. It helps the companies to better market their products.

8. Discussion

In this chapter, first scientific contributions and contributions to practice of the research are presented. It is followed by perspectives on barriers. Next, the limitations of the research are described. Further, future research that could potentially emerge from this research is recommended. In the end, validity of the research is described.

8.1 Scientific Contributions

The research conducted on the topic including steps such as literature review, data gathering and data analysis has contributed to the existing body on barriers literature.

Firstly, it could be said that the existing literature on the barriers to innovation does not have a very well-founded base for the categorisation of barriers. The work is fragmented to a large extent with different authors focusing on specific barriers. In this research, existing literature is synthesised to develop an exhaustive list of barriers. A framework is developed based on a simplified representation of the market model of the firm. Furthermore, this framework intends to categorise the barriers taking into consideration the purpose of developing strategies to overcome the barriers. It aims to cover majority of the barriers.

Secondly, the research contributes by the means of empirically finding the barriers in the nanotechnology product cases. This empirical testing for this category of technology has not been done in the existing body of work on barriers to innovation. The research helped in identifying new barriers observed in the field of nanotechnology product innovation.

Thirdly, a very few authors focused on the next step of overcoming barriers by identifying solutions in the real life cases. In this research, the solutions adopted by the companies have been analysed. This contributes to the existing body of the literature on strategies to overcome barriers to innovation.

Fourthly, a new broader level strategy of leaving the barrier unaddressed was observed in the cases. The generic strategies mentioned in the analysis chapter are inspired by a paper on reverse salient by (Ortt, 2010). In that paper, the three strategies mentioned are that of preventing, improving and circumventing the reverse salient. In the case of barriers research a new strategy is observed.

8.2 Contributions to Practice

The research undertaken also contributes to the practice. Various aspects of the research can potentially be of use to managers and even the policy makers.

Firstly, the barriers identified in the literature and the real-life cases provide an extensive list of the barriers. Furthermore, the framework categorises the barriers in several categories. This categorisation and list of barriers could potentially provide

insights into the barriers to the managers. It increases their awareness of the barriers that are generally observed in the progression of innovative products. The companies could use these as a reference prior to commercialising innovative products.

Secondly, the research goes a step forward than merely listing the barriers. The real-life strategies adopted by the companies to tackle the barriers are described in the research. Managers could use these to tackle similar barriers provided the barriers appear in a similar context as that of the cases studied.

Thirdly, the research could also be useful for policy-makers who intent to stimulate innovation at a macro-level, particularly in the field of nanotechnology. It gives an insight into the barriers encountered by the companies and the strategies, if adopted by them. Policy-makers can look at the issues which are beyond the reach of the company and help ease them to support SMEs. Policy implications have been described that could be put to application to facilitate smooth commercialisation of such product innovation in nanotechnology.

8.3 Perspectives on Barriers

The topic of barriers has been investigated through lenses belonging to different disciplines. Such disciplines are technology innovation & management, strategic management, sustainability & innovation, and policy making. Researchers in the field of technology & innovation management seem to focus on the technology industry itself and determine the impact of barriers on the business performance such as (Hall, 2002). On the other hand, the researchers in the field of strategic management, apparently, put more emphasis on the strategies that could be effective in dealing with the selected barriers such as (Greis, 1995).

Another group of researchers emerge from the discipline of sustainability & innovation. These researchers investigate barriers local to more specific technology, many a times a particular application of the large sustainable technology such as (Hirst, 1990). A few of the authors from this field take a step further by proposing strategies to the barriers.

Policy researchers too have demonstrated their interest in the topic of barriers to innovation. The topic undoubtedly holds implications for public policy. The interest in such topic is fuelled by the growing importance of innovation, competitiveness and economic growth. The researchers investigate barriers to find out the effective policy measures for making innovation successful such as (Frenkel, 2003).

8.4 Limitations of the Research

Due to the confidentiality reasons, it was not possible to ask extra questions to the respondents. It would have enriched the depth of the analysis by understanding the antecedents of the barriers. Moreover, the external validity could have been more

concrete if it were possible to send back the framework to the respondents for validation.

Another limitation of the research is the categorisation developed. A few barriers are so tightly intertwined with each other that it was really difficult to sort them out. It is possible that the new categorisation might be developed looking at the barriers through another perspective such as looking at the combination of barriers.

One of the limitations is the number and diversity of the cases. To come up with a more exhaustive analysis, perhaps more cases can be added for analysis. It would have helped in a greater level of generalisation. Moreover, it would have probably broadened the barriers and strategies list.

8.5 Future Research

While conducting the research, several areas emerged that could be considered for future research. The barrier itself can be divided into first order barriers, second order barrier etcetera. Sometimes, it was found that a barrier such as financial barrier triggered another barrier. The interplay of the barriers can cumulatively affect the strategy adopted by the companies.

Furthermore, points such as causes, consequences and perceived importance of the barriers could be investigated for the cases to find out top barriers faced by companies and subsequently strategies could be formulated. Due to the confidentiality constraints, elements such as consequences and perceived importance were not fully explored.

8.6 Validity of the Research

The validity and the quality of the qualitative research could be verified by looking at four tests namely construct validity, internal validity, external validity, and reliability. In the research conducted for the thesis, all four tests were taken into account. Following table provides an overview of these tests and how the case studies tactics are incorporated to qualify the tests.

Tests	Case Study Tactic	Research Phase	Tackled by
Construct validity	Use of multiple sources of evidence	Data Gathering	Multiple sources like in-depth semi-structured interviews, and company websites and other publications were used
	Establish chain of evidence	Data Gathering	All the interview transcripts were made but due to confidentiality reasons could not be shared in the report
	Verification of transcripts by respondents	Composition	All the interview transcripts are verified by respondents

Internal validity	Pattern matching	Data analysis	Data Patterns for all the cases matched with the theoretical framework to a large extent
	Explanation building	Data analysis	Reasons, in other words context for the occurrence of barriers and strategies, for data patterns are explored in the within and cross case analysis of the research
External validity	Use replication logic in multiple case studies	Research design	Despite using the heterogeneous dataset, the case studies were presented in a similar structure (broadly)
Reliability	Use case study protocol	Data Gathering	Case studies were performed as per the protocol defined by the experts. For each cases same protocol was being employed without any deviations
	Develop case study database	Data Gathering	Data collected from each case studies are well defined as case description

Table 23:Confronting the validity of the research Source: adapted from (Yin, 2003)

The fifth type of validity is the context validity. The research has culminated into a set of strategies. Theoretically speaking, it has resulted in the generation of hypotheses. The findings regarding the strategies are indeed context-dependent. It is emphasized that understanding the context enriches the knowledge of the researcher. Due to time, budget and confidentiality constraints, it was difficult establish the context validity of the research. Further measures are required by delving deep into the contextual variables to establish context validity.

Appendix A: Interview Questions

Interview Questions
General Information
Name
Organisation
Position
Role in the case: CEO, R&D Manager, Sales Manager, Investor, Customer etc.
History of involvement in the case: how and at what stage this stakeholder became involved in the case
Specific questions
What were the main steps of the innovation trajectory starting from its technical source of origin to its introduction to the market?
What key activities were involved in each step?
What were the key barriers at the particular stage such as R&D, Sales etc.? How were those overcome?
What are the overall barriers experienced in the innovation?
How did you overcome the barriers?

Appendix B: Literature Review Overview

Source	Literature	Categories of barriers	Barriers
Research Policy	External partnering as a response to innovation barriers and global competition in biotechnology(Greis, 1995)	Environmental and firm-related factors	**Total 22 barriers** **Environmental** – (1) the availability o f funding (FUND), (2) government regulations (REG) , (3)the patent process (PATENT), and (4) the availability of general management expertise (MGMT). **Firm-related** – (1) support for research activities (RES), (2) support for product development activities (PROD) , (3) support for manufacturing activities (MANU), and (4) support for marketing activities (MKTG).
Research Policy	Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy (David J. Teece, 1986)	Trade and investment barrier pertaining to complementary assets in foreign nation	
Journal of Economic Behaviour and Organisation	Firm organization, industrial structure, and technological innovation(David J. Teece, 1996)	None	Transfer technology to buyer , institutional barriers (the innovation in question requires allocating costs and benefits, or placing specialized investments into several parts of an industry.) Challenge - activities are not as decomposable as they used to be, and that cross-functional interaction must take place concurrently, rather than sequentially. Transferring the technology to the buyers.

Resources, Conservation and Recycling	Closing the efficiency gap: barriers to the efficient use of energy (Hirst, 1990)	Structural barriers: conditions that are beyond the control of the individual end-user; Behavioural barriers: problems that characterize the end-user's decision making	**Structural:** Distortion in fuel prices Uncertainty about future fuel prices Limited access to capital Government fiscal and regulatory policies Codes and standards Supply infrastructure limitations; **Behavioural:** Attitudes toward energy efficiency Perceived risk of energy-efficiency investments Information gaps Misplaced incentives
Technovation	A study of R&D, innovation, and business performance in the Canadian biotechnology industry(Hall, 2002)	Financial, Regulatory, Resource based	
Research Policy	Commercializing generic technology: The case of advanced materials ventures(Maine, 2006)	Market, Technical	**Tech:** IP, Customer design and development, pilot scale-up; **Mkt:** Multiple market applications, diverse regulations, incumbent's defensive response
Book (UNU-MERIT, Maastricht Economic and social Research and training centre on Innovation and Technology)/IDEAS - Economic Research	Rough Road to Market: Institutional Barriers to Innovations in Africa (Oyelaran-Oyeyinka, 2006)	Systemic institutional barriers, mentioned technical barrier too	Learning efficiency, local orientation, national innovation policy, sources of knowledge exchange and infrastructure.

Social Science Research Network(SSRN)	Complementarities between barriers to innovation: data evidence from Poland (Balcerowicz, 2010)	financial barriers, knowledge barriers, market barriers, other barriers	**financial barriers:** (lack of funds within an enterprise or group, lack of finance from sources outside an enterprise and innovation costs too high), **knowledge barriers**(lack of qualified personnel, lack of information on technology and markets, difficulty in finding cooperation partners for innovation), **market barriers** (market dominated by established enterprises and uncertain demand for innovative goods) **and reasons not to innovate** (no need due to prior innovations and no need because of lack of demand for innovations).
IEEE (Conference Publication) This paper appeared in: Science and Innovation Policy, 2009 Atlanta Conference	Methodological Challenges and Institutional Barriers in the Use of Experimental Method for the Evaluation of Business Incubators: Lessons from the US, EU and China(Yu, 2009)	Institutional barriers are further divided into Micro, Meso and Macro	The availability of human resources (levels and types of expertise, training, background and skills of policy officials), organizational structure, namely organizational procedures and management structures, systems of knowledge transfer, norms and incentive structures. the linkages with broader values, norm and societal goals, and connections with the larger policy network of stakeholders
Conference Paper - at R&D Management Conference 2011, R&D, Sustainability and Innovation, the need for new ideas, initiatives and alliances, Norrköping, Sweden 28-30 June 2011	Market barriers for environmental innovations (Englund, 2010)	Customer-related barriers, Other market barriers	costly and difficult to reach the customers, difficult to get a first customer, Customers have little capacity to pay It is difficult to explain the benefit to the customer Other needs than the ones solved by the innovation are prioritized It is costly to demonstrate the innovation and its benefits The customer experienced a tentative risk in changing technology The customer does not have the right technological knowledge

			Alternatives or competitors are less expensive **Other customer-related barriers** Competitors are actively hindering the innovation Intermediate organizations are hindering# Permits and planning processes are hindering market introduction Financial issues Current recession in Swedish economy* Other non-customer related issues
Unclassified article	Marketing barriers to innovation - the case of the entrepreneur (Seth, 1988)	Barriers to reach the market , Barriers to build the customer base	R- Regulatory, A- access to market, M - Money, P - Product development Performance Value, Image, Compatibility, Tradition, Risk
Technovation	Barriers to innovation for SMEs in a small less developed country (Hadjimanolis, 1999)	external to the firm or exogenous and internal or endogenous ones	**External** can be further subdivided into supply, demand and environment related. Supply barriers include difficulties in obtaining technological information, raw materials, and finance. Demand barriers have to do with customer needs, their perception of the risk of innovation, and domestic or foreign market limitations. Environmental ones include various government regulations, antitrust measures, and policy actions. **Internal barriers** can be further subdivided into resource related, e.g. lack of internal funds, technical expertise or management time, culture and systems related, e.g. out-of date accountancy systems (Rush and Bessant, 1992), and human nature related, e.g. attitude of top manager to risk or

			employee resistance to innovation.
Technology Analysis and Strategic Management	Regime shifts to sustainability through processes of niche formation: The approach of strategic niche management (Kemp, 1998)	Technological, Government Policy and regulatory framework, Cultural and Psychological Factors, Demand Factors, Production Factors, Infrastructure and Maintenance, Undesirable Societal and Environmental Effects of New Technologies	Technological, Government Policy and regulatory framework, Cultural and Psychological Factors, Demand Factors, Production Factors, Infrastructure and Maintenance, Undesirable Societal and Environmental Effects of New Technologies
Asian Business and Management	From lab to market? Strategies and issues in the commercializati on of nanotechnology in China (Shapiraa, 2008)	None	Obstacles identified in case studies (total 5 in number) IPR disputes; Short of money, High cost of products, Funding, R&D capability, Market
SSRN	Development and Commercialisati on of Eco-Innovations by New Ventures	financial factors, management and organisational factors, product and market factors	None
Journal of Small Business Management	Barriers to Innovation among Spanish Manufacturing SMEs (Review)(Madrid-Guijjaro, 2009)	Internal, External	**Internal:** Lack of Financial Resources, Poor Human Resources, Weak Financial Position, High Cost and Risk **External :** Turbulence, Lack of External Partners Opportunities, Lack of Information, Lack of Government Support

University Article (ism.lt)	Internal and external innovation hindering obstacles at SME (Review)(Lukjanska, 2009)	Internal, External	**Internal:** Financial barriers - hindered obstacles to external finance, - high innovation costs, Shortage of qualified personnel, limited internal know-how to manage the innovation process ,Missing market access knowledge - to meet customer's needs - to enter foreign markets , Lack of Information and knowledge about technologies , Lack of intellectual property rights **External:** Lack of efficient government support, Bureaucratic hurdles - long administrative procedures - restrictive laws and regulations Lack of external partners and networking possibilities

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