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THESIS

INNOVATION PROCESS:

AN INTEGRATED ANALYSIS OF THE ROLE PLAYED BY VARIOUS ACTORS

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DEDICATION

To my parents and my sister, for all the love and support

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Contents

1

Introduction

The objective of the thesis is to analyse the role played by various actors, both public and private actors in the process of innovation. The involvement of external actors can be dated back to the time of Edisons lab, 19th century. For instance, the development of the electric lightning, was an outcome of recombination of ideas by a team of engineers (Haragadon,2003). In the current era a growing number of organizations leverage on the information provided by external actors, like P&G, Nokia to mention a few. Another example is the renewable energy sector which benefits simultaneously from government support (Jaffe, Newell, Stavins,2002;2005) and the interactions amongst the public-private entity (Garud and Karnoe, 2003; Jacobsson and Bergek, 2004 ; Hendry and Harborne ,2011). All the above examples strike one common chord: A successful process of innovation involves a variety of external actors. The best analogy to understand this concept is: safety lies in numbers and in variety of attack (Jewkes, Sawers and Stillerman,1958;Leipon and Helfat,2010).

Innovation is a multidimensional and continuous process. The importance of technological interdependence (Rosenberg,1979), complex and tacit nature of technology(Dosi,1988;Silverberg,Dosi and Orsenigo,1988), role of standard setting bodies (Rosenkopf and Tushman,1998), institutions (Nelson,1987), environment (Mck-

elvey,1997) in process of innovation is quite often highlighted. Innovation is inherently a continuous process. A product embodying a new technology rarely ever stays constant in terms of all the services provided by it over a course of time. The product is influenced by the nature of the actions undertaken by the various actors. Despite this the core position has been occupied by arguments in which the locus of technological development during the process of innovation is within one firm hence, the competence enhancing nature of the technology is assessed at the firm level itself (Tushman and Anderson,1986; Anderson and Tushman,1990). The role of other organizations linked to the focal organization is relatively under theorized (Afuah and Bahram,1995; Afuah,2000; Kaplan and Tripsas,2008).

The idea of the involvement of external actors in the process of innovation has always been around (Rosenberg, 1979). But the last decade has picked up on this argument with the help of topics like transfer of knowledge across firm boundary (Grant and Fuller, 2004), alliances (Hamel,1991; Doz,1996), lead users (Von hippel,1988) and open innovation model (Chesbrough,2006) to mention a few. The main driver behind all these areas of research is to explore the impact of various actors on the process of innovation.

In this thesis, I explore the impact of the various actors on the process of innovation. The dependent variable of interest is estimated with the help of two methodologies: (1) Agent based modelling for the first chapter. (2) Econometric estimation procedures for the second and third chapter.

The empirical setting of the thesis is the Danish wind power market. Denmark is the center for competence of the wind power at the international level and the only country in which by 2009 wind power represented 20% of electricity supply. Furthermore, the Danish wind power market presents us with the opportunity to perform an empirical analysis of an Industry that emerged as a grass-root movement in the 1970s, with no patents or intellectual property rights till 1990s and currently represents more than 7% of the annual Danish exports (Nissen et al., 2009). The analysis builds on market data from 1979 until 2011, coupled with data on PFRNs in which the Danish market players were observed. A unique database is built with the help of public sources. The nature of information present in the database can be subdivided in two parts: (a) Market level data of the Danish wind turbine sellers.(b)

Government funded R&D projects in which the Danish players were observed.

1.1 Research motivation and Research question

The first chapter of the thesis aims to explore the role played by one of the various external actors in the process of innovation: users. The broad literature on the role of users in the process of innovation lays emphasis on the role of users (Schmoolker, 1966; Von Hippel, 1988). The widely held assumption is that involving users in the process of innovation is always advantageous (Von hippel,1986;2005).But cases have been observed when users may also be detrimental for the process of innovation (Christensen, 1997). This has led scholars to raise doubts regarding the involvement of users in the process of innovation (Bogers, Afuah and Bastian, 2010). Furthermore, recent literature point towards the need to understand if it is only the information provided by the user or the environment in which the user is embedded also matters (Luthje et al, 2005; Ogawa, 1998).The motivation for the first chapter stems from the ambiguity of results considering user involvement and the need to integrate the environment. The aim of the first chapter is to explore the role of information provided by the user to the producer and the impact this exchange of information has on the process of technological change.The exploration is done with the help of agent based modelling.

The second chapter of the thesis aims to assess the impact of public-private relationship on the novelty of innovation introduced in the market. Public private relationship is a ubiquitous phenomenon these days. And the argument of over-reliance on public funding can be heard in every corner. Public funding has been widely used for initiating innovation networks (Wagner & Mohrman, 2009; Cassi et al., 2008). The role played by network initiator is widely researched, while the role played by organizations orchestrating these networks is comparatively under-researched (Nambisan & Sawhney, 2011; Cusumano & Gawer, 2002). The objective of this chapter is to empirically explore the impact of network orchestration position on the innovative outcome of the system provider.

The third chapter of the thesis aims to assess the factors which may moderate the relationship between external search and the innovation performance of the focal

firm. Firms quite often look outside their boundary for innovative ideas or solutions for current problems (Huber,1991; Laursen and Salter,2006). An apt case in point is P&Gs connect and develop program (Sakkab,2002). Theoretical literature on this topic has quite often stressed on the fact that knowledge accessed via search cannot be integrated into the organization in one step (Wallin and Van Grogh, 2010; Grant and Fuller,2004; Zollo and Winter,2002).Case studies support this analysis (Huston and Sakkab,2006; Sakkab,2002). Nonetheless, empirical evidence supporting the theoretical claim and exploring the role played by moderators is negligible. The key driver behind this chapter is to find empirical evidence which assesses the role played by moderators in estimating the impact of external search process on innovation performance.

The remainder of the thesis is organized in four chapters. The next three chapters explore the three research problems highlighted in the current chapter. Finally, the last chapter concludes.

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2

User-Producer Familiarity And The Process Of Technological Change: An agent based approach

Abstract

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The aim of the paper is to investigate the process of technological change due to user-producer familiarity. User-producer familiarity captures the flow of information from the user to the producer about the new technology via the users behaviour. The process is situated in a heterogeneous demand and supply setting. Agent based modelling is used to explore the role played by the flow of the information between users and producers in the heterogeneous setting. The results of the model help in exploring various scenarios contingent on the user attitude and level of information contagion. The information provided by the user is always beneficial and leads to domination of the market by the better technological variant, except for two scenarios. These two scenarios are: 1.When the information contagion is high and users are more risk averse, 2. When the information contagion is low and users are less risk averse.

Keywords : User-producer familiarity, information contagion, technological change, agents based model.

"In the beginning was information. The word came later."
Fred Dretske, Knowledge and the Flow of Information (1981)

2.1 Introduction

The decision to invest in a new technology is marked with uncertainty for both producers and users. Investment behaviour of users often maps into a herd like behaviour i.e. they simply follow the majority. On the other hand, producers have the opportunity of introducing significant improvements in the product as its customer base increases. In a nut shell, increase in market share lowers the price and increases the probability of having access to an improved version of the technology. But more non-users invest in the new technology because of the low price and technological improvement. This sounds like a chicken egg situation.

What drives this chicken egg situation? In other words, what triggers the process of technological change (Geroski, 2000)? Where, technological change is best understood as an outcome of invention, innovation and diffusion. A possible reply could be flow of information, information cascade (Geroski, 2000) or information contagion (Arthur & Lane, 1993).

The model in this paper builds on the concept of flow of information but the explanation is not just limited to demand side. Rather, the role of demand side in fostering the process of technological change is highlighted. The paper studies the role of user-producer familiarity in driving the process of technological change with the help of an agent-based model (ABM). On the supply side the model has two technological variants. On the demand side non-users sample previous users to gather information and take the adoption decision (Arthur & Lane, 1993).

User-producer familiarity explains the flow of information from the user to the producer and the integration of this information by the producer. It is assumed that users have the policy of providing information to the producer via their behaviour and the producers integrate all of this information within their production system. The information provided by the user depends on the nature of the individuals adoption decision. The adoption decision is affected by the utility function. Utility function takes into account users risk attitude. The means for carrying this

information is users behaviour towards the producer. The means for integrating this information is producers absorptive capacity (Cohen & Levinthal, 1990; Zahra & George, 2002). The model builds on the assumption that the producers are perfectly capable of integrating all the information they receive. The model addresses two related research questions. First, it investigates the role played by user-producer familiarity in fostering the process of technological change. In other words, the role played by user-producer familiarity in enabling the producer to innovate effectively. The model explicitly models the heterogeneous behaviour of users towards producer. The key to understanding the process of technological change lies not in investigating how it unfolds but what started it in the first place. The demand side plays a crucial role in advancing the technological change, as it is the centre of action. Hence, the second research question: Is user-producer familiarity always beneficial for the producer? Under what circumstances framed by the demand side it could be detrimental. The explicit aim of the model is two-folded: 1. To investigate the integration of the information contained in the user behaviour by the producer and the effective outcome, 2. To investigate the scenarios in which the flow of information could lead to detrimental outcome for either user or producer or may be both.

The proposed hypothesis of the paper: The chances of domination of the market by one of the two variants of a new technology may increase if user-producer familiarity is coupled with high level of information contagion on the demand side. If there is no information available about the new technological variants or if the information is available but the mass market has no access to it then, the chances of co-existence of the two technological variant are high. . Furthermore, the impact of users risk attitude on the effectiveness of the outcome may be more pronounced when the information contagion is comparatively low.

The model pays attention towards the flow of information between users and producer and not the flow of knowledge (Nonaka, 1994). As the technology is still in its nascent stage and an adequate knowledge base does not exist on either side. Technology is defined with the help of the set of services provided by the technology to the potential users (Sahal, 1981). Technological change is the improvement in these services over a period of time. This perspective of the technological change leads us to develop an understanding grounded in the capability perspective of the firm, where the technological change introduced by the firm depends on the prior

capability set of the firm (Nelson & Winter, 1982).

Explanations for technological change are usually divided by scholars in two broad categories: supply side factors (Utterback & Abernathy, 1975) and demand side factors (Schmoolker, 1966; Von Hippel, 1988; Christensen, 1997), with Lundvall(1988) adding a third dimension to it, the interactions between supply side and demand side. Sahal(1977b) describes technological change as a multidimensional process. He recognizes that technological change is a result of learning both on the user side and the producer side. The decision of adoption of the potential users hinges on the information they have about the services provided by the technology. The service provided by the technology is expected to improve with time as more users adopt the technology. Hence, this is an interwined process and investigating one in the absence of another may lead to conclusions of biased nature.

Demand side provides complementary explanations divided in two camps: demand as an incentive to innovate and demand as a source of information. The first strands of argument support the stance that, market structure offers a proxy to measure the incentive to innovate (Schmoolker, 1966). Another strand of argument in the demand side belongs to scholars who perceive demand as a source of information. They often define it with the help of the lead user concept (Von hippel, 1988). Recently, scholars have started stressing that the lead user concept is a market focused concept. According to them, participatory innovation is a broader concept and allows the investigation of the role of user from a broader lens (Buur & Mathews, 2008).

Mowery and Rosenberg (1979) suggested that integrating the two sides of the spectrum and then understanding the phenomenon will help in developing a better understanding. The same has been proposed by Lundvall (1988) in his work on the user-producer interactions and the role it plays in the process of technological change. Scholars have raised concern about the lack of attention being paid towards understanding the importance of consumer behaviour and consumer capabilities in the process of technological change (Malerba, 2007). Resonating opinions can be found amongst scholars investigating technological change with the help of case studies or empirical models.

Case studies have stressed the role of interactions between the firms developing the technology and the user to foster the process of technological change. A lack of these interactions often results in failure of even the most promising technologies (Douthwaite et al, 2001; Ansari & Garud, 2009). Douthwaite et al. (2001) studies four cases situated in the field of agriculture and concludes that the level of interaction between users and producers is vital during the early stages of technological change for a promising technology to sustain itself. Ansari and Garud(2009) dig a bit deeper and explore the role played by the needs of users, users perception of the new technology and lack of demand leading to low positive network externalities. All these factors point towards the lack of attention paid towards the users by the producers or their failure in utilizing the information provided by the user. These are few key reasons leading to an uneven transition from 2G to 3G mobile communications. Another point that merits attention is, does paying attention to information provided by user suffice? Or, some other crucial details of demand side are missing. An apt case in point is the Danish wind turbine Industry. Garud and Karnoe (2003) draw a comparison between the Danish and United States wind turbine industry and identify high level of feedback amongst users to be one of the prime reasons for the successful take-off of wind turbine industry in Denmark. In particular they ley emphasis on the feedback provided by the users and the availability of this information to the potential users. Two key points merit attention here: 1). Importance of information provided by the user. 2). this information is widely available to the potential users. Both the points led to the establishment of a huge information base on which potential users could dwell while deciding whether or not to make the purchase (Arthur & Lane, 1993).Existence of information base is what was lacking in the case of United States.

The key point in all the above case studies has been the feedback provided by the behaviour of the user towards the new technology and the information embodied in this behaviour. Information embodied in users behaviour has not been investigated explicitly in the literature, baring few exceptions. Luthje et al (2005) explores the case of mountain biking with the help of an empirical model and Ogawa (1998) looks into Japenese convenience store Industry by undertaking a case study. The key outcome of both the papers is that the information contained in the behaviour of the user and the nature of the information is vital for the process of technological change. Also, it is not valid to assume that all the producers pay attention to the

information provided by the user or the information contained in the behaviour of the user. This has been investigated empirically by Jensen et al (2007) with the help of the Danish DISKO survey.

A lack of understanding of the adaptation phase, i.e. the role played by users in adapting a new technology and the role played by producers in taking advantage of this process has been stressed (Bogers, Afuah & Bastian,2010). Bogers et al. (2010) argue that this research is basically empirically driven and lacks an explicit theoretical focus. Also, Malerba (2007) argues that the role played by the information contained in the consumer behaviour, the involvement of user and demand side heterogeneity in the adoption of a new technology are few of the many interesting demand side factors that need to be explored.

Hence, the research problem being addressed in this paper is: What is the role played by user-producer familiarity in the process of technological change? Is it conditioned by the risk attitude of the user? The information conveyed by users behaviour cannot be undermined. But is it always beneficial? What are the scenarios in which the information provided by user can be used effectively by the producer? Effectiveness here highlights the domination of the market by the better technological variant.

By addressing this research question the paper makes two key contributions. First, it explicitly takes into account the behavioural assumptions on both sides, user and producer (Bogers, Afuah & Bastian, 2010). On user side, the risk attitude of the user is specifically considered. The producer is considered to be bounded rational and has only two sources of learning, prior experience and user-producer familiarity. When, the producer is allowed to learn only via prior experience he is learning by exploiting and the impact of this coupled with the demand side is investigated. When, the producer is allowed to learn with the help of both the learning mechanism, the outcome of his exploitative behaviour and explorative behaviour is observed. Secondly, investigating the probable scenarios when the information from user may be detrimental is helpful, as it can help the producers in framing better search strategies (Dahlander & Gann, 2010). Also, it is beneficial for the user to understand the importance and significance of framing a broad search strategy.

The paper is divided in five sections. The first section is the literature review; the second section is the structure of the model. In the third section results are discussed followed by the fourth section containing conclusion, future research and limitations.

2.2 Literature Review

In literature review, I delve into three models in detail. These three models have analysed the role of demand side heterogeneity in exploring the process of technological change. Supply side heterogeneity is modelled with the help of distinct path dependent set of capability every firm has. They do not model the process of interactions between user and producer explicitly but rather with the help of utility function or in plain terms users and producers interact via the market based price mechanism. This is the point of departure for my model. I do not model user-producer interaction in absolute terms but relatively closer. The user-producer familiarity captures the information supplied by the user to the producer and integration of this information by the producer in the process of R&D performed by the firm.

The role of demand side heterogeneity in modelling the process of technological change has been at the heart of the recent scholarly work. Demand side heterogeneity can be broadly divided in two broad categories, understanding Consumer behaviour and Consumer capabilities (Malerba, 2007).

The role of consumer behaviour has been explored by looking at what precisely constitutes, it in terms of consumer preferences (Adner, 2002; Adner & Levinthal, 2001). Adner (2002) models consumer preferences explicitly as a function of price vs performance. In their model the emergence of competition is explained with the help of demand side heterogeneity. Demand side heterogeneity is modelled by characterizing consumers and their preferences. Consumers preferences are explained with the help of their willingness to pay and the minimum threshold of performance that a product must reach. The model controls for supply side heterogeneity and assumes decreasing marginal utility. The assumption of decreasing marginal utility is based on the argument of over supplying the product characteristics to the market (Christensen, 1997). As a consequence the attention of customers shifts towards

secondary or tertiary characteristics. This allows the new entrants to introduce their products at low cost and eventually penetrate the mass market. One of the key features of the models (Adner, 2002; Adner & Levinthal, 2001) is the process of interaction between the demand side heterogeneity and supply side technology evolution, which leads to a path dependent process. This interaction is modelled with the help of the net utility threshold. Net utility threshold allows for the interaction of the price acceptable to the customer for a given performance level served by the supplier. The process of interaction is via the well-known market price mechanism (Hayek, 1948).

Consumer behaviour has also been modelled as experimental users and users with diverse preferences (Malerba et al, 2007) and sophistication (Guerzoni, 2010). Experimental users are very close to Von hippels (1988) lead user concept. Sophistication is the degree of consumers awareness of his needs. As an implication, higher is the level of sophistication higher is the ability of the consumer to communicate their need to the firms. Guerzoni (2010) defines demand heterogeneity as a function of sophisticated users and market size. The model explains supply side heterogeneity as a function of standard and variety. It is an attempt to bridge the gap between a long standing debate on the demand side: demand side as an incentive to innovate (Schoolmaker, 1966) vs. Demand side as the source of information (Von hippel, 1988).

In case of experimental users, a minor addition to the concept of lead users has been introduced; they simply have the policy of experimentation. They are not deterred by the newness of the product; they just have the policy of experimenting. Users with diverse preferences capture the argument of setting up an incubator or niche for new technologies. This shields them from the incumbents and buys them the time to improve and make it to the mass market.

Malerba et al (2007) define demand heterogeneity with the help of experimental users and diverse users. The model descends from the family of history friendly models. It takes into account network externalities on the demand side and increasing returns on the supply side. It does not build on the assumption of decreasing marginal returns. Authors also control for the process of financing, exit and entry dynamics of the firm. New technology emerges either in the presence of experimental

users or users with diverse preferences. The model explains the product life cycle with the help of the interactions between the demand side heterogeneity and supply side. These interactions are modelled with the help of merit attributed to a product by the user. Merit may be interpreted as a cobb-douglas function. The function constitutes the willingness of the customer to pay and performance offered by the supplier, given the best available in that time period. This helps in understanding the process of interaction via the market price mechanism (Hayek, 1948). Along with interaction, another key feature of the model is the attempt to include the concept of technology perception, a stochastic process.

In the above models, the interaction between the demand side and the supply side drives the process of technological change. However, the interaction is not an active interaction. By active interaction I mean that, the process is not an active feedback process of receiving and integrating the information in the process of technological change. The interaction is only via the usual market based mechanisms of price.

In what follows, I will take a step forward. I do not claim to model interaction in its absolute terms but in a way which is relatively closer. The process of interaction and feedback will be dealt with in an active way, by looking at the construct of user-producer familiarity. Another, difference is the threshold function, i.e. modelling the utility derived from adoption. Furthermore, supply side heterogeneity will also be discussed.

The adoption decision of firms is often triggered by a threshold level (David, 1969). Scholars (Geroski, 2000; Young, 2009) have often pointed that modelling adoption decisions only on the basis of direct utility received by the adopting agent leaves out the crucial phenomena of externalities. Also it does not consider the context in which the adoption occurred. The model discussed below builds on the assumption that the agents have access to the same pool of public information; the heterogeneity lies in the agents sampled by the potential purchaser and consumer behaviour. The key assumption is that the users are homogeneous in terms of the prior they have on the two competing technologies, stopping rules to sample the population and the utility function. Heterogeneity lies firstly in the adoption decision taken by every agents, the key contributor of this is the sub-population sampled by the user. Secondly, another cause of heterogeneity is consumer behaviour which is specific for

every consumer i.e. the experience they have post-adoption.

Heterogeneity inside an Industry amongst the firms is a widely accepted empirical fact since the seminal work of Rumelt (1991). Heterogeneity amongst firms in the same industry has been recognized by the above models in terms of the variety of technology (within the same generation) available on the market. In this paper, heterogeneity is modelled with a slightly different approach. It arises due to the path dependent learning behaviour of the supply side. For the sake of simplicity the model has only two firms, supplying two variants of a technology. This is definitely an idealization, but helps in drawing attention towards the dynamics that unfold due to the flow of information from user to producer.

In the section below the structure of the model is explained. The section has three sub-divisions. The demand side, supply side and time line of the model.

2.3 Structure of The Model

In this section, a detailed description of the model is given, followed by the time line of the events.

The agents, both user and firms are bounded rational. Unlike the model of Adner (2002) the firms are not able to predict the demands of their user and they cannot forecast their experience curve in the future. The agents (users and producers) do not predict into the future and follow fixed decision rules. This simplification of model gives us the freedom of not being occupied by the kind of learning approach the agents follow.

2.3.1 Demand Side

The demand side heterogeneity is a function of heterogeneous consumer behaviour and the random sampling done by the potential users. Consumer behaviour depends on the experience consumer has when he uses the services provided by one of the two new technological variant . The services provided can be understood with the help of the merit of the two variants. The model has five assumptions. [1]

[1]The Demand side builds on Arthur and Lane,1993 unless mentioned otherwise

The merit consumers attribute to a variant can be understood with the help of cobb-douglas function. The attributes of the variant are divided in two parts: performance and price. This can be understood on the basis of the Lancaster product attributes. A variant is judged on the basis of the services it can provide. The standard assumption of new technology being inferior to the old technology at the beginning holds. In this model we are investigating the process of technological change of two new technological variants. Hence, they both start from the same initial technological endowments. If the consumer buys a one of the two variants then, they definitely give some information about it to the producer. In this model the interactions between users and producers occur via two medium. Firstly, via the usual market based mechanism. The first mechanism considered in this model is market based buying and selling but it does not involve the role played by price. It builds on the simply assumption of firms experience curve. Hence, supplier learns passively via selling more of their technologically embodied new product. Secondly, through the information conveyed by the behaviour of the user.

$$M = b_0(X_{per})^{b_1}(X_{price})^{b_2} \tag{2.1}$$

Where, M is the merit attributed to every technological variant by the user.

X_{per} = performance of the technological variant offered by the producer to the consumer.

X_{price} = price of the technological variant offered by the producer to the consumer.

However, as the information received from the user is not sub-divided in two parts in the model, the dependence of merit on price is suppressed. Merit only captures the changing nature of the performance of the technological variant.

A potential purchaser looks around and samples a certain number of prior adopters of both the variants. The structure of the observation the potential purchaser has depends on the merit of the technology adopted by the prior user and the error term. The observation does not suffer from any loss of information; all the information about the prior adopter is observed. Error term is not dependent on the nature of the sampling done by the potential purchaser. Error term is independent within a purchasers sample and between the samples of different potential purchasers. It is a

normal random variable with mean μ_e and standard deviation σ_e. Each technology has a normal random distribution associated with it. A potential purchaser when decides to buy a product, he experiences as his performance characteristics a draw from this distribution. This experience of the user represents the behaviour the user has towards the technological variant. The information contained in this behaviour is integrated by the producer.

As the potential purchaser can observe all the information without suffering from any loss, the structure of the observation is composed of the merit of the technology and the error term.

$$X = M_j + \varepsilon \tag{2.2}$$

Where,

X = Structure of the observation.

M_j = Merit of the technology, j represents technological variant A and technological variant B. It also represents the two firms on the producer side supplying the two technologies.

ε is the error term which captures the experience of every adopter.

All the potential purchasers have the same structure of prior beliefs. The structure for both the technologies are two independent normal distributions π_i with means μ_i and standard deviation σ_i . The two independent normal distributions represent the information about the two technologies in the public domain. The potential purchaser encodes his opinion on the basis of the publicly available information and the private information. Source of private information is the observation that builds on the population sampled.

In order to sample across the population the potential purchasers have the same sampling rule τ. The stopping rule is essentially bounded, i.e. there exists an integer N such that,

$P[\tau <= N] = 1$. In the model below a fixed stopping rule is assumed across the entire user population.

The users are all constant risk averse. They have a constant risk averse utility

function, R_λ, with λ as one of its parameters.

$$R_\lambda(c) = -e^{(-2\lambda)(c)} \quad if \quad \lambda > 0 \tag{2.3}$$

The potential purchasers use the above parameters in calculating the utility they derive from adopting a technology. The technological variant with higher utility is adopted.

$$U_i = \mu_{posti} - \lambda(\sigma_{e,i})^2 \tag{2.4}$$

$$U_i = 1/(n_i + \alpha_i)[n_i X_i + \alpha_i \mu_i - \lambda(\sigma_e)^2] \tag{2.5}$$

Where,

$\alpha_i = (\sigma_e/\sigma_i)^2$
n_i = number of people sampled.

In the above equation X_i represents the averaged value of the observations done by the potential purchaser.

2.3.2 Supply Side

The firms on the supply side build up the set of capabilities by undertaking R&D investment at every stage. This is an incremental process, the build-up of firm level competence is cumulative and path dependent in nature (Nelson and Winter, 1982). The innovation process undertaken by the firm does take into account the inherent uncertainty involved in the process by modelling it as a trial and error process. The firms on the supply side are heterogeneous.

While innovating the firm draws on two resources: 1. Its own set of capabilities. This set is an outcome of the experience gained by selling the technological variant.

Hence, the first search is in its capability space i.e. local search 2. The information received via user-producer familiarity.

$$M_{i(t)} = M_{i(t-1)}(1 + \gamma(N_{i(t-1)})^{\beta})\theta_i \tag{2.6}$$

Where,

$N_{i(t-1)}$ represents the cumulative number of adopters in the previous time-period . The parameter γ is defined on the interval [0,1] and β is defined on the interval [-1,0] . θ_i is the summation for all the error terms for the technological variant being considered. It is assumed that the firm collects the information from the population of adopters about their experience with the technological variant.

$\gamma(N_{it})^{\beta}$ helps in capturing the learning phenomenon of the firm. This is quite often quoted as the experience curve.

2.3.3 Timeline of events

In any given time period (t), the following set of events occur in sequential order.
1. The producers present the technological variant to the users.
2. In order to avoid confusion, potential purchasers can be thought of as either representing individuals or a group. They live infinitely and decide to invest depending on the utility they receive.
3. The potential purchasers sample a group of prior adopters depending on the stopping rule. They build an observation from this group of prior adopters. This observation is their private information. The private information of the potential purchasers along with the public information helps them in calculating the utility for every technological variant.
4. The utility calculated for the two variants are compared. The technological variant with the higher utility is adopted.
5. The producer takes into account the weighted average of all the information received from the users. This weighted average is incorporated while performing the R&D to introduce the technological variant for the next period.

2.4 Results

In this section I briefly describe the results of the model. The model tries to address questions relevant for the process of technological change.

Three specific setups are compared:

1. The role of information contagion along with user-producer familiarity.
2. Drawing comparison between two scenarios: a. user-producer familiarity is absent; b. user-producer familiarity is present. In both scenarios the individual agents risk attitude and sampling rule are also looked into.

The key interest of the model is in exploring the different scenarios resulting from user-producer familiarity, i.e. flow of information from user to producer via the user behaviour. As in, if the producers engage in the active learning activity i.e. by integrating the information provided by the user, firstly, does the technology show significant improvement and secondly, is the rate of diffusion significantly altered if the firm engages in active learning. The results of the model were obtained on the basis of extensive Montecarlo simulations, with $M = 100$ replications for each run. Across run average was calculated for obtaining the final graphs and analysing the results.

2.4.1 Information contagion, Demand side and the process of Technological change

Vast literature exists on the importance of users during the initial stage of process of technological change. The claims made by this literature hold without fail. Nevertheless, does the information provided by the user always foster progress of the respective technological variant? If yes, then, does this variant always manage to dominate the market? In case it does is the phenomenon universal or exceptional scenarios do exist.

During the initial phase of introduction of a new technology, information plays a crucial role. The initial users play a vital role in generating this information (Von hippel, 1988; Geroski, 2000). The information generated by the users is used by

the producers in improving the technology they deliver (Luthje et al, 2005; Ogawa, 1998).Furthermore, this information is also sampled over by the remaining population of non-users. Following, this sampling they decide to imitate the decision of the adopters or not. The specific aim of the paper is to investigate the impact of flow of information on the effectiveness of technological change. Effectiveness of technological change means an improvement in the technological variant and the successful acceptance of this improvement in the market. Flow of information is investigated from user to producer. And, also the flow of information on the demand side is explored. Along with this the risk attitude of the demand side is also considered. In order, to pay attention to these factors, other crucial factors like price setting behaviour, network externalities, to mention a few are not considered.

The first step is to investigate the impact of information contagion in the presence of user-producer familiarity. The second step is to analyse two different setup one with user-producer familiarity present and other in its absence. The first step helps in shedding light solely on the role played by user-producer familiarity and information contagion in determining the effective outcome of technological change. The second step, leads to fine tuning parameters of information contagion and risk attitude in the presence and absence of user-producer familiarity. These two steps help in understanding the role of user-producer familiarity, the heterogeneous behaviour of the users and the context in which the process of technological change unfolds.

As part of the first step, three scenarios are analysed: 1. Firstly, no flow of information (i.e. no sampling). 2. 0.2 % sampling rule. 3. 0.6% sampling rule. Sampling rule is a proxy for the flow of information on the demand side.

In line with the basic model, none of the technological variants take-off in absence of information flow amongst users i.e. in absence of information contagion (Arthur & Lane, 1993). This leads us to focus on many trivial yet important issues. Firstly, it is more important to understand what triggers the process of technological change (Geroski, 2000). Secondly, the experimental users (Malerba et al, 2009) or lead users (Von hippel, 1988) are definitely important but it is more crucial to allow them to be visible and there information to be available to the rest of the non-users. Lack of information in public domain is a reason because of which even the most promising technologies have failed (Douthwaite et al., 2001). Information contagion is crucial

for potential users adoption decision and the progress of technology supplied by the producer.

Insert Figure 2.1 and Figure 2.2 here [2]

In the second run, when the information contagion is allowed to be at 0.2 % the new technology takes-off. Figure 2.1 shows the market share occupied by each technological variant. Figure 2.2 maps the rate of technological progress of the two variants. In figure 2.1 the stochastic path dependent nature of the process is quite obvious. Despite the technological development observed in technology A when compared to B it does not dominate the market. Furthermore, in this run the two technological variants co-exist. In stark contrast in figure 2.3, clear market domination by technology A can be noticed. In this case variant B occupies a very small niche. The interesting point is that the domination of the market by technology A is perfectly in synchronization with its high rate of technological progress. The contrast in the outcome between figure 2.1 and figure 2.3 is due to the change in the number of prior users the future potential users could sample, i.e. information contagion. As, in both scenarios except for information contagion all the other parameters are held constant. Hence, user-producer familiarity does improve the level of technology supplied by the producer but the benefit of this improvement can be reaped only if a sufficient level of information contagion exists for that technological variant.

Insert Figure 2.3 and Figure 2.4 here [3]

As, the aim of the model in this paper is to underpin the importance of user-producer familiarity, heterogeneous user behaviour and the context in the process of technological change, two broad scenarios are discussed: 1. No user-producer familiarity exists; 2. User-producer familiarity exists. Both the scenarios are further fine-tuned for two parameters: a) Sampling rate; b) users risk attitude.

In the first scenario the producers learn from their experience (Thompson, 2010). In the second scenario they learn from their experience and user-producer familiarity. The comparison between the two scenario helps in understanding the role of user-producer familiarity and the circumstances in which it leads to the domination

[2]Figures are attached after the reference section
[3]Figures are attached after the reference section

of the market by one technological variant. This helps in estimating the impact of user-producer interaction on the innovation (Jacobides& Billinger,2006) or, the role played by the information supplied by users depending on the stage of product life cycle (Utterback,1994). However, while investigating these issues it is important to underline the behavioural assumptions regarding both users and producers.

Hence, a fundamental question that can be asked using this model is that to what extent does user-producer familiarity conditioned by the risk attitude of the users accelerate technological change? And, does this lead to the domination of the market by one technological variant? Also, is the outcome altered depending on the level of information contagion?

SCENARIO 1: NO USER-PRODUCER FAMILIARITY

Insert Figure 2.5, 2.6, 2.7 and 2.8 here[4]

Figure 2.5, 2.6, 2.7 and 2.8 show the co-existence of the two technological variants. Furthermore, the co-existence is dominated by the variant with high rate of technological progress. It can be observed that the sensitivity of the final state to the risk attitude of the users is not very high. From the above figures it may be concluded that when the agents are risk averse their chances of following the herd and not stand out with their choice of adoption is high.

Insert Figure 2.9, 2.10, 2.11 and 2.12 here [5]

In figure 2.9, 2.10, 2.11 and 2.12 clear market domination by one technological variant can be observed. The risk attitude of the users does not bear any huge impact on the outcome. The surprising or not surprising element leading to this change in the outcome is the sample rule. When the potential users are allowed to observe more prior users they can dwell on a large information base. This increases the probability of drawing higher utility from a technological variant with high prior customer base. Also, availability of higher information may pacify the risk attitude though not to a very high level as it is an intrinsic property.

[4]Figures are attached after the reference section
[5]Figures are attached after the reference section

Hence, in absence of user-producer familiarity information contagion is one of the key drivers of the process of technological change. Risk attitude of the user does bear an impact on the outcome but its impact is more pronounced when the level of information contagion is low.

SCENARIO 2: USER-PRODUCER FAMILIARITY PRESENT

Insert Figure 2.13, 2.14, 2.15 and 2.16 here [6]

The second scenario explores the outcome in the presence of user-producer familiarity. In this case it is simply a policy of the user to give some feedback to the producer via their behaviour. The interesting element of this analysis is the sensitivity of the final outcome when the information contagion is low.

In figure 2.13 when the users are more risk averse both variants co-exist with the technologically better variant dominating the market share. However, the twist comes when the users are less risk averse (Figure 2.15). The two variants still co-exist, however the co-existence is not dominated by the technologically better variant. A possible explanation could be that as the users are less risk averse the probability of herd behaviour is low. Hence, even if the majority is not adopting the technology the small section of users who adopted stick to it. The effect is further magnified due to the presence of small sampling rate. As users are not able to sample large group of prior users both the technological variants co-exist and a clear domination is not observed.

Insert Figure 2.17, 2.18, 2.19 and 2.20 here[7]

It is quite alarming to notice that when the users are more risk averse and the level of information contagion is high they do more harm than good (Figure 2.17). A clear domination of the market is observed but it is by the worse technological variant. Whereas, when the users are less risk-averse a clear domination is observed by the better off technology (Figure 2.19). These results should be interpreted with some caution. It is assumed that the producer simply integrates all the information

[6]Figures are attached after the reference section
[7]Figures are attached after the reference section

provided by the users. It may happen that in the presence of high information contagion users are more confident due to the large information they can observe. As they are more risk averse by nature they may strictly follow the herd. Also, As the producer does not differentiate the behaviour depending on the nature of the user, some information may be detrimental.

Hence, it can be proposed that user-producer familiarity is beneficial for the producer both in terms of producing better technology and reaping more market share if the users are less risk averse and the level of information contagion is high. Furthermore, users may behave in a nave fashion when they have access to a lot of information and they are more risk averse or when they have access to low information and are less risk averse. In the first case, they may simply be happy to experiment and dive in. In the second case they may be reluctant and simply follow the herd behaviour.

2.5 Conclusion

In this paper, I present a model which studies the role of the information provided by the user to the producer, user risk attitude and the impact of the information contagion on the process of technological change. The users follow the rules of Bayesian information processing (Arthur and Lane, 1993). The producers are modelled with the help of incremental increase in their capability set.

In particular, the model helps in shedding light on the theoretical factors that may play a crucial role during the initial process of technological change, i.e. the process of adaptation (Bogers, Afuah and Bastian, 2010). And, how this initial process affects the subsequent stages, in other words analyzing the path dependent nature of the whole process. This is done by analyzing the flow of information amongst the users, which helps them in deciding the utility of the technological variants. And, the interaction between the user and the producer via the information flow. This sheds light on the role of user behaviour in driving the process of technological change where, user behaviour towards producer is modelled as user-producer familiarity.

The model argues that users definitely contribute to the process of domination by one of the two new technological variants but this is conditioned by users risk attitude and information contagion. Furthermore, it can be proposed that user-producer familiarity is beneficial for the producer both in terms of producing better technology and reaping more market share if the users are less risk averse and the level of information contagion is high.

2.6 Future Research

The model restricts the analysis to the flow of information and its impact on the technological change. However, information is just one of the many pillars of the process of technological change. In this paper, technology being introduced by the producer is not truly exogenous. However, it cannot be claimed that it has been modelled in a truly endogenous sense. Nonetheless, it takes a step away from being exogenous. It evolves over the time depending on experience of the producer and user-producer familiarity. A possible fruitful step could be to model the technology supplied by the producer in an endogenous fashion.

Once the technology hits the market, then technological change becomes an interactive process between the demand side and supply side. The demand side is the centre of action because if the potential users refuse to adopt the new technology then, the entire process comes to a standstill. In the model developed in this paper, the size of the market is constant. A possible area for future research could be to increase the size of the market incrementally during the runs and analyse the results. In reality this is similar to the idea that the producers slowly increase the spread of public information about their technology. Also, it would be interesting to divide the market into sub-markets and analyse the outcome. By including market size or sub-markets it will be possible to treat demand side as a proxy for not information but also as an incentive to innovate.

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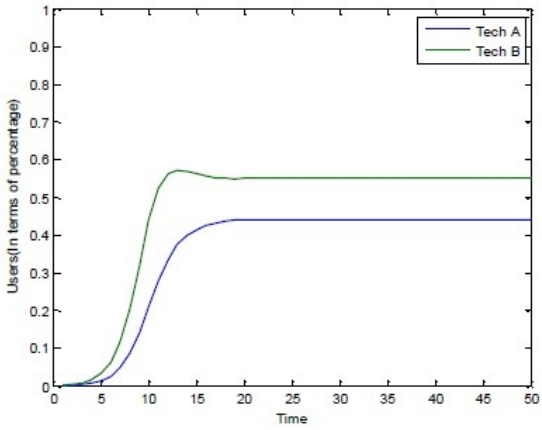

Figure 2.1: Market domination by the technologies (Sampling Rule is fixed at 0.2%.)

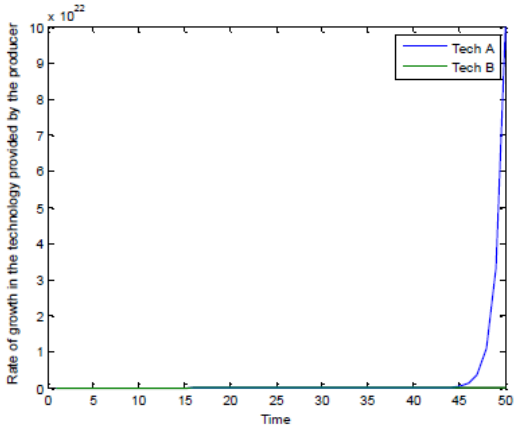

Figure 2.2: Development in the technology provided by the producers.

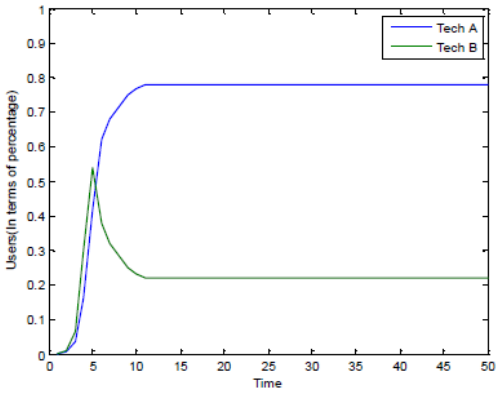

Figure 2.3: Market domination by the technologies (Sampling rule is fixed at 0.6%).

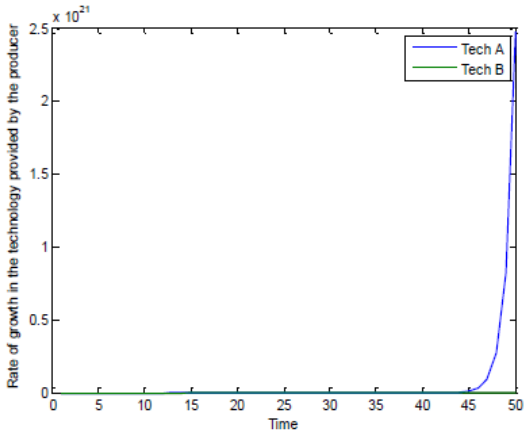

Figure 2.4: Development in the technology provided by the Producers.

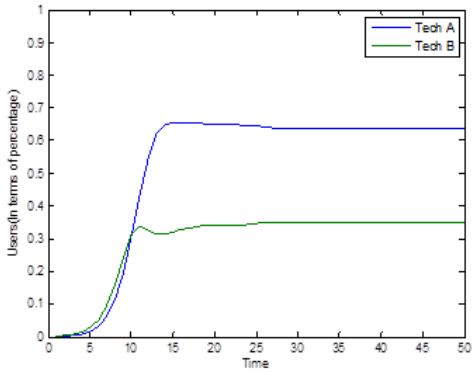

Figure 2.5: Market domination by the Technologies (User-producer familiarity is not present, the agents are more risk averse, sampling rule is fixed at 0.2 %.)

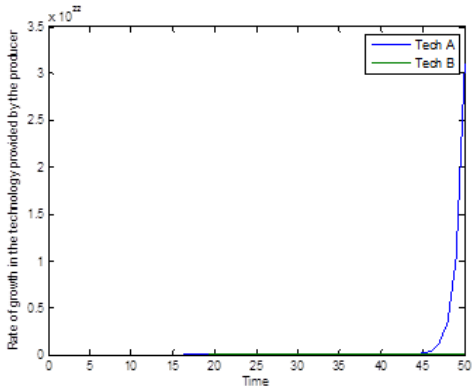

Figure 2.6: Development in the technology provided by the Producers.

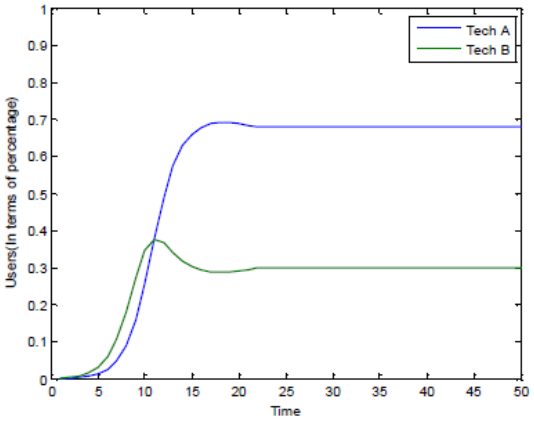

Figure 2.7: Market domination by the Technologies (User-producer familiarity is not present, the agents are less risk averse, sampling rule is fixed at 0.2 %.)

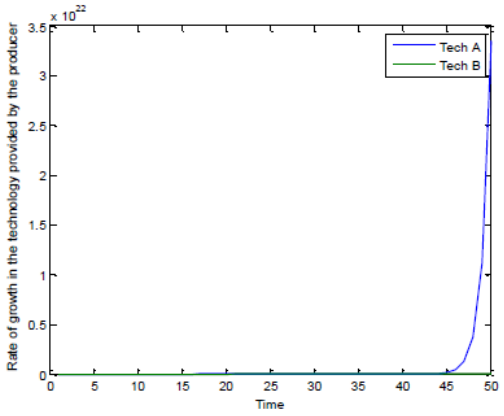

Figure 2.8: Development in the technology provided by the Producers.

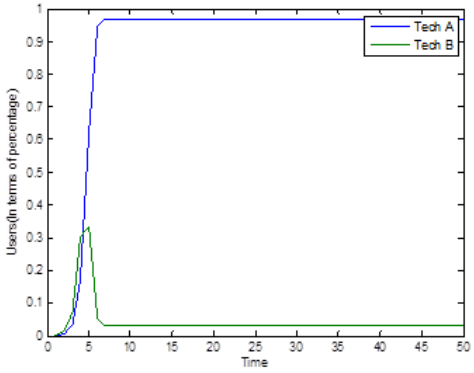

Figure 2.9: Market domination by the Technologies (User-producer familiarity is not present, the agents are more risk averse, sampling rule is fixed at 0.6%.)

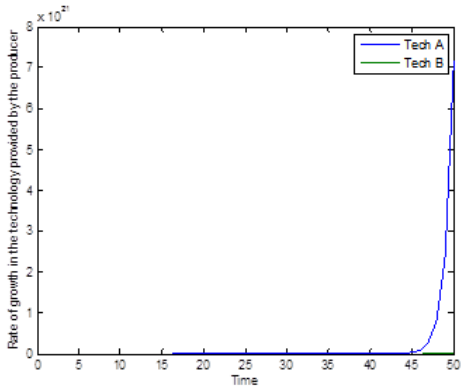

Figure 2.10: Development in the technology provided by the Producers.

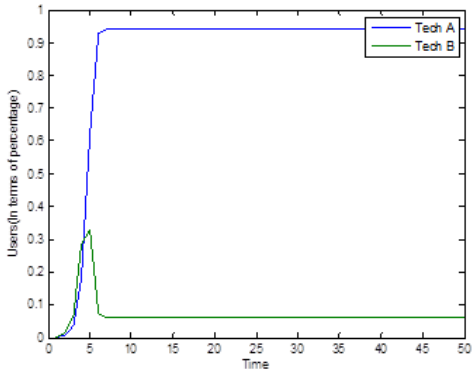

Figure 2.11: Market domination by the Technologies (User-producer familiarity is not present, the agents are less risk averse, sampling rule is fixed at 0.6%.)

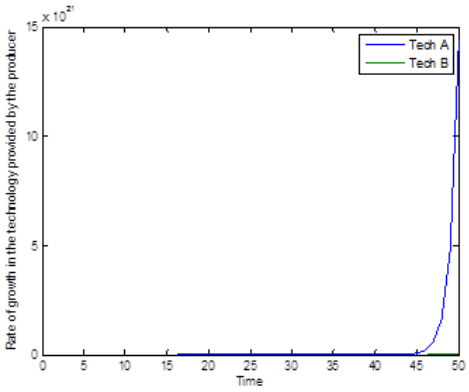

Figure 2.12: Development in the technology provided by the Producers.

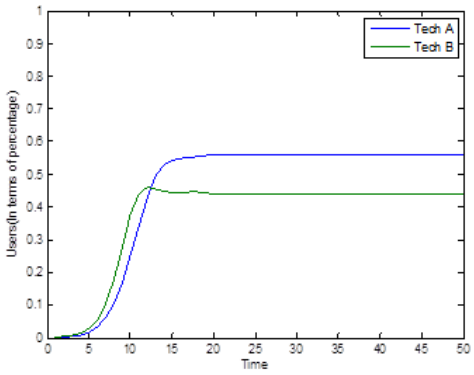

Figure 2.13: Market domination by the Technologies (User-producer familiarity present, the agents are more risk averse, sampling rule is fixed at 0.2%.)

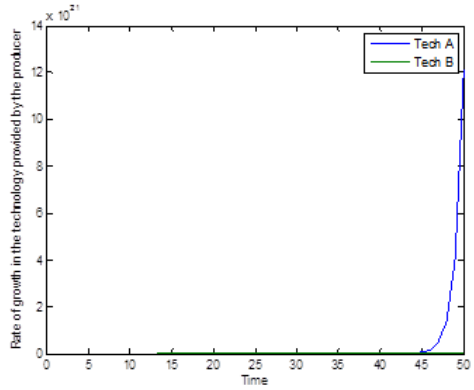

Figure 2.14: Development in the technology provided by the Producers.

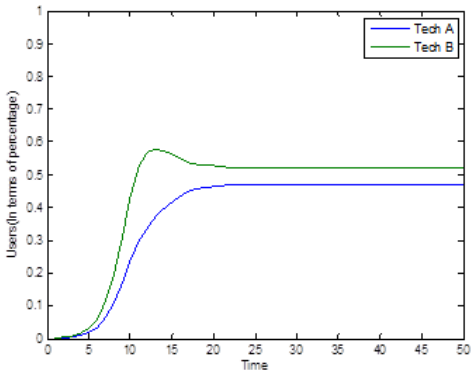

Figure 2.15: Market domination by the Technologies (User-producer familiarity present, the agents are less risk averse, sampling rule is fixed at 0.2%)

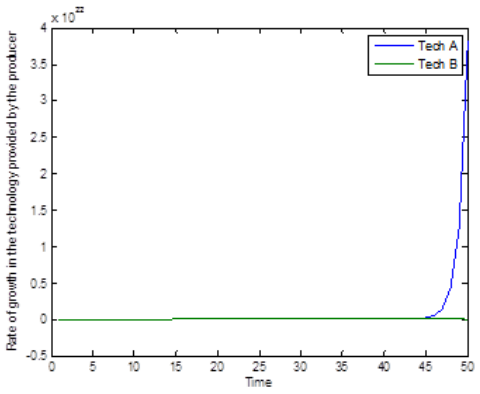

Figure 2.16: Development in the technology provided by the Producers.

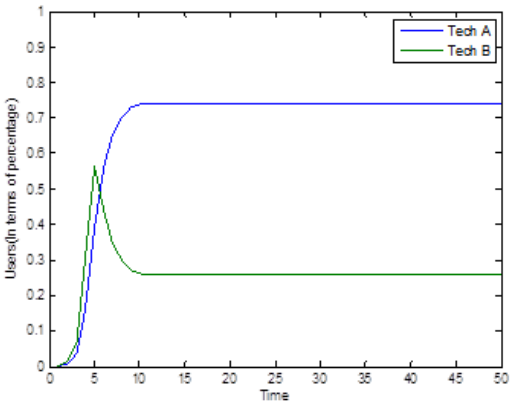

Figure 2.17: Market domination by the Technologies (User-producer familiarity present, the agents are more risk averse, sampling rule is fixed at 0.6%)

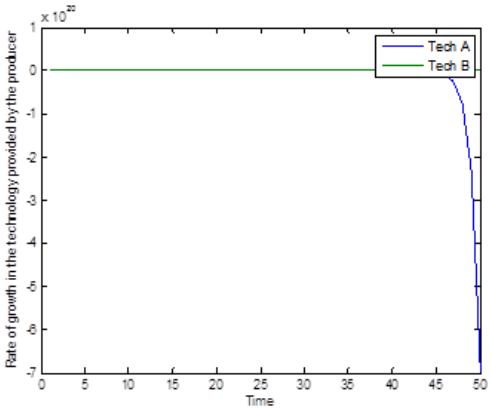

Figure 2.18: Development in the technology provided by the Producers.

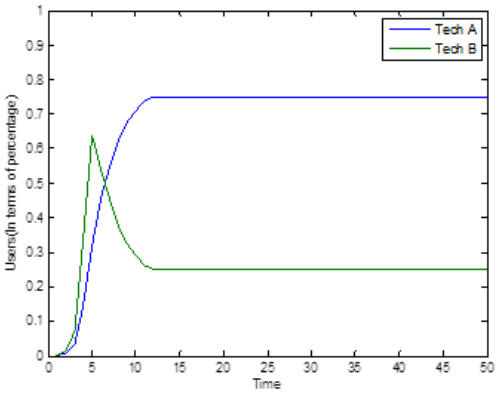

Figure 2.19: Market domination by the Technologies (User-producer familiarity present, the agents are less risk averse, sampling rule is fixed at 0.6%)

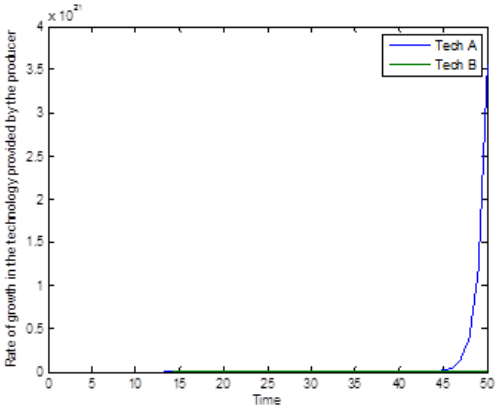

Figure 2.20: Development in the technology provided by the Producers.

3

Who Orchestrates Publicly-Funded Research Networks?

Abstract

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The role of network initiator and network orchestrator in Publicly-Funded Research Networks usually lies over a spectrum. The government acts as an initiator, however, it may select or help in selecting a focal entity and allocate the role of orchestration to it at least partially. The orchestrator may be a systems provider, a university, a research institute, a consulting company, or a user-representative body.

We empirically examine the impact of the position of different types of partners inside Publicly-Funded Research Networks (PFRNs) on the probability of product innovation. The empirical analysis builds on market data from Danish wind power sector in the period 1979-2011, coupled with the data on PFRNs in which the Danish market player systems provider were observed. The analysis is done from network perspective and systems provider's perspective. Our research showed that if the funding public body is aiming at "new-to-the-market" innovations, it is better to position organizations closer to the market (i.e. systems providers, suppliers, and users) as orchestrator. From systems provider perspective, we found that the probability of commercializing new-to-the-firm innovations is higher when the systems provider is only acting as a network cooperator and not an orchestrator. These findings contribute to better design of public funding schemes and corporate strategy.

Keywords :Network Orchestration, System provider, Innovative performance, public research funding, Danish wind power industry.

"Give a man a fish; feed him for a day. Teach a man to fish; feed him for a life time. By Lao Tzu

3.1 Introduction

The role of public funds in initiating networks of heterogeneous organizations is a ubiquitous phenomenon these days. The key question this poses is: does this not lead to over-reliance on public funding in the long run? May be not always, especially, when the government hands over the orchestration role, at least partly, to a focal entity inside the already established networks. It empowers the participants to sustain the network after government initiation. Furthermore, it also enables the focal organizations to build system integration or platform leadership capabilities (Cusumano & Gawer, 2002). System integration capabilities are said to be the new sources of competitive advantage for leading companies of the advanced countries (Pavitt, 2002). And, taking a step further, in this paper, we empirically examine the impact of different orchestration configuration inside PFRNs on the commercialization of its product innovations.

The important role of public research funding in initiating innovation networks has been extensively explored (e.g. Choi et al., 2011; Wagner & Mohrman, 2009; Cassi et al., 2008; Sakakibara, 1997; Freeman, 1991). This is consistent with the broader literature on the need for a legitimate triggering entity in the formation and growth of engineered innovation networks. Especially in cases where interdependencies are difficult to recognize, technologies are not as well specified or there is a high dosage of tacit knowledge (e.g. Doz et al., 2000; Browning et al., 1995; Corey, 1996; Sandholtz, 1992).

In Publicly-Funded Research Networks (PFRNs), it is the public body that plays the role of initiating or triggering entity. However, it is important to know "who is orchestrating these networks?" By network orchestrating we mean purposefully maintaining, coordinating and managing inter-firm innovation networks.

Prior research on cooperative arrangements for innovation has mostly overlooked the position of partners inside the network. They are largely focused on the networks initiated and orchestrated by a single large firm as the hub (e.g. Nambisan &

Sawhney, 2011; Cusumano & Gawer, 2002). Adopting a complementary approach to the literature on PFRNs, we explored the innovative outcomes of the systems providers involved in these networks with different kind of partners as their orchestrators. By systems provider we refer to those companies that have sold wind turbine as a complete system in Danish market. We examined the impact of the position of different types of partners inside PFRNs on the commercialization probability of system providers product innovations. Accordingly, an important contribution of this research is to keep separate in our analysis the role of initiator and the role of orchestrator.

We argue that from a network perspective, it is crucial for the public body to understand which kind of organizations can act more effectively as an orchestrator of the research networks it initiates and funds. Also from a systems provider perspective, it is crucial to understand the implications of trying to become the orchestrator of a PFRN or simply joining it as a cooperator. In examining the impact of PFRNs we will, according to the definition of Laursen & Salter (2006), refer to both innovations that are new-to-the-market and innovations that are new-to-the-firm.

The empirical setting of the paper is the Danish wind power market. Denmark is the center for competence of the wind power at the international level and the only country in which by 2009 wind power represented 20% of electricity supply. Furthermore, the Danish wind power market presents us with the opportunity to perform an empirical analysis of an Industry that emerged as a grass-root movement in the 1970s, with no patents or intellectual property rights till 1990s and currently represents more than 7% of the annual Danish exports (Nissen et al., 2009). The analysis builds on market data from 1979 until 2011, coupled with data on PFRNs in which the Danish market players were observed.

The use of market data is a key point of departure from previous analyses, which used patent data (Lechevalier et al., 2011; Jaffe & Palmer, 1997; Brunnermeier & Cohen, 2003) or self-reported Community Innovation Survey data (Arranz & Fdez de Arroyabe, 2008; De Marchi, 2011; Horbach, 2008) as proxy for environmental innovation as these proxies could result in under- or over-estimate of innovation.

Our dataset covers all the market players for the entire period. Hence, the data-

base does not suffer from the usual problems of sample selection bias. The results help in carrying out a comparative analysis that helps us in understanding the impact of the various kinds of orchestrators on the innovative performance of the systems providers involved in PFRNs. The orchestrator may be a systems provider, a university, a research institute, a consulting company, a user-representative body, in short a relevant organization concerned with the specific technology. The results are analyzed from two different perspectives, network perspective and systems provider's perspective. The network perspective helps in understanding how the public body can foster the evolution of complex technologies by cautiously picking the orchestrator. Whereas, the systems provider level perspective helps in understanding the scenarios in which the systems provider should try to become an orchestrator vs. when it should join PFRN only as a peripheral partner. This positioning directly affects the structure of the network, which could have consequences in terms of the decision-making process, resource access, and entry points.

Our research showed that for those PFRNs whose goal is to be pioneers and introduce new-to-the-market innovations it is better to assign the role of network orchestrator to pure market players such as systems providers, suppliers and users. Despite the emphasis on the role of universities and research institutes in the research networks, our results clearly show that having research institute as an orchestrator reduces the probability of introducing new-to-the-market innovations and university has no significant impact as orchestrator as well. Such a finding is not in contrast with studies, which emphasis the relevance of university-industry partnership. Quite the contrary, we are able to better specify the role that public research and public policy could play in steering PFRNs toward successful commercialization. On the opposite end, when the goal of PFRN is not to commercialize but rather to diffuse information and enhance the absorptive capacity of players involved in PRFNs (i.e. promoting first-to-the-firm-innovation by participating systems providers), then it is important to have research institutes, suppliers and consulting organizations as orchestrators. The probability of innovations new-to-the-firm decreases if the orchestrator is a systems provider, university, research institute or user.

From a systems provider perspective, our results show that the probability of introducing an innovation new-to-the-market is higher when the systems provider itself is the orchestrator. On the other hand, the probability of introducing an

innovation new-to-the-firm is higher when the systems provider is only a network cooperator. Therefore, if the goal of the systems provider is not to pioneer a new-to-the-market innovation but only to catch-up, it is better to position itself as a network cooperator, leaving the role of network orchestration to other players. If the systems provider wants to introduce an innovation new-to-the-market, the intensity of external search is more important compared to the variety of external search. Interestingly, if the innovation is new-to-the-firm, the larger the number of network partners the better.

The remainder of the paper is organized in four sections. The following section explores the relevant literature and specifies the research questions. Section 3 describes the data, the variables and the empirical analysis and Section 4 presents the results. Finally, Section 5 concludes.

3.2 Prior research and research questions

Increasing adoption of the open innovation paradigm is simultaneously being accompanied by an innovation process where, most of the phases are characterized by an inter-organizational network (Powell et. al, 1996; Chesbrough et. al 2006; Nambisan & Sawhney, 2011). Scholars identify many benefits for networking (Pittaway et al, 2004). Few scholars even consider firms external networks, besides its firm-specific technology and resources, as their main source of competitiveness (Mytelka, 1991; Prahalad, 2009).

Historically, networks have often evolved from long-standing business relationships (Tidd & Bessant, 2010). However, there is growing attention towards path-creating processes, in which an entity initiates an innovation network and recruits other members to participate in the network (Conway et. al, 1998; Tidd and Bessant, 2010; Doz et. al, 2000). The need for a legitimate initiating entity in forming innovation networks is particularly acute where interdependencies are difficult to recognize, technologies are not as well specified or there is a high dosage of tacit knowledge (e.g. Doz et al., 2000; Browning et al., 1995; Corey, 1996; Sandholtz, 1992).

Policymakers in many countries have realized the increasing importance of innov-

ation networks and have instituted various policies to facilitate the creation and efficient functioning of such networks (Polt, 2001). Development of research networks has long been pursued by public institutions with the aim of improving competitiveness and innovation performance of local companies (Edquist, 1997; Hagedoorn et al., 2000). Government role in initiating and funding research networks is also an effort to offset the decline in corporate research and development (R&D) spending (Fuchs, 2010). Especially for emerging sectoral systems of innovation, cooperative research funding and catalyzing the network formation have been identified as crucial policy measures (Choi et al., 2011). Public research funding as a network-facilitating policy has been widely explored in this context (e.g. Choi et al., 2011; Wagner and Mohrman, 2009; Cassi et al., 2008; Sakakibara, 1997; Freeman, 1991). Research networks funded by public bodies could take various forms, including joint R&D contracts, R&D consortia, cooperative R&D. In this paper, we refer to all of them as Publicly-Funded Research Network (PFRN).

One stream of the literature on research network is focused on explaining outcomes as a function of initial conditions (e.g. Belderbos et al., 2004; Aldrich and Sasaki, 1995; Fransman, 1990; Sakakibara, 1997). Another strand of the literature focuses on formation processes of research network (e.g., Doz et al., 2000; Browning et al., 1995; Corey, 1996; Sakakibara, 2002). Many concentrate on the effectiveness of PFRNs (e.g. Breschi & Cusmano, 2004; Cassi et al., 2008; Roediger-Schluga & Barber, 2006; Caloghirou et al., 2004; Sakakibara, 1997). Several theoretical and empirical academic contributions point to the impact of partner type on the innovative performance of firms involved in cooperative research (Miotti and Sachwald, 2003; Belderbos et al., 2004; Iammarino et al., 2009; Arranz & Fdez de Arroyabe, 2008; Tether, 2002; Mariti and Smiley, 1983; Belderbos et al., 2004b; Fritsch and Lukas, 2001; Monjon and Waelbroeck, 2003). The impact of partner type on cooperative research has been studied in the literature using either transaction cost (Williamson, 2002) or resource-based (Wernerfelt, 2006) theoretical perspectives.

However, the orchestration of the innovation networks is less researched (Nambisan & Sawhney, 2011) and, to the best of our knowledge, there has not been any report on the orchestration in PFRNs. By network orchestration we mean purposefully maintaining, coordinating and managing inter-firm innovation networks.

There is a recent line of research on orchestration processes, forms and functions.

The focus of these studies is on the hub firm and how it co-ordinate, influence, or direct other partners of the innovation network (Nambisan & Sawhney, 2011; Ritala et al., 2009; Dhanarag & Parkhe, 2006; Iansiti & Levien, 2004; Ritter & Gemnden, 2003; Gawer & Cusumano, 2002). Nambisan and Sawhney (2011) described managing innovation leverage, managing innovation coherence, and managing innovation appropriability as the key orchestration processes. Dhanarag & Parkhe (2006) highlighted three orchestration processes, namely, managing knowledge mobility, innovation appropriability, and network stability. They defined network orchestration as the deliberate, purposeful actions of the hub firm trying to create value and extract value from the network. Few scholars (Becker & Dietz, 2004; Dhanarag & Parkhe, 2006; Ritala et al., 2009) have addressed the competencies needed by network orchestrators to better execute their role.

However, almost all the aforementioned researches are focused on the networks initiated and orchestrated by a single large firm as the hub. Typical examples of such networks include Boing's Dreamliner 787 project or technological platforms led by Intel. In these networks, big companies bring together a set of global partners to co-create a new plane or co-develop a new technology and take the finished product or technology to market (Nambisan & Sawhney, 2011; Cusumano & Gawer, 2002). Considering the crucial role of network orchestration, it is important to study the impact of placing different types of organizations in the position of PFRNs' orchestrator.

The literature on network orchestration and management quite often treat network initiator and network orchestrator in the same spirit. Dhanarag & Parkhe (2006), for instance, explain that "hub firms are known variously as key actors, triggering entities, strategic centers, flagship firms, and network orchestrators." They even define network orchestration as purposefully building and managing inter-firm innovation networks. However, the reality paints a picture, which is slightly different. Although it may happen that the same entity performs the functions associated with the initiation and orchestration, the contrary is also possible. Government role in forming research networks, for instance, is usually carried out by bringing heterogeneous actors together and placing a key actor in the orchestrator's position (Choi et al., 2011). In these cases, government initiators deliberately assign, at least partly, the role of network orchestration to one of the participants. Handing

over the orchestration role, at least partly, to an organization inside the already established networks is what empowers the participants to sustain the network after government initiation. This helps in preventing over-reliance on government funding in the long run. As Polt (2001) observes, the new generation of policy programs supports self-organizing among network participants. He insists that public support of networks should not continue once they are established and participants have realized their benefits (Polt, 2001). The same policy of handing over the orchestration role also enables the orchestrator to build system integration or platform leadership capabilities, which are said to be the new source of competitive advantage for leading companies of the advanced countries (Pavitt, 2002; Gawer & Cusumano, 2002). The Defense Advanced Research Projects Agency, or DARPA, in the US is an apt case in point. DARPA, with more than 50 years of experience in initiating networks and encouraging new technology trajectories, follows the explicit policy of not sustaining the technology to avoid reliance on the state (Fuchs, 2010).

Government role in placing a key actor in the central position of a research network directly affects the structure of the network. Furthermore, it could also have consequences in terms of the decision-making process, resource access, and entry points (Choi et al., 2011; Callon, 1993). Centrality, in terms of position in a network is often associated with power and influence (Brass & Burkhardt, 1993; Wasserman & Faust, 1994). As a consequence it is usually the orchestrator who plays the key role in defining the basic architecture for the core innovation, facilitating partners complementary innovations, integrating the different components designed and developed by other members (Nambisan & Sawhney, 2011). Accordingly, appointing a key partner as an orchestrator in PFRNs is a crucial decision with many potential implications.

Prior research has overlooked the position of partners inside PFRNs. This indicates a critical limitation in our understanding of how the resulting innovative outputs could be affected by the position of participants inside the network.

We do not propose to strictly divide the role of initiation and orchestration, as the division of labor between two roles is situation and technology specific. Nonetheless, we would like to argue that there is a thin line of demarcation between the two roles. So we propose that the role of initiator and orchestrator in PFRNs lies over

a spectrum. The government acts as an initiator and helps in building a network. However, it may not choose to be the orchestrator or the only orchestrator of the network. The orchestration role is often handed over to a focal organization, which may be a systems provider, a university, a research institute, a consulting company, a user-representative body. In few words, a relevant organization concerned with the specific technology.

As a complement to the literature on PFRNs, we examined whether the position of different kinds of organizations inside PFRNs influences the probability of a product innovation being commercialized by the systems provider involved.

We argue that from a network perspective, it is important for the public body to understand which kind of organizations can act more effectively as an orchestrator of the research networks that it initiates and funds. Also from a systems provider perspective, it is crucial to understand the implications of trying to become the orchestrator of a PFRN or simply joining it only as a cooperator. As companies have increasingly opened their innovation process and engaged in a variety of inter-organizational innovation networks (Powell et. al, 1996; Chesbrough et al., 2006), they should be very selective about which networks to participate in and where to position themselves inside those networks.

Having said that, the research problem is "what could be the impact on the innovative performance of the systems provider contingent on who is orchestrating the PFRN they are a part of." In this paper, we make a fruitful attempt to address this problem by posing two specific research questions:

(1) From the network perspective, is the probability to introduce an innovation new-to-the-market affected by the nature of PFRNs' orchestrators?
(2) From the perspective of systems provider taking part in PFRN's, is the probability to introduce an innovation that is new-to-the-systems provider affected by the role it plays in the PFRN (cooperator vs. orchestrator)?

3.3 Dataset,Variables and Estimation Method

The section begins with a brief description of the database, followed by an in depth description of the variables. The last part of the section explains the econometric methodology used for estimating the coefficients.

3.3.1 Dataset

The empirical analysis is done on a unique database. Informational content of the database can be understood along two dimensions: (1) Information about the market details of the systems providers from 1979-2011 and the PFRNs they were observed in, and (2) Information about the product sold by those systems providers on the Danish market.

Market details of the systems providers were obtained from the Danish wind turbine owners association. The information about the PFRNs was obtained from two sources: (1) Public database maintained by Riso National Laboratory for Sustainable Energy. (2) Community Research and Development Information Service (CORDIS), which covers European funded projects (e.g. ENNONUC 3C, ENALT 2C and THERMIE).

The concept of systems providers in this research covers both systems seller and systems integrator concepts as used in industrial marketing literature (Figure 3.2). Systems seller concept usually refers to vertically-integrated companies that produce all the product and service components in a system, while systems integrator concept mostly describe companies that coordinate integration of components supplied by external firms (Davies et al., 2007). By supplier we refer to specialized firms selling product or service components related to wind turbines in the Danish market.

Insert Figure 3.2 here [1]

The database does not suffer from the usual problem of sample selection bias, as the whole population of the Danish wind turbine market was observed. The Danish market merits an analysis for two prime reasons. Firstly, it is the center of

[1]Figures are attached after the reference section

competence for wind technology. Secondly, different roles played by various organizations in making it a center of competence. These roles have been studied from two perspectives: (1) The role played by informative interactions amongst various organizations (Garud & Karnoe, 2003), and (2) Specific role of state funded projects, like demonstration projects is being undermined (Hendry & Harborne, 2011). Taking a step further, we try to investigate the impact of organizations falling both in public and private domain on the innovative outcomes.

The PFRNs in which the system providers were observed are financed in part by either the Danish energy authority, Energitek, Elfor or the European Union funding. Danish energy authority is a branch of the Danish government and grants funds for R&D of cleaner and more power efficient energy production. Energitek is responsible for the Danish power and natural gas system and grants funds for development and demonstrations of technologies for environmental friendly power production. Elfor is the trade association for the power distribution companies, it grants funds for R&D projects in the field of efficient use of energy.

Our dataset covered 79 systems providers, however, the regressions were performed only on 50 systems providers. 29 systems providers were dropped out due to lack of adequate number of observations. Data was collected for 818 PFRNs. In 144 research networks from 1981 until 2010 the Danish system providers were observed. The database gives us the opportunity to shed light on the role played by the actors present at different position in the network: orchestrating the network or merely cooperating in the network.

The use of market data is a key point of departure from previous analyses, which used either patent data (Lechevalier et al., 2011; Jaffe & Palmer, 1997; Brunnermeier & Cohen, 2003) or self-reported Community Innovation Survey data (Arranz & Fdez de Arroyabe, 2008; De Marchi, 2011; Horbach, 2008) as a proxy for environmental innovation. These proxies could result in under- or over-estimation of innovation. Figure 3.1 provides a brief description of the variables present in the database and used in the econometric analysis. The table contains variables under three categories, which are, dependent variable, independent variable and control variables.

Insert Figure 3.1 here [2]

An argument can be raised concerning the lack of adequate amount of data and its possible impact on the empirical outcomes. However, we follow the argument of Tether and Tajar (2008) and propose that, in such scenarios it is better to learn from the available data in the best possible manner. The other option is to simply ignore the presence of any data. And, this might mean bidding farewell to a key stepping stone of learning. Nonetheless, we do understand that the readers may have different perspectives.

3.3.2 Variable description

Dependent Variable

Innovative performance of the systems provider is measured with the help of their commercialized product innovations. In the database, a product is considered to be an innovation when it fulfills the criteria defined by the Oslo Manual (2005). Hence, product innovation is defined as considerable changes in the set of services provided by the product.

In order to measure product innovation we build two variables from the database: (1) Innovation-new-to-the-market, (2) Innovation-new-to-the-firm. Both the variables are of binary nature (0/1) and follow the already cited approach of Laursen and Salter (2006). The first variable new-to-the-market indicates when a product belonging to a new generation has been launched for the first time by a systems provider. The second variable, new-to-the-firm, indicates a product belonging to a new generation which is new to the systems provider but not necessarily new to the market.

For example, Bonus introduced a wind turbine of generation 7 (1000 Kw) in the market in the year 1994. This was the very first time a generation 7 wind turbine was launched on the market; it was an innovation new-to-the-market. At the same time, this was also an innovation new to the firm. Hence, in the database this is counted as an innovation new to market and an Innovation new to the firm. In

[2]Tables are attached after the reference section

the year 2000, Micon also introduced a wind turbine of generation 7 in the market. However, this was not new to the market but it was an innovation to the firm. Hence, this is counted only as an innovation new to the firm. To sum it up, an innovation new to the firm, is a product which is necessarily new to the firm but not necessarily new to the market. However, an innovation new to the market is also an innovation new to the firm.

Figure 3.3 gives a quick snapshot of the evolution of the different generations of the Wind turbines. The technical features of the wind turbine like, diameter and hub height are used to capture the essence of the different generations of the wind turbine. The corresponding output capacity of the turbines can be noticed in the figure 3.3. Output capacity is a key criterion for categorizing the different generations of the wind turbine. It is also the approach adopted in this paper.

Insert Figure 3.3 here [3]

Independent Variable

The independent variables are categorized on the basis of the two research questions: network perspective and systems provider perspective. Network perspective investigates the impact of the kind of the research network on the innovative performance of the systems provider participating in that network. Kind of research network is defined with the help of the nature of the network orchestrator. The network orchestrator may be a university, research institute, supplier, user, consultancy, or systems provider. Each type of network orchestrator has two possible values: 0 or 1. None of the values are mutually exclusive. It may happen that a firm is part of a research network orchestrated by a university and is simultaneously part of another research network orchestrated by a research institute.

The issue being investigated from a systems provider perspective is the impact of its position in the public-private research network on its innovative performance. The systems provider can either be a network orchestrator or a network cooperator. Both variables can have two values, 0 or 1. The value is 1 if the firm is a network orchestrator (network cooperator) otherwise is 0. The positions are not mutually exclusive. It is important to note that an organization can take the role of orches-

[3]Figures are attached after the reference section

trator in one research network and at the same time be only a participant in another network.

In order to capture the influence of other variables, related to research networks the systems providers are participating in, system provider-specific and complexity of the technology, control variables are used while estimating the models.

The control variables for research networks are of two types. The first one controls for the nature of the R&D funding provided by the public bodies. The second one controls for the variety of partners present in a network.

The R&D funding provided by the public bodies can be categorized depending on their objectives (David & Hall, 2000). Project funding may range from non-mission oriented, like basic R&D, to mission oriented, like contract-based to demonstration projects or field trials (Hendry & Harborne, 2011). Categorizing the R&D funding is vital for understanding the nature of the project supporting the learning by searching activities of the players involved. Depending on the nature of the fund granting organizations the empirical analysis is carried out by categorizing the projects in two broad categories: (1) Demonstration projects and (2) Contract projects.

Recently, the variety of partners present in a network and the intensity of search across these partners has been the focus of several studies (Laursen & Salter, 2006; Becker & Dietz, 2004; Marchi, 2012). In this paper, we generate two variables, breadth and depth, building on the approach of Laursen and Salter (2006). Breadth is to measure the number of partners in a research network. Depth measures the intensity of information available through these partners.

Firm size has always occupied a center stage in almost every realm of innovation-related studies. Scholars have observed higher propensity to participate in a research network depending on the firm size (Tether, 2002; Miotti & Sachwald, 2003; Bayona et al., 2001). If we dwell deeper, we understand that firm size has been treated as a proxy for set of capabilities the firm has, risk-averse behavior, market power (Geroski, 2000), reputation of the firm (Morris et al., 2006; Dhanaraj and Parkhe, 2006). In order to interpret it in the most appropriate way, it is necessary to define what exactly is firm size expected to proxy in the study. In this paper, we treat

firm size as a proxy for the set of capabilities a firm has, similar to the approach of Tether (2002). Along with the firm size, we also control for the experience of the firm, in terms of number of years, in selling its products. And, an interactive variable controlling for the firm size and experience is also included.

The systemic and complex nature of wind technology has been the center of many discussions lately (Andersen & Drejer, 2008; Kemp et al, 2004; Kemp, 2002; Bergek & Jacobsson, 2003). Complexity can be due to the number of sub-component present (Rosenberg, 1982). The sub-components contribute to the functioning and success of the product as a whole. However, all the sub-components do not grow in the same proportion (Sahal, 1981). Sahal (1981) argues that in order to consider the evolution of a complex technology, it is important to consider three aspects: (1) Growth of the functional forms, i.e. sub-components; (2) The change in the material; and (3) The change in the complexity of the technology embodied in the product. By considering the dimensional characteristics of the technology embodied in the product we control for the growth in the sub-components, namely the height and diameter of the turbines.

Insert Figure 3.4, 3.5 and 3.6 here
[4]

Figure 3.4 maps the growth of turbine diameter over the years. Figure 3.5 tries to explain the linear relationship between the hub height and the rotor diameter. Figure 3.6 maps the relationship between the diameter and the rated power of the turbines (Kw). The three figures help in explaining the relationship between the growth of the sub-components and the evolution of a complex technology.

3.3.3 Estimation method

Pooled logit estimation

To explore which factors affect the innovative performance of the market players we first employ a pooled logit model. The probability that systems provider 'i' introduces an innovation new-to-the-firm or new-to-the-market is assumed to be given by the equation below:

[4]Figures are attached after the reference section

$$Prob(Y_{it} = j|x) = e^{(x\beta)}/(1 + e^{(x\beta)}) \quad j = 1or0 \tag{3.1}$$

Where Y_{it} represents the innovation introduced by the firm i, new-to-the-firm in the market in year t. The vector of all the covariates is represented by x and β represents the corresponding parameter of the covariate.

The pooled logit estimation is used while estimating the parameters for the dependent variable innovation new-to-the-firm and innovation new-to-the-market both from systems provider perspective and network perspective. Due to the rare occurrence of new to market innovation, the conditional logit estimation is performed only for new-to-the-firm innovation.

Conditional logit estimation

The conditional logit estimation is used to estimate one of the two dependent variables: Innovation new-to-the-firm. The database contains data along three dimensions: 1. Firm, 2. Time, 3. Product. As a results, few charateristic for a firm stay constant for a given year and few change. Due to the three dimensional nature of the logitudinal dataset, logit model is not the right option for estimating fixed effects. Hence, a model is needed that can take into account simultaneously independent variable charateristics that change and others that stay constant. Conditional logit helps in taking into account simulataneoulsy data for both changing characteristics and the once that stay constant (Cameron and Trivedi,2005).Models of this family are used when the selection of sample is determined in part by the values taken by the dependent variable or being biased in part by values taken by the independent variable (Cameron & Trivedi, 2005).

To explore which factors affect the dependent variable: Innovation new-to-the-firm, we employed the conditional logit model. The probability that systems provider i introduces an innovation new-to-the-firm is assumed to be given by the equation below:

$$Prob(Y_{it} = j|x) = e(\lambda(x_{if}))/sum(e(\lambda(x_{if}) + \mu(z_f))) \quad j = 1or0 \tag{3.2}$$

Where, Y_i represents the innovation introduced by the systems provider, x_{if} is the vector of variables representing the characteristics of the products, z_f is the vector of the variables representing the characteristics of the systems provider. This includes

both the systems provider's characteristics and the characteristics of the publicly funded research networks it has participated in.

The conditional logit model is often criticized for the assumption of independence of irrelevant alternatives and it is proposed to be tested by the Hausman test (Hausman and Mcfadden, 1984). However, in the present case as we have only two alternatives and both are being considered while estimating the model, the model estimated in this paper does not suffer from this issue.

3.4 Empirical results

3.4.1 Impact on innovation new to firm

Insert table 3.1 and 3.2 here [5]

From network perspective, our results suggest that the probability of introducing an innovation new-to-the-firm is lower if the position of network orchestrator is occupied by a university, a research institute, a user or a systems provider. On the other hand, the networks whose goal is to help participating systems providers to catch-up with a technological trend, then it is in the best interest of the network to position research institutes, suppliers and consulting organizations in the role of network orchestrator. Table 3.1 contains the empirical results for pooled logit (Model 1) and conditional logit (Model 2). The results for model 2 are discussed here.

Innovations new-to-the-firm usually proxy imitations and bridging institutes like, research institutes and consultancies are known for information and idea dissemination, the key ingredient for imitation (Tether & Tajor, 2008; Kohler et al., 2013). In Bessant and Rush's (1995) words, consultants act like "bees in cross-pollinating ideas" in helping firms to define their particular needs for innovation and pairing companies with needs and solutions. Furthermore, the positive impact of suppliers points towards the crucial role played by changes in the material used in a complex technology, even if the innovation is not truly novel (Sahal, 1981).

[5]Tables are attached after the reference section

The orchestrator is expected to play a key role in value creation by the network and to capture a big share of it (Dhansai & Parkhe, 2006). Not surprisingly the impact of systems provider as the orchestrator decreases when it comes to new-to-the-firm innovations. It seems that the value of an innovation only new-to-the-firm is not encouraging enough for systems providers to engage in network orchestration. Our results also show that the presence of users as network orchestrator has a negative impact on the probability of introducing an innovation new-to-the-firm. During the period of analysis the wind industry was not a mature industry. Hence, it is possible that the purpose of user orchestration is to help in introducing an innovation which is truly novel. Prior research also acknowledges the benefits associated with cooperative arrangements with users, especially when the innovation is more complex, or when the market for the innovation is not fully defined (Tether, 2002).

The results for other control variable can be found in table 3.1, Model 2. Furthermore, firm size increases the probability of introducing an innovation new-to-the-firm. However, if the system provider is big and has more experience then it augments the probability of introducing an innovation new to the firm.

From systems provider perspective, our results indicate that, the probability of introducing an innovation new-to-the-firm is higher if the systems provider acts only as a network cooperator. Whereas, the probability of introducing an innovation new-to-the-firm is lower if the systems provider acts as a network orchestrator. Table 3.2 contains the empirical results for pooled logit (Model 3) and conditional logit (Model 4). The results for model 4 are discussed here.

Product innovations usually embody a high level of tacit knowledge. Socialization is important for tacit knowledge to be made explicit (Nonaka, 1994). Hence, Inter-organizational socialization in the research network helps the cooperating firm in getting access to the tacit knowledge and in absorbing it (Brown & Duguid, 2000; Dhanasai & Parkhe, 2006). Access to tacit knowledge may remove the bottlenecks the cooperating firm faces and hence increases the probability of introducing an innovation new-to-the-firm.

The orchestrator has the highest responsibility for creating value and extracting

value from the network (Kogut, 2000; Dhansai & Parkhe, 2006). As innovations only new-to-the-firm are not truly novel, the whole value to be created within the network and the share to be captured by the orchestrator may not be large enough to encourage systems providers to commit the efforts needed for network orchestration. The orchestrator is responsible for managing the research network in a strategic way. Therefore, it is reasonable for systems providers that are engaged in orchestration to aim for significant value added, i.e. not just an innovation new-to-the-firm.

Our study also shows that the probability of introducing an innovation new-to-the-firm is higher if the systems provider has more breadth (diversity) and is lower if the systems provider has more depth (intensity) in its external knowledge sourcing. Inter-organizational socialization leads to realization of synergies amongst heterogeneous partners. This leads to realization of cumulative learning with positive impact on the probability of introducing an innovation new-to-the-firm (Becker & Dietz, 2004). Depth has a negative impact on the probability of introducing an innovation new-to-the-firm. A possible reason could be that firms tend to over search (Laursen & Salter, 2006; Katlia & Ahuja, 2000).

The estimates results of other control variables are present in the table 3.2, model 4. The systems provider size is not significant. Nonetheless, a large system provider with sound experience increases the probability of introducing an innovation new-to-the-firm.

3.4.2 Impact on innovation new to market

Insert table 3.3 and 3.4 here [6]

The scenario is different when the innovation new-to-the-market is considered. From network perspective, our results show that the probability of introducing an innovation new-to-the-market is higher if the position of orchestrator is occupied by a user, a supplier, or a systems provider. Table 3.3 contains the empirical results.

The benefits associated with cooperative arrangements with users in the innova-

[6]Tables are attached after the reference section

tion process have long been acknowledged (Von Hippel, 1976, 1988; Rothwell, 1977; Quinn, 1985), especially when the innovation is more complex, or when the market for the innovation is not fully defined (Tether, 2002). Suppliers provide access to potential solutions for crucial bottle necks, key ingredients for innovations new-to-the-market (Sahal, 1981; Kohler et al., 2012). Systems providers, on the other hand, seem to be better equipped with organizational skills and capabilities needed for effectively orchestrating innovation networks. These include the communication skills, the collaboration capability, the ability to influence other actors, and the visioning capability (Ritala, 2009).

The interesting point in our study is that when it comes to introducing an innovation new to market, the presence of universities and research institutes as orchestrator has no significant impact. In other words, although prior research indicates that cooperative research with universities and research institutes is more aimed at new-to-the-market innovations (Tether, 2002; Monjon and Waelbroeck, 2003), their role as orchestrator in PFRNs shows no significant impact on the probability of truly novel innovations by participating systems providers. This could be due to the fact that research institutes and universities usually lack the visioning capability to see how technology or the business field will develop and to devise a proper business model that works right for the new to the market innovation. This visionary capability is considered as a key orchestration capability in the literature (Ritala, 2009).

Not surprisingly, the probability of introducing innovation new-to-the-market is lowered if the orchestrator is a consultancy. Consultancies are known to be market driven and market driven activity usually doesn't result in innovation new-to-the-market (Kohler et al., 2012). Surprisingly research institutes and universities' position as orchestrator of PFRNs have an insignificant impact on the probability of introducing an innovation new-to-the-market. Table 4 contains the empirical results.

Regardless of the nature of innovation being introduced, from a network perspective the system providers' size increases the probability of introducing innovation new-to-the- market.

From systems provider perspective (table 3.4), our finding indicates that the probability of introducing an innovation new-to-the-market is higher if a systems provider

is the network orchestrator. However, if the systems provider acts as a network co-operator the impact is insignificant. Therefore, if the goal of the systems provider is not to be pioneering a new to the market innovation but only to catch-up and introduce new to the firm innovations, it is better to position itself as a network cooperator, leaving the role of network orchestration to other players.

Orchestrator is expected to be responsible for the strategic management of a network, facilitate the flow of knowledge, learn from the partners and exploit resources made available (Ahuja, 2000; Pisano, 1990; Dhansai & Parkhe, 2006). As mentioned earlier, the orchestrator is usually after creating a big value from the network and taking a share of the value outcome (Dhansai & Parkhe, 2006). It is mainly the strategic interests of systems provider that can justify its involvement in orchestration role. Hence, it is not surprising to see a positive impact of market players' presence as the orchestrator of PFRNs on the probability of introducing an innovation new-to-the-market.

Estimates for the respective control variables can be found in table 4 and 5. Not surprisingly size of systems provider increases the probability of introducing an innovation new-to-the-market. This is also supported by prior research, which indicate that big and reputable firms have a higher propensity to participate in innovation networks (Tether, 2002) and as network orchestrators better help to maintain the collaboration and attract potential network partners to join the initiative (Morris et al., 2006; Dhanaraj & Parkhe, 2006). In short, large organizations are better equipped with organizational level determinants of innovation network orchestration capability (Ritala et al., 2009).

Surprisingly, from system providers perspective, a big systems provider with more experience diminishes the probability of introducing an innovation new-to-the-market. A possible explanation for this could be the organizational inertia which slows the process by which a truly novel idea is introduced (Kelly & Amburgey, 1991). Furthermore, from networks perspective, the impact of a big systems provider with more experience as an orchestrator is insignificant.

3.5 Llimitation

Pavitt (1984) characterizes every sector with its own specific patterns of technological change. Ritala et al. (2009) also indicate that innovation orchestration capability is a firm and industry-specific phenomenon. Since our empirical setting is the renewable energies in general and Danish wind turbine sector specifically, the results of the paper should be interpreted mostly in similar contexts.

Every technology is known to have its own set of interdependencies (Rosenberg, 1979), dosage of tacit knowledge (Dosi, 1988; Silverberg et al., 1988), role of standard-setting bodies (Rosenkopf & Tushman, 1998), institutions (Nelson, 1987), and environment (McKelvey, 1997). Hence, the results of this paper should be applied preferably to technologies with similar set of attributes.

Although our data only covers Danish wind turbine industry and it could be looked upon as a limitation, this could be a blessing in disguise. The Danish context aggravated the pace at which the wind industry took off to become a world pioneer in this sector. This helps us in analyzing the research networks from the perspective of multiple contexts: country and government.

As Huizingh (2011) highlights there is a need to take into account the context factors while studying open innovation with the help of a systematic empirical research. In this paper, we have analyzed the effectiveness of participation in research networks on the innovativeness of the systems providers. Investigating only the PFRNs helps us in appreciating the role played by context in open innovation. However, one must be cautious while generalizing the results of this paper. As the funding organizations are public bodies and not the classic profit-maximizing entity, the final outcomes lie in a domain of public-private interactions, an area which is still known as a black-box by few researchers (David & Hall, 2000). For instance, there is usually public disclosure obligations attached with government funds, while in the context of private companies' initiated networks this often is not the case.

3.6 Conclusion

The governments decision of putting different kind of entities in the orchestration position and handing over the network orchestration role to them could have many implications. The best analogy for understanding these implications is to throw a stone in water and try to measure how far the ripples travel. In this research we touched upon one of these possible implications, namely the innovative performance of the involved systems providers. This was done from two perspectives: (1) network and (2) involved systems provider perspectives.

One major policy implication of our work is the need for public bodies to be more careful when deciding the kind of organization to orchestrate the research networks they initiate and fund, as it influences the propensity to innovate, or the level of innovative results.

For instance, if they aim at high level innovation, as it is usually the case, it is preferable to choose entities closer to the market, like systems providers, suppliers, and users, as orchestrator. Moreover, our research shows that the size of systems providers involved in PFRNs increases the probability of introducing innovation new-to-the-market. Accordingly, one of the best scenarios for public bodies is to put big systems providers in the orchestration position of PFRNs and handing over the orchestration role to them. Doing so increases the probability of introducing innovation new-to-the-market. This may also help in preventing over-reliance on public funding and enabling these orchestrators to build system integration or platform leadership capabilities. These capabilities could be the new sources of competitive advantage for leading companies.

DARPA, as a leading public body in stimulating U.S. innovation, through years of experience in initiating PFRNs has come to a similar conclusion. Fuchs (2010) describes DARPA's changing approach toward choosing the focal entity in network formation: "Unlike in 19922001, when start-up companies would have been funded directly, in 20012008, start-up companies were frequently not able to be the primary contractor on a proposal. [They] needed to team up with an established vendor to receive funding for the project." She further illustrates that: "DARPA funding shifted from universities to industry (especially, established vendors)." Simply put,

DARPA has adopted a policy of handing over the orchestration role of its funded research networks to established systems providers.

Our empirical study benefited from the in depth analysis of a single market, single country over a time period. However, studying the same phenomenon both empirically and qualitatively for other complex technologies and extending the similar studies to different countries, will help in shedding light on the impact of the different institutional set ups and government policies on the innovative performance of the systems provider.

Geroski (2000) suggested that in order to develop a complete understanding of any phenomenon it is crucial to investigate not just success stories but also failures. Another fruitful venture could be to build a comparative study. In this case, a comparison could be drawn between a setting where the efforts yielded fruitful results and another setting where the efforts failed. This will help in shedding light on the factors that may hamper the final outcome.

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List of Variables		
Variables	**Description**	**Empirical measurement**
DEPENDENT VARIABLES		
Innovative Performance of		
firm_inn	Innovation new to the system provider	1: Realization of an innovation new to the firm, 0:Otherwise
mkt_inn	Innovation new to the system provider and the market	1: Realization of an innovation new to the market, 0:Otherwise
INDEPENDENT VARIABLES		
System provider perspective		
net_orch	system provider occupies position of the orchestrator in the network	1: System provider occupies the position of the orchestrator, 0: Otherwise
net_coop	system provider is a cooperator in the network	1: System provider occupies the position of the cooperator, 0: Otherwise
Network perspective		
net_uni	university occupies position of the orchestrator in the network	1: University occupies the position of the orchestrator, 0: Otherwise
net_rsh	research institute occupies position of the orchestrator in the network	1: Research Institute occupies the position of the orchestrator, 0: Otherwise
net_user	user occupies position of the orchestrator in the network	1: User occupies the position of the orchestrator, 0: Otherwise
net_const	consultancy occupies position of the orchestrator in the network	1: Consultancy occupies the position of the orchestrator, 0: Otherwise
net_company	system provider occupies position of the orchestrator in the network	1: System provider occupies the position of the orchestrator, 0: Otherwise
CONTROL VARIABLES		
Related to Public funded R&D research		
Breadth	Number of cooperation partners	numerical value: number of partners, 0:Otherwise
Depth	Intensity of search across the cooperation partners	numerical value: type of partner present in the public funded research network, 0:Otherwise
dem_stock	Project is funded as part of a demonstration Project	1: Participated in a Demonstration project, 0:Otherwise
con_stock	Project is funded as part of a cost-sharing R&D contract	1: Participated in a cost-sharing R&D contract, 0:Otherwise
Related to System Providers		
firm_size	Firm size	Sales in log
exp_nm_year	Firm experience	The number of year for which the firm was observed selling turbine on the market
firm_mul_exp	interaction between firm size and firm experience	interaction between firm size and firm experience
Related to complexity of products		
Rotor_d	Turbine diameter	Diameter of the Turbine in metre
hub_h	Turbine height	Height of the turbine in metre

Figure 3.1: Detail of Variables

Table 3.1: Innovation new to the firm, Network perspective (Model 1: Pooled logit; Model 2: Conditional logit;Coefficient

	(1) Model	(2) Model
firm_inn		
net_uni	-0.973***	-1.394***
	(0.000)	(0.000)
net_rsh	-0.455**	-0.550**
	(0.008)	(0.009)
net_sup	4.379***	4.846***
	(0.000)	(0.000)
net_user	-2.526***	-3.083***
	(0.000)	(0.000)

net_const	0.342**	0.977***
	(0.006)	(0.000)
net_company	-2.110***	-1.982***
	(0.000)	(0.000)
con_stock	-1.240***	-1.719***
	(0.000)	(0.000)
dem_stock	0.955***	1.226***
	(0.000)	(0.000)
firm_size	-0.354***	-0.663***
	(0.000)	(0.000)
exp_nm_year	-0.186***	-0.257***
	(0.000)	(0.000)
firm_mul_exp	0.0631***	0.0810***
	(0.000)	(0.000)
rotor_d	0.0258***	0.0124
	(0.000)	(0.052)
hub_h	-0.0404***	-0.0276***
	(0.000)	(0.000)
_cons	0.337	
	(0.098)	
pseudo R-sq	0.277	0.282
N	7034	6637

p-values in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Table 3.2 : Innovation new to the firm, System provider perspective (Model 3: Pooled logit; Model 4: Conditional logit;C

	(3) Model	(4) Model
firm_inn		
net_orch	-0.745***	-0.385**
	(0.000)	(0.001)
net_coop	2.657***	3.195***
	(0.000)	(0.000)
breadth	0.128***	0.157***
	(0.000)	(0.000)
depth	-0.657***	-0.955***
	(0.000)	(0.000)
dem_stock	-1.306***	-1.225***
	(0.000)	(0.000)
con_stock	-2.042***	-2.022***
	(0.000)	(0.000)
firm_size	-0.302***	-0.779***
	(0.000)	(0.000)
exp_nm_year	-0.144***	-0.255***
	(0.000)	(0.000)
firm_mul_exp	0.0379***	0.0621***
	(0.000)	(0.000)
rotor_d	0.0521***	0.0472***
	(0.000)	(0.000)
hub_h	-0.0580***	-0.0407***
	(0.000)	(0.000)
_cons	0.117	
	(0.530)	
pseudo R-sq	0.204	0.213
N	7034	6637

p-values in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Table 3.3: Innovation new to the market, Network perspective (Model 5: Pooled logit; Coefficients)

	(5) Model
mkt_inn	
net_rsh	-0.363
	(0.523)
net_sup	1.855***
	(0.000)
net_user	2.051**
	(0.001)
net_const	-10.53***
	(0.000)
net_company	5.594***
	(0.000)
con_stock	6.869***
	(0.000)
dem_stock	-8.043***
	(0.000)
firm_size	3.226***
	(0.000)
exp_nm_year	-0.243*
	(0.034)
firm_mul_exp	0.000208
	(0.994)
rotor_d	-0.0837***
	(0.000)
hub_h	-0.0593**
	(0.004)
_cons	-11.38***
	(0.000)
pseudo R-sq	0.498
N	7034

p-values in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Table 3.4: Innovation new to the market, System provider perspective (Model 6: Pooled logit; Coefficients)

	(6) Model
mkt_inn	
net_orch	5.773***
	(0.000)
net_coop	-2.557
	(0.615)
breadth	-0.180**
	(0.002)
depth	2.595***
	(0.000)
dem_stock	-7.594***
	(0.000)
con_stock	1.727
	(0.734)
firm_size	3.859***
	(0.000)
exp_nm_year	0.0854
	(0.404)
firm_mul_exp	-0.110***
	(0.000)
rotor_d	-0.0521**
	(0.002)
hub_h	-0.0589**
	(0.001)
_cons	-13.77***
	(0.000)
pseudo R-sq	0.461
N	7034

p-values in parentheses
* p<0.05, ** p<0.01, *** p<0.001

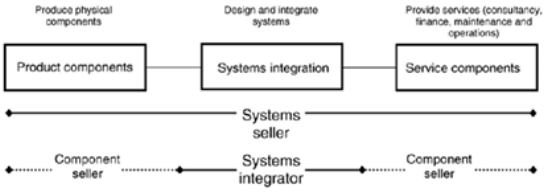

Figure 3.2: System providers: systems sellers and systems integrators (Davies et al., 2007)

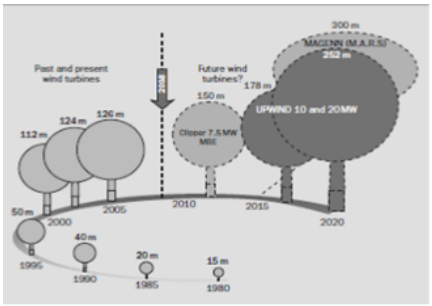

Figure 3.3: Growth in size of commercial wind turbine design (Fichaux, N., 2009)

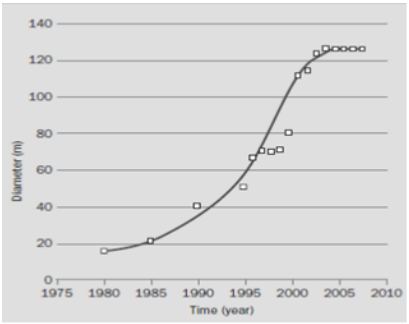

Figure 3.4: Turbine diameter growth with time (Fichaux, N., 2009)

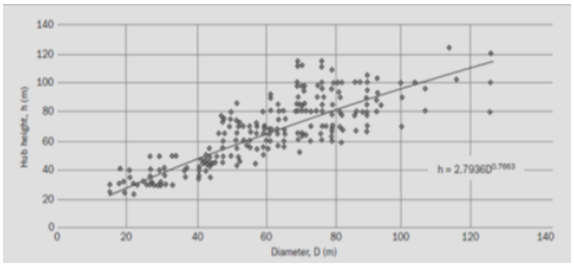

Figure 3.5: Hub height trends (Fichaux, N., 2009)

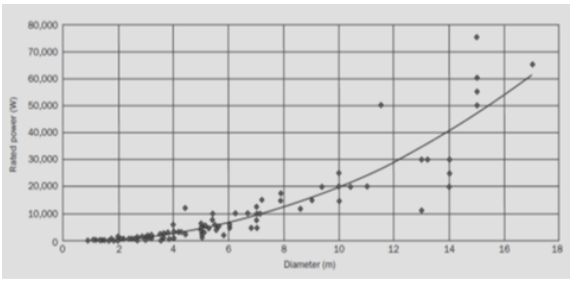

Figure 3.6: Manufacturers' defined rated power as a function of rotor diameter (Fichaux, N., 2009)

4

Assessing The Impact Of External Search On The Innovative Performance Of Firms In Danish Wind Power Industry

Abstract

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The objective of this paper is to contribute to the empirical literature investigating the impact of external search process on innovation performance under the open innovation framework. The role played by information interpretation, collaboration experience and collaboration objectives as moderators between external search process and innovation performance is investigated. Empirical setting of the paper is Danish wind power Industry. Publicly funded collaborations in the Industry are studied. The main results indicate that collaboration objective and collaboration experience significantly moderate the relationship between external search and innovation performance. They also corroborate the prior research which underlines the importance of prior knowledge base in being able to leverage the external search.

Keywords : External search, Information interpretation, Collaboration experience, Collaboration objective, Danish wind power Industry

4.1 Introduction

Almost a decade of research of the open innovation model has given the centre stage to external search process. The importance of external search process can be felt widely both in the real world business scenarios and the academic literature. When the firm starts to focus outside its boundary for information or expertise, it embarks on a journey of connecting with the outside world. During this journey, it learns where to search, how to search, and most important how to set the objective for the search.

Knowledge accessed via external search does not become part of the organizations routine base in one step (Grant and Fuller,2004). Many factors alter the impact of the search on the innovation performance both financially (Mancusi and Vezzulli,2010) and non-financially (Deste et al, 2012). An example with focus on managing non-financial aspects is, P&Gs 'critical supplier partnership'. The program sets clear objective in its 'Master Collaboration Agreement' and the employees of P&G work with the employees from the suppliers firm at the R&D lab of the suppliers. These collaborations were developed over a significant time period and have resulted in promising outcomes like development of Chemicals in record time. The close interactions between employees, clear objective and learning from past experience have been few critical aspects amongst many others (Sakkab, 2002).

While exploring the impact of external search process on innovation performance, it is crucial not to build on the assumption that knowledge can be easily accessed from outside (Dahlander and Gann,2010) and integrated within the organization in one step (Winter and Szulanski,2001). Also, the sole motive of implementing open innovation model is not to acquire knowledge but to access knowledge (Grant and Fuller, 2004). Identifying innovation related knowledge helps the firm in identifying the complementarities in the knowledge base of its collaborators. Leveraging on the complementary knowledge base of the collaborators and integrating the knowledge makes the process of integrating knowledge efficient (Demstez, 1991). Prior to accessing knowledge, the information via which the knowledge is available needs to be interpreted (Huber, 1991). Also, leveraging on the complementary knowledge base can be done when the firm knows where to look, an answer it can have only by learning from its own past experience (Cyert & March, 1963). Furthermore,

when many diverse firms are involved in the process of leveraging complementary knowledge, lack of a clear objective (Cohen & Malerba, 2001) may have significant consequences.

Extensive prior literature exists exploring the impact of external search process on innovation performance (e.g: Laursen and Salter,2006; Katila and Ahuja,2002). In this paper, I propose to take a step further and explore the role played by three factors which may or may not alter the strength of the impact of external search on innovation performance: 1. Information interpretation, 2. Collaboration experience, 3.Collaboration objective.

The empirical setting of the paper is the Danish wind power market. Denmark is the centre for competence of the wind power at the international level and the only country in which by 2009 wind power represented 20% of electricity supply. Furthermore, the Danish wind power market presents us with the opportunity to perform an empirical analysis of an Industry that emerged as a grass-root movement in the 1970s, with no patents or intellectual property rights till 1990s and currently represents more than 7% of the annual Danish exports (Nissen et al., 2009). The analysis builds on market data from 1979 until 2011, coupled with data on PFRNs in which the Danish market players were observed.

The use of market data is a key point of departure from previous analyses, which used patent data (Lechevalier et al., 2011; Jaffe& Palmer, 1997; Brunnermeier & Cohen, 2003) or self-reported Community Innovation Survey data (Arranz & Fdez de Arroyabe, 2008; De Marchi, 2011; Horbach, 2008) as proxy for environmental innovation as those proxies could result in under- or over-estimate of innovation.

The research shows that collaboration objectives and collaboration experience moderate the relationship between external search and innovation performance. However, information interpretation does not provide statistically significant results.

The main contribution of the paper is that it analyses the role played by moderators in the process of external search. This is crucial as it sheds light on the factors that help the firm in performing an effective external search process (Dahlander and Gann, 2010). Learning from the past experience sheds light on the role played by

knowledge accumulation (Zollo and Winter, 2002) in the process of external search. Also, the mechanisms deployed to interpret the information help in understanding the role played by transfer of knowledge in enhancing the efficiency of external search. And, integrating the role played by objectives sheds light on the nature of research and development motive driving the innovation process (David and Hall, 2000).

The paper is structured as follows. In the first section I analyse the prior literature followed by hypothesis building. The sections that follow contain the database description, empirical results and finally the limitations and conclusion.

4.2 Prior research and research question

The classic lone Schumpeterian entrepreneur introducing successful innovation to the market or the linear model of innovation pursued by the firms are well documented former models of innovation. The former models of innovation have now been supplemented by models of innovation in which role of external players is well documented, acknowledged and much sought after (Von hippel, 1988; Kline and Rosenberg, 1986; Rosenberg, 1979). One of the most resent noted developments acknowledging the role of various external players is the model of open innovation. Quite frequently the definition used to explain open innovation is: Open innovation is the purposive inflow and outflow of knowledge to accelerate internal innovation and to expand the markets for external use of innovation, respectively (Chesbrough et al., 2006). Imprints of the idea of open innovation can be noticed in the literature on lead user arguments (Von Hippel, 1988), strategic alliances (Hamel, 1991; Doz, 1996).

In absolute layman terms open innovation is a process in which the focal firm searches extensively for knowledge outside its boundaries and integrates it with its own knowledge base in order to improve its innovative performance. External search process is one of the most widely researched pillars of open innovation (eg: Laursen & Salter, 2006; Katila & Ahuja,2002; Nerkar,2003). The external search process of the firm can be broadly divided along four dimensions: 1. Technology; 2. Organizational; 3.Time; 4.Geography. A search along any of these dimensions bestows the

firm with both benefits and drawbacks. Both benefit and drawback depend on the intensity of search performed by the firm. The dependent variable in these analysis ranges from potential of firms innovation, firm innovative performance, technological evolution, to mention a few.

For instance, Nerker(2003) investigates the search strategy of the firm across the time dimension. He concludes that the nature of the knowledge the firm searches from the past has an impact on the innovation outcome. Taking a step further, Phene et al (2006) explores the search strategy along the dimensions of technology and geography. They conclude that technological knowledge belonging to the same country but distant in terms of technology has a curvilinear relationship with innovation outcome. Furthermore, if the knowledge is distant both in terms of technology and geography it has no impact on the outcome. On the other hand, Katila (2002), Katila and Ahuja(2002) investigate the search strategy across two dimensions, time and technology. They investigate the impact of age of knowledge and the depth and scope of search process on the potential of innovation. These authors find support for the over searching behaviour of the firm. Building on their research, Laursen and Salter (2006) investigate the impact of the external search strategy of the firm on its innovative output. The external search strategy or the openness of the firm is analysed with the help of breadth and depth of search. Breadth is the number of external players across which the firm searches. Depth is the nature of knowledge provided by these external players. They find that external search i.e both breadth and depth have a positive impact on the innovative performance of the firm but only until a certain limit. Hence, firms tend to oversearch and this is detrimental for the innovation performance of the firm. They further corroborate the finding related to over searching behaviour of the firm. Or, if we look at it from other perspective, they all point towards the fact that external search is indeed crucial for the innovative outcome of the firm, however, too much of it is detrimental to the innovative outcome. Another crucial point identified by Laursen and Salter (2006) is the importance of breadth and depth depending on the degree of novelty of the product innovation. Depth has a higher impact on degree of novelty when compared to breadth. This hints towards a trade-off that exists between breadth and depth in the open innovation model.

The external search in open innovation or knowledge exploration is only half of the

story. As, 'open innovation is both a set of practices for profiting from innovation, and also a cognitive model for creating, interpreting and researching those practices (Chesbrough et al.,2006). The information acquired or the knowledge gained from the external sources needs to be successfully combined with the knowledge base of the firm to yield fruitful results. The search for external sources of knowledge and the transfer of this knowledge to the firm are two separate processes (Hansen, 1999). As Dosi(1988) highlights, Information is available pretty quickly, however the key is the transfer of the related know-how or the tacit component. This highlights the tacit component or the sticky aspect of the knowledge and the difficulties of transferring tacit knowledge (Von hippel, 1998; Suzalnski, 1996). Nonaka (1994) suggests socialization to be one of the ways by which tacit knowledge can be made explicit and transferred from one organization to another.

Quite surprisingly, the mechanisms deployed to benefit from the external search and the trade-off between the different construct of openness is relatively under researched (Dahlander and Gann, 2010; Lichtenthaler, 2011; Huizingh, 2011). In order to benefit from external search process it is crucial to transfer the knowledge across the firm boundary (Hansen, 1999; Lichtenthaler, 2011; Dahalnder and Gann, 2010; Grant and Fuller, 2004; Wallin and Van Grogh, 2010).

In the same spirit, Fabrizio (2009) investigates the impact of absorptive capacity building activities and innovation search process on the pace of innovation. The external search partner analysed by them is university. Apart from investigating the usual question related to the external search strategy they also investigate that how the external knowledge is combined with the firms existing knowledge with the help of degree of connectedness. Degree of connectedness reflects the social network of the firm (Nahapiet & Goshal,1998; Sheremata, 2000). Connectedness helps in building information bridges which facilitates the transfer of tacit knowledge.

Sakkab (2002) defines connectedness as the relationship between things that depend on each other; a logical linking or coherence. And, sheds light on the fact that the idea for illogical, unobvious connections that helps in combination of technology beyond their original limits lies at the heart of the business of P&G. This ideology draws attention towards the argument of recombination in the process of innovation. The novelty here does not lie in the idea of recombination but rather the fact that

the aim is to routinze recombination within the organization. Huston and Sakkab (2006) highlight the fact that the idea of connectedness which in formal terms inside P&G is known as the strategy of connect and develop accounts for 35% of companys innovation. The authors argue that the key to leverage from open innovation is to understand not just where to connect but also how to use the connections. In other words what are the mechanisms used to leverage from open innovation. They also draw attention towards the fact that learning from open innovation is not an instantaneous process and takes considerable time; also integrating knowledge across the boundary can be a challenging task (Van der Meer, 2007). Connectedness is one of the transfer mechanisms used to integrate knowledge across the boundary of the firm, amongst many others like group problem solving (Wallin and Van Grogh, 2010).

A quirky observation follows from the above cases: Do firms learn how to learn from open innovation instantaneously? Or does the process of learning improve as firms participate in more open innovation?

An external search process needs the firms to learn from a frame of reference which is new for them in other words the cognitive make-up of the focal firm needs to be tuned in, so that it can help the firm in learning from collaborators (Gioia and Chittipeddi, 1991). Along with cognitive make-up, over-coming not invented here syndrome (Chesbrough, 2006; Laursen and Salter, 2006) and inertia towards change (Armenakis and Bedeian, 1999) to mention a few. However, overcoming these challenges needs experimentation, adaptation and the whole process unfolds over a time period (Chiaroni et al, 2010). The process of experimentation and adaptation requires repeated involvement in the process of external search. In other words, replicating the strategy of implementing open innovation model over a time period is required. This replication is not as if the focal firm has a blue print that can be blindly followed. The focal firm needs to understand from its past experience what can be replicated and what needs to adapted to the current situation in order to receive fruitful results (Winter and Szukanski, 2001; Zollo and Winter,2002). Hence, understanding the role played by the past experience in rendering the current search strategy effective is crucial.

The external search strategy of the firm is a function of both the past experience

and future expectations (Laursen and Salter, 2006). The future expectations of the organizations are usually understood by looking up their research and development agenda or the kind of research projects they participate in. Either the agenda of the internal research and development program or the kind of research project they participate in, both can be understood by exploring the objectives of these projects or collaborations. Leipon and Helfat (2010) measure the breadth of the firms innovation objective and the breadth of its external search. The find significant impact for both: firms breadth of innovation objective and external search breadth on the firms innovation performance. However, they do not find a statistically significant result for the interaction effect. They attribute the reason to the level of multicollinearity present. They measure innovation objectives in the same spirit as that adopted by Cohen and Malerba (2001): 1. Product level objectives like developing new products, 2. Process level objective like reduction of labour cost. They explore the objective from the perspective of the focal firm. However, the collaboration in which the firm enters with its collaborators could also have a specific objective. This objective is crucial in enabling the different collaborators to have a shared purpose. An objective gives the different collaborators a shared purpose. This sense of shared purpose smoothens the process of collaboration and increases the chances of fruitful outcome (Schien, 1988).

The present paper builds on and contributes to the previous literature in the following way. Firstly, following the same approach of Laursen and Salter (2006) I measure the external search strategy of the firm or its openness with the help of breadth and depth. The impact of these two variables is assessed on the firms innovative performance. The search channels assessed are suppliers, users, universities, research institutes and consultants. Furthermore, the analysis is not performed on patent data or survey data but on real market data. This avoids the issue of over or under estimation of parameters. Secondly, the aim of paper is to explore the other factors which may alter the impact of external search process on the innovation performance of the firm. Having said that, three research questions are addressed.

The three research questions are:
1. Is the impact of external search on the innovation performance of the focal firm moderated by level of information interpretation?
2. Is the impact of external search on the innovation performance of the focal firm

moderated by the focal firms past external search experience or in other words collaboration experience?
3. Is the impact of external search on the innovation performance of the focal firm moderated by the objectives of the collaboration?

4.3 Hypothesis Building

Laursen and Salter (2006) investigate the role played by external search breadth and external search depth on firms innovative performance. They conclude that external search breadth is beneficial for the firms innovative outcome up to an optimal point, after which it is detrimental. And, the same holds for external search depth. In line with Katila (2002), Katila & Ahuja (2002) they empirically proof that firms tend to oversearch. A common cord that all these papers strike is the cost of external search process. Estimating the impact of search in the absence of the knowledge transfer mechanisms may narrate only half the story.

'Information about what other firms are doing spreads quite quickly; however the ability to produce or replicate successful results is much more sticky(Dosi, 1988).The sticky aspect point towards the tacit nature or the know-how related to a set of knowledge input needed to introduce a successful innovation. Availability of the information leads the focal firm to search across various potential organizations and learn from them either by being in an alliance with them, a project or simply considering their opinion. Understanding the medium through which the focal firm searches externally and attempts to transfer the information and knowledge gained is crucial for interpreting the dynamic nature of this process (Nonaka, 1994). When the focal firm engages in the external search process, it gains information. This information is the potential source through which the focal firm can gain the knowledge it is searching for (Dretske, 1981).Successful interpretation of the information and the transfer of the required information from the external organization to the focal firm depends on the prior knowledge base of the focal firm (Cohen and Levinthal, 1990) and the proximity between the knowledge bases of the involved organizations (Lane and Lubatkin,1998).

Inter-organizational knowledge transfer is widely acknowledged to face many obstacles

(Kogut and Zander,1993). However, presence of cross-functional interfaces (Gupta and Govindarajan, 2000) in the process of inter-organizational knowledge transfer leads to higher and intense communication (Daft and Langel, 1986). An intense communication leads to enhance the process of socialization, which is much needed for the transfer of tacit knowledge (Nonaka, 1994; Wallin and Van Grogh, 2010). Successful transfer of tacit knowledge enhances the rate at which organization is able to routinize the new changes (Zollo and Winter,2001) and further foster organization learning (Huber, 1991).

A group is one of the richest forms of media present for communication (Daft and Lengel, 1986) and they foster the process of socialiazation, which further enhances the information interpretation. Information interpretation is the process by which distributed information is given one or more commonly understood interpretation (Huber,1991). Successful information interpretation enhances the impact of search breadth on the innovation performance of the focal firm.

Hence the hypothesis,

H1a: Focal firms innovation performance has a curvilinear relationship (Inverse U shaped) with external search breadth and this relationship is moderated by level of information interpretation.

Depth captures the intensity of external search (Laursen and Salter, 2006). Investigating the impact of intensity of external search in the absence of the mechanism via which the information gained was transferred to the focal organization narrates only half the story just as in the case of external breadth.

Depth in external search facilitates the intense search process via which the focal firm can search deeply as per its need or agenda. This may lead to information distribution (Huber, 1991) resulting in recombination of old ideas with new, a vital ingredient for product innovation. Also, this may even lead to fusion of ideas which may foster information interpretation (Huber, 1991) resulting in a higher degree of novelty in product innovation.

The distribution of information or its interpretation is carried out via the knowledge transfer mechanisms or the cross functional interface. As a result, it may be

proposed that the external search depth and cross functional interface bear a significant impact on the focal firms innovation performance. Hence, the hypothesis,

H1b: Focal firms innovation performance has a curvilinear relationship (Inverse U shaped) with external search depth and this relationship is moderated by level of information interpretation.

The search behaviour of an organization builds on its past behaviour (Laursen and Salter, 2006). Firms implementing the model of open innovation as search broadly and this leads to recombination of knowledge and increases the possibility of success. Hence, the primary motive for getting involved in external search is capturing the opportunities present in the environment or in other words searching for a solution to a present problem or to an expected scenario (Cyert and March, 1963). However, the direction of search is not a random process, the direction is chosen depending on the fruitful chances of success (Schwab,Ungson and Brown, 1985). The probability of success is cacluated on the bases of some heuristics assessment of costs and benefits associated with the process (Cyert and March, 1963). This assessment is based on the organizations past experience from which it learns (Huber, 1991). The past experience help in building (Cohen and Levithal, 1990) the current search strategy of the firm. The search strategy may appear to be a replication of the same concept but this replication is always done in different context, with different actors and hence has a considerable tacit component (Winter and Szulanski, 2001). As time passes firms accumulate experience and are able to codify the needed concepts from the past experience (Zollo and Winter, 2002), this helps in framing the current external search. An example of the impact of past learning experience on the current organizational effectiveness can be found in the pizza stores studied by Argote and Darr(2000). They conclude that learning from recent past have a higher impact compared to distant past. However, one may argue that the level up to which the learning is retained depends on the kind of organization and cannot be generalized. Hence, learning accumulates over a time period and if it successfully becomes part of the organizational routine, its impact can be noticed in the current strategies pursued by the firm (Winter and Szulanski, 2001).

Hence, one may conclude that the impact of external search process on the innovation performance is moderated by the focal firms past collaboration experience.

H2a: Focal firms innovation performance has a curvilinear relationship (Inverse U shaped) with external search breadth and this relationship is moderated by the focal firms collaboration experience.

H2b: Focal firms innovation performance has a curvilinear relationship (Inverse U shaped) with external search breadth and this relationship is moderated by the focal firms collaboration experience.

Future direction of a firms search depends on the research related objectives of the firm (Cohen and Malerba, 2001; Leiponen and Helfat, 2010). These objectives can be understood by either looking at the R&D objective of the firm or the objective of the collaboration it participates in. Collaboration objectives help in facilitating the interpretation of information during the search process (Huber, 1991). In the presence of a clear objective the information is always framed under that objective. The framing of the information has significant impact on its interpretation (Tversky and Kahneman, 1991). Shared interpretation of the information facilitates the process of integrating the information in the right fashion in the organizational routines (Nelson and Winter, 1982). Developing shared interpretation is crucial as every organization has its own established cognitive framework with the help of which it interprets information (Dearborn and Simon, 1958) and directs search process (Tripsas and Gavetti, 2000). Hence, once the firms participate in a search process via collaboration the objectives of the collaboration help in developing a shared interpretation framework. As a result, the shared interpretation helps in effectively leveraging from the search process and this impact can be felt on the innovation performance of the focal firm. Hence, the following hypothesis:

H3a: Focal firms innovation performance has a curvilinear relationship (Inverse U shaped) with external search breadth; this relationship is moderated by the objective of the collaboration.

H3b: Focal firms innovation performance has a curvilinear relationship (Inverse U shaped) with external search depth and this relationship is moderated by the objective of the collaboration.

4.4 Dataset, Variables and Estimation Method

The section begins with a brief description of the database, followed by an in depth description of the variables.

4.4.1 Dataset

The empirical analysis is done on a unique database. Informational content of the database can be understood along two dimensions: (1) Information about the market details of the focal firm from 1979-2011 and the state funded projects they were observed in, and (2) Information about the product sold by the focal firms on the Danish market.

Market details of the focal firms were obtained from the Danish wind turbine owners association. The information about the state funded project was obtained from two sources: (1) Public database maintained by Riso National Laboratory for Sustainable Energy. (2) Community Research and Development Information Service (CORDIS), which covers European funded projects (e.g. ENNONUC 3C, ENALT 2C and THERMIE).

The database does not suffer from the usual problem of sample selection bias, as the whole population of the Danish wind turbine market was observed. The Danish market merits an analysis for two prime reasons. Firstly, it is the centre of competence for wind technology. Secondly, different roles played by various organizations in making it a centre of competence. These roles have been studied from two perspectives: (1) The role played by informative interactions amongst various organizations (Garud & Karnoe, 2003), and (2) Specific role of state funded projects, like demonstration projects is being undermined (Hendry & Harborne, 2011). Taking a step further, we try to investigate the impact of organizations falling both in public and private domain on the innovative outcomes.

The projects in which the focal firms were observed are financed in part by either the Danish energy authority, Energitek, Elfor or the European Union funding. Danish energy authority is a branch of the Danish government and grants funds for R&D of cleaner and more power efficient energy production. Energitek is responsible for the Danish power and natural gas system and grants funds for development and

demonstrations of technologies for environmental friendly power production. Elfor is the trade association for the power distribution companies, it grants funds for R&D projects in the field of efficient use of energy.

The dataset covered 79 focal firms. Data was collected for 818 state funded projects. In 144 projects from 1981 until 2010 the Danish system providers were observed. The use of market data is a key point of departure from previous analyses, which used either patent data (Lechevalier et al., 2011; Jaffe & Palmer, 1997; Brunnermeier & Cohen, 2003) or self-reported Community Innovation Survey data (Arranz & Fdez de Arroyabe, 2008; De Marchi, 2011; Horbach, 2008) as a proxy for environmental innovation. These proxies could result in under- or over-estimation of innovation.

An argument can be raised concerning the lack of adequate amount of data and its possible impact on the empirical outcomes. However, we follow the argument of Tether and Tajar (2008) and propose that, in such scenarios it is better to learn from the available data in the best possible manner. The other option is to simply ignore the presence of any data. And, this might mean bidding farewell to a key stepping stone of learning. Nonetheless, we do understand that the readers may have different perspectives.

4.4.2 Variable and Estimation method

Dependent Variable

Innovation performance has been at the heart of many scholarly debates. In this paper we measure innovation performance by measuring the sales from new product (Lausen & Salter, 2006). Where, new product is considered to be a product new to the firm only. The key benefit of using the proxy is that it is able to account for the innovation performance from a commercial perspective. In other words, it helps in capturing the success of commercializing innovation (Leiponen and Helfat, 2010). The distribution of the sales new to firm is highly skewed. Following the approach of Nerker & Roberts (2004) I take the log of real sales new to firm to construct my dependent variable.

Independent Variable

Breadth and depth are measured building on the approach of Laursen and Salter(2006). Breadth measures the number of external sources the firm is collaborating with.

Depth measures the intensity of this search or in other words the knowledge base of these sources.

Level of information interpreted is measured with the help of group size. The size of the project group is a strong proxy for communication inside the group (Ancona and Caldwell, 1992; Labianca, 2004). As Nonaka (1994) points out socialization is the key to make tacit knowledge explicit. And, information spreads quickly but the know-how aspect of knowledge is a time consuming process with a strong need of communication (Dosi, 1988). The collaboration experience of the focal firm is calculated by counting the number of past collaborations the firm participated in.

The objective of the collaboration is measured by taking into account the nature of R&D funding the collaboration was provided. The R&D funding provided by the public bodies can be categorized depending on their objectives (David & Hall, 2000). Project funding may range from non-mission oriented, like basic R&D, to mission oriented, like contract-based to demonstration projects or field trials (Hendry & Harborne, 2011). Categorizing the R&D funding is vital for understanding the nature of the project supporting the learning by searching activities of the players involved. Depending on the nature of the fund granting organizations the empirical analysis is carried out by categorizing the projects in two broad categories: (1) Demonstration projects and (2) Contract projects. Along with the nature of the projects, the number of projects the focal firm has participated in is also controlled. This helps in taking into account the experience the focal firm has in the open innovation.

Control Variable

The age of the firm is introduced as a control variable. The variable is constructed on the basis of its market presence. The number of years a firm is observed on the market is the age of the firm. This helps in controlling for the experience base of the firm.

The systemic and complex nature of wind technology has been the center of many discussions lately (Andersen & Drejer, 2008 ; Bergek & Jacobsson, 2003). Complexity can be due to the number of sub-component present (Rosenberg, 1982). The sub-components contribute to the functioning and success of the product as a whole. However, all the sub-components do not grow in the same proportion (Sahal, 1981).

Sahal (1981) argues that in order to consider the evolution of a complex technology, it is important to consider three aspects: (1) Growth of the functional forms, i.e. sub-components; (2) The change in the material; and (3) The change in the complexity of the technology embodied in the product. By considering the dimensional characteristics of the technology embodied in the product we control for the growth in the sub-components, namely the height and diameter of the turbines.

Estimation Method

The dependent variable, innovation performance is continuous in nature. Hence, the coefficients are estimated with the help of a fixed effect OLS model. Robust results are presented in the result section.

4.5 Empirical results

Insert Table 4.1 here [1]

Table 4.1 contains the descriptive statistics. Danish wind turbine power Industry is studied in order to explore the role played by focal firms external search and the moderators that may affect this relationship its innovative performance. The sources for external search are: 1. University, 2. Research Institute, 3. User-representative body, 4. Supplier, 5.Consulting firm. Table 1 presents the descriptive statistics. The mean value for breadth is higher than the mean value for depth. This sheds light on the fact that on average firms tend to search more broadly rather than more deeply. The maximum value of breadth is 30. This value may appear to be a bit misleading. Let us consider an example in order to understand how breadth is measured over a time period. For example, Bonus was part of collaboration from 1997 to 1999 and had three external collaborators: 1. Forknigscenter Riso, 2. Nordtank Energy Group A/S, 3. Vestas Wind Systems A/S. Hence, from 1997 to 1999 Bonus had an external breadth value of 3. However, during the same period it was also part of anothercollaboration with four external collaborators: 1. Forknigscenter Riso, 2. Tripod Wind Energy ApS, 3. InterCon I/S, 4. Vestas Wind System A/S, 5. NEG Micon A/S. Hence, Bonus had an external breadth of 5. As a result, for the period 1997 to 1999 it had a breadth of 8. The variable for depth has been constructed

[1] Tables are attached after the reference section

in a slightly conservative fashion. Five dummy variables were constructed for: 1. University, 2. Research Institute, 3. User-representative body, 4. Supplier, 5.Consulting firm. If the firm had a partner in any of these categories the value was one otherwise zero. Finally for a given year all the dummies were collapsed under the variable depth.

In the collaborations the firm could occupy two positions: 1. Network orchestrator, 2. Network Cooperator. In a given year the positions of network orchestrator and network co-operator are not mutually exclusive. Let us consider an example. From 1994 to 1996 Bonus was part of collaboration as cooperating organization. And, from 1995 to 1996 it was part of collaboration as performing organization. As a result, for the year 1995 and 1996 Bonus was both a network co-operator (cooperating organization) and a network orchestrator (performing organization). From the descriptive statistics it can be noticed that the firm occupies the position of Network co-operator more frequently than the position of Network orchestrator. The construction of the variable of project size also follows similar approach and averages around 13.

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Insert table 4.2, 4.3,4.4, 4.5,4. 6, 4.7 and 4.8 here [2]

Table 4.3, 4.4,4.5,4.6,4.7 & 4.8 presents the regression results. In table 4.3, model 1 presents the results for all the control variables. All the control variables are sig-

[2]Tables are attached after the reference section

nificant. Model 2 (table 4.3) performs an exercise to justify the use of the lagged group size variable to measure knowledge accessed. The argument behind performing this exercise stems from the fundamental theories of knowledge based view of firm (Grant, 1996) and organizational learning theories (Huber, 1991; March, 1991). Communication within a group are considered to be intense (Daft and Lengel, 1986), this facilitates the codification of tacit knowledge (Nonaka, 1994). The group size helps is a proxy for information interpreted. The fundamental point here is that the process of information interpretation is a time consuming process. A group with individuals from different organizations falling in different knowledge domains requires them to learn from a new frame of reference (Huber, 1991). And, as prior literature (Argyris,1976) and case studies(Sakkab,2002) have highlighted this may take considerable time. The time taken can also be interpreted as cost of coordination (Grant,1996). In model 2, group size has a significant negative impact on the innovation performance whereas when the variable is lagged by one year the impact is positive and significant. Hence, the effectiveness of forming a group to access knowledge can be observed in a years time. Hence, the need to lag group size by one year is justified.

In model 3 (table 4.4), I do not control for breadth and depth. The reason behind this is the fact that the correlation of group size with both breadth and depth is very high. Hence, in model 3 I estimate only group size to understand what is its impact in absence of breadth and depth. As it can be observed, even in the presence of breadth and depth its impact is not altered significantly.

Hypothesis 1a is not supported. The results are present in model 5 (table 4.5). A possible explanation for this could be the multicollinearity between breadth and the group size which is used to measure information interpretation.

Hypothesis 1b is partially supported. The results are present in model 6 (table 4.5). Information interpreted measured via group size negatively moderates the relationship between depth and innovation performance. Hence, with increasing group size, a large depth will have a significant negative impact on the innovation performance. However, the impact of group size as a moderator between square of depth and innovation performance is statistically insignificant. A possible explanation for the partial support of the hypothesis could be for due to the fact that the

multicollineairty between group size and depth is less when compared to the level between group size and breadth. Another possible explanation for the moderation effect not holding up could be the following theoretical reasoning when large depth and large group size are observed simultaneously. Prior literature has quite often mentioned that when the group size is too large and functional diversity is high this may impede social integration within the group (Ancona and Caldwell,1992). Furthermore, in the lack of social integration the process of creative problem solving and implementation of new process may be hampered (OReilly and Flat, 1989). Also, beyond a certain group size, sub groups may develop increasing cost of coordination (Keller,1986; Keller,2001).

Hypothesis 2a is partially supported. The results are present in model 7 (table 4.6). Collaboration experience does moderate the relationship between breadth and innovation performance. However, the effect of moderation between square of breadth and innovation performance is statistically insignificant. Hypothesis 2b is completely supported. The results are present in model 8 (table 4.6). Collaboration experience moderates the relationship between depth and innovation performance; square of depth and innovation performance. The relationship between depth and collaboration experience is negatively moderated. Hence, the impact of depth on innovation performance decreases as collaboration experience increases. A possible explanation for this decrease could be the failure in learning from the tacit component of the past experience. As replication of the same strategy also has significant tacit component (Winter and Szulanski, 2002). On the other hand, the relationship between square of depth is positively moderated. Hence, Depth has a decreasing impact on innovation performance as collaboration experience increases but the rate of this decrease reduces as depth increases. However, as depth increases the firms have more experience accumulation (Zollo and Winter, 2001) and is able to learn from its experience (Huber, 1991).

The third hypothesis is tested by further sub-dividing it in two parts. In part one, table 4.7 i.e. model 9 and model 10, the moderation effect of demonstration based collaboration is investigated. In table 4.8 (model 11 and model 12) the moderation effect of contract based collaborations is investigated.

Hypothesis 3a holds. The results are present in model 9 and model 11. The

relationship between external breadth and innovation performance is negatively moderated by demonstration collaborations. The relationship between square of breadth and innovation performance is positively moderated by demonstration collaborations. Hence, breadth has a decreasing impact on innovation performance as demonstration collaborations increase but the rate of this decreases impact reduces as breadth increases. The relationship between breadth and innovation performance is positively moderated by contract collaborations. The relationship between square of breadth and innovation performance is negatively moderated by contract collaborations. Hence, breadth has an increasing impact on innovation as contract collaborations increases but the rate of increasing impact declines as breadth increases. Hence, when the collaboration objective is demonstration, which means engaging in research which is in development stage, then higher value of breadth is helpful. Whereas, if the collaboration objective is contract based then, which means research in early stage, a high value of breadth could proof to be detrimental for the innovation performance. These results could point towards the well-established fact that it is easier for the firm to learn from outside when it has a prior knowledge base (Cohen and Levinthal,1990) which is quite the case in demonstration projects as the firm is only trying to improve the development of the product. Whereas, in contract based products the firm is in error and trial mode and as a result lack learning process may be hindered due to distances between the organizations (Lane and Lubatkin,1998; Kogut and Zander,1993).

The hypothesis 3b holds partially. The results are present in model 10 and model 12. The role played by demonstration collaborations as a moderator between depth and innovation performance is statistically insignificant. Whereas, the role played by demonstration collaborations as a moderator between square of depth and innovation performance is negative. In case of depth and contract collaboration the hypothesis for moderation does not hold. From the results for hypothesis 3 one can conclude that, it is important to consider the impact of collaboration objectives as different kind of public R&D fundings have different impact on the outcome (David and Hall,2000).

4.6 Conclusion and Future Research

Impact of the external search process on its innovation performance could be moderated by many factors. In this paper, I explored the role played by three moderators: 1. Information interpretation, 2. Collaboration experience, 3. Collaboration objective.

For instance, if the firm aims to improve innovation performance by engaging in external search activities then, it is beneficial to participate in collaborations with objective closer to the prior knowledge base of the firm. Also, it is beneficial to have a large prior experience of collaboration. The results helped in shedding light on the trade-offs of external search process. An insight into the trade-offs helps in estimating the complete potential of open innovation model, a crucial input needed for the complete development of a framework (Foss, 2003).

The empirical study in this paper benefited from analysing longitudinally single country, single industry, as it provides the analysis with a context (Huizingh,2011). Future research could benefit from extending the research to scenarios and time periods. Also, exploring the role played by firms research objectives along with the collaboration objective could deliver many insightful results. In particular, it will help in shedding light on the debate of public R&D vs private R&D (Gonalez and Pazo, 2008) from a cognitive perspective.

4.7 Reference

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Table 4.1: Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
breadth	7515	6.287957	7.044526	0	30
depth	7515	1.50845	1.592428	0	5
proj_size	4403	13.27186	10.6455	0	46
num_proj	5289	3.851957	2.682347	1	9
exp_nm_year	7515	13.26733	7.097649	1	35
net_orch	7515	.2326015	.4225184	0	1
net_coop	7515	.6545576	.475544	0	1
dem_stock	7105	.5584799	.4966033	0	1
con_stock	7035	.4648188	.4987962	0	1
rotor_d	7514	36.54396	22.25703	0	120
hub_h	7514	36.85782	17.27035	0	107

Table 4.2: Correlation Matrix

	log_sa~n	breadth	depth	proj_s~e	num_proj	exp_nm~r	net_orch	net_coop	dem_st~k	con_st~k	rotor_d	h
log_sales_n	1.0000											
breadth	0.0518	1.0000										
depth	-0.1426	0.6457	1.0000									
proj_size	-0.0388	0.8563	0.6042	1.0000								
num_proj	-0.1922	0.6647	0.4507	0.4887	1.0000							
exp_nm_year	0.0414	0.5757	0.5683	0.6371	0.3616	1.0000						
net_orch	-0.3256	-0.2187	-0.0906	-0.3552	0.3296	-0.1824	1.0000					
net_coop	0.1352	0.3939	0.2643	0.3304	0.3623	0.2660	-0.3823	1.0000				
dem_stock	-0.0759	0.2418	0.2556	0.0958	0.3023	0.2995	0.2485	-0.1345	1.0000			
con_stock	-0.0605	0.2431	0.3891	0.2345	0.4198	0.2272	0.0750	0.4500	-0.3565	1.0000		
rotor_d	0.0132	0.2924	0.4656	0.4022	0.0097	0.2327	-0.4127	0.1490	-0.1838	0.2087	1.0000	
hub_h	-0.0242	0.2697	0.4316	0.3959	0.0213	0.2879	-0.3599	0.1223	-0.1146	0.1770	0.9251	1

Table 4.3: Control Variables and group size

	(1) Model	(2) Model
breadth	0.0783***	
	(0.000)	
depth	-0.228***	
	(0.000)	
proj_size	-0.0170***	-0.0342***
	(0.000)	(0.000)
num_proj	-0.0667***	
	(0.000)	
dem_stock	-0.0702	
	(0.242)	
con_stock	0.0708	
	(0.136)	
l_proj_size		0.0695***
		(0.000)
exp_nm_year		-0.0981***
		(0.000)
net_orch		-0.305***
		(0.000)
net_coop		0.447***
		(0.000)
rotor_d		0.00397*
		(0.012)
hub_h		-0.00548**
		(0.001)
_cons	0.681***	1.555***
	(0.000)	(0.000)
R-sq	0.263	0.506
adj. R-sq	0.259	0.504
N	4313	3873

p-values in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Table 4.4: Lag of group size and search variable

	(3) Model	(4) Model
proj_size	-0.0371***	
	(0.000)	
l_proj_size	0.0595***	
	(0.000)	
depth	-0.199***	-0.0505*
	(0.000)	(0.041)
breadth	0.0300***	0.128***
	(0.000)	(0.000)
exp_nm_year	-0.0496***	-0.00574*
	(0.000)	(0.016)
net_orch	-0.171***	-0.361***
	(0.000)	(0.000)
net_coop	0.333***	-0.00957
	(0.000)	(0.746)
rotor_d	0.00456**	0.00527***
	(0.005)	(0.001)
hub_h	-0.00610***	-0.00516**
	(0.000)	(0.002)
breadth_sq		-0.00367***
		(0.000)
depth_sq		-0.0389***
		(0.000)
_cons	1.113***	0.295***
	(0.000)	(0.000)
R-sq	0.537	0.273
adj. R-sq	0.534	0.267
N	3873	7514

p-values in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Table 4.5: Hypothesis 1(p-values in parentheses; * p<0.05, ** p<0.01, *** p<0.001)

	(5) Model	(6) Model
breadth	0.116***	
	(0.000)	
breadth_sq	-0.00487***	
	(0.000)	
l_proj_size	0.0809***	0.122***
	(0.000)	(0.000)
breadth_l_~e	-0.000248	
	(0.718)	
breadth_si~q	-0.0000145	
	(0.486)	
exp_nm_year	-0.129***	-0.0869***
	(0.000)	(0.000)
net_orch	-0.190***	0.0274
	(0.000)	(0.388)
net_coop	0.0330	0.420***
	(0.541)	(0.000)
rotor_d	-0.00199	0.00726***
	(0.208)	(0.000)
hub_h	-0.00121	-0.00834***
	(0.477)	(0.000)
depth		0.227***
		(0.000)
depth_sq		-0.0489***
		(0.000)
depth_l_pr~e		-0.0213***
		(0.000)
depth_size~q		0.000600
		(0.415)
_cons	1.511***	0.654***
	(0.000)	(0.000)
R-sq	0.542	0.579
adj. R-sq	0.539	0.577
N	4138	4138

Table 4.6: Hypothesis 2(p-values in parentheses; * p<0.05, ** p<0.01, *** p<0.001)

	(7) Model	(8) Model
breadth	0.201***	
	(0.000)	
breadth_sq	-0.00450***	
	(0.000)	
num_proj	0.0108	0.0993***
	(0.534)	(0.000)
breadth_pr~m	-0.0105***	
	(0.000)	
breadth_nu~q	0.0000821	
	(0.439)	
exp_nm_year	-0.0366***	0.0101*
	(0.000)	(0.019)
net_orch	-0.531***	-0.328***
	(0.000)	(0.000)
net_coop	-0.716***	0.190***
	(0.000)	(0.000)
rotor_d	-0.00523**	0.00916***
	(0.004)	(0.000)
hub_h	0.000340	-0.0108***
	(0.857)	(0.000)
depth		0.427***
		(0.000)
depth_sq		-0.141***
		(0.000)
depth_proj~m		-0.0835***
		(0.000)
depth_num_sq		0.0179***
		(0.000)
_cons	1.177***	0.108*
	(0.000)	(0.048)
R-sq	0.268	0.254
adj. R-sq	0.265	0.250
N	5289	5289

Table 4.7: Hypothesis 3(p-values in parentheses; * p<0.05, ** p<0.01, *** p<0.001)

	(9) Model	(10) Model
breadth	0.147***	
	(0.000)	
breadth_sq	-0.00471***	
	(0.000)	
dem_stock	0.0560	0.0820**
	(0.061)	(0.002)
breadth_dem	-0.0380***	
	(0.000)	
breadt~em_sq	0.000816*	
	(0.017)	
exp_nm_year	-0.0236***	0.0000942
	(0.000)	(0.971)
net_orch	-0.502***	-0.320***
	(0.000)	(0.000)
net_coop	-0.0761*	0.296***
	(0.049)	(0.000)
rotor_d	-0.00143	0.00811***
	(0.406)	(0.000)
hub_h	-0.000664	-0.00680***
	(0.715)	(0.000)
depth		0.191**
		(0.008)
depth_sq		-0.0510***
		(0.001)
depth_dem		0.0507
		(0.484)
depth_dem_sq		-0.0361*
		(0.021)
_cons	0.515***	0.181***
	(0.000)	(0.000)
R-sq	0.230	0.252
adj. R-sq	0.223	0.246
N	7104	7104

Table 4.8: Hypothesis 3(p-values in parentheses; * p<0.05, ** p<0.01, *** p<0.001)

	(11) Model	(12) Model
breadth	-0.0372**	
	(0.002)	
breadth_sq	0.00478***	
	(0.000)	
con_stock	-0.397***	-0.240***
	(0.000)	(0.000)
breadth_con	0.115***	
	(0.000)	
breadth_co~q	-0.00791***	
	(0.000)	
exp_nm_year	-0.00681**	0.00815**
	(0.010)	(0.002)
net_orch	-0.364***	-0.269***
	(0.000)	(0.000)
net_coop	0.236***	0.438***
	(0.000)	(0.000)
rotor_d	0.00183	0.00927***
	(0.271)	(0.000)
hub_h	-0.00236	-0.00823***
	(0.184)	(0.000)
depth		0.115*
		(0.038)
depth_sq		-0.0690**
		(0.002)
depth_con		0.107
		(0.053)
depth_con_sq		-0.00772
		(0.733)
_cons	0.399***	0.160***
	(0.000)	(0.000)
R-sq	0.256	0.251
adj. R-sq	0.250	0.245
N	7034	7034

5
Conclusion

The role played by various external actors in the process of innovation has as many ways having an impact on innovation, as are the number of stars in the universe: Too many to count, old once die with time and new are born. External actors have different kind of impact and this contingent on the time, industry and technology, to mention a few. In this thesis, I made a fruitful attempt to explore the role played by few of these actors in the innovation process.

The first chapter draws attention towards the fact that technological variants usually co-exist (Malerba , 2007). Furthermore, despite the wide acknowledged opinion that information provided by users is always beneficial for the process of innovation, particularly technological change, I explored two contrary scenarios in chapter 1. The flow of information from user to producer and the impact of this flow on technological change is assessed by tuning two parameters: 1. Users risk attitude, 2. Level of information contagion. Quite surprisingly, when the level of information contagion is high and the users are more risk averse, the technological variant dominating the market is not the best available option. Similar results are found when the level of information contagion is low and the users are less risk averse.

The second chapter lays down few implications for policy makers and managers. For instance, if the policy makers aim at high level innovation, as it is usually the case, it is preferable to choose entities closer to the market, like systems providers, suppliers, and users, as orchestrator. Moreover, the research shows that the size of systems providers involved in PFRNs increases the probability of introducing innovation new-to-the-market. Accordingly, one of the best scenarios for public bodies is to put big systems providers in the orchestration position of PFRNs and handing over the orchestration role to them. Doing so increases the probability of introducing innovation new-to-the-market. This may also help in preventing over-reliance on public funding and enabling these orchestrators to build system integration or platform leadership capabilities. These capabilities could be the new sources of competitive advantage for leading companies.

The third chapter provides empirical evidence in support of the argument that the relationship between external search and focal firms innovation performance is moderated by few factors. Three factors are explored: 1. Information interpretation, 2. Collaboration experience, 3. Collaboration objective. The results further corroborate the argument that searching outside yields fruitful results when the firm is well equipped to benefit from the search (Cohen and Levinthal,1990) and experience accumulates over a time period.

Future research could benefit in two specific ways:
Firstly, the role of users could be modelled more explicitly by considering the local information on which the dwell. This will be beneficial for exploring how the utility and perceptions of a user are formed. An understanding of this is crucial for developing an idea of why a user behaves in a certain way in some environments? To be specific, why are few users passive, few provide active information; few take a step further and embark on journey of becoming innovators themselves?

Secondly, performing a qualitative study which looks into the external network the firm is participating in and the inside network of the firm could provide with many critical insights. An understanding of knowledge management (Grant and Fuller,2004) lacks a clear data based distinction between knowledge accessed and knowledge acquired. A qualitative study investigating the external and internal firm networks and the flow of information across this network will be beneficial in filling

this gap.

In both the above cases complete access to data could be a serious impediment. A possible way to navigate through this problem could be to estimate the parameters with the help of an agent based model. And, as a second step validate it with this available data. An approach like this will be helpful in performing scenario analysis of all the what if cases. Furthermore, it will help in looking into the causal relationship which is quite difficult when only one methodology is adopted.

5.1 Reference

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