SCIENTIFIC AND BUSINESS RESOURCES IN INTERACTION

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ABSTRACT

This paper deals specifically with how the transformation of a new scientific achievement into a business innovation can be understood from a resource interaction perspective. To achieve innovation, that is to say to transform an invention, or a product or process development, into a widely used commercial solution, is seen as a very desirable accomplishment to the single entrepreneur or company (Cooper, 1982), but it is also considered an important goal in terms of inducing economic growth on a larger scale. (Nelson, 2008) Therefore, successful innovation processes are advocated by a range of financial and political actors such as venture capitalists and policy makers. (Gompers and Lerner, 2001) In the general view of the novelty in itself being the most important ingredient in creating successful innovation journeys, inventions stemming from scientific research have during the closing decades of the twentieth century from a policy and investment perspective been appointed particular value in acting as the basis for subsequent commercialisation within business. (See e.g. Beckman et al., 2008; Eklund, 2007) However, from a resource interaction point of view it is far from obvious that a new solution which is considered to be of scientific significance is also useful in a business context when trying to create a new product or service.

The empirical case revolves around a new method for *DNA sequencing*, or reading genetic code, which was presented at The Royal Institute of Technology (KTH) in Stockholm in the late 1990's. The new technique enabled an automated procedure for analysing short DNA strands with high precision. Being based on a particular methodology allowing for extremely accurate type of analyses, it became the first in its kind and was in due time recognised as a big scientific breakthrough, not least through a publication in Science, one of the most prestigious journals within the natural sciences, in 1998. The method *pyrosequencing* was also deemed to have big commercial potential in terms of becoming a successful innovation. When an already established pharmaceutical company dropped it as a commercialisation project a venture capital firm stepped in and created a company around the new method. Early on the company which was built around pyrosequencing to enable its large-scale production got an image as a successful business endeavour; the company launched a product, was introduced on the stock market and received various awards for its "focus on innovation". However, just a couple of years after these initial successes the financial losses of the company were so severe that it was forced to merge with another company, which more or less made pyrosequencing obsolete within the new company constellation. A major problem was that the analytical instrument was found useful mostly within the same type of context where it had been developed; scientific research. As these customers represented neither a large-scale nor a standardised type of use of the product this created a fundamental problem for the business venture around pyroseqeuncing.

This paper investigates if there indeed is anything particular about innovation processes for new solutions stemming directly from scientific research, and why. The investigation is

carried out by the use of the 4R model (See Håkansson & Waluszewski (2002) for an overview). By studying the resources involved in using, producing and developing this new scientific solution, new light can be shed on the process of basing business ventures on solutions which stem directly from scientific research.

Keywords: resource interaction, innovation, commercialisation, scientific research, biotechnology

INTRODUCTION
The Difficulty of Achieving Innovation -an Empirical Viewpoint

The achievement of *invention* is the attainment of novelty in itself; it is a new idea or a new solution to a specific problem. Achieving *innovation*, on the other hand, implies that an invention, material or immaterial, has become commercialised and has gotten a widespread use. The innovation is thus the invention *in use* and as such it entails both the organisational and physical structures needed to enable a general utilisation of the new solution. (Fagerberg, 2004; Van de Ven et al., 1999) Empirically based research being produced during the last decades with a process oriented focus has emphasised the non-linear characteristic of the innovation process and how few of the attempts to create benefits from engaging in innovation has actually been victorious. (See e.g. Rosenberg, 1982; Hughes, 1987; Van de Ven et al., 1999; Håkansson et al., 2009) Coming up with a new idea is one thing, establishing a widespread use of it is another:

> "An invention or creative idea does not become an innovation until it is implemented or institutionalized. Indeed by most standards, the success of an innovation is largely defined in terms of the degree to which it gains good currency, i.e., becomes an implemented reality and is incorporated into the taken-for-granted assumptions and thought structure of organizational practice." (Van de Ven, 1986, p. 604)

The citation implies that the success of an innovation does not lie in the hands of the single inventor or inventing company but rather in the *context*, or how it is received by its users. Consequently, the focus of how to succeed with an innovation is not on the single company but on the receiving end of potential customers, and it is not on the invention in itself but on the interplay between invention and the contexts where it is used and produced. (Håkansson & Waluszewski, eds., 2007) This suggests that in order for anything new to turn into an innovation it has to relate to a *using setting* and the different elements that exist there. (See e.g Rosenberg, 1982; Kline & Rosenberg, 1986; Pinch & Bijker, 1987; Van de Ven et al., 1999; Håkansson & Waluszewski, eds., 2007) In this setting there are various individual consumers which belong to different cultures, possess specific knowledge or are dependent on particular technical solutions. (Pinch & Bijker, 1987) There are also companies and other types of organisations which engage in a variety of activities connected to the use of specific organisational and technical solutions. The using setting thus consists of a structure of various types of actors and a number of *activated solutions* already in use. (Håkansson & Waluszewski, eds., 2007)

Any new solution which is to be commercialised also needs to relate to a *producing setting* that is involved in providing products or services to individual consumers, companies or other

organisations. In order for a company to be able to manufacture and offer its products or services, and also for these to be of use to various customers, investments are made in relation to the requisites of the users but also to the range of companies, such as suppliers and sub-suppliers, which the individual producing company depends on to perform the numerous activities connected to the production of a single product or service. (Håkansson & Waluszewski, eds., 2007)

Thus, when something new is developed, whether it is a cell phone or a technical component in a car engine, in order to become a widely used solution it will need to become embedded in a producing setting where it is manufactured and prepared for distribution, and in a using setting where it is to be utilised as one among many other solutions. (ibid.; Håkanssson et al., 2009) Due to the complex nature of concerning technical, organisational and economic systems, attempting innovation is "a leap into the unknown" (Van de Ven et al., 1999, p. 66) which implies that it is very difficult to state which new ideas that will actually become widely used solutions (Rosenberg, 1994). With this empirically based view of the process of introducing new knowledge or technical solutions into structures of established resources we will now turn to the innovation process as viewed in the model world.

The Vision of Successful Innovation Processes –a Model Viewpoint

To achieve innovation, that is to say to transform an invention, or a product or process development, to a widely used commercial solution, is seen as a very desirable accomplishment to the single entrepreneur or company (Cooper, 1982), but it is also considered an important goal in terms of inducing economic growth on a larger scale.(Nelson, 2008) Therefore, successful innovation processes are advocated by a range of financial and political actors such as venture capitalists and policy makers. (Gompers and Lerner, 2001; Tidd & Bessant, 2009) In spite of the empirically grounded innovation research being conducted during the last three or four decades, underlining the non-linear characteristics of this process, innovation being seen as a spurring force of economic growth has led much innovation management literature to portray it as the outcome of a rather linear process. (Håkansson & Waluszewski, eds., 2007) The view of innovation as resulting in positive economic outcomes, and the subsequent wish to be able to plan the innovation journey, also appears in the rhetoric of policy and investment actors. The following citation is part of the announced innovation strategy of the OECD[1] to create policy tools for a promotion of innovation:

> "Today, innovative performance is a crucial factor in determining competitiveness and national progress. [P]olicy coordination is essential- only a comprehensive and wide-ranging strategy to foster and strengthen innovation can help address social and environmental goals while building a lasting foundation for future economic growth and competitiveness. " (OECD, 2007, p. 26)

From this perspective the goal of policy and investment becomes first to achieve *novelty* in itself, second to finance it and third, if this novelty is found in non-commercial environments, to *transfer* it to commercial actors. (Håkansson & Waluszewski, eds., 2007) In turn this

[1] The Organisation for Economic Co-operation and Development (OECD) is an international participative organisation with 30 member nations working together with the goal of promoting economic growth and activity as well as further international trade, primarily for the member nations. For more information visit www.oecd.org

means that in the effort to identify the reason for failure of an innovation, focus is often put on the qualities of the novelty, its financing as well as on how it is to be moved from one context to another but more seldom on how it will *fit* into these differing contexts.

In the view of the novelty in itself being the most important ingredient in creating successful innovation journeys, inventions stemming from scientific research have from a policy and investment perspective been appointed particular value in acting as the basis for subsequent commercialisation and innovation within business. (See e.g. Eklund, 2007; Håkansson & Waluszewski, eds., 2007; Beckman et al., 2008) According to this notion it appears only natural that scientific work is the most important basis of the newness required for economic growth and that the knowledge it results in thus should be taken up by industry far more extensively. (See e.g. Elzinga, 2004; Pavitt, 2004; Eklund, 2007; Håkansson & Waluszewski eds., 2007; Beckman et al., 2008) There is consequently a prevailing image of science as an "untapped source" of innovations which leads us to the main theme of this thesis, namely what it takes for an invention to become an innovation and if there is anything particular with the innovation journey when the invention stems directly from scientific research. From this theme the following general research question has been formulated:

What is peculiar about innovation processes for new solutions which stem directly from scientific research? Why?

THEORETICAL DEPARTURE
An Interactive Perspective on Innovation- IMP and STS

In mid-1970 the first IMP study focusing on the interactive nature of the business landscape was commenced and its findings have since inspired a long line of studies emphasising the interdependent and heterogeneous character of business actors and the resources that are exchanged (see Håkansson et al. 2009, Håkansson & Waluszweski, (eds.) 2007 for an overview or www.impgroup.org). Through a great number of empirical studies on the practices taking place in the business landscape the adopted perspective is that companies operate not as independent units but are, through their interdependencies, embedded in a network-like structure. (See e.g. Håkansson & Snehota, 1995; Håkansson & Waluszewski, 2002; Araujo et al., 2003) These interdependencies concern organisational and physical adaptations stretching across organisational borders, for instance in the shape of logistical solutions or adjustments in the production process. In turn this means that no solution exists in isolation but depends on a various number of other investments or solutions, material as well as immaterial, stretching across the organisational borders of the single company. To enhance the efficiency of needing to combine different solutions across organisational borders, the different material and immaterial solutions are chiselled out in reference to each other as to create a better fit. Over time any solution will therefore be better adjusted to a specific set of solutions than to any other solution or set of solutions. It is such networks of interdependent and interrelated investments, represented by a number of different actors, that any *new* idea or solution will need to relate to. (See e.g. Rosenberg, 1982; Håkansson & Snehota, 1995; Håkansson & Waluszewski, eds., 2007)

The idea of interdependence between the development of new solutions, in the shape of knowledge or technology, and context is also generally argued for within the STS (Science and Technology Studies) research field. (See e.g. Jasanoff et al., eds., 1995 for an overview) In studying the work of scientists and engineers in their endeavour of developing and using

scientific knowledge or technology, the general finding is that neither knowledge nor technical solutions exist in a vacuum but is shaped, and re-shaped, by the culture, the institutions and the physical structures related to their construction and use. (See e.g. Latour, 1987; Shapin & Schaffer, 1985; Mol & Law, 1994; Jasanoff, ed., 2004; Widmalm, ed., 2008) This means that when new knowledge is to be stabilised into established scientific knowledge it will need to be related to a structure consisting of already established knowledge as well as physical and organisational solutions such as laboratory equipment and the production of publications. (See e.g. Callon, 1995; Knorr Cetina, 1995; Latour, 1987) When the same new knowledge or solution is used or considered in another context it might, however, propose other meanings or functions. (Knorr Cetina, 1995; Rosenberg, 1982; Latour, 1987) So, if it is how a new solution is combined with contexts of already existing material and immaterial solutions that determines its function or use, what does this mean when it is to become an innovation? Next we will learn about three empirical settings which any new solution needs to "survive" in order to become a widely used product or service, in other words an innovation.

Three Empirical Settings which any Attempted Innovation Needs to Survive –Use, Production and Development

Already in mid-1970 Utterback and Abernathy (1975) stated that one of the most important aspects of the innovation process is how *the new* is related to the "investments in place", or the context where something new is taken into production and use. Let us take a step back and consider what this means. In considering all products or services which already exist, which are already produced, sold and used, there are two main settings that withhold their continuation; a *producing* setting and a *using* setting. There are thus suppliers that uphold the production of these products and services and there are users who have activated them by integrating them in their day-to-day activities. For these suppliers and customers to be able to produce and use these particular types of products or services, investments have been made and over time a structure of established production systems, routines, logistical solutions and other types of "activated knowledge" has been created. (Håkansson & Waluszewski, eds., 2007) What does this mean for the introduction of new solutions? Any producer has to evaluate how the production of a new solution is to be realised without the necessary investments exceeding any future prospect of ROI (return on investment). (ibid.) For this reason the producer needs to consider the current production system and how a new solution might be manufactured by the use of these existing investments, or by the introduction of as few new ones as possible. (ibid.) The same applies for any user; the more that any new solution breaks with the existing pattern of solutions, the more changes it induces and the more expensive it will be to implement. In order for a new solution to become a successful innovation it thus needs to create a fit with both a producing setting and a using setting consisting of two different sets of specific physical and organisational investments. (ibid.: Håkansson et al., 2009)

When a new solution is being developed, the requisites of the producing and using settings might be more or less unknown. This means that when the solution is being developed it might not be adjusted to fit neither a potential producing nor using setting which consequently can create problems when it is to be implemented in either one of these settings. Equally, the more knowledge that the developing setting has of the producing/using settings, the easier it will be to develop something which will create benefits from the standpoint of both production and use. (Håkansson, 1989; Håkansson & Waluszewski, eds., 2007) Thus, the "closer" the settings of use, production and development of a new solution are to one another in terms of being more familiar with each others' physical and organisational prerequisites,

the less challenging it will be to develop and produce something which is beneficial for all three settings. (Håkansson, 1987; Håkansson, 1989)

In order for any new solution to become widely used it thus needs to become embedded in three different but related settings. With this view of what it takes for any new solution to become an innovation, I will now account for the theoretical tool which has been used to perform the investigation.

Using the 4R Model as a Tool to Capture Interaction

To be able to investigate the innovation process from an interactive perspective a tool which can capture how the connection between material and immaterial solutions change over time is needed. One such tool is the *4R model* that views each organisation or company as representing a specific set of resources, which are shaped in relation to a larger network. It distinctly divides the resources involved in developing, producing and using new solutions as well as maintaining them, in four resource categories. Two are mainly physical: a) products and b) facilities or equipment, and two are mainly organisational or human: c) organisational units, and d) organisational relationships. (For a detailed discussion of the theoretical background, see Håkansson & Waluszewski, 2002) It is further assumed that resources exist in a constant interaction from which they, over time, develop specific *resource interfaces* in relation to each other. Thus, through interaction each resource develops particular features in relation to a specific set of other resources. In addition, as part of a larger network each resource is connected to a number of indirectly related interfaces which in one way or the other will affect or become affected by any related resource. (Håkansson & Waluszewski, eds., 2007) Here, in a study of the attempt to achieve innovation based on a new scientific solution, the model has been used as a method to capture the respective effects of shaping a potential innovation in a using, producing and a developing setting. This has resulted in a case showing how physical and organisational resources 'co-produce' contexts which, in turn, affect the ability to benefit from a particular innovation.

Data Collection and Method

The paper is the result of a data collection encompassing three different settings involved in the innovation process of the pyrosequencing method; development, production and use. The *developing setting* is represented by two research groups at the Department of Biochemistry and the Department of Biotechnology at KTH (The Royal Institute of Technology) in Stockholm. The *producing setting* is represented by the founding partner of the Health Cap funds called Odlander, Fredriksson & Company and by the formed company, also named Pyrosequencing. The *using setting* is represented by four different users: the Department of Evolutionary Biology, the Department of Medical Biochemistry and Microbiology and the Genetics Department (Rudbeck Laboratory), all at Uppsala University, as well as the Clinical Chemistry Laboratory at Örebro University Hospital. In total, about 40 interviews (see appendix 1) have been carried out and a vast selection of scientific publications authored by both the developing and the using setting has been studied. Besides the traditional collection of primary and secondary data, a seminar has also been held on the issue at the Department of Biochemistry at KTH. In addition, the study is part of a larger study of the emergence of life science based companies in the Uppsala region, where 25 companies and their connections to the academic and business world are mapped over time. (Waluszewski, 2004)

This paper is based on an in-depth case study, and as it is necessary at some point in the process of building a case to decide what the particular research focus is and how it should be presented, theoretical tools that can be used to pinpoint this focus and present a certain view are needed. (Voss et al., 2002) Thus, the *4R model*, developed within the framework of IMP (See Håkansson & Waluszewski, 2002), has been adopted as an explicit research tool that has guided the content of the investigation in terms of interview questions and their transcription. It has also shaped the presentation of the empirical material as well as the analysis of the case. The perspective of resource interaction is an attempt to catch what happens in the "in-betweens" or put differently, how changes to one resource affects each directly or indirectly related resource and thereby create economic effects. When a technical component is replaced by another, what effects does this create on related production equipment, suppliers, and logistical solutions? When a company decides to work with a new raw material, how does this affect the related production process, the work routines or the existing material or immaterial solutions within the customer setting? All these changes represent economic consequences. The 4R model is thus a tool that can be used to trace and analyse the economic effects of technical and organisational changes. It is the very interplay or relationship between the unit of analysis and context which is scrutinised and the central issue is how *change,* i.e. how new resources or new combinations of established resources, comes about and generate direct and indirect economic consequences. (ibid.) The heart of this study is the process of a *new* solution being forced to *interact* with *established* resources in terms of activated physical and organisational solutions. Furthermore, in this process new relationships and new units or groups of people working together are formed which implies that the interaction between individuals and between organisations is also in focus. In order to catch this process of new combinations of solutions being formed or clashing and new relationships becoming established or dissolving, it is necessary to learn what happens *between* and *within* these different entities as they become related and which economic effects it creates. Next we will learn more about the organisational and physical resources involved in and affecting the scientific development and the commercial production and use of the new invention acting as the basis for this paper.

THE THREE SETTINGS INVOLVED IN DEVELOPING, PRODUCING AND USING THE PYROSEQUENCING METHOD

Developing a New Scientific Solution

In 1986, an idea of a new way of performing DNA sequencing or reading genetic code occurred to a Swedish biochemical researcher, Pål Nyrén, while attending his postdoctoral year at Cambridge University, UK. At Cambridge he was introduced to the most established way of doing sequencing, the Sanger method[2], for the very first time. The method was manually handled and included many manoeuvres with delicate gels, different samples and techniques. During Nyrén's years as a PhD student he had been working with methodological development within bioenergetics and had specialised in photosynthetic enzyme activity[3]. Still, in spite of his experience in laboratory work Nyrén had great difficulty in learning how to master the Sanger method's numerous steps and procedures. Therefore, he started to think of a simpler way to do it. By using a generally well-know and established technique and not being able to master it Nyrén thus began a thinking process of starting to develop a different method. However, since his background was within the research area of biochemistry, and not molecular biology traditionally connected to DNA related research, his idea of how to design

[2] Named after one of the inventors Frederic Sanger and published in 1977.

[3] He had been studying the enzymes involved in photosynthesis which simplistically explained is the process where solar energy, water and carbon dioxide is transformed into dextrose (a sugar) and oxygen. This process constitutes the foundation for life on earth.

a new method originated not in genetics per se but in energy conversion processes by the use of enzymes. Nyrén based his idea for the new method on an abandoned sequencing principle called sequencing-by-synthesis (SbS) which nobody yet had succeeded in transforming into an effective sequencing procedure. This and the existence of the well-established and ever evolving method Sanger left the research community within genetics sceptical of Nyrén's new idea. (Interview Nyrén; Interview Pettersson; Marsh, 2007)

Due to the lack of funding Nyrén could not start experimenting with his new idea until a few years later when entering the Department of Biochemistry at KTH in the early 1990's. Here the development of the new method became the issue of a larger research group consisting of several PhD students. It was also connected to another research group, within the Department of Biotechnology, which contributed with knowledge concerning DNA sequencing as well as an additional technical solution which temporarily solved some initial problems with the new method. The issues at hand was to make the different components of the method, in the shape of reagents interacting and creating different biochemical reactions, to interact in a way as to constitute an efficient sequencing procedure. This required a work order characterised by a broad approach of finding new development directions in the search of possible solutions. The development work was also related to various PhD projects and thus reported in both PhD theses and other publications. This in turn affected the development of the method in terms of constantly trying new development directions and attempting to optimise every condition of the method. (Interview Nyrén; Interview Pettersson; Interview Uhlén; Marsh, 2007)

As the research group concerned with the development of the Pyrosequencing method wanted to make it available to other researchers there was a great interest in getting the method commercialised. However, an attempt of getting an established company, Pharmacia Biotech, one of the world's largest producers of biotech tools, to engage in making the method into an automated sequencing procedure and a commercial product was terminated. As the potential product's use was considered limited within the existing using structure of Pharmacia and there would have to be additional investments in order to support its production, the company choose not to commercialise it. Instead the method became involved in the founding of a new company based on venture capital, and just as the new method it was named Pyrosequencing. This commenced a development work of establishing an automated sequencing procedure based on the new method, which was facilitated by a major breakthrough in the KTH research group. A new added reagent which simplified a before manually handled step of the procedure opened up the door for a more straightforward way of automating the sequencing method. The method was now an enzyme formula of four enzymes taking care of the biochemical reactions connected to the sequencing procedure. This breakthrough connected the method to several new publications, not least one in Science, one of the most prestigious scientific journals within the natural sciences, in 1998.

The commercialisation of the method, however, resulted in the development work within the developing setting at KTH proceeding in one direction and the creation of a commercial product within the new producing setting in another. The researchers constantly wanted to try new directions and find different application areas for the now automated sequencing instrument while the start-up company quickly locked it for one particular type of application; the analysis of so called "SNP:s"; particular genetic markers often connected to different conditions or diseases. As this was considered a very narrow continuing development direction by the KTH researchers this created a miscommunication between the developing and the producing setting. Within the developing setting the automated sequencing instrument was instead continuously developed in terms of new types application areas and optimisation

which in turn connected it to more publications in highly ranked journals. This gradual involvement of the new method in various research projects and publications, both within the developing and the using setting, which will be accounted for below, eventually stabilised it into a significant scientific achievement. However, first let us take a look at how the specific set of organisational and physical resources within the producing setting affected the production of the commercial solution based on the new method.

Building a Producing Structure based on the New Solution

The production of the pyrosequencing method taking place within business was related to a specific set of organisational and physical resource interfaces which affected how the method was "locked" and "productified" as a commercial solution. This process however took a somewhat different direction than within the developing setting. In the producing setting the new method needed to be shaped as a standardised product in order to become embedded into a producing structure responsible for standardised large-scale production. Initially Pyrosequencing, formed in 1997, consisted of only a small group of people. However, soon enough the venture capital firm Odlander, Fredriksson & Co., which through the Health Cap funds had placed large investments in the production of the new method, appointed one of its own partners, Eugen Steiner, CEO. In doing so the venture capital firm to a great extent became operationally involved in setting the guidelines for how Pyrosequencing would develop, both the company and the product. They formed the tactics of how to operate and niche the company which also made them strategically involved. Because of this high level of involvement it became difficult to determine where Odlander, Fredriksson & Co. ended and the company Pyrosequencing began; the commercial venture around the new method was more or less a borderless blend of the two. The company was given seven years to produce return on investments for the various big financial actors committed to the Health Cap funds. (Interview Nyrén; Interview Uhlén; Interview Ekström)

The production system built up around the manufacturing of the commercial Pyrosequencing product was divided mainly between two companies. Partnertech, a well-established producer and supplier of various technical equipment, which set up a production of the instruments containing the different mechanical parts needed for an automated procedure of the method, and Pyrosequencing, which arranged a production facility for the assembly of reagent kits containing the "enzyme formula" developed at KTH. To do this the company also required a set of suppliers specialising in producing and delivering enzymes. The enzymes were produced and supplied in a standardised fashion by the suppliers. This standardisation resulted in a significant feature of the enzymes. In order for them to be part of an industrial production, where they needed to be transportable and last for a long time without being spoiled, they had to be in a freeze-dried condition. This means that in the production of the reagent kits at Pyrosequencing it was the quality of the enzymes in a freeze-dried condition which had to be the starting point for the properties of the resulting product. This was very different from the fresh chemicals which were used in the laboratory at the developing group at KTH. (Interview Ekström; Interview Söderbäck; Interview Krabbe)

The instrument supplied by Partnertech was designed much like a box which required an input and subsequently delivered an output. The input was the test samples of DNA, which the user would provide, along with the reagent kit of enzymes supplied by Pyrosequencing. Once these inputs had been inserted the sequencing procedure would take place inside the box creating an output of the DNA sequence shown on a computer screen. The first product

was called PSQ96 because of the 96 wells[4] in which the biochemical reactions took place.[5] (Interview Ekström; Interview Nyrén; www.biotage.com)

The company board which was arranged around the new company consisted of representatives from Odlander, Fredriksson & Co. as well as several prominent people from both the business and research world. Two of the members were for instance former CEO's of Ericsson and SEB (Skandinaviska Enskilda Banken) and one was a Nobel Prize winner in chemistry from the Karolinska Institute. The board thus represented knowledge both within business and academic research and was expected to be able to forecast an appropriate development direction for the new company and its products. In evaluating the future for the new sequencing method the board saw defined application areas where the Pyrosequencing product would serve an important purpose. However, in order for Pyrosequencing to become an acknowledged company within a certain time frame it needed to establish a producing structure and sell products. The technological status on which the board founded their decisions was in the shape of a sequencing method specialised in sequencing short DNA fragments with great accuracy. This ability spoke in great favour of SNP-applications. Thus, considering the features of the method in its initial state, SNP-analysis was seen as a reasonable firsthand goal. (Interview Odlander; Interview Walldén; Interview Ekström)

When being able to launch a product after just three years and becoming a public limited company after yet another, Pyrosequencing had seemingly accomplished turning a new scientific achievement into a solid innovation within a very short period of time. The company was awarded prizes such as "spin-off company of the year" by the Royal Swedish Academy of Engineering Sciences (IVA) and was mentioned on Forbe's list as "best newcomer". However, just a few years after the first product launch it became clear that based on the commercial solution's utilisation within the using setting the company could not sustain its production of the analytical instrument; merely a fraction of the expected sales earnings was achieved and only about half of the instruments remained in use after they were sold by the company. This left the high expectations on earning a great profit on a continuous demand of the reagent kit, which was needed to operate the instrument, unfulfilled. The economic effects of embedding the commercial solution in the using setting led to radical organisational changes in the producing structure. In order to sustain a production the start-up company was merged with several other companies involved in producing biotechnical solutions. A new company called Biotage, based on two divisions, was formed. One division was based on the acquired companies' products and the other was based on the Pyrosequencing product. However, as these two divisions had very dissimilar user structures in terms of which the general user was and how the products were used, the combination did not create the expected economic benefits. This ultimately resulted in Biotage and the venture capital firm divesting in Pyrosequencing which instead was acquired by a German company, Qiagen. (Interview Joergensen; Interview Ekström; Interview Schanche) Next we will get a deeper understanding of the using setting of the Pyrosequencing instrument and how, even if it created benefits for the users, its embedding in this setting resulted in unsustainable economic effects for the producing setting.

[4] In molecular biology, assay plates with 96 wells is standard procedure.

[5] In 2009, there were five versions of the original instrument; PSQ 96 MA, PSQ HS 96(A), PyroMark ID, PyroMark MD, PyroMark Q24, including adjusted reagent kits as well as complementary equipment. (source: www.biotagebio.com)

Embedding the Commercial Solution in a Using Setting

The main part of the using setting connected to Pyrosequencing turned out to be academic research departments and hospitals. In each studied user context where the new instrument became embedded and thus an integrated part of the existing resources, both the instrument and the existing solutions in the user environments needed to be adjusted in one way or the other for the new solution to make a contribution. As will be exemplified, this was done either by making physical adjustments in the features of the solution, by how it was used or by complementing it with other solutions.

Within the user group performing research at the Department of Evolutionary Biology at Uppsala University the instrument was embedded in a project concerned with analysing ancient DNA found foremost in pre-historic bones. For the instrument to be able to perform the proper analyses in this research environment, characterised by a highly delicate handling of sensitive and deteriorated DNA samples, specific assays needed to be developed in collaboration with the company. Once this was done the instrument became an indispensable part of the analyses performed in the research group and connected their work to a number of publications. (Interview Svensson; Malmström et al., 2007; Svensson et al., 2007)

Within another user environment, the forensic group at Rudbeck Laboratory, also at Uppsala University, the new instrument needed to be complemented with the use of the established sequencing method Sanger. This was due both to the regulation of forensics steered by law and for the security in having two sequencing results for verification. The research group's performance of analyses of DNA samples found at crime scenes makes their work an issue of following regulations connected to forensics. Therefore, since Sanger is the most established and trusted sequencing method it is the most used technique within the group and whenever a new method is to be tested it is done so by being run in parallel to Sanger. This was also the case when the Pyrosequencing instrument was purchased. Eventually, through the use of the new instrument new types of assays connected to forensics could be performed and much faster than had it been done by the use of Sanger. This development work was partly performed in collaboration with the company but also with the developing setting at KTH. However, due to some of its features, for instance of not being able to read several hundred 'nucleotides', the building blocks of DNA, in a row as could be done with Sanger, it has been proven not be able to be included in all of the research projects performed by the group. When these projects have been carried out the Pyrosequencing instrument remains unused. This in turn does not generate a need for reagents provided by the company. However, as the instrument presented new opportunities of examining DNA which in turn enabled new research studies and publications it became a highly regarded method within the forensic group. (Interview Allen; Interview Ekström; Interveiw Nyrén; Andréasson et al., 2006)

A third user example is posed by the context of the Department of Medical Biochemistry and Microbiology. Here it was initially embedded in a project concerned with pig DNA in connecting different genetic markers to coat colour and the needed assays was set up in collaboration with the company. As it proved useful in these kinds of applications it also became part of the most central project at the department examining the connection between malign melanoma and coat colour, in horse DNA. Its use within these projects connected the research work of the department to publications in highly ranked journals. Also, as a result of its use a specific feature of the reagents was altered as to reduce time and money spent on sequencing. (Interview Pielberg; Pielberg et al., 2002)

Finally, within the user context of the Clinical Chemistry Laboratory at Örebro University Hospital the instrument was first incorporated in their every-day work of diagnosing patients with conditions such as lactose intolerance or hemachromatosis (iron overload). As it proved to be of good use in these activities and the staff was becoming adjusted to its features, it was also integrated in several of the laboratory's research projects. Within one of these projects specific assays were developed for advanced analysis of lactose intolerance making them the first Swedish laboratory to ever offer genotyping of this type of condition. In turn the great influx of test samples enabled a number of research studies and publications recognised on an international level. The use of pyrosequencing thus contributed to the laboratory's every-day work of offering health services and of performing internationally recognised research. (Interview Nilsson; Interview Olsson; Nilsson et al., 2008)

Through these user accounts it is shown that the use of pyrosequencing has provided the customers with further means to do research, publish and thus make scientific progress. This is the same tendency pointed to in the account of the original developing setting at KTH and their academic collaborators; in using and developing the Pyrosequencing instrument the method works as a promoter of scientific research as it allows for further research, both on itself as a research result and on the analytical results it in turn produces. A striking feature about these users are, however, that they are all rather small and financially restricted research facilities and that they have only bought one or two instruments as well as use a relatively small amount of consumables. It is also indicated that even though the instrument is highly useful it is not included in all of the performed research projects. The Clinical Chemistry Laboratory at the Örebro University Hospital here stands as an exception as it is a rather large laboratory facility but still its good use of pyrosequencing has not forced them to buy several instruments or large amounts of consumables. This is a common quality among Pyrosequencing customers. Thus, even though the users find their purchased instrument highly valuable for their research and daily routine-work, their use does not generate a large or steady demand for neither instruments nor consumables. Next the commercialisation process of the Pyrosequencing instrument will be analysed from the standpoint of its interaction with the organisational and physical resources within the developing, producing and using settings and the effects which this created for each setting.

ANALYSIS

The Resource Interfaces between Scientific Research as a Developing Setting and Business as a Producing Setting

As was argued in the introductory and theoretical sections of this paper, for something new to turn into an innovation it cannot only be the issue of a developing setting but also needs to be incorporated into large-scale production and become widely used. When, as in this case, the developing setting is involved in scientific research and the producing setting is within business, *the new* needs to develop interfaces with resources of a rather dissimilar character appearing in the two different settings. In this case, representatives from both the developing and the new producing setting jointly constructed a new start-up company. This created a number of physical and organisational resource interfaces between the developing and the producing settings which affected the way that they interacted and which direction that the development respectively production of the new method took. When the method became involved in the construction of a new start-up company it was embedded in a producing setting consisting not only of the new company but also of already established physical and organisational resources related to production. These resources came in the shape of suppliers, technical components and venture capital, to which the new method needed to create

resources interfaces. As the new method had to become part of large-scale production in order to become commercialised, it needed to relate to this established producing structure. In turn this had an effect on the method's features as a commercial solution and a business resource. These physical and organisational interfaces necessitated a "locked" commercial product and a short-term perspective on profitability.

This commercialisation process was detached from the continuous development process around the method which took place within the developing setting. Here it was connected to a totally different set of resources in the shape of laboratory equipment, PhD projects and publications. The physical features of the method which this particular set of resources resulted in were very different from those achieved in the producing setting. Also, the methods and components which were used within each setting differed greatly in terms of which other resources these were indirectly connected to, such as patents and licenses, or physical circumstances connected to industrial production, which the producing setting had to consider but was more or less irrelevant to the developing setting. Or such as the formulation of new research and PhD projects to acquire research funds, which in many regards was the basis for a continuing existence for the developing setting within academia, but which the producing setting did not need to relate to. It was nevertheless partly through the existence of the commercial solution which the developing setting could make new research progress and connect its research to other important resources such as publications and new research projects. Also, as the commercial solution was locked both to specific qualities and applications within the producing setting a quick product launch was enabled which created benefits for the producing setting in terms of capital stock and venture capital. Thus, even though the interaction between the developing and the producing setting became problematic, in regard to the commercial solution which came out as a result it was initially in many regards creating benefits for both settings.

The Resource Interfaces between Business as a Producing Setting and Scientific Research as a Using Setting

As the instrument was creating resource interfaces with the existing resources within the using setting, the effects of putting the instrument into use, for this setting as well as for the producing setting, became apparent. As a commercial solution the instrument was produced in accordance with a frequently used type of business solution; a device which was locked to the use of a particular set of consumables that were expected to bring in a great part of the incomes. However, the typical customer interested in the Pyrosequencing instrument was not the "average" commercial buyer or company that the producing setting primarily had had in mind, but individuals and departments involved in scientific research or health related services. As we have seen, this induced a particular type of user behaviour; due to the nature of scientific research these users' needs were changing over time and were very specific. This made their requirements for what type of analytical instrument they wanted to purchase and how they used it different from other types of customers in a number of ways. Not least in the sense that the research projects were oriented towards constantly performing new types of tasks and finding answers to new types of questions. It was thus not about doing the same thing over and over again in a standardised fashion. Within the included user contexts the new solution and the existing resources within the user environments needed to be related to each other in order for *the new* to be able to create any benefits. As shown, the solution had to relate to different types of research projects associated to specific types of knowledge, methods, sample material, equipment as well as criminal law. These physical and organisational resources interfaces put different demands on the method than those posed

within the developing and producing settings. As we have seen, the resource interfaces created between the producing and the using setting in the shape of jointly adapting the instrument and the consumables to particular types of uses created benefits for the users, by connecting their use of the instrument to other important resources in the shape of new research projects and publications, but not for the producing setting and the production of the commercial solution. The product created within the producing setting could consequently initially induce economic benefits *within* this setting in terms of capital stock and venture capital but due to a set production focus and the existing resources within the using setting it could not create economic benefits for the producing setting from its use within the using setting.

The way that the new solution became an embedded resource within the settings of use, production and development created benefits for the developing and the using settings as a promoter of scientific research but was hindering an efficient production for the producing setting. The findings of this study thus demonstrate how it is the existing organisational and physical resources which determine the achievement of innovation and how the commercialisation of a new solution can create different benefits for different settings. In this case one and the same solution was a research asset within scientific research being further developed within the developing setting and various user contexts but an economic burden for the producing setting based on large-scale production. This has implications for the view of scientific research as the most important provider of innovation; as any new solution needs to survive a developing, producing and a using setting in order to become an innovation, and thus create resource interfaces with rather dissimilar sets of resources if the developing setting is involved in scientific research, the economic benefits of embedding any new scientific solution within a commercial producing and using setting cannot be determined beforehand. Also, because of the clear imprints which the new method carried from its developing setting it was considered most valuable within the same type of environment as where it had been developed; scientific research. In addition to the challenge of supporting large-scale production on a single product, it was even harder to base it on the new solution's use within the using setting, which represented very specific needs and a sporadic utilisation.

CONCLUDING DISCUSSION

The case of pyrosequencing illustrates the complexity of trying to achieve innovation based on new scientific solutions; what was considered an important and highly usable method from a scientific standpoint, from both the developer and user perspective, became an economic burden for the producing setting set up to maintain its standardised production. Because of the method's unique qualities, which solved key methodological issues within rather specific research areas, it was highly relevant within production of scientific knowledge and was in due time considered of great scientific significance. In order for the method to contribute to the *developing setting* it needed to represent a contribution to the existing stock of scientific knowledge concerning DNA sequencing. This meant that it needed to work on an experimental level and be included in scientific publications. It was not a matter of making it work on a large-scale basis or spreading a standardised procedure for sequencing, rather its value was measured in terms of what type of knowledge contribution it was making. In the *producing setting*, on the other hand, scale was essential; in order to cost-effectively withhold a production based on the new product economies of scale needed to be achieved both in regard to in-house production and in collaboration with suppliers. However, to become embedded in the *using setting* the instrument needed to interact with the existing resources within a setting also involved in scientific research. This was once again not a matter of scale

but rather of making the instrument contribute to specific research questions and projects –to make knowledge contributions.

This study has shown that in spite of the indications from policy and investment actors, scientific and economic significance are not two sides of the same coin; they are not even values within the same currency. Rather they are determined through different processes at different times. To scientifically establish a new piece of knowledge is about making a specific knowledge contribution and it is the extent to which this contribution is considered a leap forward within the production of scientific knowledge that determines its generation of benefits within this setting. This implies that in order for anything new to represent an important *scientific* resource it must be connected to the value-creating resources and processes which exist within the production of scientific knowledge, e.g. publications, research grants and new research projects. To establish anything new as an important resource within *business*, i.e. commercial production and use, it must represent economies of scale. This means that in order to support large-scale production *the new* needs to become connected to resources which enable reductions in unit costs. These are vastly different value-creating resources than those constituting the production of scientific knowledge.

In contrast to the policy and investment recipes of achieving innovation within business by basing it on new, groundbreaking and "excellent" scientific knowledge, this study shows that this is not only a matter of trying to control an unpredictable and highly uncertain process, as with any innovation process, but also a matter of inducing benefits through combining the new solution with vastly different resource structures. In considering commercialisation of new scientific knowledge this aspect must be taken into consideration. If not, the difference between scientific and economic significance is not taken seriously.

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APPENDIX 1

Name	**Position**	**Type of Interview**	**Date of Interview**
Allen Marie	Associate Professor, Department of Genetics and Pathology, Rudbeck Laboratory, Uppsala University	In person	2005-02-28
		By email	2005-05-26
		By email	2008-04-24
Ekström Björn	Co-founder of Pyrosequencing	In person	2003-11-04
		In person	2005-10-14
		By email	2005-05-27
		By email	2008-04-17
		By email	2009-01-12
		By email	2010-02-15
Gharizadeh Baback	Former PhD student in Nyrén´s group KTH	By email	2008-06-03
Hjortsmark Maria	Vice President of Technology Development at Biotage	By email	2005-10-24
Irzyk Gerard	Laboratory technician at 454 Life Sciences	In person	2006-04-25
Joergensen Torben	CEO of Biotage since 2007	In person	2007-05-07
KaraMohamed Samer	Former PhD student in Nyrén´s group KTH	By email	2008-06-05
Krabbe Margareta	Former Senior Scientist at Pyrosequencing 2001-2004	In person	2005-12-05
McLeod Christopher	CEO of 454 Life Sciences	In person	2006-04-26
		In person	2008-01-16
		By email	2008-02-26
Nilsson Torbjörn	Senior physician and Professor at Örebro University Hospital	By email	2008-07-14
Nourizad Nader	Former PhD student in Nyrén´s group KTH	By email	2008-06-04
Nyrén Pål	Professor, Department of Biochmistry, KTH. Inventor of the Pyrosequencing method. Co-founder of Pyrosequencing	By email	2003-11-10
		In person	2005-09-22

		In person	2007-01-31
		By email	2009-02-11
Odeberg Jacob	PhD, Department of Biotechnolgy, KTH	In person	2006-03-29
Odlander Björn	Co-founder of Odlander, Fredriksson & Co	In person	2007-02-15
		By email	2009-01-13
Olsson Lovisa	Chemist at The Clinical Chemistry Laboratory, Örebro University Hospital	In person	2005-11-11
Pettersson Bertil	Former PhD student in Mathias Uhlén's research group, KTH. Co-founder of Pyrosequencing	In person	2007-02-23
Pielberg Gerli	Associate Professor, Department of Medical Biochemistry and Microbiology, Uppsala University	In person	2005-11-25
		By email	2008-09-23
Reid Marion	Former PhD at the Laboratory of Molecular Analysis, NYBC. Now Head of the Immunochemistry Laboratory, NYBC	By email	2008-05-21
Schanche Jon Sverre	Vice President of R&D at the division of Discovery Chemistry, Biotage	In person	2005-05-11
Steiner Eugen	Partner of Health Cap and Odlander, Fredriksson & Co. CEO of Pyrosequencing 1997-1998	In person	2005-10-11
		By email	2009-01-14
Svensson Emma	PhD student, Department of Evolutionary Biology, Uppsala University	In person	2005-11-07
		By email	2008-04-29
Söderbäck Erik	Former Senior Scientist at Pyrosequencing 2001-2004	In person	2005-12-05
		By email	2008-08-28
Uhlén Mathias	Professor, Department of Biotechnology,	In person	2007-04-02

	KTH. Co-founder of Pyrosequencing		
Valinsky Jay	Vice President of Information and Technology, NYBC	In person	2006-04-27
Walldén Erik	Former CEO of Pyrosequencing 1998-2003	In person	2007-03-29