The unavoidable linear thinking

Or the need to consider what type of economic model a forecast is based upon.

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Abstract

Linear thinking is both prevalent and questioned. Regardless of how much an economic actor distrusts linear thinking, as a representative for a private, public or business economy she has to make forecasts. And as soon a forecast is made, some type of linear thinking have to be accepted. The research question of this paper concerns what type of economic model the assumed linear relation among the present and the future is based upon.

In order to shed light over this question we are taking a closer look at three economic actors considering the opportunity to invest in a specific innovation journey. Based on the recognition that the potential innovation corresponded to an important societal and economic need; to carry out fast and accurate DNA analysis, two of the economic actors; one venture capital firm and one governmental policy agency, forecasted a very positive relation among the scientific discovery and a successful innovation while the third one – an experienced company made a much more negative forecast.

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In the conclusion of the paper it is argued that when the forecast is based on a market model of the business landscape, the point of departure is the preferences of the buyer. I.e. the linearity is assumed to be affected by if there is a demand for such a function as the potential innovation can offer, and if it can correspond to this demand in a more efficient way than established products. The two actors making a positive forecast are basing it on such analysis. If the forecast is based on a network model of the business landscape, the point of departure is the investments in place. I.e. the linearity is assumed to be affected by a context full of material and immaterial investments which are related – across company borders, and were the new has to contribute with positive economic effects in order to be embedded. Hence, if a forecast is based on, or is close to, a network model, the linearity among an investment decision and the economic outcome is assumed to be influenced by the existing substance. This was also the type of analysis made by the company making a more negative evaluation. And in this specific case this was also the right forecast.

1. Introduction

In the late 1990s a radically new way of carrying out DNA sequencing was presented in an article in *Science*.[4] In the wake of the HUGO era, both the researchers behind the method and a number of economic actors were considering the possibility to turn the invention into an innovation which could contribute with scientific, technological and economic benefits. Thus, what all of these economic actors experienced, was the need to make forecasts. In this paper we will take a closer look at three economic actors considering the opportunity to invest in the innovation journey. Based on the recognition that the discovery corresponded to an important societal and economic need; to carry out fast and accurate DNA analysis, two of the economic actors; one venture capital firm and one governmental policy agency, forecasted a very positive relation among the scientific discovery and a successful innovation. In the following sections we will take a closer look at this innovation journey, and more precisely, on what type of linearity among investment decision and economic outcome that was forecasted by the three economic actors.

The paper is organized as follows: In section 2 the need for making forecasts is discussed, and the research design is presented. In section 3 the innovation journey in focus is presented. In section 4 the different types of forecasts, based on market respectively network models are analysed. And in chapter 5, finally, the different types of linearity's outlined with these two models are discussed. But first, let us start with a brief overview of how the relation among scientific discovery and successful innovations has been considered in economic thinking.

1.1 A linearity longed for

The economic actors that saw a great innovation potential in the new DNA sequencing technology were not the first, and probably not the least, to express great trust in science and technology as benefactor of innovation, industrial renewal and economic growth.

> "Technical and scientific progress continues ever more rapidly in the service of both war and peace. It is characterised by the penetration of science into all forms of production, and by an ever increasing degree of organisation and intercommunication".

[4] ***Science*** 17 July 1998, Vol. 281. no. 5375, pp. 363 – 365, 'DNA SEQUENCING: A Sequencing Method Based on Real-Time Pyrophosphate', by Mostafa Ronaghi, Mathias Uhlén and Pål Nyrén.

The statement quoted above was made more than 70 years ago by Bernal (1939:902), one of the most optimistic advocates of a direct, linear relation among scientific and economic progress. Although the 20th and the early 21st centuries' economic reality brutally has ruined Bernal's forecast that the advances of "natural science" and the "techniques of making use of it" is enough to "solve all the problems of the world economy", his idea of a linear relation among scientific advances and economic benefits has solid support in neoclassical economics – and in a modified way also in innovation studies and contemporary innovation policy. In the neoclassical thinking scientific advances is assumed to be exogenous to the economic system. (Eklund, 2013, Basalla, 1988) However, during the last decades of the 20th century scholars engaged in industrial renewal noticed that scientific advancement was not automatically absorbed by the market, even if a demand related to the new knowledge could be identified. In what later on has been labelled the National Innovation System approach, a slightly adapted type of linear thinking was presented. The complementary assumption made was that economic and societal benefits can be achieved through creating support for "sticky knowledge", such as academic research results, to reach business and industry. (Elzinga, 2004, Elzinga & Jamison, 1995, Eklund, 2007, Högselius, 2010, Mirowski, 2011) This inspired to the so called '1990s science and innovation policy doctrine' (Elzinga, 2004), were the linearity is interpreted as follows: a) scientific and technological advances made outside the business landscape is the most important source of economic and societal progress, b) through policy orchestration scientific research results can be privatized and commercialized on the market and c) the commercialization, if met by a corresponding demand, will result in innovation and economic and societal benefits. (Slaughter & Leslie, 1997, Nowotny, Scott & Gibbons, 2001, Edquist, 2005, Lundvall & Borrás, 2005, Mirowski, 2011) The trust in this type of linearity is for example expressed in the EU framework programme for research and innovation, labelled "Horizon 2020". [5]

> "Horizon 2020 will tackle societal challenges by helping to bridge the gap between research and the market by, for example, helping innovative enterprise to develop their technological breakthroughs into viable products with real commercial potential."

If a linear thinking based on the scientific and technological advances in themselve more or less consciously has been embedded into contemporary economic policy, this has a long

[5] http://ec.europa.eu/research/horizon2020/index_en.cfm?pg=h2020

tradition of being questioned in empirical based, process oriented research. (van de Ven et al, 1999, Håkansson et al, 2009) The promises of this type of linear thinking; that something radically new is forecasted to have a direct and positive impact the industrial and economic development; i.e. that an economic future is expected to be a direct consequence of present advances in science, has been a far to simplified view to accept for a researchers engaged in empirical based research on the relation among science and society. (Eklund, 2007, Håkansson, Waluszewski, 2007) The main objection is that the context where the new is going to be embedded into a large scale production and use is assumed away – and consequently the tricky question if the existing investments in these setting will support or hinder this process.

2. The need for forecast – but resting on what type of linear thinking?

Linear thinking is thus both prevalent and questioned. However, regardless of how much an economic actor distrusts a linear thinking, as a representative for a private, public or business economy she has to make forecasts. And as soon a forecast is made, some type of linear thinking have to be accepted. A forecast is always as guess about a future state – but in order to make decisions economic actors have to live with this guessing. Taking a private loan for a house or a company loan for a facility – both types of decisions is based on some type of predictions of future consequences; i.e. that there is a line between present acting and future outcome. Thus, everyday economic actors have to make decisions that are based on more or less explicit forecasts. This is especially the case in innovation attempts; for example as when a larger investment is considered, with the attempt to transform a new idea into a new product and service. When forecasting, for example the sales of a yet not launched product, the expected future will be grounded on a mix of hope and present facts. The hope is an important driving force, but the facts this is combined with are always based on different aspects of the history and the present. A crucial question is thus how the facts are identified. How they are identified and sorted out is related to how the logic of the history and the present is interpreted; i.e. of what model we (consciously or unconsciously) apply. (Håkansson et al, 2009, Marglin, 2008, Wilk, 1996)

If linear thinking is an unavoidable part of forecasting, it is of great importance to consider what type of model the assumed linear relation among the present and the future is based upon. The latter is also *the overall research question* of this paper:

We will consider how the linearity is expected to function in two, rather different types of models of the business landscape. The first is the traditional market model, which assumptions of the characteristics of the business landscape to a great extend is embedded into contemporary, neo-liberal research and innovation policy. The second is a process oriented industrial network approach, grounded in empirical observations of the interactive features of the business landscape. We will illustrate how different the linearity are framed in these two models, through analysing how they are applied on an innovation journey concerning the attempts to transform a new DNA analysing method into a biotech analytical innovation.

More precisely, we will study three economic actors who have to make forecasts in this innovation process. They have to make these forecasts as they have to make investments long before there is a defined product. In these forecasts they have to build on some kind of linear thinking – how the future will be created out of existing circumstances that in turn have more or less of historical roots. In this situation they have all applied, more or less consciously, two rather different kind of thinking which have kinship with the two models presented above. How the context is reflected in these models have, as we will see below, a great impact on what factors that are identified and utilised in the forecasts.

2.1 Research design

The research design starts out with an identification of how a linear thinking is embedded into two types of models of the business landscape. As mentioned above, the first concerns the linear thinking embedded into the market model (Wilk, 1996,) and the second a network model (Håkansson et al, 2009). If we utilize the market model when forecasting the future of a potential innovation, following logic is outlined.

1. If the business landscape is assumed to have the characteristics of a market as depicted in the market model, it means that the actors populating it are understood as being free to choose any solution that is best for them; in terms of what to buy and what to sell. Consequently, in the future the economic actors will be free to choose what is best for them – and they will take these decisions individually. When an economic actor is faced with something new, this will be judged in terms of whether it can solve a problem better than existing solutions/products/services. Thus, the comparison among the new and existing solutions/products; i.e. the relative performance, will determine

the future of the new. The linearity is expressed in terms of a comparison between the relative performance of the new in relation to existing products. The future use can in this way be forecasted, based on the use of existing products. (Wilk, 1996, Marglin, 2008)

If we instead utilize a network model when forecasting the future of a potential innovation, following logic is applied:

2. If the business landscape is assumed to have the characteristics of a network the linearity is expressed in a different way, which also makes the forecast different. A network model is a description of the economic environment in terms of a certain activity and resource structure. The actors are assumed to be interdependent with external actors, resources and activities. This in turns means that actors are investing in relationships to others in order influence the combination of resources and activities in the business landscape. The existing business landscape can thus be characterised as a structure were each actor have invested in how its resources and activities are combined with others. When an economic actor is faced with something new, this will be judged in terms of what it can add to the existing structure of activated resources. In this way it includes both the activities in which the actual product is used as well as all related activities. The linearity is expressed in terms of the assumed effect on the total existing activity structure including activated resources and actors. It is the total effects in this activity structure that will determine the outcome in terms of volumes and revenues for any new product. Thus, the forecast is based on a comparison among the existing structure and the changes of the structure that the new calls forth. (Håkansson et al, 2009, Ford et al, 2003, Håkansson, Waluszewski, 2002,)

In order to illustrate the different types of forecasts that are outlined depending on which type of model that are applied, we will utilise a larger empirical study on the relation among scientific research results and industrial renewal in the life science setting, which started in 2001 and is still on-going. The point of departure was an investigation of the development paths behind the life science companies located to the Uppsala region in Sweden, were the

main historical and contemporary resources interfaces of 25 companies, including how these were activated in supplying and a using setting, were investigated.[6] (Waluszewski, 2004)

One of the development paths mapped in the overall project became the object for three related, detailed studies. This specific development path concerned an attempt to commercialize a new gene mapping method, considered as a significant scientific break-through. A first special study focused on the influence of venture capital in this process. The research question concerned how the venture capital firm's view on the relation among research results and commercialization intervened in the creation of a physical product and in the embedding of this in a supplying and using setting. (Waluszewski & Wedin, 2003)

The second, and the most encompassing investigation of this specific development path was undertaken in a PhD study made by one of the authors of this paper, on how the future benefits of the new gene mapping method were considered in three different settings; an academic research setting, a venture cap financed producing setting and a user setting consisting of private companies and public health care organisations. (Ingemansson, 2010, Ingemansson, Waluszewski, 2009) The main research question concerned how the future economic benefits of the new gene mapping method was considered in each setting – and how these were empirically outlined when the method was embedded in each of them. The third study was a complementary investigation of how the future benefits of the gene mapping method in a commercial setting was interpreted by Sweden's Innovation Agency 'Vinnova', which also was one of the financiers' of this process. (Waluszewski, 2011)

We will utilize the empirical data collected in these studies in order to illustrate how the linearity of the gene mapping method as a commercial product appears, if the forecasting is based on a market respectively a network based model. We will illustrate the different views of linearity through making three specific actor related analysis; based on market respectively network thinking. The first analysed actor situation appear when the gene mapping method for the first time is exposed to a forecast in terms of the ability to transform it to a commercial product. The expectations of the actors behind the commercialization attempt is that the future

[6] This meant that the study included all companies in the region which had developed so far that they had a product/service under development, including emerging interfaces with a supplying and user setting. This main part of the study was complemented by an investigation of the policy view on the emergence of this industry. The identified companies were investigated in 2001, 2003 and 2004. A bout hundred personal interviews concerning each company's direct and indirect resources interfaces was carried out. During 2011 the investigation was complemented by collection of secondary data concerning each company's present stage.

of a product based on the gene mapping method will appear bright enough for one of the world's largest supplier of biotech analytical equipment, Pharmacia Biotech (later merged with Amersham Biosciences, today GE Healthcare), to engage in the commercialization process. It is this actor's use of forecasts that is in the centre of the first analysis.

The second and third analysed actors' uses of forecasts are identified when the gene mapping method is exposed to a venture capital firm's attempt to commercialize it. The second analysed forecast is the one made by the venture capital firm, which makes it to invest in a start-up company based on the gene-mapping method. The venture capital finances firm is also applying for innovation support from a governmental policy agency. The forecast made by the governmental policy results in financial support for the commercialization process, and this third one analysed.

Before we will present how the linearity of these situations appears through a market respectively a network analysis, we will make a brief overview of the gene-mapping innovation journey.

3. Pyrosequenceing – a new way of mapping short DNA strings

> 'It is realistic that already within one or two years after the project is concluded commercial products will be available on the market.' [7]

The forecast quoted above was made in an application presented to the Swedish industrial policy agency Nutek in 1998.[8] The application concerned a co-operation between a newly established start-up company and an academic research unit that had provided the company with its basic technology; a new gene mapping method, for analysing short DNA strings. The application seemed to be in line with the aim of the policy agency's biomedicine program, which was to strengthen 'the development of networks among biotech science and business',

[7] Final version of the Pyrosequencing application, 1998-06-18.

[8] Today the Swedish Agency for Economic and Regional Growth.

to increase the ‘quality in business’ and to stimulate ‘a more rapid commercial utilization of science based knowledge’.[9]

The project was managed by a venture capital financed start-up company named Pyrosequencing, which also was the name of the gene mapping method it was about to commercialize. The other main participant was the academic research leader behind the invention of the pyrosequencing method, who also represented one of Sweden’s most recognized scientific research units within the biotech area; the Department of Biochemistry at the Royal Institute of Technology in Stockholm (KTH).[10] The idea was that the Pyrosequencing company should ‘develop and market’ an automatized product system based on the method, as well as the reagents necessary for ‘reading’ short DNA strings. In the wake of the HUGO[11] era the expectations on an increased use of DNA analysis were high, or as expressed in the application to Nutek, an expansion was assumed both within ‘today’s research market and tomorrow’s diagnostic market’.

The pyrosequencing method that had been developed by the researchers at KTH represented a radically new way of ‘reading’ the DNA code. The established Sanger method[12] was a Nobel prize rewarded investigation method based on electrophoresis. Through the Sanger method, which was utilized in the HUGO project, it was possible to read longer DNA strings. However, the method was partly manual and demanded a skilled user, and was thus considered to have a low productivity. The pyrosequencing method was based on a different technology; it was built on a four enzyme system that reconstructed the DNA string when separate DNA components were added, a process which in turn created a by-product that transformed into a detectible light signal indicating the sequence. While DNA sequencing with the Sanger method took about three days to perform, with the Pyrosequencing method this could be done within a few hours.

[9] Nutek annual report 1998.

[10] Two other small Uppsala based biotech companies had a minor part in the project, Eurona Medical AB and Professional Genetics Laboratory AB.

[11] This was a US governmental project that set out to read the entire human genome. It was instigated in 1990 and considered finished in 2003.

[12] To be added: back ground information on Sanger.

At the time when the Pyrosequencing company applied for policy support, the new DNA sequencing method was already acknowledged as a radical breakthrough within science; it had among others been rewarded with an article in *Science*, one of the most prestigious scientific journals.[13] The scientific breakthrough made the pyrosequencing method a valuable resource in the scientific setting; a substantial number of acknowledged new scientific publications were based on it as well as a number of PhD theses, funding was attracted through it, and the research group was enlarged and strengthened. The commercial challenge was to embed the new method in an automated, accurate and user friendly product system; an instrument and reagents.

A scientific breakthrough of with future commercial benefits?

Already before a venture capital financed start-up company was established based on the pyrosequencing method, it had attracted commercial interest. One of the research leaders engaged in the development of the pyrosequencing method at KTH was also engaged as scientific advisor on the board of one of the world's largest producers of biotech instruments and systems, the Uppsala based company Pharmacia Biotech. The discussions in the board resulted in the initiating of a collaboration among researchers at KTH and a specific group at Pharmacia Biotech dedicated to investigations of new, potential technologies, the Exploratory Research Department. While the academic researchers contributed with knowledge about the new enzyme-based DNA sequencing method, the role of the Pharmacia Biotech's Exploratory Research Department was to contribute with insights into how the method could be automated, especially how a flow system could be designed, and furthermore, to consider possible user applications. The participants' expectations on the new method were high, and both the researchers in the academic and the business setting were interested in forming a joint venture to commercialize it.

However, at about the same time as the participants from KTH got their scientific breakthrough published in *Science,* the management of Pharmacia Biotech decided that the company should withdraw from the joint project. The official explanation was an on-going merger with another large supplier of biotech analytical instruments, Amersham International,

[13] ***Science*** 17 July 1998, Vol. 281. no. 5375, pp. 363 – 365, 'DNA SEQUENCING: A Sequencing Method Based on Real-Time Pyrophosphate', by Mostafa Ronaghi, Mathias Uhlén and Pål Nyrén.

and that a development project based on the pyrosequencing method did not fit into the strategy of the new constellation Amersham Pharmacia Biotech.

However, this was not the only reason for an abandonment of the Pyrosequencing project. There were also managers within Pharmacia Biotech who considered the applications of the new DNA sequencing method to be far too specific and scattered to ever carry the costs of large scale production, marketing and application development.

The manager of Pharmacia Biotech's Exploratory Research Department and the research leaders at KTH, however, made another interpretation. The rough estimation was that the market for instruments and reagents for DNA analysis reached more than €300 million in mid 1990s, and that a third of this market concerned the reading of short DNA strings. It was also estimated that this market, which was dominated by academic users, should be more 'balanced' already within a decade, in terms of a growing diagnostic market within life science companies and health care organizations. This view was also shared by a Swedish venture capital firm, Health Cap, specialized in the life science area. In Health Caps' opinion, there had been very little progress within the DNA sequencing area since the 1970s when the Sanger DNA sequencing method was introduced. Combined with the increased interest in DNA sequencing that the HUGO project had created, the venture capitalists' interpretation was that there existed a 'great, potential unmet need' for a more rapid and automated sequencing method. The pyrosequencing method was seen as a unique opportunity to produce and market an instrument that corresponded to that demand. From this vision, the company Pyrosequencing was founded in 1997 with full financial support for the next seven years and with the Pyrosequencing patents as its technological base.

Pyrosequencing becomes a venture capital and policy supported innovation journey

The Swedish policy agency Nutek made the same interpretation as the venture capitalist, and reacted with a positive response on the application for support to the co-operation between the Pyrosequencing company and the researchers at KTH. In September 1998 a project with the title 'Development and marketing of new DNA sequencing technology with application within science and routine diagnostics' was granted with approximately €200, 000. This was

48% of the total project cost. The motivation behind the decision, which followed Nutek's traditional evaluation criteria, was following: [14]

- *Relevance*: The project fulfils the general requirements of Nutek'sBiomedical program.
- *Environmental aspects:* A faster and simpler DNA sequencing is considered as having a positive environmental effect. The project also provides a more rapid and secure diagnostic opportunity for several severe diseases at a lesser cost than available techniques.
- *Cooperation/Financing:* The project consists of a functioning, integrated project group with participants from industry and academics. The participating researchers at KTH are internationally recognized and the company's work is built on their participation and transfer of knowledge.
- *News value:* Great. The new technology has the possibility of going from research to routine with increased security and capacity in the DNA sequencing area.
- *The quality of the research/project group:* Very high. All members are acknowledged internationally and have shown high competence in earlier development projects. Within a short time (about 2 years) the group succeeded in developing two generations of a functional system.
- *Ability to realize the project.* Good. Experienced senior researchers are tutoring doctoral students participating in the project. The project management is convincing and based on genuine experience.
- *Anchoring:* A personal meeting between representatives from Nutek and Pyrosequencing revealed that the project is accepted and prioritized by all participating members. It is also of great importance for the company's further development.

A new product launched and a new company on the stock market

In the application to the Swedish policy agency the Pyrosequencing company had made the brave estimation that a product would be launched within one or two years after the project

[14] Nutek protocol 1998-09-29, nr 1N19-98-03316

was concluded. This was actually delivered with a good margin; the policy supported project should be concluded in 2000, but already in 1999 Pyrosequencing could launch the first product system, the so called PSQ96.

In 2000 Pyrosequencing was introduced on the stock market and valued at about€400 million. In terms of the company's own interpretation, it had managed to transform a scientific breakthrough into a successful business venture:

> 'With only 85 million SKr [around €8.5 million] invested in development costs we have transformed an idea into a globally commercial product' [15]

When Pyrosequencing delivered the final project report to Nutek the same year, the conclusion was that the project had 'reached the goals', that the 'produced results in line with what was expected' and that it had 'strengthened the participating business partners' national and international competitiveness'. The understanding that Pyroseqencing was an innovative, commercial success was also shared by external evaluators. The RoyalSwedishAcademy of Engineering Sciences (IVA) named Pyrosequencing as the 'start-up company of the year' in 2001, with the following motivation:

> 'Pyrosequencing has developed an exciting business opportunity from a research environment to a stock market introduced company with a focus on innovation'.

The same year Pyrosequencing was also recognized by Forbe's, which listed it as the 'best newcomer'.

A remarkable technology with lack of users

However, a bit more than a year after Pyrosequencing's successful epithet it became obvious that the expected 'market expansion' was not realized. Instead of selling the estimated several hundred instruments per year, Pyrosequencing managed to 'place out' about 50 per year, and not all instruments were paid for. Second, the main users were not, as expected initially, life science companies with regular and large scale DNA sequencing activities, but academic or non-profit research units with short term, project based DNA sequencing activities. Third, this

[15] Pyrosequencing Annual Report 2000, p.3.

meant that it was not only the sale of instruments that was dramatically lower than initially calculated but also the frequency of use of the instruments. This caused even greater problems, since the main income was not planned to be based on sales of instruments, but on a continuous purchase of consumables (the reagent kit). Thus, instead of 'black figures' Pyrosequencing had to report a loss of over €30 million per year. And when Pyrosequencing could not live up to the stock exchange's expectations on increased sales and subsequent increased value of the company, the valuation of the company fell. Just 18 months after its stock introduction the estimate had decreased to a tenth of the original valuation.

A merger

The difficulties of creating a 'substantial market' led the venture capital firm Health Cap to merge Pyrosequencing in 2002 with another company in its portfolio. The merger was with another Uppsala based biotech instrument company, Personal Chemistry, which was not yet introduced on the stock market. Shortly after this initial merger another acquisition followed. This time an American company, Biotage LCC, became the owner of the two Uppsala based biotech instrument companies. This also became the new name of the whole company, which mainly was engaged in the production of chromatography equipment.[16]Pyrosequencing was of great importance in this process of mergers and acquisitions. However, this was not due to its technological base, which did not get much attention in the new company constellation.

Instead it was the approximately €10 billion which Pyrosequencing earned in the stock market introduction which made it an invaluable asset. All of this was spent on acquisitions; during the first decade of the 2000s more acquisitions followed, all of them exclusively compatible with the Biotage main technological areas, chromatography.[17] Meanwhile, the work with the pyrosequencing product system and applications was done with the left hand. Thus, the pyrosequencing method which had been the sole technology and focus within the Pyrosequencing company, was more or less put on the shelf, to the benefit of the chromatography technologies represented by the new American owner. This made

[16] A technology used for protein purification, i.e. a completely different basic technology compared to the Pyrosequencing method concerning reading of DNA strings.

[17]In late 2008 the division Biosystems was acquired by the German company Qiagen, which is a global provider of sample and assay technologies. One such acquisition was Argonaute which produces consumables for chromatographic equipment.

Pyrosequencing a small, un-prioritized product group within the Biotage business constellation and the sales more or less faded away.

However, this did not mean that all of the commercial use of the pyrosequencing technology also faded away. After the merger a start-up company named 454 Life Sciences[18] showed an interest in the Pyrosequencing technology. The plan at 454 Life Sciences was to put together a 'high throughput sequencing system' with the goal of enabling cheap whole genome sequencing. The idea was to create an automated system for massive DNA sequencing in parallel, thus making whole genome sequencing both faster and less expensive. In this system the pyrosequencing technology was regarded as a valuable component if the read length, along with other features, could be further developed. After a couple of years of development work, the first 454 Life Sciences' instrument based on the Pyrosequencing technology was sold in 2005. Since 2008 the production, marketing and development of user applications of the 454 Life Sciences' instrument takes place as a subsidiary within one of the world's leading pharmaceutical and diagnostics companies, the Swiss based multinational Hoffmann-La Roche Ltd.

To summarize, although several of the actors involved in the development of the pyrosequencing method in turning it into a commercial product system ascribed it great benefits, and although there were users who shared this view, the invention never became the successful, wide-spread innovation that initially was forecasted. If the commercialization of the pyrosequencing technology ever takes off and reaches a widespread use through being embedded into 454 Life Sciences' instrument, it will be as an anonymous component in a larger system solution.

4. Three actors in need of forecasts

As reflected in the case above, the individuals engaged in the pyrosequencing innovation journey are to a large extent believing in a successful outcome. They are very much building their continuous and energetic activities on "hope". However, three of the involved actors in this innovation process have to make some more or less explicit forecasts. This is the biotech equipment company Pharmacia Biotech, the venture capital firm Health Cap, and the

[18] 454 Sequencing had spun off from American CuraGen, a midsized biopharmaceutical company formed during the beginning of the HUGO-project focusing on identifying disease-causing genes.

governmental agency Nutek. All these three actors are becoming involved in the innovation journey – and if they are going to make any investments in relation to it they also have to carry out some type of forecast to base the decision; to invest or to not invest, on. Hence, all three actors are offered an opportunity and they have to assess this from an economic point of view. Two of them have to do it because they are companies with explicit economic goals and one because it has to follow governmental regulations. If the three actors have the need to make forecasts in common, they are different in terms of history, investments in place and roles in the innovation journey. Let us now have a closer look at each of them.

Pharmacia Biotech's forecast

When the pyrosequencing method entered Pharmacia Biotech as an exploratory commercial endeavour, this company was one of the world's largest suppliers of biotech equipment, from laboratory instruments over to large scale facility equipment. This means that the company had extensive experience and knowledge of both the producing and using side of this type of equipment. Pharmacia Biotech was since decades a part of a wide-ranging network of direct related suppliers and sub-suppliers, of complementary suppliers and competitors, of customers engaged in academic research and industrial R&D, of customers engaged in large scale biotech based pharmaceuticals, etc.

Pharmacia Biotech's exploratory department was small internal unit that through a rather informal decision making could engage in the the pyrosequencing method. The idea behind the exploratory departments was that it should carry out initial tests of ideas under development, and identify those with commercial potential down the line after initial testing and prototype development. As such this was a test laboratory detached from the company's other activities, such as production, purchasing, marketing and after-sale support. The structure which the pyrosequencing method would have needed to become a part of, if deemed suitable for commercialisation, was on the other hand an established inter-organisational network of various suppliers and academic and company customers, each representing a particular set of investments in place. Any adaptation of the pyrosequencing method in relation to these investments, or the established network, would mean costs which the sales of the future product would have to be able to carry.

This means that when evaluating commercialisation of the new method Pharmacia Biotech had to consider:

1) *The supply network*: Would the existing suppliers cover the needs for component and system solution necessary for taking up the pyrosequencing method in production,, and if so, how? Or would there have to be additional suppliers brought in?

2) *The customer network*: Would the existing customer base also want to purchase the new product, and if so which customers; business or academic, research or large scale producers, and in what volume? Or would new customers need to be identified?

3) *The internal production network*: Would Pharmacia Biotech's internal facilities be able to support the new product and if so, how? Or would there have to be changes to the existing production process? In addition, the on-going merger with another world-leading company within biotech tooling, Amersham International, meant that the Pharmacia evaluation needed to take this merging company's internal and external network into consideration as well.

The merging of two such extensive supply and customer networks most certainly complicated the situation of actually trying to forecast what investments in the development, production and customer support in relation to a new product based on the pyrosequencing method would mean economically, except for the certainty that it would be a costly journey. After all, in order for the new product to be able to carry its costs it needed to fit into a large-scale production system where the customers, or the using system, would have to correspond to that type of production of this particular type of product. This would require investments both in regard to the internal and external network connected to the production and sales functions of the company.

Pharmacia Biotech ultimately decided to shut down the project around the new method right as a prototype was starting to take shape. It was needless to take it any further as there did not seem to be any room for such a product in the new company constellation, mostly due to the type of use which it was forecasted to induce; low-scale and highly specific for different types of users, probably most in an academic research setting. Firstly, this was not considered as the type of heavy user setting that an economic adventure such as developing and launching a new product based on a totally new analysing methodology required. Secondly, such an innovation journey did not fit into the current activities related to development, production and user support taking place within the company and its network. And thirdly, it did

definitely not fit into the on-going endeavours to merge Pharmacia Biotech with Amersham Biosciences.

The considerations made by Pharmacia Biotech strongly suggest that the forecast, including an identification of the future context in which the new product needed to fit, was based on some type of network thinking. The awareness of the network like characteristics of the context is expressed in terms of considerations of how a new, pyrosequencing analytical product could function within an already existing production system in a user setting, and in terms of awareness of what elements of that structure that needed to change in order for the new to fit in and create future benefits. Furthermore, it was expressed in attention to how the new should fit into existing supplier and sub-supplier relationships as well as into the own production structure. In other words, it was the surrounding network of Pharmacia Biotech (and Amersham Biosciences), which ultimately decided the forecast of whether the new method would be a profitable investment or not.

Let us now move on to consider what type of evaluation that was made by a very different type of actor; namely the venture capital firm.

Health Cap's forecast

Health Cap is the name of a number of funds administered by the firm Odlander, Fredriksson & Co. When this firm was formed in 1996 it became the first Swedish advisory firm for investment funds restricted to the life science area. Presently Health Cap is the largest provider of venture capital within the life sciences in the Nordic countries and one of the largest in Europe. It functions as a consultant for the Health Cap funds, which in turn work as limited partnerships and have diverse large financial actors as owners, such as the National Swedish Pension Funds, large insurance companies and banks.

Committing to support a company formed around the pyrosequencing method would mean that this venture capital firm would act a mediator between the new company and the various investors which had invested in the Health Cap funds. As such its role would be to make sure that these investors got their expected return on investment, which meant creating a suitable "exit" out of the investment that could generate the needed capital within a certain time frame, usually done through a trade sale or a public offering within three to seven years. Thus, in order for the new investment to carry its costs for this firm it needed to be an attractive investment for another company or for floatation on the stock market. Pyrosequencing would

then be just one out of a dozen other investments which this firm had in its portfolio and managed at the time, and it was really the total value of this portfolio which was key for the firm's, and its investors', economic situation.

The venture capital firm's most central relationships were those with its investors and its portfolio companies. The relationships with the investors provided the capital needed to create possible profits and the portfolio companies, all in which the firm had more or less central board and management positions, represented investments opportunities to create such profits. This means that when making an evaluation of commercialisation of the new method it was mainly a set of investors, with capital generation as their primary goal, and a variety of other companies, which the venture capital firm managed as an investment portfolio, which was taken into consideration. There was no existing own supply or customer network that the new product would need to fit into, everything needed for producing and selling the new product would be built up around the new method and its technical qualities. The evaluation that was made stated that the Sanger method was outdated and that users were in need of a more efficient method that was user-friendlier. As such the new method was thought to have no relation to any existing product on the market, nor any existing production or using system that needed to be taken into consideration.

Once this evaluation was made and the investment decision was that the firm would support a start-up company around the new method for the next seven years another early decision was that the product be standardised and locked to as few applications as possible. These decisions reflect a view of users as moving freely on a "market" in which purchasing decisions are made from the standpoint of what is the most effective solution at each given moment. It does not reflect the image of users being tied to earlier investments or relationships, or having different types of needs. The evaluation was based on there being a potential market for these kinds of instruments once the HUGO projects was finished, and the possibility of obtaining a "share" of that market.

Finally, let's consider the evaluation of yet another type of actor; a public policy unit.

Nutek's forecast

Nutek was a Swedish governmental unit formed in 1991 with the role of supporting the growth of trade and industry, later divided into Vinnova; Sweden's Innovation Agency, and the Swedish Agency for Economic and Regional Growth. In today's terms it was an

innovation policy actor, with the possibility to support new ventures and commercialisation projects in accordance with specific requirements which the ventures needed to fulfil. This means that the role of this actor was to identify development projects which needed financial support for a limited time period. In addition, as the application for financial support for commercialising the pyrosequencing method came to Nutek they were part of a biomedicine program with the aim of strengthening 'the development of networks among biotech science and business', to increase the 'quality in business' and to stimulate 'a more rapid commercial utilization of science based knowledge'. Also, support should especially be directed to research areas characterised by 'scientific strength'.

The evaluation criteria to which this unit needed to relate its "investments" were clearly stated and to take some examples it was about the 'relevance' of the project, its 'news value' and 'the quality of the research/project group'. The relevance had to do with how well the project, in this case the pyrosequencing method, strengthened the networks among scientists and business and presented good opportunities of commercial utilisation. This was a well description of the new method as this was exactly what it was doing; there was great interest from both scientists and business people which created connections between them, and there were plans of how to make it into a user-friendly commercial instrument. The project, or the new method, also represented "strong" science as there was a good scientific foundation of publications and researchers on which the method was based. The 'relevance' had however nothing to do with prospective suppliers or users. There was also no question that the news value of the method was great, as it was about a new scientific breakthrough which also indicated good quality of the research group, but who other than scientists and investors that would value this type of news was not considered. And therefore, the decision was to financially support the new method, as it fit into the evaluation criteria so perfectly.

For this actor the quality or use of the new product was evaluated according to criteria that were based on the idea that as long as the new project showed good scientific quality and involved experienced and devoted business people, users would appear and chose this product over other established ones. Just as in the case of the venture capitalist this indicates a view of products existing on a "free market" where earlier investments and relationships are of little importance. The forecast was based on there being a market waiting to react to new offers and where more efficient or cheaper solutions would be chosen over others.

5. The innovation journey forecasted from two different perspectives, the market respectively the network model.

What the three actors presented in the empirical example above had in common, was that all of them faced the need for making forecasts, and thus, for applying some kind of linear thinking. However, as the empirical example also illustrates, the linearity looks rather different depending on if is close to a network or a market influenced thinking.

If the forecast; i.e. the assumption of linear relation among an investment in an innovation journey and a certain economic outcome, is close to a network model of the business landscape, the point of departure is the investments in place. I.e. the linearity is assumed to be affected by a context full of material and immaterial investments which are related – across company borders, and were the new has to contribute with positive economic effects in order to be embedded. Thus, the context is assumed to have a substance, in terms resources that are adapted in relation to each other; for example products, facilities, organisations and relationships, and this substance will determine the economic future of the new. If a forecast is based on, or is close to, a network model, the linearity among an investment decision and the economic outcome is assumed to be influenced by the existing substance. Although Pharmacia Biotech's decision was not consciously based on a network model, it definitely had the characteristics of practical based network thinking.

The relation among investment and outcome was thought to be highly influenced by existing investments; internal as well as external ones, and physical as well as organisational ones. The forecast made was that this structure of related investments in place would not be able to benefit from the potential innovation to any larger extend, and would therefore act like a hindrance for the embedding of this in a large scale production and use. Thus, a linearity was assumed among an investment decision and an economic outcome – however a negative such.

If the forecast; i.e. the assumption of a linear relation among an investment in an innovation journey and a positive economic outcome, is close to a market model of the business landscape, the point of departure is the preferences of the buyer. I.e. the linearity is assumed to be affected by if there is a demand for such a function as the potential innovation can offer,

and if it can correspond to this demand in a more efficient way than established products. A market based forecast is also more or less explicitly used by two of the actors presented in the empirical example above; the venture capital firm Health Cape and the governmental policy agency Nutek. Both of these actors were making forecasts were little attention were paid to investments in place. The forecasts were instead based on comparisons among the potential innovation and the established solution, in terms of which of them that would best fit with the customer preferences. The Nutek forecast was furthermore based on the estimation of if the project leaders had the skills to design a product with the described capabilities. Both forecast were thus based on the potential innovation in themselves, as an individual project and as a stand-alone machine. Based on the relative performance of the potential innovation in relation to the existing solution, both of these actors forecasted a successful innovation journey and product which would be a sales success. Thus, a linearity was assumed among an investment decision and an economic outcome – and a positive such.

If both a network and market model inspired decision making addresses the needs for making forecasts; i.e. for applying some kind of linear thinking, it is obvious that a linearity based on the first includes aspects that not at all considered if based on the latter. A linearity outlined based on a network model is stressing the influence from an existing, elaborated structure of related investments, in both a producer and user setting. Although this structure understood as changing over time, this change will take place in steps – were the main part of investments in place will be taken advantage of. Hence a network based forecast is not always – as Pharmacia Biotech did in the case presented above – to say ‘no’ to potential innovations which does not fit with the existing structure. It is just to base the assumed linearity among the new in relation to investment in place. This was exactly what the company 4-5-4 Life Sciences based their forecast on, when they decided to invest in a licencing of the pyrosequencing technology. The investments in place in the supplying and using setting were thought to benefit from 454 Life Sciences embedding of the pyrosequencing in their ‘high throughput sequencing system’. If this linear thinking was right or wrong the future will outline.

References

Basalla, G. 1988. '*The Evolution of Technology'.* UK. Cambridge History of Science Series.

Bernal, J-D, 1939. *"The Social Function of Science".* London: Watts.

Edqust, C., 2005. 'Systems of Innovation. Perspectives and Challenges'. In *The Oxford Handbook of Innovation*, pp. 181-208.

Eklund, M., 2007. '*Adoption of the Innovation System Concept in Sweden'.* Doctoral dissertation. Uppsala Studies in Economic History, 81.

Eklund, M. 2013. "Science Policy in a Socially Embedded Economy". In Rider, S, Hasselberg, Y, , Waluszewski, A, eds. "*Transformations in Research, Higher Education and the Academic Market. The Breakdown of Scientific Thought"*, pp. 111-123. Dordrecht: Springer Science & Business Media.

Elzinga, A., 2004. 'The new Production of Reductionism in Models Relating to Research Policy'. In *'The Science-Industry Nexus. History, Policy, Implications'.* Grandin, K., Wormbs, N., Widmalm, eds.,pp. 277.304. Science History Publications, MA.

Elzinga, A., Jamison, A., 'Changing Policy Agendas in Science and Technology'. In *'Handbook of Science and Technology Studies'*, pp. 572-597. Sheila Jasanoff et al eds. London: Sage

Waluszewski, A., Håkansson, H., 2007 'Economic Use of Knowledge'. In *'Knowledge and Innovation in Business and Industry. The importance of using others.',* Håkansson, H., Waluszewski, A., eds., pp.1-27. London, Routledge.

Håkansson, H., Ford, D., Gadde, L-E, Snehota, I., Waluszewski, A., 2009. 'Business in Networks'. Chichester: Wiley & Sons

Högselius, P., 'Lost in translation? Science, Technology and the State since the 1970s'. In Lundin, P., Stenlås., N., Gribbe, J., 2010. '*Science for Welfare and Warfare. Technology and State Initiative in Cold War Sweden'.* Sagamore Beach: Science and History Publications.

Lundvall, B.-Å and Borrás, S., 2005. 'Science, Technology, and Innovation Policy'. In Fagerberg, J., Mowery, D. C. and Nelson, R. R. (eds): *The Oxford Handbook of Innovation*, pp 599-631. Oxford University Press: New York

Marglin, S.A.. 2008. '*The Dismal Science: How Thinking Like an Economist Undermines Community'.* Cambridge, MA: Harvard University

Nowotny, H., Scott, P., Gibbons, M., 2001. '*Re-Thinking Science. Knowledge and the Public in an Age of Uncertainty'*: Chichester: Wiley & Sons

Slaugther, S., Leslie., L., 1997. *'Academic Capitalism: Politics, Policies and the Entrepreneurial University.* Baltimore and London: John Hopkins University Press.

Van de Ven, A.H., Polley, D. E., Garud, R., Ventkatarman, S., 1999. 'The Innovation Journey'. New York, Oxford University Press.

Waluszewski, A., 2004. ‘A Competing or co-operating cluster or seven decades of combinatory resources? What’s behind a prospering biotech valley?’ *Scandinavian Journal of Management,* 20, 125-150.

Waluszewski, A. and T. Wedin 2003. ‘ *Is it really speed we need? The Role of Venture Capital in (Biotech) Start-ups’.* Proceedings of the 18th IMP Conference, Lugano, September

Waluszewski, A. 2011. *The Policy Practitioners Dilemma. The National Policy and the Transnational Networks.* Stockholm: Vinnova report 2011:07.

Wilk, R. R. ‘*Economics & Cultures. Foundation of Economic Anthropology’.* Oxford: Westview Press 1996.