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1. Introduction: The missing links or the importance of being earnest about the meso level

The literature on technological innovation and technology and social change has been growing at an impressive pace. New journals appear, a stream of books befalls us, and research grants have been made available. This rather recent surge of interest fits in with a growing international concern for technological innovation as a stimulus to economic growth. OECD has e.g. started to supplement its reviews of national research policies with reviews of national innovation policies.

The theoretical discourses produced in this context of increasing political and scientific interest in technological innovation, vary in terms of level of analysis and choice of focus. While most of them are inspired by the economic theories of Joseph Schumpeter, we find both macro and micro approaches. At the macro level, one is concerned with the analysis of radical or basic innovations - their preconditions, emergence, diffusion, and economical impact. The results may be applied through the development of government technology policies, including R&D policy and industrial policy, and such policy work seems to be an important stimulus to this type of

*This is a slightly revised version of a aper presented at the joint conference of the Society for the Social Studies of Science (4S) and the European Association for the Study of Science and Technology (EASST) Amsterdam, 16-19 November 1988.

research.[1] Micro analysts have been more concerned with the innovation strategies of industrial companies and their ability to innovate. This has produced efforts to guide companies in their development of technology and market strategies.[2]

A somewhat different approach has developed from the social studies of science. Instead of analysing the learning processes of companies, market signals or government policies, the emphasis is on the strategies and actions of industrial scientists and technologists. The emerging understanding of the social construction of technology is definitely micro-oriented in its efforts to describe and explain technological innovation in terms of individual action.[3]

There are important merits to all these approaches. One common weakness, however, is their neglect of what might be called the meso level of innovation processes. Organization theorists and business analysts tend to explain innovation in terms of business strategy, structure of organization, ability to learn and ability to understand user's needs. These are features of the individual company, its managers and employees. Sociologists and antropologists - at least some of them - analyses innovation through reference to persuasive abilities of individual scientists and engineers; their strategies to gain support of their choice of problems, solutions, and design criteria, and their effectiveness in connecting their research efforts to what other people see as a desirable future. Economists and political theorists are, on the other hand, employing concepts like economic growth, business cycles, political programs, and diffusion of technology. They refer to the national economy or the government. Consequently, we are

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[1]See e.g. C Freeman: The economics of industrial innovation, Cambrigde, Mass.: MIT-press, 1982; R Rothwell and Walter Zegveld: Reindustrialization and technology, London: Longman, 1985; C Freeman and B-Å Lundvall, eds.: Small countries facing the technological revolution, London: Pinter, 1988.

[2]See e.g. W Abernathy: The productivity dilemma, Baltimore: John Hopkins University press, 1978; K B Clark et al, eds.: The uneasy alliance, Boston: Harvard Business School Press, 1985; R M Kanter: The change masters, New York: Basic Books, 1983; M L Tushman and W L Moore, eds: Readings in the management of innovation, Boston: Pitman, 1982.

[3]See W Bijker et al, eds: The social construction of tehcnological systems, Cambrigde, Mass.: MIT-press, 1987; B Latour: Science in action, London: Open University Press, 1987.

in a situation where innovation is usually explained either in terms of individuals (scientists/engineers or organizations) or in terms of the national economy and government policies.[4]

This is not satisfactory because there are institutions and institutional arrangements that affect or even may be a precondition for development and use of technology. Consider for example the role of banks, venture capitalists, colleges and universities, research institutes, etc. The ever-occuring success-story of "Silicon valley" is more easily interpreted in terms of inter-institutional arrangements than in terms of characteristics of either the individual companies or government policy in the region.[5] The argument is perhaps most forcefully put by Rosenberg and Birdzell in their recent book "How the West grew rich". They strongly emphasize the importance to the rapid economical growth in Western societies of institutional and inter-institutional variety in terms of different ensembles of companies, research institutes, and political institutions.[6] However, Rosenberg and Birdzell are very general and abstract in their presentation. Thus, further and more detailed analysis of the meso level is needed.

This paper is meant as modest contribution in this direction. It presents two small case-studies of industrial innovation which are focused on the importance of institutional arrangements found within the organizations and their involvement in inter-organizational relationships. The analysis will explore and expound differences between science and technology, and, consequently, between the roles of scientists and technologists/engineers, respectively. This focus owes to the assumption that neglect of the meso level in analyses of technological innovation is caused by deficiencies of the standard approaches. More spesifically, we believe that it is necessary with a closer and more critical examination of the usually assumed fruitfullness of transferring concepts and methods of social studies of science

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[4]There are of course, some exceptions to this rule. See e.g. C Sabel: Work and politics, Cambrigde University Press, 1982, M Aglietta: and M Piore and C Sabel: The second industrial devide

[5]E M Rogers and J K Larsen: Silicon Valley fever, New York: Basic Books, 1984.

[6]N Rosenberg and L E Birdzell, jr: How the West grew rich, New York: Basic Books, 1986.

to the social study of technology. This transfer may have produced blind spots which should be removed.

We will start by a brief outline of some attempts at such transfer which will be discussed with reference to some relevant and recent contributions from the history of technology. Then we will present the two case-studies. The first one, on the establishment of Norsk Hydro, is staged to highlight the difference between science studies and technology studies, applied to innovation. The second case-study presents a small Norwegian "high-tech" company developing subsea instruments. The analysis emphasize the demands of inter-institutional collaboration and arrangements that is experienced by those working in the company.

2. The scientific and the technological enterprise: Sisters or distant cousins?

Sociologists and historians of science used to perceive of technology as applied science. This conception made the scientific and the technological enterprises quite different; one pathbreaking, original, and risky, the other more straightforward and routine. Or, in practice: Science was a worthwhile object of study, technology was not. However, this situation has changed in two important ways. Firstly, the study of technology has been set on the agenda. Secondly, in the available literature, the once-perceived differences between science and technology have become increasingly nebulous. This is evident from recent contribution to the social study of technology. For example, Bijker and Pinch argue that the development of technology should be studied by use of concepts and methods similar to those employed in the empirical, relativist programme of science studies.[7] Bruno Latour goes even further in stating that science and technology should be studied as one object which he calls "technoscience".[8]

Latour's argument is interesting, albeit problematic. He argues that the practice of science as well as technology can be interpreted as a mobiliza-

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[7]W Bijker and T Pinch: "The social construction of facts and artefacts", i Bijker et al (note 3).

[8]Latour, op. cit.

tion process where scientists and engineers are engaged to enroll human and non-human "actors" to support their cause. To construct supporting networks of actors, scientists and engineers have to their disposal an array of persuasive strategies, some appropriate to human and some to non-human "actors". When studying how the "interests" of the various "actors" are translated into a commonly accepted scenario, different strategies may be identified. This allows for a quite detailed and informative account of some examples of how science and technology are produced, without reference to individual genius or accident.

One problem with this perception is its lack of sensitity to the different conditions of the scientific and the technological enterprises. While certainly the translation strategies employed by scientists have common features with those applied by engineers, the terrains in which these translations are to be made, are quite different. These differences can be studied in terms of economical importance and political impact, but also by reference to intrinsic qualities of the two enterprises. The reference to economical and political factors is an allusion to the fact that technology usually is surrounded by a larger number of stronger economical and political actors than is science.[9] A crude indicator of this fact is the very large amount of money spent on technological R&D, compared to the more limited resources available to science. However, we will leave this line of argument for the moment and concentrate on the matter of intrinsic qualities of science and technology.

When comparing science and technology, one faces the problem of what to compare. Science and technology is in this respect shorthand for a large ensemble of theoretical, political, economical, and institutional relations. To begin with, it seems a well-founded assumption that the disciplinary autonomy of technology is not very different from that of science. Technological disciplines also have their departments, curricula, conferences, and journals that constitute a scientific community. In terms of methods, it is also difficult to argue any fundamental difference as the variations within the disciplines of science and technology are quite large.

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[9]See K H Sørensen: Deciding technology, working paper 1/87, Trondheim: STS, 1987.

Ed Constant, in his effort to compare science and technology, maintain that technology is characterized by a more clearly hiearchical structure and a satisfising mode of thought and action.[10] The notion of hiearchy is used to emphasize three features: 1. Decomposability of technological problems, 2. Interface constraints and 3. Interaction of different specialist communities. Inventions, innovation or design may involve - at least in the case of complicated systems - a decomposition of the technological problem into subproblems. This decomposition implies a more complicated social organization of the problemsolving. Often, subproblems are contracted to "outsiders" from other disciplines and/or institutions. Networks then have to be established, allowing the initiators some assurance that the "subcontractors" will solve the problem by meeting technical spesifications within certain time limits. Consequently, interaction between different specialist communities has to be disciplined, both temporally and in terms of interface constraints. Moreover, the sub-solutions have to be integrated in a whole that represents a total solution to the original problem. This means that they have to fit together, and this integration process may consequently involve changes in the sub-solutions that eventually are applied.

Constant's assumptions about this hiearchical nature of technology should be compared to John Law's concept of heterogeneous technology.[11] This concept is used by Law to emphasize the "seamless web" (Hughes) of technical and social elements which constitute a particular technological project or enterprise. While heterogenity in this sense above all allows for the introduction of non-technological factors in the explanation of successes and failures, we will suggest the fruitfullness of a broader concept of heterogenity to cover some of Constant's points in addition to Law's. This implies the introduction of the idea of first and second order of heterogenity. Heterogenity of the first order conceptualizes the necessary decomposition and integration of technology in terms of technical and social parts a la Law. Heterogenity of the second order depicts the decomposition

[10] E Constant: "Communities and hiearchies: Structure in the practice of science and technology", in R Laudan, ed: The nature of technological knowledge, Dordrecht: Reidel, 1984.

[11] J Law: "Technology and heterogenous engineering", in Bijker et al, op. cit.

and integration of technological and sociological subproblems to solve a total technological problem. This covers some of Constant's points, but adds emphasis on social characteristics.

The argument can be illustrated by Figure 1 which schematically indicates characteristics of first and second order heterogenities. It should be noted that the relationship between the two orders are logical and not temporal, i.e. there is no necessary sequence that one should be able to observe.

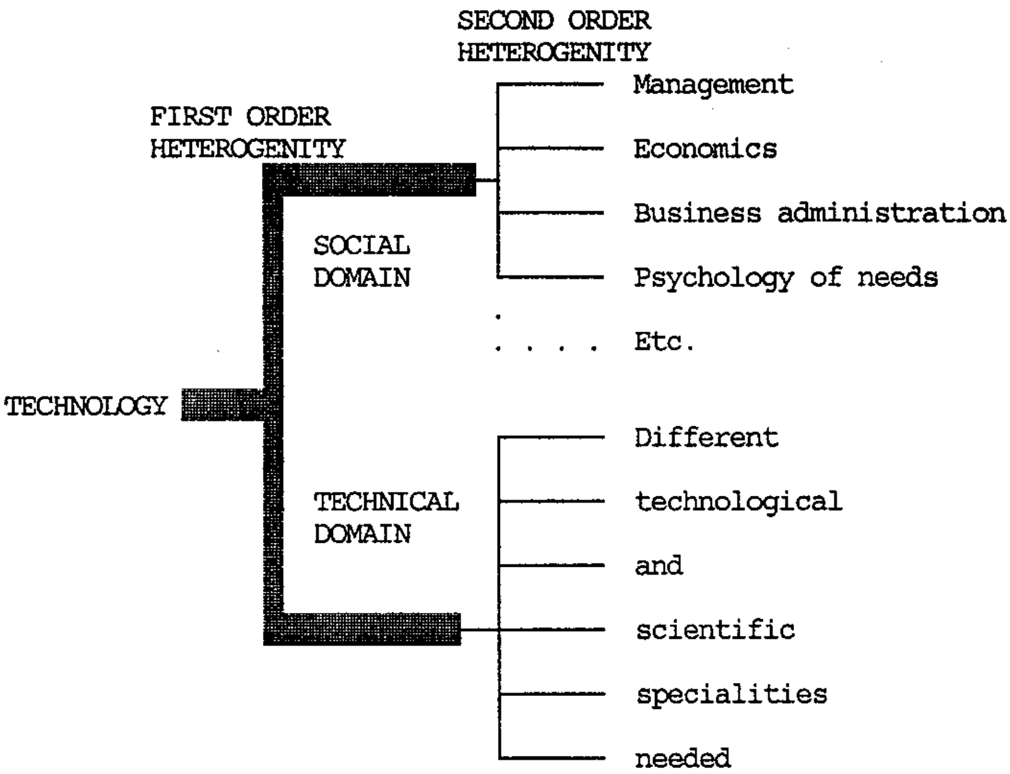

Figure 1.

Returning to the issue of comparing science and technology, we suggest that technology is far more complicated than science in the sense that its level of heterogenity usually is much higher than that of science, both in terms of first and second order heterogenities. Science involves less of the social, and the social terrain on which scientists manuever, is much simpler than that of engineers. Science is also decomposed in the sense that scientists nearly always are working with sub-problems of their discipline, but this decomposition very seldom give rise to interdisciplinary undertakings, and efforts of integration are much smaller.

The assumed similarity of science and technology has also been questioned by those who argue that "the key function of engineering is design, and it is always likely to be so. (...) Research may be a part of the total engineering effort, in those cases where new knowledge has to be generated; but the R and D function often has nothing to do with continous technical change with which the majority of engineers are concerned".[12] These points have been the basis of a quite heated exchange in one of the latest issues of "Technology and Culture",[13] but even if one feels that Fores overstates his case, it is difficult to dismiss the claim (probably none of his opponents would do that) that technology as a body of knowledge and institutions for producing knowledge, is far more than what can reasonably be subsumed under the concept of engineering science. Development of technology is still too much of an art form, in the sense that practical intuition and a developed "engineering gaze" are at least as important as calculations and analysis.

However, it can be argued that there is a similar "hidden side" to science. This is the argument put forward by Michael Polyani when he coined the concept of tacit knowledge. His orginal intention was to counter suggestions of J D Bernal[14] and others that science should be politically directed. Polyani argued that such direction would not be possible because of the difficulties arising when trying to account for all aspects of scientific knowledge. His message was that "we can know more than we can tell", and this "know more" is what he called tacit knowledge.[15] More recently, the importance of tacit knowledge has become generally appreciated through

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[12]M Fores and J Pratt: "Engineering: our last chance", Higher education review, 12(13), 1980, p. 7-8.

[13]See M Fores: "Transformation and the myth of 'engineering science'", E T Layton: "Science as a form of action: The role of the engineering sciences", D F Channel: "Engineering science as theory and practice", Technology and culture, 29(1), 62-103, 1988.

[14]J D Bernal: The social function of science, London: Routledge & Kegan Paul, 1939.

[15]M Polyani: The tacit dimension, London: RKP, 1967, p. 4.

debates about artificial intelligence and so-called expert systems.[16] However, the tacitness of scientific knowledge seems to be a problem usually overcome in paper-based scientific communication, even if it is known that some experiments may be quite diffcult to replicate. To engineers, it is part of their professional lore that technological papers and books very seldom are a sufficient basis to design and run technological systems. Today, even social scientists probably have got this message after endless efforts to program their computers according to instruction manuals and handbooks.

This may prove to be another argument of the importance of the surrounding institutional arrangements to understand technological innovation. Locally available knowledge - explicit and tacit - embodied in living persons may be critical to innovation. This availability depends upon the workings of different institutional arrangements, for example mobility patterns of engineers and others with seeked-for competence and the local market of materialized and immaterial knowledge.

To summarize, our theoretical arguments lead to the necessity of bringing in what we have called the meso level in the analysis of technological innovation. In our two case-studies, we will show what such an analysis can bring of insights in innovation processes. Moreover, we will indicate how innovation analyzed from the perspective of science studies will differ from a perspective acknowledging important differences between science and technology - differences in terms of technology having a far more complicated heterogeneous structure and being far more dependent on tacit knowledge than science.

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[16] See e.g. H Dreyfus and S Dreyfus: Mind over machine, New York: The Free Press, 1986; B Göranzon and Ingela Josefson, eds: Knowledge, skill, and artificial intelligence, London: Springer-Verlag, 1988.

3. The establishment of Norsk Hydro: Scientific cunning or engineering stamina and "savoir faire"?[17]

The establishment of Europes largest producer of fertilizer, Norsk Hydro, in the first decennium of this century, is a story of the making of new combinations of technology and sources of energy par exellence. What makes the history particularly interesting for our purposes, is the important part played by a scientist, Kristian Birkeland, a well-known Norwegian professor of physics, and an engineer and entrepreneur, Sam Eyde. To make use of this situation, we have produced two versions of this case-story, one written from a point of view where scientific research is assumed to be the heart of the matter, the other constructed from a belief in the greater importance of engineering practice and the dissimilarity of science and technology. Since the latter happens to be in accord with the views of the authors, the versions are not presented as being equally probable. On the contrary, our intentions are to illuminate some problems occurring when innovations are described and analyzed through data collected by studying scientists or engineering scientists only. This may be interpreted as an exercise in reflexivity,[18] but, in fact, the points that are made, are quite traditional methodological exercises.

Let us then set the stage for the two stories by reproducing Sam Eydes account of the birth of the idea that became the basis of the partnership of

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[17]It should be emphasized that this case-story has not been written up as a historical account of the establishment of Norsk Hydro. That story is far to complicated to be rendered in a few pages. Moreover, the available books are insufficient and would have to be checked against other sources. Our aim here is only to give a rough description of some of the actions of the two main characters, Kristian Birkeland and Sam Eyde, including the networks that were established and the knowledge that were applied. For these purposes, two sources have been used: Firsly, Eydes autobiography, Mitt liv og mitt livsverk ("My life and my lifework"), Oslo: Gyldendal, 1939, and secondly, the official company history, K A Olsen, ed.: Norsk Hydro gjennom 50 år ("Norsk Hydro through 50 years"), Oslo: Norsk Hydro, 1955.

The rhetorics of the case-story is inspired by recent writings of Bruno Latour, in particular his Science in action. Since the world is unfair, he also has to suffer some irony. Readers finding it difficult to see any irony, may try to consult Latours article "Give me a laboratory and I will raise the world", in K Knorr-Cetina and M Mulkay, eds: Science observed, London: Sage, 1983.

[18]See S Woolgar, ed: Knowledge and reflexivity, London: Sage, 1988.

the two men. They met for the first time at an informal dinner hosted by the Norwegian Prime Minister Gunnar Knutsen February 13, 1903. This meeting resulted in the two men joining up to develop what later has been known as the Birkeland-Eyde method of nitrogen production. Eyde writes in autobiography that:

> "During our conversation, Birkeland asked what I was doing these days. Having in mind my occupation with nitrogen experiments, related to the great number of waterfalls that I had acquired, I spontaneously exclaim that I wished for the largest flash of lightening that could be created on earth. 'I can give you that', replies Birkeland and starts to tell about a shortcircuit that had occured during a demonstration of an electric canon. (...) The spark that flew out, was stretched out to a flame by a system of strong electro-magnets".[19]

3.1. The establishment of Norsk Hydro as scientific entrepreneurship[20]

We will begin this story by introducing Ruth, our observer-in-the-text. She has been trained in the social studies of science and has learnt that one of the tricks of the trade is to follow the scientists. Consequently, when she is planning her study of the establishment of Norsk Hydro, she decides to follow in the footsteps of the famous professor Kristian Birkeland, the obvious choice to observe in order to write up her treatise of the issue.

Ruth has prepared for the task and has learnt that professor Birkeland is a hardworking, gifted and inventive scientist. Arriving late at the abovementioned dinner, she finds that the professor has succeeded in enrolling an engineer and a businessman, Sam Eyde, to pay for a further development of his recent experiments in electricity. Already, her belief in the entrepreneurial spirit of the professor seems to be confirmed.

Some time later, Ruth find Birkeland equipped with money, instruments, and assistents, able to begin an important series of experiments in with different arrangements for making electric sparks into artificial flashes of lightening, inside something that looks like an oven. He succeded in

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[19]Eyde, p. 187.

[20]Since a biography of Kristian Birkeland has yet to be written, this section is based on Eyde, op. cit. and Olsen, op. cit., in additon to the short biographical article on Birkeland in Norsk biografisk leksikon ("Norwegian biographical encyclopedia"), Oslo: Aschehoug, 1923.

achieving the goal of producing nitrogen, a feat that gave him international fame (although he did not get the Noble prize as the Germans Haber and Bosch did for their approach to the same problem several years later). In the world of science, Birkeland was able to enroll more scientists into accepting his method as a black box. Our hard-working observer finds that this was due partly to the visits of important foreign professors that came to the laboratory and became convinced by reading results and observing special experiments. Ruth sees that this takes a lot of skill and cunning on the part of professor Birkeland.

Even more impressed is she when she has finished studying how Birkelands scientific efforts are being transformed into the technological basis of the new, large industrial company named Norsk Hydro. This is the final proof of how the professor, through the laboratory, has been able to change the face of the earth. The great importance of laboratories and the great powers of science can no longer be denied, Ruth feels after visiting Rjukan, observing large waterfalls being tamed and made into electric power.[21]

3.2. The restless engineer

Ruth is not our only observer-in-the-text, working on the establishment of Norsk Hydro. Her good friend, colleague and sociologist of technology, Otto, has also been assigned to the task. Following his instincts, he has chosen to follow the other part, the engineer and businessman Sam Eyde. Learning about Eyde's career as a civil engineer in Germany and later in Norway, including his efforts to buy waterfalls, Otto suspects that he has gotten the hard part. Losing his appetite, he drops the dinner where Eyde meets Birkeland and has to rely on the notes of Ruth.

In a few days, Otto learn more about the hardships of being a sociologist of technology. Ruth tells him that her professor Birkeland is mostly to be found in his office or in his laboratory. Eyde, in contrast, seems to be plagued by restlessness, always travelling from one meeting to the next, or to and from the laboratory and the construction sites. Otto is in fact getting more and more confused, trying to figure out what this guy Eyde is

[21]See Latour, 1983, op. cit.

up to. For some time he appears to be a research engineer, discussing the experiments with professor Birkeland and his assistants and making new suggestions, or meeting with German professors to get their view of this new idea. Then, for a short moment, he changes into some kind of landed proprietor, worrying about his waterfalls and the rights to exploit them, before he put on the cloak of a politician, meeting with the Norwegian Prime Minister and other important members of the political elite in Norway.

Suddenly, Eyde remembers his appointment with his old friend, the banker and venture capitalist Marcus Wallenberg of the Swedish Enskilda Banken. He runs for his business suit and budgets, to be able to talk Wallenberg into supporting him to obtain sufficient capital to start building the big hydro-electric powerstation at Rjukan and the factory that is to produce nitrogen. Missing the train, Otto arrives in Stockholm late, only to find the two men engaged in a game of robbers. He expect a quiet evening, but Eyde suddenly stands up, thanks his host for his kind support and hospitality, and express his regrets that he has to leave for Germany to meet with dr. Braumüller of Deutscher Salpeterwerke to inquire about the market situation of salpetre. Otto regrets this even more, especially when he learns that Eyde also plans to meet a dr. Behrend and several others to discuss some chemical matters, and the Herr Professors Hottop and Barkhausen of Hanover to get some advice about the plans for constructing the dams of the hydroelectric plant. On his travels Eyde runs into professor Ost and discusses some new experiments with him, before catching a new train to visit the Vereinigte Thonwarenwerke in Charlottenburg.

Totally exhausted, Otto returns to Oslo where Eyde already is busy in setting up new experiments to scale up the laboratory equipment. This keeps Eyde stationary for some time, and Otto is getting some well-deserved rest. But as the new experiments rapidly became a great success and the new company finally is formed, Eyde really begins to move. Now the construction work has to start. A lot of different companies are to be engaged, a lot people have to be employed, and a lot of design problems have to solved. Otto finds out that he cannot take the pace any longer, and start to look for a quiet scientist that loves her laboratory.

Comparing notes, our friends Ruth and Otto find that their different experiences should not be interpreted only in terms of sweating. To her surprise, Ruth learns that Otto strongly doubts that Birkeland is the hero of the establishment of Norsk Hydro. Otto tries to convince her that the design of the great power-station at Rjukan primarily is a result of the intense efforts of the engineer Eyde who integrates different technological knowledge with knowledge from fields like finance, marketing, work organization, and politics. While Ruth could leave the laboratory, following Birkeland on a few travels, knowing that no important changes had been made in Birkelands absence, Otto complains about having to be twenty different places at the same time. A lot of important things happens everywhere in the footsteps of Eyde, but they also keep happening when he is absent. Otto says he would have wanted a host of assistants if he ever where to do such a study again. Unless, he adds thoughtfully, he should decide to join up with the French bankers that eventually put up the capital for Norsk Hydro, profiting more from Eydes efforts than anyone else. Bankers may sit quietly, waiting for the entrepreneurs to come to ask for capital. They do not have to run around to assemble technological undertakings like the engineers. "Follow the bankers, that is my future rule of method", says Otto.

Ruth is not totally convinced that Otto's case is really different from her own. In particular, she is very doubtful of what she conceives as Otto's lack of attention to the laboratories. Is it not true, she argues, that Eyde's efforts - besides less interesting conversations with bankers and politicians - mainly consisted in putting together pieces of knowledge produced in the laboratory. Wasn't the production of salpetre at the new factory at Notodden due to the fact that this factory was built to recreate the conditions of Birkelands laboratory inside the factory. Wasn't it true, she said paraphrasing her French idol Bruno Latour, that the factory was transformed into a gigantic laboratory?[22]

Otto looks at her, crestfallen. Did she really think that it was that simple to set up the factory? He cites Eyde's angry outburst when he and his engineers started to build the absorption towers where the nitrous gases were to mix with water to make nitric acid. Having received a very high cost estimate from German experts, he exclaimed that during his efforts to create Norsk Hydro, he had learnt much about the stubborness of so-called experts and authorities. "I would never have built a Norwegian salpetre industry, if

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[22]See Latour, 1983, op. cit.

I had listened to all the expert advice that I have received". Otto recalled how Eyde had reminded his engineers that no one had been able to help them designing and construction the electric flame oven. Consequently, they should be able to build their absorption towers on their own.

After a whole evening of Otto telling about a series of similar incidents where theories and laboratories were of little use, even incidents where craftsmen had to solve problems which the engineers couldn't, Ruth remembered an appointment with her boyfriend and left. Over a late glass of skimmed milk, she complained to him that after this evening, she surely would keep to the study of science in the future. She hopes to continue her work on professor Birkeland, as this may get her a nice trip to Egypt where Birkeland is planning to do some geophysical measurements.

4. Innovation: New combinations of knowledge or new combinations of engineers?[23]

Subtronics, Inc. is a small Norwegian company, situated in Trondheim, which "spun off" in 1984 from a research institute specializing in off-shore R&D. It was started by two senior engineers who perceived this as an opportunity to commersialize some research projects, on which they had been working for some time. Growing relatively fast, Subtronics reached a level of 22 employees by the beginning of 1988. 12 of these had M. E.-degrees and 6 had degrees from engineering colleges.

The company is a curious mixture of a production unit, an R&D unit, and a consulting firm. It develops, produces and sells advanced instruments for offshore purposes, in addition to providing consulting services in the same area. Nearly half of the company's income are grants given by the Royal Norwegian Research Council for Technological and Scientific Research, implying considerable government subsidies of its development costs.

In our terms, the company can be conceived as a meeting-place for different kinds of competence. The most striking feature is the magnitude of the

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[23]This case-story is based on interviews with managers and employees of the company. Morten Hatling has assisted with the interviewing.

second-order heterogenity, particularly in the technical area. The in-house competence is concentrated in the field of subsea instrumentation, mainly related to electronics and computer science. However, developing sub-sea instruments demands a much broader spectrum of knowledge and experience, and the company is consequently dependent on a quite substantial network of different organizations. This should be evident from Table 1, which gives estimates of the number of different partners within different areas. (Exact numbers have proved difficult to get, but the estimates are sufficiently precise for our purposes).

Table 1. Number of suppliers to Subtronics. Estimates 1987.

	Intervals		
	1-3	4-7	7 +
Services:			
R&D institutes, technological fields		x	
Technological consulting firms	x		
Goods:			
Suppliers of tailored electronic products			x
Suppliers of tailored mechanical products		x	
Suppliers of computer equipment		x	
Suppliers of software			x

However, the customers of Subtronics are slo important suppliers of problems, knowledge and skills. Subtronic engineers are often sent to work with customers to learn from them and to try out and make changes in Subtronic products, in order to satisfy the needs of the customer. Such work periods may last for several weeks, and they are important in several respects. While Subtronics have considerable expertice in the area of designing and building tailored, electronic, measurement systems, they lack knowledge about the conditions under which their products are to be employed. Such knowledge is not always easily transferrable in terms of specifications because the costumer lacks knowledge about the relevant properties of Subtronic' products. Consequently, specifications are constructed as a collaborative effort where Subtronic engineers and engineers employed by the costumer negotiate, experiment, and design. The relationship is at the same time development, design, marketing, and learning. It is a good example of the very tacit nature of technology, even in a so-called science-based, high-tech area. Instruments working well under laboratory conditions may have to be rebuilt in order to stand the pressures of real off-shore conditions. A stormy North sea is difficult to move inside a laboratory.

Moreover, since the respective competence of Subtronic and its costumers should be characterized as complementary, their collaboration represents a proper example of how second-order heterogenity is organized. We see no simple, additive process of knowledge integration. Instead, we meet with unorderly problemsolving negotiations, in which different knowledge are contraposed and checked, and where the outcome also depends on the persuasive ability of the engineers involved. The problem is usually not fixed. Consequently, what counts as relevant expertise and equipment is rather open.

This situation, viewed from the position of Subtronics, demands a lot of the engineers. The orginial entrepreneurs, the managers-engineers managing the company, cannot themselves secure a favorable outcome. They are dependent on recruiting engineers with adequate expertice, technically as well as socially, and giving them working conditions that encourage the improvement of such competence. It is consequently no accident that the company is organized in a non-hiearchical, network-like way, with considerable autonomy for the engineers. This implies that knowledge can float more freely than is the case in more hiearchical settings, and that the engineers may stay flexible, able to adapt to new tasks and different costumers. The organization even has to be able to simulate a hiearchy in cases where important costumers make demands in terms of strict routines, quality control procedures, and project planning.

Management is consequently not without challenges. In addition to what we have already mentioned, there is of course the question of market relations. Even if the engineers do important work in this respect, the managing engineers have to maintain and develop more longterm, policy-based relations with costumers. The quality of products and services are always of great importance, but skills have to be exercised also to organize potential costumers access to what Subtronics has to offer. In addition to keeping the representatives of the Research Council satisfied, Subtronics has engaged itself in setting up two daughter companies, one in collaboration with a national programme to diffuse new technology, and one together with a Danish company in order to combine two complementary sets of expertise to develop new products. A third engagement is taking place in setting up a company to build and manage a large office and laboratory building.

The role of Subtronics is in a very concrete sense to produce new combinations. Compared to scientific work, the engineers of Subtronics are not doing much to develop new knowledge about general characteristics of Nature. They collect existing knowledge either in the traditional mental form or materialized in electronic components, computer programs, mechanical parts, etc. But exactly in this production of new combinations, they are very sensitive to the nature of the infrastructure within which they work. Without access to the knowledge and experience of customers and suppliers, of accessible consulting firms and research institutes, they would not be able to make these combinations. Subtronics could be organized in the best possible ways and the engineers could develop the most subtle strategies of persuation - without the surrounding infrastructure of knowledge and skills, they would not innovate.

Within this infrastructure, engineers are human carriers of knowledge that is not easily transferable by other means. Even if some of the engineers in fact write an occational paper and even if a considerable amount of drawing, programming and other paperwork is needed, they cannot be certain that the paperwork really contains all the knowledge, all the facts needed to build and operate their instruments. The very tacit nature of technological knowledge complicates the transfer of technology and demands mobility of engineers.

In a way, Subtronics' managers are aware of this fact. This is evident from their recruitment policy. To put it crudely, this policy states that if you need new competence, you should try to hire a new person with this competence before you eventually let someone already employed be trained for the task. Or, if you need to know the problems of an important group of customers, recruit one of their employees. One consequence of this is that a company like Subtronics depend on keeping their engineers, and keeping them to do technical work more than to manage. This may create a change in the career pattern of engineers which in turn may prove important to the innovation capabilities of an industry. But that is another story.

5. The return of the science-technology gulf?

The two cases outlined above give ample evidence to the claim that technology is far more complicated than science in the sense that is level of heterogenity - of both orders - are much higher than that of science. We have shown how technology in the disguise of innovation is a very tricky operation of combining a lot of different kinds of knowledge, stemming from different kinds of technological specialities and different social fields. However, this does not necessarily imply that technology and science is not of the same kind. Difference in terms of order of magnitude is of less importance than differences of a structural kind.

Nevertheless, we think that recent efforts to argue that science and technology are of the same kind, overstate the case. When comparing the Subtronics case to availble etnographies of science, like Latour and Woolgar[24] or Knorr-Cetina,[25] one finds that natural scientists usually have greater autonomy than engineers and technological researchers. They are much less dependent on local infrastructure in terms of collaborating companies and institutions, and they have greater freedom of movement in relation to national institutions like ministries, science councils, industrial associations, labour unions, etc. Consequently, their possibilities of becoming "entrepreneurs" - at least on a medium scale - seems to be greater. More important, by following scientists one is getting a more complete picture of the processes of making science than one is getting of the making of technology by following an engineer. In the case of science, far more is explained through the individual actions of scientists than in the case of technology.

This should at least be taken to indicate some important problems arising when the development of the field of social studies of technology is based on theories and methods from the social studies of science. Firstly, while outstanding scientists usually know about the scientific implications of their research, this is by no means necessarily the case for outstanding engineers and technological researchers. The solving of sub-problems of

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[24]B Latour and S Woolgar: Laboratory life, London: Sage, 1979.

[25]K D Knorr-Cetina: The manufacture of knowledge, Oxford: Pergamon Press, 1981.

technology does not automatically give access to the socio-technological problem that generated the sub-problem in the first place. While Sam Eyde probably had a quite good overview of the process of etablishing Norsk Hydro, this would probably not be the case of subordinate engineers working either with construction of the dam, or technological problems with the oven, or with the absorptions towers, etc. etc. Even the managing engineers at Subtronics lack a complete understanding of the system in which their instruments eventually could be used.

Secondly, the student of technology has to be careful to map out inter-institutional relations not only inside the technological community in question, but also outside of it. Both in the case of Eyde and in the Subtronics case, we see how important and complex the first and second order heterogenities are, and how this demands competence and knowledge outside the realms of science and technology. This means that the student of technology also has to take notice of how these institutional relations contribute to the bringing-together of different technological and socio-logical/economical competences in efforts of integration. Thirdly, s/he has to be aware that while scientific developments usually implies the production of new scientific knowledge, new technology quite often is brought about through new combinations of well-known principles and artefacts.[26] This is evident from both our cases, even if Norsk Hydro as well as Subtronics are examplars of what usually is termed "science-based industry".

Fourthly, the student of technology has to take into account that the flow of knowledge in technology is organized differently from that in science. This relates in particular to the importance of tacit knowledge. Even if s/he knows more than s/he can tell, the scientist is usually able to convey sufficient information through a paper to make other scientists able to understand what the results are and, eventually, what they mean. In the case of technology, when building an artefact or setting up a technical system, theoretical knowledge is almost never sufficient to make things work. Practical "fingerspitzgefühl" is also needed. At Subtronics, we encountered

[26] "(T)he notion that innovation is initiated by research is wrong most of the time". (S J Kline and N Rosenberg: "An overview of innovation", in R Landau and N Rosenberg: <u>The positive sum strategy</u>, Washington: National Academy Press, 1986, p. 288).

a situation where it proved impossible to recreate a particular invention. The second examplar did not function like the first. This illustrates the limits of "pure" knowledge. In particular, the Subtronic case gives ample evidence that the flow of knowledge has to be accompanied by a flow of people. The mobility of engineers is much more critical to the dissemination of technology than the mobility of scientists is to the diffusion of scientific knowledge.

This argument is not intended to recreate the traditional gulf between science and technology. Obviously, important gains have been made from perceiving them as similar kinds of enterprises. However, when transferring concepts and theories from social studies of science to social studies of technology, greater care has to be exercised. To be brief, we will argue the importance of the fact that technology usually involves far more integration than science. If we return to the concept of first and second order heterogenities, it is in an abstract sense applicable to science as well as technology. However, in particular, the idea of second order heterogenities does not seem very important to the study of science.

In contrast, technological innovations are usually quite dependent of the success of integrating the various inputs of second order heterogenities. As we saw in the two cases above, in particular the Norsk Hydro story, this process may be very demanding in terms of time, resources, and resourcefulness. The Norsk Hydro case is an example of how - when in command of much money - it is possible to make use of competence located far away. However, it is also an example of the necessity to command sufficient local competence to compensate for transfer problems. The building of Norsk Hydro was, in a technical sense, dependent on the presence of a sufficient number of Norwegian engineers and scientists with necessary training and experience. Some of them, including Eyde, was trained and had worked for a long period in Germany. German technological knowlegde was thus transferred, embodied in these engineers. The Subtronics case shows how critical the local access of competence/skills/knowledge is, even in an era of jet planes and electronic networks.

The point is then that technological innovation, in its dependence on the heterogenous nature of technology, also depends on the infrastructure of competence/skills/knowledge. In fact, this infrastructure can be seen as a visible embodiment of the heterogenous nature of technology. Large companies may be more selfserving in this respect than small ones, but the increasingly complicatedness of technology makes infrastructure more important for all companies.

There is also a methodological lesson here, bearing on the limits of "following in the footsteps of scientists and engineers". These limits relates to the problem that the terrain on which engineers and technological scientists move, has been thoroughly shaped by previous actions.[27] To encounter the historical processes that have brought about e.g. the available infrastructure of competence/skills/knowledge through observation of engineers/scientists, is - to put it mildly - difficult. For this purpose, other methodological approaches are more appropriate.

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[27]See Sørensen, op. cit.

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