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Editorial

With the present issue, the *Science, Technology & Innovation Studies* are online for three years. Born at a coffee table in Munich during the 2004 conference of the German Sociological Association, it was an experiment with uncertain outcome at first. Some three years later, the *STI Studies* did not only survive but are about to become a more and more well-known journal. A particular aim of this project has been – and still is –to enhance the international visibility of German social research on issues of science, technology and innovation, by using the advantages of an open access journal and by encouraging colleagues to publish in English. Feedbacks from all over the world and international requests for reprinting STI-articles suggest that this was not too bad an idea.

Up to now, in five regular issues and one special issue a total of 23 articles have been published. It is time to thank our pioneering authors for taking the risk of submitting their papers to a journal which still had to gain scientific reputation. As well, we want to thank all those colleagues who carefully and thoughtfully wrote the reviews which further enhanced the quality of our papers. Special thanks go to the student tutors of Johannes Weyer for language editing, formatting, and technical support.

The present issue of the *STI Studies* provides three papers: Grit Laudel and Jochen Gläser present a methodological approach that deals with the problem of interviewing scientists. In their contribution they answer the question: "To what extent do we have to understand scientists' work *scientifically* in order to explain their behaviour *sociologically*?" Rüdiger Mautz argues "that the expansion of the renewable energies in Germany is not only the result of technical innovations, but also the outcome of specific social and institutional innovation processes." In his analysis the relationship between the "competing paradigms" of "the 'renewables' and the traditional industry of power generation" turns out to be the crucial factor for explaining the innovation process. Simon Fink finally questions "the frequently heard thesis that strict embryo research laws can hinder innovation in embryo and stem cell research, and thereby impede the innovative ability of the medical biotech sector." He provides empirical evidence suggesting that long-term structural differences of the national innovation systems rather than short-term political steering efforts explain the national differences in the innovativeness of the respective biotech sectors.

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Interviewing Scientists

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Abstract

With this article, we would like to initiate a discussion about a methodological problem that is central to many empirical science studies but has received far too little attention, namely scientifically informed interviewing. To what extent do we have to understand scientists' work *scientifically* in order to explain their behaviour *sociologically*? As far as it is existent at all, the methodological debate in science studies has focused on ethnographic observations. In this debate, the two approaches of naïve observation and informed observation (which sometimes takes the form of native observation) can be distinguished. The general methodology of ethnographic observation clearly favours the informed approach, as does the general methodology of qualitative interviewing. 'Scientifically informed interviewing' specifies this general methodological insight for science studies but is also necessary because in some investigations we must systematically collect data on the content of our respondents' research. This kind of interviewing requires extensive preparation of interviews, the construction of an 'ad hoc – pidgin' for the communication during the interview and the negotiation of an appropriate level of scientific depth between the interviewer and the interviewee. We make suggestions how to solve these tasks (and how not to) and discuss limitations of the approach of informed interviewing.

1 Do we need to understand science?

With this article, we propose a discussion about a methodological problem and its practical consequences for interviewing scientists.[1] To what extent do we have to understand scientists' work *scientifically* in order to explain their behaviour *sociologically*? This question specifies a fundamental methodological insight for science studies. If we need to acquire an "interpretive understanding of social action" in order to achieve "a causal explanation of its course and consequences" (Weber [1922] 1978: 4), than we routinely face the task of getting acquainted with the life-world under study – be it a youth subculture, a firm, a community, or a scientific field.

While all sociological studies must accomplish an interpretive understanding of social action, the extent to which this is necessary and the difficulties resulting from this task vary between fields of inquiry. We will argue that some studies of science depend on an understanding of science not only because it is important to understand frames of reference of respondents but also because we need to include the materiality of research actions in our explanatory models, and the research of our respondents provides the only access to these explanatory factors.

Another property of our subject that makes understanding a difficult task is the way in which its practitioners have been prepared for their tasks. Being a competent member of the scientific culture requires an extended systematic prior training, a training the sociological observer usually cannot undergo. This puts the observer at a disadvantage that cannot be overcome: Because exogenous learning is necessary, sociological observers will not usually be able to perform the typical activities of the studied culture. Length of stay in the field can significantly reduce the gap between a member's and an observer's knowledge. However, the gap cannot be completely closed by staying in the culture.[2] In this respect, the sciences are different from the many social settings that are 'self-explanatory', i.e., which contain all knowledge that is needed to be a competent member (e.g. the communities of sports fans). People enter these social settings without any specific prior knowledge, and acquire all the knowledge a member of that setting is supposed to have by endogenous learning. Sociologists entering such a setting are in the same situation, which means that in principle they can acquire as much knowledge as any other prospective member of the culture.

In this article, we address the general problem of understanding scientists and the ramifications for qualitative interviewing by answering three questions. Why should sociologists attempt to understand the science of their interviewees? What happens prior to and during a scientifically informed interview? What are the limitations of scientifically informed interviewing?

Except from some early reflections by Zuckerman, the problem of scientifically informed interviewing has not yet been discussed. When methodological problems of science studies are considered at all, the debate is almost exclusively focused on problems of ethnographic studies. In this debate, the problem of scientifically informed observation has been an important point. We therefore begin by identifying three approaches to the problem of 'informed observation' in science studies

[1] Along its way since its first presentation at the joint 4S/EASST conference in Vienna 2000, this paper has benefited from critical comments by Martin Meister, Jörg Strübing, and Lucy Suchman, neither of whom will probably agree with the use we have made of what we have learned from them. We are also grateful to the reviewers of STI studies, whose critical comments led to another significant revision.

[2] The sciences share this property at least with the professions; see Ten Have's (1995: 254-256) distinction between "the lay world" and "the professional world".

(2). Thereafter, we outline the position of general qualitative methodology, which is all in favour of informed interviewing, and demonstrate why some research questions demand an engagement with the content of our subjects' work that goes far beyond what is demanded by general methodology (3). Using our own experiences and mistakes, we then discuss the three main practical tasks that must be solved in scientifically informed interviewing of scientists (4). As a conclusion, we will discuss risks and limitations inherent to the strategy we propose (5).

2 Methodologies of observation

2.1 Naïve observation

The first extensive ethnographic study of scientific practice was published by Latour and Woolgar ([1979] 1986). Latour and Woolgar took a surprising methodological position by stating explicitly that their ethnographic observation was conducted by applying the perspective of a "very naïve observer" (Woolgar 1988: 83-96; Latour 1990: 146; Latour and Woolgar [1979] 1986: 12, 29-30). Latour characterised this methodological approach as deviating from mainstream anthropology (the 'source field' of the ethnography of science), which has agreed upon the necessity to understand the content of actions under investigation (Latour 1990: 146). He describes the "naïve" investigators' perspective as that of an

> "... outside observer who does not know the language and the customs of the natives who are not supposed to read what he writes. As Woolgar has pointed out many times, [...] this is a very naïve version of the naïve observer - a version that is now abandoned in mainstream ethnography and which seems to survive in so called 'lab studies'." (ibid.)

Latour and Woolgar give good reasons for their methodological decision:

> We take the apparent superiority of the members of our laboratory in technical matters to be insignificant, in the sense that we do not regard prior cognition (or in the case of an ex-participant, prior socialisation) as a necessary prerequisite for understanding scientists' work. This is similar to an anthropologist's refusal to bow before the knowledge of a primitive sorcerer. In our perspective, the dangers of "going native" outweigh the possible advantages of ease of access and rapid establishment of rapport with participants. (Latour and Woolgar [1979] 1986: 29)

Woolgar later reinforced this point by stating that there is a higher risk of 'going native'[3] when observations of science are concerned:

> "The standard tension of any ethnographic study is present here. We want to see things from the natives' point of view but we don't want uncritically to adopt their belief system. [..] Note, however, that in one important sense it is more difficult to remain 'strange' in the exotic culture we call science than it is when conducting an ethnography of, say, the Navaho Indians. When the latter informants tell us that they are dancing in order to make it rain, we can readily draw upon scepticism, which is 'inbuilt' in virtue of our membership of 'advanced Western culture'. But when informants amongst the tribe of scientists explain that the right-hand side of an equation 'follows' from the application of the rule of commutativity, we find it much more difficult to resist the apparent authority of this explanation. Why? Simply because respect for scientific rationality is deeply embedded in our own (ethnographers') culture." (Woolgar 1988: 86)

This is of course an important methodological point: Everybody who is going to observe science has received a science education and a partial socialisation as a scientist prior to the observation. It is therefore more difficult for an observer to stay the 'stranger' in a scientific environment than in others. Scientific practice is laden with reasoning and justifications, and "in the case

[3] 'Going native' is one of the central methodological problems in anthropology. It describes the observer's gradual adoption of the observed culture's belief systems and perspectives, which leads to a loss of analytical distance and to the inability of questioning taken-for-granted positions and practices (Hammersley and Atkinson 1995: 109-112).

of a scientific culture in particular, there is a strong tendency for the objects of that culture (facts) to provide their own explanation" (Latour and Woolgar [1979] 1986: 278). To reveal and to investigate taken-for-granted practices of scientific work can be assumed to be more difficult, and the danger of 'going native' is higher.

While the danger of 'going native' is real and the consequences would be severe, the methodological conclusion drawn by Latour and Woolgar has problematic consequences of its own (Lynch 1982: 506-509; Lynch 1993: 93-102). Lynch raised two objections by pointing out (a) that Latour's and Woolgar's descriptions prove that they hadn't been able to maintain their naïve approach, and (b) that the naïve approach would severely limit the understanding of the object of observation.

(a) Lynch observed that

> "... the account which resulted from their inquiry is far more comprehensive and detailed in its access to technical practices than could possibly have resulted from the 'observers' initial man-from-Mars posture towards the work of lab members." (ibid.: 507)

According to Lynch, a stranger's "accounts of what scientists do are continually and necessarily reflexive to the stranger's understanding of those practices" (ibid.: 509). Interestingly enough, in Latour's and Woolgar's book the observer's understanding of scientific practices appears to vary significantly throughout the book. Chapter 2 takes the "vary naïve" perspective:

Our anthropological observer is thus confronted with a strange tribe who spend the greatest part of their day coding, marking, altering, correcting, reading and writing. (Latour and Woolgar [1979] 1986: 49)

Later in the same chapter, when the authors are describing the laboratory practice (ibid.: 53-69) and are categorising scientific statements (ibid.: 69-88), more background knowledge about the practices creeps in. Otherwise, Latour and Woolgar could not have decided on what principles assays are based and what it means to repeat an assay (ibid.: 59-60); or what parts of a scientific statement are modalities, i.e. can be deleted without rendering the statement completely senseless (ibid.: 77-85). The story of the construction of a fact - TRF(H) - in chapter 3 could not have been told without reference to the scientific content of the respective activities. For example, statements such as "In total, four groups have worked on the isolation of TRF ..." (ibid.: 114) are based on what "working on the isolation of TRF" means to the scientists in the observed field. In chapter 4, the observers draw a picture of scientists socially negotiating when constructing facts. In these discussions, the scientific content of scientists' actions and accounts is systematically re-interpreted as being a resource in social negotiations. However, this is possible only because the analysts understand the significance of the scientific content of conversations and practices.

(b) This purposeful ignorance of the content of the observed actions and the sole occupation with their outward appearance reduces the understanding of the observed practices to what is intelligible to the scientifically ignorant sociologist, as Lynch describes:

> "... Latour and Woolgar present their ethnography from the point of view of a fictional "observer" who sees what is going on in the lab without being taken in by the scientists' beliefs in an unseen biochemical order of things. The observer describes just what he finds intelligible in the lab: the traces, texts, conversational exchanges, ritualistic activities, and strange equipment." (Lynch 1993: 96)

Not only is the observation reduced to what the naïve observer finds intelligible – the observers also can record their observation only in their own language. Thus, the naïve observers were forced from the beginning to select events and actions that seemed intelligible to them and to record them in a sociological language and attached conceptual frameworks. Influential concepts such as "inscription devices" appear to be the result of that naïve approach (Latour and Woolgar 1986 [1979]: 51-53).

We agree with both points made by Lynch. The perspective of a "naïve observer" is not only difficult to maintain but also methodologically problematic. While some general concepts such as 'inscription device' (or possibly even the whole Actor-Network Theory) may be a consequence of a naïve observation, the explanation of the "microprocessing of facts" is obviously not. Another indicator of the limitations of "naïve observation" is that this approach has not been applied by other ethnographers of science.[4]

2.2 Informed observation

With "informed observation" we refer to social studies of science undertaken by sociologists who acquire a scientific understanding of the field they study by self-education prior to or at the beginning of their empirical study. The necessity of understanding scientists' work scientifically has been first discussed by Zuckerman in her methodological reflections on interviewing Nobel laureates (Zuckerman 1972, see 3.1). After the sociology of scientific knowledge has become the mainstream of the sociology of science, the problem has been repeatedly addressed in the context of ethnographic studies of scientific practice. With the exception of Latour and Woolgar, all ethnographers of science have taken the position that an informed observation of this kind is necessary.[5] Collins and Pinch conducted their participant observation of research on 'spoonbending' as an informed observation (Collins and Pinch 1982; for a methodological discussion see Collins 1984). They took part in an investigation of paranormal phenomena by taking the role of researchers. Therefore, they had to acquire "native competence" (ibid.: 54). In one of his articles on his studies of the search for gravitational waves, Collins explicates his methodological position:

> "The more narrow methodological stance adopted in this article is 'participant comprehension' (...) Participant comprehension is an interpretation of participant observation under which the field-worker tries to acquire as high a degree of native competence as possible and interaction is maximized without worrying about disturbing the field site; this ideal should always direct the research effort, even though the degree of native competence attained will vary from study to study." (Collins 1998: 297)

Collins further states that while he has not "achieved anything like full native competence in gravitational radiation research", he believes that he has gained "enough understanding to be able to carry out the kind of sociological analysis presented here" (ibid.: 298). He bases this judgement on comparisons to parapsychology (where he became a "full-blown expert") and to the theory of amorphous semiconductors, which he had to abandon because he could not understand any of the science. (ibid., note 6).

The same approach can be assigned to Lynch (1982; 1985; 1993; 1994), who bases it on ethnomethodology's principle of "unique adequacy" which requires ethnomethodologists gain the capability to perform the characteristic practices in the field under study (Garfinkel and Wieder 1992: 182-184; Lynch 1993: 271-275).[6] When these

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[4] Interestingly, Latour used a review of Lynch's (1985) book, which is based on informed observation, to state: "that one should become familiar with the practices of the people one wishes to study (...) is the basic tenet of all ethnographic work, and it is hard to dispute." (Latour 1986: 544).

[5] This was also Woolgar's position before he turned to laboratory studies. In an article on the discovery of pulsar phenomena, he wrote: "In research of this kind, I obviously needed to be aware of the scientific issues in order to correspond with or interview participants." (Woolgar 1976: 396).

[6] Lynch links his methodology to the work of Winch (1958; 1974). Hirschauer (1994: 338-345) traces the principle of informed observation back to Malinowski ([1922] 1972) and Schütz (1962). The necessity of informed observation was also stated explicitly by Knorr-Cetina in an article on anthropology and ethnomethodology

capabilities could not be developed by simply staying in the field long enough, some of the ethnomethodologists took the relevant formal training (Lynch 1993: 274). Lynch himself did not undergo the formal training. Instead, he was given "a rather informal course of training in the substantive and methodological features of the lab's research" (Lynch 1985: 1-2). After his training, he was still

> "... unable to participate in the lab's researches, though I achieved a competence in some of the analytic skills used in assembling and interpreting electron microscopic displays of brain tissues. These limited competences gave me considerably more access to the talk and conduct which I witnessed in the lab than would have been possible had I relied solely on the analytic skills of a social scientist while observing members activities." (Lynch 1985: 2)

The practical difficulties of informed observation are rarely addressed. Collins reports that he had to abandon one case study because he was not able to acquire enough competence (see above). Lynch mentions his "limited competence" but comments that it is impossible to tell what is missing because of these limitations (Lynch 1982: 529). Thus, both authors confirm the principal limitation of informed observation – the sociological observer can achieve some understanding of the science that is being observed, but cannot become competent enough to perform the research they observe. The consequences of these limitations for science studies are not discussed.

2.3 Native observation

One special way of conducting informed observations is 'native observation', i.e. an observation conducted by scientists from the field who have turned into sociologists. Examples of this biographical turn are the radio astronomer Edge (Mulkay and Edge 1976), the physicists Pickering (Pickering 1984, 1995), Pinch (1986)[7] and Merz (Merz and Knorr-Cetina 1997; Merz 1999), the immunologist Löwy (1997), and the biologist Cambrosio (Cambrosio and Keating 1988, 1995). All these observers studied scientists of their own research field or at least of their broader research discipline. Cambrosio even attended a special scientific training session on the subject he and his colleague were studying (Cambrosio and Keating 1988: 249).

We think that the strategy of 'native observation' deserves a special discussion. Being 'a native of the tribe' is an important asset for an informed observation. Only native observers are able to close the gap between the observer's and the subjects' knowledge. As Knorr-Cetina and Merz argued in a comment, native observation enables a deeper understanding of scientific practice. They argued that "thin descriptions of the material dynamics and performative orderings of behavioural domains" are of interest to science studies (Knorr-Cetina and Merz 1997: 129-130). Given the limitations of informed observation, native observation appears to be the only way to arrive at this kind of account of scientific practice. Mulkay even went as far as stating "if we are to study in detail the operation of scientific communities, we must have the active cooperation of participants or ex-participants" (Mulkay 1976: 210-211).

While native observation solves the problem of understanding the field under study, it is not without problems. The observed or interviewed scientists are likely to relate differently to a former colleague who has turned into

(Knorr-Cetina [1980] 1993: 170) and applied by her in her ethnographic studies (Knorr-Cetina 1981: 31, note 64). Another ethnographer who chose informed observation is Traweek (1988: 9-11).

[7] Pinch notes the requirement that the sociologist has "to familiarize himself or herself with the technical issues which are at the core of the scientific 'life world'" and states that his "own background in physics has proved invaluable in this task" (Pinch 1986: 197). He even included a section on "Some Technical Details of Solar-Neutrino-Detection" in his book (ibid.: 41-48).

a sociological observer. This was first observed by Mulkay and Edge:

A second possible source of bias arises from the fact that one of us was originally trained as a radio astronomer. In many ways this was, of course, an immense advantage. It enabled us, for instance, to explore in detail the scientific and technical literature, and it made possible an exceptional degree of cooperation between researchers and respondents. On the other hand, it meant that one of the interviewers was regarded by respondents, on some issues at least, as another participant. It was, therefore, impossible for the interviewer to avoid being drawn sometimes into a dialogue with his subjects, during which he was expected to act, not as an impartial outsider, but as an involved colleague. As far as we can judge, however, respondents did not hesitate to disagree with the interviewer in these exchanges of judgements and opinions. (Mulkay and Edge 1976: 3-4)

An emerging role ambiguity of the observer/interviewer was also observed by Löwy who commented that some of the scientists she observed regarded her as an ex-colleague with an unclear professional identity. Her observation was sometimes assessed as "secret longing to return to the laboratory". Some scientists "were not sure how to classify a fellow researcher who shared with them expert knowledge and familiarity with the laboratory culture, but professed radically different goals". She herself felt as a "'native of nowhere' – an inadequate immunologist and an awkward historian". (Löwy 1997: 93) She concludes:

'Going' native is perhaps helpful in studying modern science, but investigators who observe scientists' activities still need to decide how 'native' should one go, and for how long. (ibid.)

Unfortunately, the authors who noticed particular relationships between scientist-observers and respondents did not discuss the possible impact of these relationships on their study. We are therefore unable to tell how the described problems influenced the social accounts of the scientific practices they studied.

Another problem is the greater danger of 'going native'. In the study on radio astronomy, Mulkay observed that there is a danger that native observation "may lead to the investigators' taking over false, or incomplete, assumptions from the group under study" (Mulkay 1976: 211). In the case of another native observation, the observers were directly accused that their "going native" had compromised the study. To conduct a native observation was also a deliberate decision in an ethnographic analysis of theoretical physics (Knorr-Cetina and Merz 1997: 125; Merz and Knorr-Cetina 1997: 74). It was criticised by Gale and Pinnick (1997). Gale and Pinnick accused Merz and Knorr-Cetina of introducing a third, "explanatory" language (additionally to the participants' and the observer's language) that was so close to the participants' language that it imports the participants' metaphysical realism in their explanation. By using this third language, Merz and Knorr-Cetina adopt the perspectives (especially the philosophical perspectives) of their participants – a specific case of 'going native' (Gale and Pinnick 1997: 117-121).

Knorr-Cetina and Merz rejected the critique by pointing out that Gale and Pinnick criticise their methodology without criticising the results obtained by applying this methodology (Knorr-Cetina and Merz 1997: 126). Indeed, Gale and Pinnick mentioned only one negative consequence of the approach chosen by Merz and Knorr-Cetina – the adaptation of physicists' metaphysical realism. But not even this critique is justifiable. Rather than invoking metaphysical realism, the reference to mathematical structures' "hardness" by Knorr-Cetina and Merz is nothing but the application of a well-known sociological insight that applies to mathematical objects as well: "The paradox is that man is capable of producing a world that he then experiences as something other than a human product." (Berger and Luckmann 1967: 57). As is the case with the particular relationships discussed above, the risk of 'going native' has been acknowledged but not discussed with regard to possible changes in the results of the studies. While native observation certainly bears the risk of 'going native', it has not yet been proven that this actually occurred, and the consequences for the empirical studies are unknown.

3 Informed interviewing in science studies

3.1 Informed interviewing as a principle of general qualitative methodology

While the argument for 'naive observation' of scientific practice has admittedly been made against the methodological mainstream of ethnography, no such stance has been taken with regard to qualitative interviews.[8] The general methodological tenet – that preparation of interviews and informed interviewing are prerequisites for success – has remained unchallenged in science studies.

The central argument for informed interviewing is based on the understanding of the interview situation as a communication process in which the two partners jointly construct the meanings of both, questions and answers (Cicourel 1964: 96-100; Briggs 1986; Holstein and Gubrium 1995: 45-46). In order to solicit the specific and detailed information they need, researchers must translate their interests into the contexts of their interviewee. Otherwise, neither formulating appropriate questions nor understanding the interviewee is possible (Merton, Fiske, and Kendall 1956; Hopf 1978: 99-101).[9] As Briggs' discussion of "communicative blunders" in interviews proves, the failure to understand the respondents' social world may result in asking the wrong questions, receiving answers to questions not asked, or simply not comprehending the right answers to questions (Briggs 1986: 39-60).

Thus, general methodology of qualitative interviewing unanimously considers informed interviewing as essential for the crucial task of understanding. Briggs demonstrates that even in the interviews he conducted as part of his ethnographic observation, his lack of understanding of the social context and worldviews of his respondents was a source of errors, of the inability to ask properly and to understand the answers. He was able to overcome these problems because his stay in the field made it possible to learn enough about the frames of reference of his informants. As we have noted in our discussion of naïve observation, even the deliberately naïve approach of Latour and Woolgar yielded to learning, which led to a better understanding of frames of reference and meanings of the field.

A second argument for informed interviewing refers to the social relationship between interviewer and respondent. Being informed helps to demonstrate competence, and thus to be taken seriously. As Rubin and Rubin put it:

Your informed questions signal the interviewees that you have done your homework, made an effort, and have not just come to pick their brain. You have gone as far as you can go with the

[8] The extent to which 'informed interviewing' is necessary at all depends on the research question and on the kind of qualitative interview that is used in research. In this article, we focus on semi-structured interviews, i.e. on interviews based on an interview guide, which are used to obtain information about the impact of specific conditions on respondents' work processes (see 3.2). Other kinds of interviews (e.g. narrative interviews conducted with the aim to explore how respondents construct their life-stories) may not require or enable informed interviewing.

[9] Zuckerman (1972: 165) confirmed that her preparation of interviews with Nobel laureates often called forth responses that otherwise would not have been elicited.

available material and now you need some help. (Rubin and Rubin 1995: 198)

This advice is in accordance with the experience of Zuckerman, who interviewed Nobel laureates. She describes the functions of her preparations as "giving evidence of the seriousness of the interviewer" and "legitimise expenditure of time on the interview":

Almost all the Nobelists are acutely concerned with maximizing the use of that inevitably scarce resource, time (...) In part, their commitment to the intellectually profitable use of their time led them to subject the interviewer to an almost continuous series of tests to ascertain the degree of her competence and commitment. (Zuckerman 1972: 165)

Sometimes the Laureates perceived her as a "combination layman-expert" in their research fields (ibid.: 173). Zuckerman quoted one interviewee who told her

"I said to myself before you came, 'If she wants to ask me about social things, I will get her out of here fast.' But you asked me about important things. What is written about science is never quite right. You have to hear it from the people who were there." (ibid.: 165)

3.2 Scientifically informed interviewing for collecting scientific data

When we apply the general methodological principles to qualitative interviews with scientists, we inevitably arrive at the conclusion that we need to learn their science in order to understand them. This holds true for all research in science studies that uses scientists as informants. In particular, it applies to qualitative interviews both as a 'stand alone'-method and as interviews with key informants as part of an ethnographic study.

In some areas of science studies, the necessity of scientifically informed interviewing follows not only from general methodology but also from the theoretical intentions of the research. Whenever the content of the science under investigation forms part of the aimed-for sociological explanation, it is not sufficient to understand our respondents' research as a relevant social context and frame of reference. We must systematically investigate the content of our respondents' research in order to obtain information about knowledge, technology and nature, which ultimately informs our sociological explanations. Empirical research of this kind requires to understand the problems, strategies, and logic of scientific research, and to include non-social factors in our explanations. We can leave aside here the differences between the concepts of 'non-human actants' (e.g. Callon 1986; Latour 1988; Law and Callon 1988), the 'mangle of practice' (Pickering 1995), and 'thin description' (Knorr-Cetina and Merz 1997, see 2.3) and focus on the point they have in common: Understanding and explaining scientific practice requires the inclusion of the non-social phenomena scientists deal with (Gläser and Laudel 2004).[10]

We can illustrate this point by using our own research as an example. We are interested in how institutional conditions of action (as provided by funding programs, science policy, law, formal organisations, informal rules within scientific communities etc.) affect the production of scientific knowledge. For example, we ask how institutional conditions of actions affect interdisciplinary collaboration (Laudel 1999, 2001), how the institutional change that accompanied German unification affected links between basic research and applications (Gläser 1998, 2000), or how evaluation-based funding of university research affects

[10] This problem is not unique to science studies but has been acknowledged and explicitly discussed here. One of the solutions to the problem of integrating social and non-social factors in explanations – Actor-Network-Theory (e.g. Callon 1986; Latour 1988; Law and Callon 1988)– has become influential beyond science studies.

the content of this research (Gläser and Laudel 2007). We are interested in how these factors affect the content of scientific knowledge that is produced. This research interest differs from the Mertonian sociology of science in that it regards the content and forms of practices and knowledge as *explanandum*.[11] It differs from the sociology of scientific knowledge in the explicit regard of social macrostructures, namely institutions, as part of the *explanans*.[12]

Following ideas of the new institutionalism that have emerged in political sociology, organisational sociology and economics, we regard institutions as only one of several factors that shape social action. In science studies institutional effects are likely to be field-specific, because the influence of institutions is modified by the epistemic practices that are characteristic of specific areas of inquiry. Thus, epistemic conditions of action and epistemic practices must be included in institutionalist analyses as intervening factors. We must conduct comparative studies across scientific fields and assess the mediation and modification of institutional influences by field-specific epistemic conditions of action and epistemic practices (Gläser and Laudel 2004).

An empirical example for this kind of research is an investigation of institutional conditions for interdisciplinary collaboration (Laudel 1999, 2001). In order to find causal relationships between the institutional conditions of action and results of collaborative work, all factors that promoted, hindered, enabled or prevented a collaborative project's success must be analysed. When a scientist answered: "the collaboration didn't work", it had to be clarified what "it didn't work" actually meant i.e. to what kinds of causes the scientist referred. In one case, the further probing solicited the following explanation:

> The (...) protein (...) he [the biochemist] gave us, (...) was always too contaminated (...) it has never worked. (...) If you want to crystallize it, it must be perfectly pure, otherwise it doesn't work. Some proteins are very difficult to purify (...).

The scientist referred to a 'material resistance' (the protein's insufficient purity) as the main cause for the collaboration's failure. This was confirmed by other interviews and documents. It became clear that neither institutional conditions or actions, nor lack of resources, nor difficult personal relations (the partners collaborated successfully in other projects and got along well) nor other social reasons could explain the collaboration's failure. Epistemic conditions of action (the difficulties of protein purification and the high purity that is required by crystallization methods) had to be included in this explanation. More generally, epistemic conditions of action had to be included in the investigation in order to provide accounts for the success or failure of collaborations that took place under similar institutional conditions. In order to do that, we had to address the content of research in our interviews, and had to ask about it in the interviewee's language and frame of reference. We had to understand that it is necessary to crystallize a protein in order to analyse its structure, that the protein had to be "perfectly pure" for crystallization to work (and what "perfectly pure" meant in this context), and that purifying proteins is not an equally straightforward procedure for all proteins.

Our point is that studies of institutional influences on the content of research, and probably many other areas of science studies, need scientifically informed interviewing not only to properly construct meaning and understanding of social factors a study is interested in but also of factors that are

[11] For comments on this 'blind spot' of Mertonian sociology of science, see e.g. Whitley (1972).

[12] For comments on this 'blind spot' of laboratory studies, see e.g. Knorr-Cetina (1995: 162) and Kleinman (1998: 288-289).

alien to social studies of science, and are commonly described in the scientific languages of the respondents' fields. In these studies, we need to scientifically prepare interviews not only to achieve the kind of communication between interviewer and respondent that is deemed necessary by general qualitative methodology. We also need to gather information on non-social factors that need to be included in our explanations. The source of this information is our respondent, and the only frame of reference in which they can provide this information is their science.

4 Informed interviewing: Three tasks

4.1 Creating an 'ad hoc- pidgin'

One important aspect of any qualitative interview is that it must be conducted in a language that enables the investigator to obtain relevant information. Consequently, the language must be understandable to both the interviewer and the interviewee, and must facilitate the description of the interviewee's world. If the world is sufficiently remote from the everyday world that can be assumed to be shared by interviewer and interviewee, the emerging language can be regarded as an 'ad-hoc – pidgin'. We borrow the term pidgin from Galison who used the metaphor of pidgins and creoles to explain the stabilisation of interdisciplinary collaborations (Galison 1996). It seems useful because a sociological interview of scientists is very similar to an interdisciplinary collaboration. The interactionist perspective on interviewing maintains that interviewer and respondent collaborate with the aim of producing information needed by the interviewer. In this ad hoc-collaboration, two worlds – the world of sociological investigation and the world of the scientist's work – intersect, and in order to communicate about it, a common language must be constructed. In this process, the task of the interviewer is not merely to adjust their language to the different cultural background of the respondent, but to create a language in which the relevant work experiences can be described in a way that is intelligible to both sides. In this process, the interviewer must adopt elements of the respondent's language and vice versa.

The interviewer is suggesting such a language by using concepts from the scientist's world (which she obtained during her preparation, see 4.2) and simplifying the relationships between them. The main difference between the original meaning of the concept 'pidgin' in Galison's account and the situation in an interview is that despite all of the interviewer's preparations, the language must be created almost instantaneously, namely in the course of one interview.

The strategies for creating such a pidgin depend on the subject matter the sociologist is interested in as well as on the way this subject matter is experienced by the scientist in his or her everyday practice. In our interviews, we repeatedly observed that scientists switch between more technical and more social descriptions. When asked about their research processes, scientists described them in a predominantly technical way by referring to the epistemic content of their work – research problems, objects and methods of experimentation, instruments etc. For example, scientists present the system of experimental operations (synthesizing substances, measuring etc.) when describing collaborations. They told us that they used certain research methods, special substances etc. and therefore collaborated with scientists from other research groups who could provide them. Social relations and interactions that enabled, performed and accompanied this system of operations appear to be more in the background of the interviewees' reconstructions. Conversely, scientists describe their research fields as a constellation of actors (mainly research groups) and don't seem to perceive it as an evolving body of knowledge.

On the basis of this tentative conclusion from our interviews, we developed different strategies for obtaining information about the interviewee's 'local' work and about her community, respectively. When interested in single research processes, we suggest a more technical pidgin, i.e. we try to use a more technical language in order to investigate both epistemic and social aspects of the situation. In explorations of characteristics of scientific fields, we apply a more social pidgin and use it to obtain information about both types of characteristics.

a) Communication about the interviewee's 'local' work

For the exploration of a scientist's research projects we use a pidgin that is predominantly technical. As a skeleton of such a language, some concepts describing general elements of research processes can be used. In any empirical research process researchers start with a question that is somehow rooted in a theoretical background, investigate a research object by applying methods that must be developed or adapted, and interpret the empirical results. Although there will be only a few research projects that follow exactly that sequence of steps, the steps themselves will occur in one form or another in all research processes, and scientists' perceptions of research processes correspond to this model.

We can use this very abstract level of common experiences to formulate questions about the interviewee's research. In the investigation of scientists' collaborations interviewees were asked about the elements of their research processes, e.g. by using the following questions:

- What research problem do you deal with?
- Could you explain to an outsider what it is you try to find out?
- What methods do you apply? What equipment do you use?
- What substances do you use? Where do these substances come from?

Wherever possible, these questions were specified by detailed knowledge that had been acquired in the preparation of the interview by reading research proposals, research reports etc. (see 4.2). The questions about elements of research processes led to hints about other researchers who contributed to the interviewees' research in different phases. Thus, the cognitive links that were created via the exchange of substances, joint use of equipment etc. hinted to other researchers who were identified as collaborators.

Q: The first thing is already this tricky question about understanding what you are trying to find out; what your current research is about. I had a look at your website and there was mentioning that you basically use this low energy electron microscope (...) to study the dynamics of processes on surfaces of semiconductors.

A: Yes, particularly the III-V systems.

Q: Yes. So, that would establish your object and the method, but what's the problem you are trying to solve?

A: Yes, well there are really two aspects to what we're trying to do. One is to look at III-V semi-conductors - so the idea is to really understand how atoms move around on the surfaces, the very basic statistical mechanics, thermodynamics of self organizations, how objects such as quantum dots form and that's a very big controversial area at the moment (...)

In this part of the interview, the interviewer and the interviewee jointly deconstructed the interviewee's research project, which led to the identification of collaborations. The basis of this deconstruction was that both partners knew that a variety of method could be used to achieve the aim of the project and that the equipment of the interviewee's lab limited the range of methods that could be used locally. The deconstruction strategy worked well in all interviews on collaboration. By 'disassembling' the research process into its elements it was possible to find opportunities for collaboration, as well as real (successful and unsuccessful) collaborations. The variation of links between the research processes that were reported in the interviews supported the construction of types of collaborations.

A similar strategy was applied in an investigation of East German basic research. The aim of the project was to find out whether the radical institutional changes that accompanied German unification led to changes of the basic/applied character of East German research (Gläser 1998, 2000). In this project, an in-depth description of the basic/applied character and its dynamics was needed. As was the case with collaborations, the elements research problem, research methods and research objects were used to ask detailed questions about actual and possible links of interviewees' projects to contexts of application.

Q: If I understand it correctly, your work is purely theoretical.

A: This is a theoretical research group, basic research, but we have always worked close to the experiments and do it now more intensively because we benefit from new opportunities to collaborate with the right groups.

Q: That would have been my next point: It is possible in the field of theory to work far remote from experimental systems, which means to work with models that are so abstract that they do not correspond to experimental systems. Does this happen in your group?

A: We don't do this. Actually, the work with the polymers might be slightly more Hamiltonian-oriented, but not in our group. We have very, very close connections to experimental groups.

Q: Work on semiconductors and connections with experimental groups suggest that there is a link to applications?

A: Yes, this link surely exists in the end. Depending on how the funding agency regards its importance, one can emphasise it more or less. I wouldn't regard it primary for me and my work. It is actually the explorative side of basic research. It is not excluded that there is an application in the end, but that is not our primary concern.

Q: Would these applications emerge from your research, or would they be a result of experimental research?

A: This would be a result of the experimenters' work.

Constructing this conversation required knowledge about the two kinds of theoretical practice in physics – investigating theories that have no links to experimental research at all and theoretical interpretation (modelling) of experimental data - and about possible links between theoretical physics and applications – the object that is modelled (semiconductors) and the experimental research groups whose data form an input for theoretical research. The interviewers' success depended primarily on the common language that was constructed at an appropriate level of simplification. This was particularly problematic in the investigation of theoretical research processes that cannot be talked about in terms of comprehensible manual operations. Extensive mathematical knowledge might be necessary even to understand the elements of the research process. Therefore, in some interviews with theoretical physicists we had to rely on global descriptions because we didn't comprehend the mathematics well enough.

b) Communication about the interviewee's research field

To achieve an 'ad-hoc pidgin' for the communication about research fields is more difficult. Attributes of research fields are aggregations of research processes or emergent characteristics at the field level. A big problem that hinders all communications about research fields is the latter's fuzzy and fractal structure. The simple question "To which research field does your work belong?" already leads to difficulties because the interviewee can subsume his or her research under a broader or narrower research field at will. The term 'field' is subject to widely varying interpretations, as was described for 'collaboration' and 'basic/applied character' (see 3.3). The interviewees name their field close to the level of a discipline (for instance, "Organic Chemistry"), or as a subfield, or even by describing the subject matter of their current research. Therefore it is very difficult to agree on the conversation's subject matter in these parts of an interview.

A second problem is that characteristics of a field that are needed in science studies - size, age, growth dynamics, internal structure (how many subfields and their degree of connectedness) etc. – are not part of scientists' everyday experience.[13] Scientists, of course, do understand the terms "size of a field" or "dynamics of the field". However, questions about these characteristics force them to look from above on their own field and even to compare it with other fields to which they do not belong. Thus, a badly operationalised question could lead to answers that were hardly interpretable, or even to a blunt rejection.

Q: How would you – to provide me with a picture – describe the field 'integrated optics'? How big is it approximately?

A: How big it is I can't answer because I don't know what the scale is.

The characteristics of fields that sociology of science is interested in are not established with an absolute scale but only in a comparative perspective. Younger scientists often have difficulties comparing their own field with others. In our interviews, only senior scientists who are core members of one scientific community and are familiar with others were able to give comparative descriptions of their fields, and even they had sometimes difficulties. Moreover, their descriptions are shaped by the fields they select as references.

For these reasons, we translate the cognitive characteristics of research fields into social indicators, thus creating a pidgin that is primarily social and thus closer to the scientists' experiences of social interactions with other members of their field. For example, the following questions were used to obtain information about a field's size:

- How many scientists do you know who work in your field?
- Is there sharp competition in your field?
- Does your field have its own conferences? How many people usually attend these conferences?
- Does your field have its own journals?
- Which groups work in your country/world-wide in your field?

In the following example, the interviewee was able to answer the question and additionally introduced a comparison with another field whose conferences he has attended.

Q: When you attend conferences: How many polymer physicists are there? I am trying to learn something about the size.

A: This can be answered relatively precisely: In the German Physics Society a Committee 'Polymer Physics' exists which usually brings together 250 to 300 people. That is a small group. If you compare it with others, solid state physics are 1000 or even more. We can't match this.

The interviewee could easily answer the question because it was related to his personal experience. He was not forced to interpret an abstract concept he never or rarely applies to his field (size), but was asked for empirical information he had no problems providing.

4.2 Preparing the interview

Conducting a scientifically informed interview requires extensive prepara-

[13] This does not mean that research fields are not an important environment for scientists, as was claimed by Knorr-Cetina (1982) and Luukkonen (1995: 364). In our interviews, fields were always an important frame of reference for scientists even though our respondents constructed them in varying and often idiosyncratic ways, which complicated the task of soliciting comparable descriptions.

tion. We must not only develop our own conceptual schemes and translate them into interview questions but also (at least to some degree) the conceptual schemes and research strategies of our respondents. Unfortunately, interviewing as a 'stand alone' strategy of data collection does not enable learning processes in the field. The interviewer has only one opportunity – the one to two hours of interaction in the actual interview - 'to get it right'. Therefore, in qualitative interviewing the learning must take place prior to data collection. This is particularly demanding when a study features a comparative approach that includes several fields, thus requiring the understanding of not one scientific culture (as usually is the case in ethnographic studies), but several of them simultaneously. We have faced this problem in our own comparative studies of institutional influences on the production of scientific knowledge. The comparative approach severely limits the time one can spend for understanding the fields.

We usually apply three strategies of information collection. Firstly, we try to obtain general information about the research field(s) under investigation by studying reference books of the discipline the field belongs to or of the field itself. We used these books especially to get information about the field's most important methods and to understand basic, often used terms. Of course, it is impossible to catch up with years of scientific training by studying reference books. But it was possible in almost all cases of experimental research to develop a general understanding of what the work in the field is about and how problems are tackled. The following quotation exemplifies why it is useful to get this kind of knowledge:

Q: What is the common background of the projects you are conducting?

A: Organic Chemistry.

Q: This is very general. Organic chemistry is a very large field.

A: Synthesis and Preparation of natural substances and synthesis of derivatives. That could be said, generally.

Since the interviewer knew that organic chemistry is too large to form the common background of a single scientist's projects she was able to extract a specification. The strategy of studying reference books becomes rather difficult or even impossible if a whole range of research fields has to be investigated. However, we would still propose to try.

The second strategy is essential for informed interviewing and should always be applied. It is crucial to collect information about the interviewee's research prior to the interview. Zuckerman (1972: 163-166) reported how extensively she prepared her interviews with Nobel laureates. She studied the laureates' addresses given on the occasion of their Prizes, prepared publication lists, and read publications like those written by the laureates for lay audiences. She prepared a summary of each laureate's career and his work as a preparation for the interview.

We usually prepare our interviews in a similar way. As a rule we use the following sources to get information about the scientists work:

- Research proposals and research reports;
- Publication lists from publication databases like the Science Citation Index; and increasingly in the last years
- Information obtained from the internet about research projects, methods and equipment of the group and the like.

In the following quotation the interviewer used information about collaboration from the interviewee's PhD thesis:

Q: You wrote in your PhD that the general thing, doing time lapse studies, has been done before, but not with the object that you were studying. Is that right?

A: Yes, that's right. There was a lot of early work in grasshoppers, which have huge neurons, just massive, and they are very easy to do, bring a needle down and inject them. And it's all very clear what the cell is doing in the grasshopper because everything is so big (...).

In his much longer answer, the interviewed biologist provided detailed information about the field and the position of his research in it, the reasons why he did follow this line of research, and about the specific methodological problems he has to deal with. The informed question and the reference to his PhD triggered the hoped-for response.

It is also useful to study posters often located in front of the working rooms and labs in the time directly prior to the interview. This sometimes makes it easier to start the informal talk with scientists, which leads into the interview. If the opportunity occurs we visit the interviewee's laboratory (we often get invited to a lab tour after the interview). This is an excellent opportunity to enhance one's understanding of the science, e.g. by getting a graphical image of the equipment and how it is used, and by obtaining additional explanations of the laboratory practice.

A third strategy we developed recently is analysing the interviewee's publications. This method circumvents the difficulties of understanding the science by bibliometrically analysing structural properties of the interviewee's oeuvre. The results can be visualised as 'bibliometric research trails' – evolving networks of publications -, which we used to discuss the content of the interviewee's research as it unfolded over time (Gläser and Laudel 2007). While bibliometric analyses are a useful additional tool for understanding a respondent's research, they cannot replace the understanding of content – without having some idea about the content of the science, we would not even understand what the structure means.

4.3 Negotiating the level of communication

Each interview begins with a phase of implicit negotiations. Part of these negotiations is that the interviewer suggests a vocabulary for the pidgin, which is changed by the interviewee's responses. In this introductory phase, while it is being negotiated what technical terms can be used by the scientists so they are properly understood by the interviewer, it is simultaneously negotiated how 'scientific' explanations may be in order to be understood. This negotiation phase has been experienced by Zuckerman:

> "Intensive preparation brings growing familiarity with the technical language deployed by the laureates. In the early phase of most interviews, the laureates tried to avoid the use of language I might not understand. When given cues that they would be understood – particularly by my using such terms –they relaxed and their vocabulary more closely approximated their usual one. (...)
>
> The scientific language as well as the trade vernacular was used to convey the sense that the laureate was not talking to a total alien. It was not intended to convey expertedness on the part of the interviewer and did not seem to be perceived as such an attempt." (Zuckerman 1972: 170)

The introductory phase of the following interview (from the project on East German basic research) is an instructive example of carelessness in the negotiation phase. The interviewer had done his homework but blunders in the introduction by asking shallow questions and downplaying his preparation:

Q: The first question is: What are you currently working at, that means, your department? I have read a bit in your yearly report, but I am a layperson in physics. What I have found out is that you are dealing with laser physics.

A: Yes.

Q: And, if I understood it correctly, primarily with the development of methods?

A: Yes. And application of these methods.

Q: And application of these methods, too?

A: Yes, yes. It is of course the question how precise an answer you want. When you say you are a layperson, then it is of course not really important for your investigation what we do in detail, but probably only a rough description.

Q: Yes.

A: It is of a basic character and indeed aimed at the further development of certain methods of laser spectroscopy, which can reveal very fast processes in molecules. (...) But it is basic investigations, first steps, which are investigated. When we had nanoseconds it turned out that the fastest reactions appeared to take nanoseconds. You know what a nanosecond is?

The interviewer presented himself twice as a rather uniformed layperson and was consequently treated by the interviewee as such. The interviewee considered details of his work as unimportant to the interviewer and explained his works as simple as possible. This created a problem for the interviewer who needed detailed descriptions of the scientists work to answer his sociological research question. Thus, he had to repair the damage in the subsequent phase of the interview in order to get the appropriate level of communication.

In the following example, the interviewer starts with the very general question without indicating her knowledge about the communication's subject. She is being treated as a layperson, and the communication begins at this level. However, the interviewer begins a negotiation, which raises the level at which communication takes place.

Q: What is your research field and since when have you been working on it?

A: Well, you are not a natural scientist. How precise would you like to know it? My research field is biochemistry of the neural system, neural chemistry as it is called. I have been working on it for a long time ... Biochemistry of the neural system concerns the signal processing and signal transmission by certain protein molecules, which are called receptors.

Q: And your special object of investigation is the acetylcholine receptor.

A: This is a receptor that acquires neural impulses and transforms them into an effect.

By informing her interviewee that she knew about the acetylcholine receptor, the interviewer signalled that technical terms could be used in the interview, and began to move the interview to a level of more detailed descriptions of research processes. Later in the interview, the interviewee without hesitation used his technical language to describe the emergence of collaborations.

(...) If I remember correctly, we had several plans at this time. We primarily investigate structures. One assumes that these biologically important molecules - such a receptor – can be understood if its spatial structure is understood. And we talked to the X's Group, which consists of very good crystallographers, about how we crystallize this thing. (...) This was a starting point for trying this together with them.

Our final example demonstrates a better introductory phase, namely a truly informed beginning of the interview.

Q: (...) I have looked up in the internet what you are working at, what your research field is. And I understood it as follows: You conduct surface investigations of semiconductors and metals and aim at a microscopic understanding of the interaction of molecules and atoms on surfaces.

A: That is a big part. Another important part are organic thin layers, organic materials that are deposited on anorganic solid states and reverse, in order to make devices. But we are primarily concerned with the foundations. This belongs to the area of soft matter (...) And there we use our technologies for advancing the microscopic understanding.

In this interview, the interviewer begins with a description of the interviewee's research field as she understood it from information collected prior to the interview. In doing so, she is trying to communicate the level of her understanding of the interviewee's research and the technical terms that can be used in the interview. With his answer, the interviewee is adapting to this level of communication.

There is also a danger in the interviewer's self-presentation as scientifically well informed. Scientists can for-get that it is not a colleague they are talking to, and can therefore move up to a scientific level the interviewer cannot understand. Whenever this happens, the interviewer must negotiate the level downwards by stating that the scientific argumentation was incomprehensible. Thus, the aim of these negotiations cannot be to pretend an understanding that does not exist (e.g. to impress the interviewee), because the interview can produce useless (because incomprehensible) scientific talk. It is important to achieve a level at which the interviewer can still understand all the dialogue of the interviewee.

5 Conclusion

Scientifically informed interviewing is necessary in science studies because it is the only way of understanding what our respondents mean when they answer our questions, and because we often must use interviews to collect data about the content of our respondent's research. This kind of interviewing requires extensive preparation of interviews, the construction of an 'ad hoc – pidgin' for the communication during the interview, and the negotiation of an appropriate level of scientific depth between the interviewer and the interviewee.

While the necessity of informed interviewing has not been explicitly questioned, the extent to which interviews are prepared scientifically is likely to vary. Owing to a lack of material, it is impossible to compare naïve and informed approaches to interviewing the same way as we have done for observations in this article. Neither are there outspoken advocates of naïve interviewing, nor is it easy to recognise studies that applied such an approach. Though both, the danger of 'going native' and the danger of shallow accounts of scientific practice are real in interview-based studies, too, we cannot yet discuss them because we do not have sufficient information about methodologies of science studies, let alone links between methodologies and results. Judging from results of quantitative studies on the impact of evaluation-based funding on the content of research, which are by design forced to rely on naïve interviewing, the shortcomings of such an approach may be severe (Gläser et al. 2002).

Since the main purpose of this article is to invite readers to a methodological discussion and exchange of experiences, we conclude this article by pointing out limitations to our approach. A first limitation is produced by specific fields like mathematics or theoretical physics. While it was usually possible for us to understand the problems and strategies of experimental research at some level of simplification, we couldn't achieve a similar simplified understanding of the practices of mathematics and theoretical physics. In these fields, simplified descriptions of problems, objects, and methods of research appear to be more difficult to achieve. We tried, and our respondents tried – but in many cases 'the collaboration didn't work'. Thus, it seems that some fields can be studied only by native observation respectively interviewing.

A second limitation occurs if comparative research across several fields is conducted. In this case, the sociologist, who of course has the prime task of preparing the investigation sociologically, is endangered by information overload. There are limits to a scientific preparation when one has to interview a molecular biologist on Monday, a solid state physicist on Tuesday, an electrical engineer on Wednesday and a physical chemist on Thursday. Acknowledging this problem implies to give up the idea that qualitative (semi-structured) interviews are an 'easy' or 'quick' method. One has to invest an enormous amount of time in order to interview scientists properly.

A third limitation is that informed interviewing cannot be extended to the background knowledge of scientific work that is acquired by systematic scientific education and experience. In our opinion, the scientific taken-for-granted assumptions and the tacit knowledge cannot be investigated by qualitative interviews. The method of choice for studying the role of this knowledge is ethnographic observation. The fact that even ethnographic observations have their problems here (as the comments of ethnographic observers on the limits of their understanding indicate, see 3.2) hints to a difference between science studies and studies of many other social groups. Scientists carry knowledge that is implicitly present and partially communicated but had been acquired by ways that are qualitatively different from the practices that can be currently observed, and are located outside the field under study. Since we cannot investigate this background, it is not clear to what extent we can identify the scientific taken-for-granted assumptions of scientists unless they are challenged by the scientists themselves.

Applying a scientifically informed interviewing strategy even increases the danger of not being able to identify taken-for-granted assumptions. Our respondents might not tell us because they think we know. This point has been argued in the context of ethnographic methodology. Yes, there is the serious danger of *not* getting certain information in an informed interview. The interviewee will form assumptions about the interviewer, and about what the interviewer already knows. Therefore, informed interviewing increases the danger of not being told something that should be told because your interviewee thinks you already know this. This can be partly helped by careful in-depth probing during the interview. However, there seems to be an unavoidable trade-off between not being told something because you are assumed to already knowing, on the one hand, and not being told because you are assumed to being unable to comprehend.

Our methodological discussion is, of course, limited by our own experience. While some clear patterns exist in our interviews, any generalisation requires the inclusion of the experiences of as many investigators as possible. Given the current level of methodological discussion on informed interviewing, any discussion must start from scratch, and doing this with one's own experiences is not the worst way to begin.

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The Expansion of Renewable Energies in Germany between Niche Dynamics and System Integration – Opportunities and Restraints

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Abstract

The main assumption is that the expansion of the renewable energies in Germany is not only the result of technical innovations, but also the outcome of specific social and institutional innovation processes. The article first examines the reasons for the increasing diffusion of renewable energies. Some attention will be directed to the relevance of political regulation and to actor networks, which have been important for the process of innovation. Secondly, the question will be discussed if there is another side to the rapid growth of the sector for renewable energies, in the sense of specific problems and ambivalent results caused by the growth. One example could be conflicts, which emerge from divergent interests of actors involved or from the risks of technological niche promotion. The third main topic takes as its point of departure the fact that the relationship between the "renewables" and the traditional industry of power generation was marked from the outset by competing paradigms. The renewable energies could at first only be propagated in small niches, which had to be protected by political regulation. The question will be discussed whether the increasing expansion of the niches causes growing problems with integrating the renewable energies into the given centralized electricity system and what kind of different interests and ideas about system integration have to be taken into consideration.

1 Introduction

Two different characteristics are significant for the German electricity sector. On the one hand there is the *traditional path* – with technical and economic structures that emerged at the beginning of the twentieth century and remained up to date in their substantial parts; but the importance of renewable energies is increasing. Until now the dominating paradigm has been that of a *centralised* generation and distribution of electricity within an interlocking technical system (Hoppe-Kilpper 2001; Leprich 2005). Market concentration is as well characteristic for the German electricity sector; an oligopoly of a few energy suppliers traditionally dominates the production and distribution of power. In spite of several "disturbances" the continuity of the traditional energy path remained steady in Germany. Neither the oil crisis of the 1970s and the growth-critical debates which followed nor the critical debates on nuclear power and on environmental protection caused ruptures, or even withdrawal, from centralised power generation on the basis of fossil and nuclear energy resources. The liberalization of the German electricity market, which dates back to the year 1998, even stabilized the process of economical concentration. Four suppliers were to remain dominating and a "duopoly" of two main suppliers is by now responsible for about 70 percent of the entire electricity production (Leprich 2005: 15-16). Considering their economic dominance, their organisational structures and their long-term investment strategies, there is much evidence that the major companies in the electricity sector will pursue their well-tried path in the future. Recently they announced to invest in new brown coal and hard coal power plants, which will be built in Germany in the years to come.[1]

On the other hand there is structural change and innovativeness of the German electricity sector, as the main perception is guided by the success story of the renewable energy sector. Here Germany is perceived as playing an internationally acknowledged "pioneering role": as the "world market leader" in the field of wind energy and as a member of the world wide top league for other types of renewable energy technologies, for instance solar cells (Reiche 2004: 189). The business strategies, especially those of the manufacturers of wind turbines and solar cells, have an international focus today – the industrial site Germany has become "a lead market for the renewables and a leader for technology and innovation in several fields" (BMU 2005: 9). The renewable energy sector takes a share of around 12 percent in German power generation by now. It therefore can no longer be assessed as economically insignificant. Thus, it became an expansive branch of economic activity, with total turnovers of 21.6 billion Euro in 2006 (BMU 2007: 6), meanwhile securing "significantly more" jobs (214000 in 2006) than "coal and nuclear power plants in all" (BMU 2005: 4; BMU 2007: 6).

The present article is based on empirical research performed at the Sociological Research Institute Göttingen (*Soziologisches Forschungsinstitut Göttingen, SOFI*). It concentrates on the development of the renewable energies in Germany[2]. The main assumption is that the expansion of the "renewables" is not only the result of technical innovations, but also the outcome of social and institutional innovation processes. Furthermore we con-

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[1] The German news magazine DER SPIEGEL reports that the energy suppliers are planning to build 26 new coal power plants, with a total capacity of 25,500 Megawatt (DER SPIEGEL 12/2007: 43).

[2] The research project was financially supported by The Deutsche Forschungsgemeinschaft (DFG). The final report was completed in May 2007 and will be published within a short time in the Universitätsverlag Göttingen (Mautz/Byzio/Rosenbaum 2007).

ceptualize renewable energies as a *radical innovation*.[3] This assumption has to be substantiated, as biomass, water power and wind energy already constituted the energy basis of the pre-modern ages, and most of the modern technologies for using renewable energy sources were invented some decades before the 1970s. Hence it would seem inadequate, from a technological point of view, to describe the renewable energies as radical innovations. The innovation process rather has to be conceptualized as the rediscovering and further development of the above-mentioned technologies, embedded in new social contexts and linked to societal and environmental objectives of a wider range. From *this* point of view, the early process of innovation and diffusion of the renewable energies was – in Germany – to a high degree connected to the rise of the new social movements in the 1970s, especially the ecological and the alternative movement. At the beginning of this process we do not find radical technological innovations, but radical - and in part even utopian – new ideas and objectives, which resulted in a *reinterpretation* of established technologies. Following this conceptual focus our research underlines the relevance of social shaping of technological innovations and the importance deliberate agencies of collective actors play in this game.[4] Today and ever since, supporters and actors directly involved in the field of renewable energies try to enforce a radical *paradigm shift* in the energy system. The fundamental principles of the new paradigm are:

- Technical and economic decentralization of the energy production.
- Extension and pluralizing of the relevant groups of actors in the energy sector.
- Protection of the environment and climate as a guiding principle of action in the energy sector.

In the following stage, the article first tries to examine some important reasons, which played a major role for the increasing significance of the new paradigm, as indicated by the progressing diffusion of renewable energies in Germany. Some attention will be directed to the relevance of political regulation and its embeddedness in wider forms of governance. The analysis will further concentrate on actor networks and their relevance for the process of innovation and for the technological "path creation" within protected niches.[5]

The second section of the analysis concentrates on the question as to whether there is another side to the rapid growth of the renewable energies sector, in the sense of specific problems and ambivalent results caused by the growth. There is some evidence that the technical growth and the economic expansion of power generation based on renewable energies can be blocked or delayed by specific barriers of diffusion or by conflicts emerging from divergent interests of actors. Both factors lead to an increased demand of political steering in the field of renewable energies.

The third main topic takes as its point of departure the following question: Can one detect any growing problems with integrating the renewable energies into the given system of power generation and distribution? Ever since the relationship between the "renewables" and the traditional industry

[3] The concept of *radical innovation* as a specific type of technological innovation is discussed, for instance, by Werle 2003: 6-16; Braun-Thürmann 2005: 42-51; Dolata 2007: 25-46.

[4] The "social construction of technology" approach is discussed, for instance, by Pinch/Bijker 1987; Hughes 1987; Rammert 1995; Weyer et al. 1997: 23-52; Ornetzeder 2000: 29-58; Degele 2002, 98-103; Meyer/Schubert 2007: 33-36; Rammert 2007: 37-46.

[5] For the concept of "path creation" see Ortmann 1997; Schreyögg/Sydow/ Koch 2003; Windeler 2003; Garud/Karnøe 2003; Meyer/Schubert 2007.

of power generation was marked by competing socio-technical paradigms. Taking the large companies' perspective, one can say the renewable energies were merely perceived as an alien element, compared to the dominant system. At first, the renewable energies could only be established in small technological niches, which had to be protected by political regulation. Political support and regulative protection are still necessary, but with the increasing expansion of the niche the question of integration became more acute. This is caused by growing incompatibilities between the existing centralized electricity systems on the one hand and the increasing number of decentralized and renewable power sources on the other.

2 Renewable energies – reasons for success

Most research, which focuses on the development of renewable energies in Germany, emphasizes the tremendous importance of political regulation as the driving force in this field (e.g. Heymann 1997; Lucke 2002; Umbach-Daniel 2002; Durstewitz/Hoppe-Kilpper/von Schwerin 2003; Jacobsson/Andersson/Bangens 2002; Jacobsson/Lauber 2006). This fact is little surprising, as researchers agree on the high impact governmental steering and regulation normally has on the opportunities and the restraints of environmental innovations (from the viewpoint of institutionalism theory in economics: Zimmermann et al. 1998; Linscheidt 1999; Hübner/Nill 2001; in the context of sociological analyses of technological environmental innovations: Huber 2004, 2005; from the viewpoint of studies on environmental and sustainability policy: Blazejczak et al. 1999; IÖW 2001; Jaenicke 2001; Coenen 2002). Examining the present success of renewable energies, some relevant studies do not only analyse the effects of specific key measures, like the Renewable Energy Law (Erneuerbare-Energien-Gesetz), but rather put a particular emphasis on the fact that "political patterns" (Hemmelskamp 1999; Blazejczak et al. 1999) or a broad "policy mix" have been created in this field of environmental and political action. The main elements of the "policy mix" are technology-specific feed-in-tariffs for the producers of electricity generated from renewable energy sources, financial support for R&D and for private investments in renewable energies (e.g. for house owners intending to install solar panels), and the implementation of appropriate instruments in the field of planning law (Reiche 2004; Reiche/Bechberger 2006b).

In terms of evolutionary theory of innovation, the political regulation has helped to generate and stabilize a *market niche* for renewable energies (Markard/Truffer 2006; Smith/Stirling/Berkhout 2005). Geels/Schot (2007: 400) describe such niches as "incubation rooms" for radical novelties. Niches are "protected spaces" to shield radical new technologies or experimental projects "from mainstream market selection" and to enable heterogeneous actors to cooperate in a new and innovative way. If successful, niches "provide locations for learning processes, e.g. about technical specifications, user preferences, public policies, symbolic meanings". Another important quality niches can provide is the possibility to force actors "to deviate from the rules in the existing regime" (Geels 2004: 912). Garud/Karnøe (2003: 281) consider the "process of mindful deviation" as a substantial condition for the emergence – respectively for the deliberate creation – of new technological paths. In the case of renewable energies the existence of a politically protected niche was – and is – an important prerequisite for the rise of a new socio-technical paradigm in the field of power generation and supply.

A considerable part of the relevant research nevertheless considers governmental regulation and promotion of the sector for renewable energies to be a necessary, but not sufficient, condition for successful diffusion processes.

First, there is much evidence that the political regulation of the energy sector is embedded in broader institutional changes, for instance changes of political main constellations on the national level or changes on the level of international institutions regulating environmental issues (Reiche/Bechberger 2006a, 2006b). Furthermore the interactions between political regulation and other social processes – like changing technical visions in society, the emergence of public debates on specific environmental issues or the integration of new social movements into society – call for careful consideration. From this point of view the governmental support for the renewable energies is as much the result of the political, economic and societal "institutionalization of environmental protection", as it is a driving force for this process (Byzio/Mautz 2006: 67-68).

Second, most of the studies put emphasis not only on governmental actors, but they also try to include different types of non-governmental actors, which are involved in the process of adapting, disseminating or using renewable energies, in their analysis. Such an analytical focus can be useful to illustrate the limits of governmental means to act in the field of renewable energies. This sector of politics is regarded as a good example to depict the relevance of complex forms of governance, in which governmental steering is embedded. Some studies show that the development and success of socio-technical "niche regimes" (Smith/Stirling/Berkhout 2005) does not only depend on market protection by law and on appropriate financial incentives, but also on effective collaboration or interaction of different actors such as researchers, technicians, manufacturers of technical installations (e.g. wind turbines), different types of users, or protagonists of non-governmental organisations, for instance environmentalists, conservationists or citizen groups concerned with energy policy or with the promotion of renewable energies (Geels 2004). Jacobsson/Lauber (2006) focus on specific governance structures, which have been developed at an early stage of the "renewables" and which have been stabilized by positive feedback between several social actors. In the late 1980s protagonists of non-governmental organisations, the Green Party, citizen groups etc. and early economic actors in the field of renewable energies formed an advocacy coalition to put pressure on the government. One result was an incipient relationship and collaboration with some political protagonists involved in the milieu of environmentalists, who did not only support the expansion of renewable energies but also became an integral part of the advocacy coalition themselves. Such feedback – especially under the auspices of a federal government led by the red-green coalition (1998-2005) – was able to help to strengthen actor strategies. These strategies were aimed to create better political measures on one hand and better technical possibilities and economic conditions for the expanding renewable energy sector on the other.

The interaction between political regulation and various actors involved in this industry is related to another factor of success, which is still a driving force of innovation and sectoral growth in this field. The key phrase is "decentralized systems of diffusion".

The rediscovering and early dissemination of renewable energies within the networks of the environmental or the alternative movement of the 1970s and 1980s already showed patterns of decentralized systems of diffusion, as examined by Rogers (1983). Later on – in the 1990s – these early systems of diffusion evolved into networks of innovation, which were still characterized by decentralized transfers of knowledge and experience – with decentralized "change agents" as a main driving force of the diffusion process. The Renewable Energy Law provided favourable conditions for the further differentiation and professionalization of innovation networks. These innovation networks provide opportunities of feedback between the operators and the manufacturers of power generation on the basis of renewable energies. While the operators do control the usefulness, the reliability or the safety of the applied technologies, the manufacturers are a main driving force of technical innovations. Under ideal circumstances such feedbacks lead to an upward spiral of "recursive innovations" (Kowol/Krohn 1995; Krohn 1997; Degele 1997; Degele 2002).

Examples, appropriate to illustrate the recursive innovations, which help to stabilize a newly created technological path, are *biogas power plants*. The development of this technology was initially characterized by the commitment of many non-professional change agents (e.g. students of agricultural science or members of the environmental movement). Today this is a field of activity for a multitude of professionals: besides planning companies and several manufacturers of biogas power plants (most of the manufacturing companies have been founded since the middle of the 1990s) representatives of professional associations (e.g. *Fachverband Biogas*), of regional farmer associations or of agricultural departments of the German federal states, are involved. Up to now, the power generating biogas technology has evolved, following a process of *learning by doing*. Farmers, the main operators of biogas power plants in Germany, play an important part in this process: Initially – due to a former lack of professional manufacturers in this field – some pioneers among the farmers built the first small biogas power plants in a do-it-yourself manner. Today farmers still contribute substantially to the improvement and the technical maturing of professionally constructed biogas plants (Mautz/Byzio/Rosenbaum 2007: 73-75).

In the sector of *wind power* generation, wind farm operators promote the steady advance of innovations in the field of wind turbine technology. This process is guided by the vast interest to obtain systematic know-how about material faults, about breakdowns of wind turbines etc.. Systematic reports on damage, prepared by the Federal Association of Wind Power (*Bundesverband WindEnergie, BWE*), and information pools on cases of damage have become important tools supporting recursive innovation in the sector of wind power. According to the wind farm operators' expectations, these tools lead to an increasing transparency concerning typical technical problems they have to deal with. Additionally, an increasing ability to solve those problems in cooperation with manufacturers and service companies is expected. And last but not least a generally strengthened position in the field of communication and bargaining with manufacturers or suppliers is hoped-for (Weinhold 2006).

Compared to the above-mentioned technologies, the *solar energy sector* still shows a remarkable coexistence of professional and non-professional change agents, for instance in the context of local actor networks. Here we often find craftsmen (e.g. plumbers or electricians), energy consultants, citizen groups committed to solar energy or representatives of the local government, collaborating to support the dissemination and use of solar energy. Innovative activities in this field are typically located within the "high tech" laboratories of the manufacturers of solar cells or solar panels; for instance innovations, which are aimed at more efficient use of material (e.g. thin layered solar cells) or at an increase of the total energy efficiency of solar panels. When the solar cell and, respectively, the photovoltaic technology, was invented in the 1950s the range of application was initially rather small. Until the 1970s photovoltaic cells were only used for spacecraft and for some niche applications (e.g. toy cars, watches)

(Grober 2004). Hence the pioneers of solar energy, who emerged in the 1970s and 1980s, had to open up new possibilities for using this technology. They soon concentrated their efforts on the problem of how to disseminate solar panels as roof installations among private users – at first especially among private home owners, later on also among citizen groups who were willing and able to buy joint solar panels, which had to be installed upon larger roofs (e.g. on top of churches, municipal buildings, trade buildings or apartment houses). This quest for applicable solutions had (and still has) an influence on the manufacturers of solar panels and the suppliers of specific components. One result was the development of weather proofed and more robust solar panels; another result is evidently to be found in the increasing efforts to improve the integration of solar panels into buildings (roofs and facades), for instance by using variable coloured solar panels or thinner and more flexible photovoltaic cells (Mautz/Byzio/Rosenbaum 2007: 75-76).

The positive impact of renewable energies on regional economics and labour markets is another factor, which helps to disseminate them. For this reason, numerous promoters from outside the branches of "renewables" (e.g. representatives of regional governments or trade-unionists) became interested in increasing the diffusion of these technologies. These promoters are now an integral part of the decentralized systems of diffusion, which serve to support and improve the effectiveness of governmental measures in the field of renewable energies. In sum, the political support of the "renewables" has been highly successful. The governmental regulation in this field – especially via the Renewable Energy Law – revealed innovative potentials and supportive capacities which already existed inside the social networks promoting renewable energies. As a result the diffusion of these technologies was accelerated – especially since 2000[6] – and the social range of those who are involved in the renewable energies sector became noticeably broader.[7]

3 Restraints and obstacles

However, there is some evidence that the diffusion of renewable energies – driven by social, institutional and technical innovations – is accompanied by ambivalent outcomes, which could conceivably restrict the further growth of this economic sector to a certain degree.

3.1 Renewable energies as a matter of conflict

First, we have an *increasing number of conflicts* accompanying the accelerated dissemination of renewable energies.

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[6] From 1999 to 2006 the number of wind turbines in Germany went up from about 8000 to nearly 19000; the installed capacity of all wind turbines was about 4200 megawatt in 1999 and increased up to nearly 21000 megawatt at the end of 2006 (www.wind-energie.de/de/statistiken/?type=55). In the same period the number of German biogas power plants went up from 850 to 3500; the installed capacity of biogas power plants increased from 50 megawatt in 1999 to about 1100 megawatt in 2006 (www.fachverband-biogas.de). In the same period the installed capacity of solar panels in Germany went up from 69.5 megawatt to about 2500 megawatt (www.solarwirtschaft.de).

[7] In the field of power generation based on renewable energies, we nowadays find a multitude of small and medium-sized businesses (e.g. companies operating wind farms, biogas power plants or large solar power plants), an increasing number of utilities which operate their own biomass power plants, thousands of farmers who operate their own wind turbines, biogas power plants and/or solar panels, citizen groups operating their own wind turbines or solar panels, an increasing number of home owners with a solar panel on the roof, and meanwhile some big energy suppliers who have already invested in (offshore-) wind farms or biomass power plants.

Indirectly, this is a result of the governmental support for the "renewables". The feed-in-tariffs guaranteed by the "Renewable Energy Law" are combined with technology-specific rates of digression,[8] which can be regarded as effective incentives for producers and operators to minimize their costs and to maximize the energetic efficiency of wind turbines, biogas power plants or solar panels (Nitsch et al. 2005). In addition to several other possibilities, one way of reducing costs is to *centralize* the power generation. Here, centralization means concentrating a large number of wind turbines in huge wind farms, building up extensive solar power plants consisting of hundreds (or thousands) of solar panels, or concentrating several biogas power plants in so-called "biogas parks". But, the renunciation from small and extremely decentralized units of power generation – which were the dominating technologies in the early years of the renewable energies – can lead to increasing problems of acceptance and to specific conflicts in the field of "renewables. Recently, there is a growing number of conflicts caused by large outdoor solar power plants (Janzing 2004, 2007), and in some German coast regions conflicts emerged, when the plans for huge offshore wind farms in the North Sea and the Baltic Sea were publicly announced (Byzio/Mautz/Rosenbaum 2005).

One important type of conflict caused by renewable energies can be described as a local or regional *clash of interests*, which often occurs in the case of competing interests with regard to the utilization of specific areas (onshore and offshore; see for instance the competing interests of offshore wind farm operators and the coastal tourism industry; Byzio/Mautz/Rosenbaum 2005: 63-80). In other cases *controversial risk perceptions* play a major role. The location of wind turbines in close proximity to residential areas, for instance, is regarded as a source of serious health problem by some people – an accusation normally rejected by wind farm operators. More generally: many people who live in the neighbourhood of wind farms, biogas power plants or large solar power plants fear a negative impact on their *quality of life*. In the case of wind turbines, for instance, people are strained by noise problems or by visual disturbances (e.g. by the so called "disco-effect" caused by the rotating wings). In the case of biogas power generators, people who live nearby often feel disturbed by the offensive smell. And large-scale outdoor solar power plants provoke some critics to complain about the disfigurement of the rural landscape (Janzing 2007). If such critical perceptions go hand in hand with concerns about the loss of property value in the vicinity of wind farms, biogas parks etc. conflicts can become even more explosive.

Last but not least, the expansion of renewable energies causes *conflicts within the ranks of the ecologist movement* itself. "Ecology" is open to various interpretations and to the establishing of different priorities. Wind turbines, solar panels or biogas power plants are "technology" and not "nature". Often they intervene in nature (e.g. disturbing birds and other animals or having negative effects on land- or seascapes) and therefore cause environmental "costs", which have to be balanced with the ecological benefits renewable energies can provide (Meyerhoff/Petschow 1999; Dehnhardt /Petschow 2004). The expansion of renewable energies has led to "inner-ecological" conflicts caused by the following guiding principles, which both play an important role within the ecologist movement. One guiding principle can be described as "ecological modernisation of the energy sector for the protection of the environment and the climate". The other guiding principle is "conservation for the benefit of

[8] Digression means that year by year feed-in-tariffs for *newly* installed wind turbines, solar panels etc. decrease at a fixed rate.

biodiversity and the protection of endangered species" (with regard to inner-ecological conflicts see Byzio /Mautz/Rosenbaum 2005: 108-165; Hirschl/Hoffmann/Wetzig 2004; Krewitt/Nitsch/Reinhardt 2004; Musiol 2004).

The conflicts described narrow the range of possible locations for power plants, which generate on the basis of renewable energies, and exert pressure on planning and operating companies. But, these conflicts are also integral parts of a *societal learning process*, which helps to find out about the opportunities and limits of a socially acceptable expansion of renewable energies. Doubtless, there will be no general solution, as the constellation of the conflicting parties and the actors involved can differ in every special case. However, it can be expected that experiences and learning processes of people, concerned about negative effects of renewable energies, will help to form general opinions with respect to the following questions: Under what circumstances is living in the neighbourhood of these technical artefacts unproblematic? Under what circumstances is it unacceptable? And what kind of solution should be taken into consideration in such a case? To some degree it will depend on the viability and transferability of solutions once found (e.g. compromises which are accepted by all sides) whether the future development of renewable energies will be strongly supported by politics and society, or not.[9] With regard to inner-ecological conflicts there are good chances to find "productive" solutions, for instance as a result of increasing mediation efforts within the environmentalist organizations, or as a result of learning processes, which are based on conflicts already resolved.[10] However, the large environmentalist' organizations still have to reconcile different preferences and guiding principles within their own ranks – it depends on one's point of view whether this fact should be regarded as a necessary corrective or as a serious obstacle to the "energy turn".

3.2 Structural restraints of diffusion

Second, there are some indications for *structural restraints of diffusion*, which could impede the dissemination of solar panels and of biogas power plants. The dissemination of solar panels for the most part still follows the paths of decentralized systems of diffusion, which took shape in the late 1980s. The efficiency of that kind of diffusion is illustrated by several regions with a higher-than-average rate of solar panels on the roofs. But there are enormous differences with regard to the regional distribution of solar panels. This indicates that successful diffusion of solar power in some regional strongholds (especially in Bavaria and Baden-Württemberg) cannot be transferred easily into other regions. Even today, it is less difficult to establish such a process in the social environment of a rural village than in an urban environment. Besides the fact that the rate of home owners is normally higher in small communities, compared to the big cities, there is some evidence that promoters of the "solar scene" or local opinion leaders generally meet with more response within the dense social networks and the face-to-face-relationships inside a rural village, than within the more anonymous and heterogeneous social environment of an urban area. In correspondence to this fact, our findings show a relatively slow-moving dis-

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9 For the analysis of conflict constellations, conflict dynamics and conflict solutions, especially in case of offshore wind farms see Byzio/Mautz/Rosenbaum 2005; Byzio/Mautz 2006. Typical conflicts caused by onshore wind farms are described in Byzio/Heine/Mautz 2000: 363-372; Scheer 1998; Franken 1998.

10 For the discussion and documentation on "productive" solutions of inner-ecological conflicts see "Ökologisches Wirtschaften" 5/2004.

semination of joint solar panels owned by citizen groups in some of the big German cities (Mautz/Byzio/Rosenbaum 2007: 101-102). Furthermore – with regard to the intensity of solar radiation – there is a significant "solar divide" between the south and the north of Germany. This has inevitable consequences for the average electricity production of solar panels and thus for the average feed-in-reimbursements the operators of solar power plants can expect. If the average incomes are low, as they are in several northern regions of Germany, it is rather difficult – but not impossible – to find prospective buyers of solar panels beyond the limited circles of "eco-idealists" or technology enthusiasts. Since there are higher rates of return in southern areas of Germany, there is a larger potential of mainly economically motivated buyers of solar panels compared to the north of Germany. This target group is indispensable, if recent expansion rates on the German photovoltaic market should be stabilized for the future (Mautz/Byzio/Rosenbaum 2007: 102). On account of rising prices for solar panels such a marketing strategy has become more difficult. In 2006 solar panel sales among German farmers – one of the most important groups of purchasers in this market section – decreased, because many farmers expected diminishing rates of return and therefore looked for better chances of investment (Rentzing 2006).

Similar to solar power the sector of *biogas power plants* – for the most part operated by farmers – has been booming since 2004.[11] But, with regard to considerably high investment sums for a biogas power plant and with regard to competences and working hours necessary for operating such a plant, the expansion of the biogas sector will possibly touch limits. Considering the different sizes and financial situations of farms and considering different qualifications, motivations and mentalities of their owners, only a limited number of farmers will presumably be able or willing to go into the production of biogas (Mautz/Byzio/Rosenbaum 2007: 103-104). Bensmann (2007: 53-55), who analyses the development of the biogas sector in 2006/2007, underlines the fact that farmers certainly are the main driving force in the present expansion of this sector of energy production, but he also states that "the group of individual farms, which are possible investors", has become "calculable" in the meantime.

3.3 The opportunities and risks of technological niche promotion

Third, it must be taken into consideration that the development of renewable energies has so far been, to a great extend, a *politically driven process*. Success or failure of the political regulation in this field depends much on the quality of legislative readjustments and the fine-tuning of governmental measures and instruments. The example of large-scale *outdoor solar power plants* shows that the constructional features of the Renewable Energy Law influence the ups and downs this important market segment has to face within the solar power sector. In 2004 the first amendment to this law was enacted, which raised the feed-in-tariffs for solar power significantly and thus led to a boom for photovoltaic panels in general, and for large-scale solar power plants in particular. To stimulate the increase of energetic efficiency the amendment prescribes comparatively large steps of digression for the feed-in-tariffs paid for outdoor solar power plants.[12] Due to the mode of digression

[11] In 2004 the German parliament enacted an amendment of the Renewable Energy Law with raised feed-in-tariffs for electricity generated by photovoltaic panels and by biogas power plants.

[12] In 2004 the feed-in-tariff, which will be paid for 20 years for solar power plants in outdoor areas, was 45.7 Cent. On January 1st 2005 the 20-year-long feed-in-tariff

a sudden boom in this market segment was followed by a significant slump in sales, intensified by a recent rise in prices for solar cells (Rentzing 2005a). Alternative strategies pursued by the companies involved are aimed at two different directions: Some companies try to intensify their activities in the realization of major projects abroad, for instance in southern European regions with a high degree of solar radiation. Other companies are increasingly interested in building large solar power plants on suitable roofs (e.g. on top of commercial or public buildings). The obvious reason for this strategy lies in the higher feed-in-tariffs for roof-based solar panels, if compared to the tariffs paid for outdoor solar power plants. But, “going onto the roofs” does not seem to be an altogether promising alternative: Many roofs do not meet the structural requirements for large solar power plants. Other projects fail, as the interest of the owners of municipal or commercial buildings lacks in this case (Rentzing 2005b).

The planned *offshore wind farms* in the North Sea and the Baltic Sea are further examples for the difficulties, which can arise if innovative technological niches are to be supported by legislative measures and readjustments. In the late 1990s, when the German federal government decided to promote offshore wind farms, appropriate incentives had to be offered to those wind power companies, which seemed to be ready to go into offshore projects. Besides special feed-in-tariffs the government gave the companies considerable room for manoeuvre to choose appropriate offshore locations for the planned wind farms. After the Renewable Energy Law had been passed in 2000, numerous licensing procedures for offshore wind farms were initiated (more than 30 until 2002). Until now a considerable number of applications has been granted by the responsible authorities. In 2004 the amendment of the Renewable Energy Law comprised a readjustment of the feed-in-tariffs for offshore wind farms. Now the companies could expect better payments for electricity from offshore wind farms, compared to the past.

But to this day, not any of the planned offshore projects has been realized – one reason for this is the fact that the governmental promotion of offshore wind farms led to some *unintended outcomes*. First, several of the planned offshore projects caused internal ecological disputes and met with opposition from conservationists who feared the increase of environmental stress for seabirds or sea mammals and a serious threat to the ecologically unique mud flats of the North Sea coast. Second, a multitude of people living on the North Sea islands or in the coastal area remained sceptical about the expected economic results an “offshore boom” might bring, especially with regard to the regional tourism and the regional fishing industries. Representatives of the tourist industry argued that offshore wind farms would chase away many guests and therefore cause serious problems for a region, whose economy is to a great extend dependent on an expanding tourist industry. Additionally, the fishermen expected a decrease of their own economic chances, if important fishing areas were to be occupied by large offshore wind farms. Thus, the situation in the coastal area was soon marked by conflicts between the promoters of offshore wind power on the one side, and the opponents of these projects (e.g. environmentalists, representatives of seaside resorts, fishermen) on the other side (Byzio/Mautz/Rosenbaum 2005: 91-107). A further need for legislative readjustments was determined: Due to the above-mentioned conflicts there were no realistic chances of building wind farms on less cost-intensive near-shore locations, at

for newly built solar power plants in outdoor areas decreased by 5 percent; on January 1st 2006 it further decreased by 6.5 percent.

a maximum distance of 12 to 15 kilometres from the coastal line, as practised in Denmark and Sweden. Thus, most of the German offshore wind farms will be located far out in the open sea. Besides the fact that an appropriate and economical location for the projects was hard to find, the wind power companies also had to deal with rising prices for steel (which is needed in large quantities to build wind turbines). Only one year after the amendment of the Renewable Energy Law was enforced, representatives of the wind power industry called for further legislative readjustments. They argued, that the planned projects "could hardly be financed" on the basis of the present feed-in-tariffs (9.1 Cent/kWh) for offshore wind farms (Lönker 2005: 12). A further legislative readjustment followed in autumn 2006: The German net operators were bound by law to assume the costs for the main connection of offshore wind farms. Consequently there are increasing expectations within the ranks of the wind power industry that the profitability of offshore projects could now be achieved (Bauchmüller 2006).

The above-mentioned cases of outdoor solar power plants and offshore wind farms underline the fact that governmental promotion of innovative niches opens up new possibilities for environmental technologies, but also entails some risks – especially the risk to fail in pushing forward a new technology, which could achieve a real deduction and full marketability. To minimize this risk appropriate readjustments of the political measures and instruments are necessary – as exemplified by the gradual improvements of financial conditions for offshore wind farm operators. Nevertheless, political protagonists are caught in a *dilemma*: The strategy of continuous improvement in favour of a specific technology (e.g. by measures of financial or legal support), which up to now has been very successful in the case of the "renewables", can mutate into false political steering, if the "endogenous potential" of a new technology turns out to be overestimated.[13] Hence, one cannot exclude that the political promotion of certain technologies in the field of renewable energies – contrary to the intentions of the Renewable Energy Law – could end up in an enduring "subsidies trap".

4 The integration of renewable energies into the electricity system

As long as renewable energies only contributed a rather marginal part to the power generation as a whole, the question of how to integrate small, decentralized and (in the case of wind turbines and solar panels) intermittent[14] power sources into the given electricity system was considered of secondary importance. With the accelerated expansion of the renewable energies this question has become more urgent recently. Incompatibilities between this new sector of power generation and the established system of power supply will probably increase and become a serious obstacle for the further dissemination of the "renewables". Meanwhile several authors who contribute to the debate on climate change and the "energy turn" under-

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[13] This problem is discussed by Huber focusing on concepts of political support for technological environmental innovations: "With new technological regimes it is in principle much the same as with newly industrialising nations. If there is not enough endogenous potential, an artificially levelled playing field can even be counter-productive in that it pushes or conserves inefficient and unconnective structures" (Huber 2004: 237).

[14] "Intermittent" means that wind turbines or solar panels are technologies of variable output: The changing wind forces or calms are not exactly foreseeable and have a direct impact on the generation of wind power. Solar panels generate electricity only by day; in the course of the year solar power production is at maximum during the summer and at minimum in wintertime.

line the importance of optimizing the integration of decentralized power sources (on the basis of renewable energies or high-efficiency combined combustion of heat and power) into the electricity system (Jochum/Pfaffenberger 2006: 24; Bauknecht et al. 2006: 260; Hennicke/Müller 2006: 144). On the one hand this discussion has a far-reaching "visionary" aspect, aimed at a completely decentralized system of power generation and distribution. From this point of view, according to the new socio-technical paradigm for the energy system, only a relatively small market niche for centralized power plants, which operate on the basis of fossil energy, will finally be left (Leprich 2005: 16).

On the other hand the present debate on system integration has a pragmatic aspect, as the expansion of renewable energies actually puts pressure on a multitude of actors – in the fields of the "renewables" and of the conventional electricity system – prompting them to enforce the integration of decentralized power sources into the system of electricity supply. The principle of "priority-dispatch" made the process of power balancing in the electricity system even more difficult.[15] "Priority-dispatch" is regulated by the Renewable Energy Law and normally opens up possibilities for wind farm operators, owners of biogas or solar power plants etc. to generate and feed in electricity, irrespective of the present demand for power or of changing grid situations. But, with regard to state-of-the-art technologies in the field of renewable energies, an increasing number of currently active operators (especially operators of large wind farms) could contribute to power balancing, for instance by selling electricity on the balance market, where short-term power reserves are traded at relatively high prices. This requires the foregoing priority dispatch as a general principle for renewable power sources, because "upwards control" of power balancing – in the case of wind power – can only "be provided by partly curtailed wind farm generation, kept within a predefined capacity band and made available within seconds" (EWEA 2005: 101). Under ideal conditions, solutions which help to improve the system integration of renewable energies could become attractive to the actors involved – on the part of grid operators *and* on the part of power plant operators in the field of renewable energies (Leprich et al. 2005; Bauknecht et al. 2006). But currently, the possible solutions are controversial: Appropriate solutions have to be adjusted to two competing socio-technological systems, which coexisted fairly peacefully as long as power from renewable energies was produced in a small niche. The expansion of the "renewables" certainly requires new ways to achieve better system integration, but the corresponding technical or organisational solutions can cause specific transaction costs and economic risks, especially for operators of small and decentralized power plants (Bauknecht et al. 2006).

A present-day example to illustrate this would be the active wind farm power control (*Erzeugungsmanagement*), which is practised by grid operators in some North German regions to prevent temporary overloading of lines and to better adjust the regional wind power generation to the actual demand. But, wind farm power control has often become a matter of conflict: On the one hand grid operators are interested in the most effective use, technically and economically, of the power grid; on the other hand wind farm operators are interested in keeping losses of feed-in payments as low as possible. The

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15 "In power systems, the power balance between generation and consumption must be continuously maintained. The essential parameter in controlling the energy balance in the system is the system frequency. If generation exceeds consumption, the frequency rises; if consumption exceeds generation, the frequency falls. Ultimately, it is the responsibility of the system operator to ensure that the power balance is maintained at all times" (EWEA 2005: 71).

German wind energy branch has repeatedly complained about reduced incomes of millions of Euros, as grid operators occasionally scaled down the output of wind farms or temporarily disconnected a considerable number of wind turbines from the power grid (Schäfermeier 2006; Pries 2006). Several of these conflicts have ended up in court by now, for instance in the case of controversies about the legality of scaling down wind farm outputs, or in the case of disputes about financial compensations for reduced feed-in payments. Using legal pressure as an instrument, the wind energy branch wants to force the large energy suppliers to optimize or extend their power grids. This is for the sake of expanding amounts of wind power to be transmitted in the future.

The increasing controversies about wind farm power control led to the result that some protagonists in the wind energy sector try to push forward an alternative solution (of which a pioneering project has already been realized in the north east of Brandenburg): the linkage of several wind farms by means of appropriate power lines, which are property of the wind farm operators themselves. The declared objectives pursued by promoters of such "networked power plants" (*vernetzte Kraftwerke*) are independence from the established grid operators, and provision of a steadier and more reliable supply of wind power (Lönker 2006). If such pioneering projects set a precedent and can help to further stabilize the wind energy path in Germany will depend on gaining political support for this kind of innovation, for instance via financial incentives for networking activities of wind farm operators or wind power companies.

From a more principle-rooted perspective, political regulation which aims at a better system integration has to deal with different challenges, compared to those of governmental support for niche technologies in the field of renewable energies. To support system integration governmental regulation will be dependent on governance structures, which also have to embrace relevant protagonists of the dominating electricity system, for instance the large energy supply companies and grid operators – along with their economic interests and their instruments of economic power. Political support could certainly serve to reduce structural divisions between the conventional and the renewable electricity sector and could help to open up new ways of diffusion for the "renewables". But, the question is if this will lead to sufficient willingness or ability to cooperate, on the part of both the established and the new actors in the electricity system. The chances of efficient cooperation must not be considered as being all that favourable if one follows Reiche (2004: 139-144) and the advocacy-coalition approach he applies. Besides economically caused conflicts of interest, Reiche also describes a socio-cultural divide between the oligopoly of the large power suppliers (who are the main owners of the power grid) and the promoters of renewable energies. He underlines a far-reaching controversy between two "belief systems", which has characterized the German energy policy and energy industry since the 1990s. One belief system – socially and politically connected to an "ecological coalition" – is based on the premise that for the benefit of environmental and climate protection all renewable energy sources available have to be promoted by the government. The other belief system – supported by an "economic coalition" – is based on the premise that ecological modernization of the energy system primarily has to correspond with economic efficiency and competitiveness. Therefore only technologies with a high potential of efficiency and marketability should be promoted in the field of renewable energies (Reiche 2004: 140).

The ideas about system integration might correspond with quite different strategies and political measures, as they depend on the different premises.

From the standpoint of the "ecological" belief system an appropriate integration of renewable energies will require a far-reaching conversion of the existing power supply system and power grid, aimed to better technically fit in decentralized and partly intermittent power sources, which in the end will increasingly replace centralized power plants. From the point of view of the "economic" belief system renewable power sources are useful as long as they fit into the centralized system of the conventional power sector and as long as they are able to compete on the general electricity market, at least in the medium term.

The controversial debate about the integration of renewable energies into the electricity system reproduces the rivalry of paradigms, which already left its mark on the German electricity sector since the early confrontations between the pioneers of renewable energies and the large energy companies. If the German government sticks to the broad promotion and the financial support of renewable energies in the future, the pressing issue of *system integration* will sooner or later – after an essential phase of technological *niche promotion* – require a further landmark decision in energy and environmental policy.

5 Conclusion

Since the (re-)discovering of renewable energies in the 1970s, the German electricity system has passed through a transformation process, which is described here as a confrontation of two competing socio-technical paradigms. In the course of this confrontation the "renewables" have become a serious challenge for the traditional German electricity sector. Its protagonists formed the fundamental principles of the new paradigm – decentralization of energy production, pluralizing of the relevant groups of actors, environmental and climate protection – taking a way of deliberate dissociation from the given energy system; thus they became the main attributes of a radical innovation in the electricity sector. The development of decentralized governance structures, including a wide range of non-governmental organisations and citizen groups, enduring governmental promotion, a supporting legal framework, and a partly close feedback between the operators of renewable power generation and the manufacturers, were important reasons for accelerated niche dynamics and the dissemination of renewable energies.

Despite the remarkable expansion of the renewable energy branch in recent years, the traditional electricity sector still remains the dominant economical and technological force in the field of power generation and distribution, showing strategies which aim at a (re-)stabilization and long term maintenance of the traditional energy path – on the predominate basis of fossil and nuclear energy resources. Moreover, the protagonists of renewable energies are confronted with some *new challenges,* as the former clear-cut profile of the new socio-technical paradigm meanwhile has become more or less diffuse. *First,* there is a tendency in the renewable energy sector towards larger technical units and towards centralization of power generation. *Second*, the expansion and centralization of renewable power generation causes increasing environmental costs. This often leads to opposition by people living in close proximity to wind farms, outdoor solar energy plants etc. and furthermore gives rise to conflicts within the ranks of the ecological movement itself. *Third*, with the increasing amount of electricity produced by the "renewables" it has become more and more clear that the legally guaranteed "priority-dispatch" – and so climate protection as a fundamental principle of alternative power generation – can only be maintained as far as the protagonists of the renewable energy sector themselves will serve to achieve a better system integration of renewable power sources, and do not leave this task to the large electricity suppliers.

The transformation of the German electricity sector is not completed. In the course of this process the principles of the alternative paradigm have been modified significantly. As a result there is more than one option for the further development of renewable energies. On the one hand the *new openness*, regarding fundamental principles, could give a fresh impetus to the further expansion of renewable energies by attracting a wider range of actors (for instance investors, innovative companies, municipalities) to join this ecological *and* economical relevant industrial sector. On the other hand this openness could reinforce an already perceptible tendency of splitting up relevant actor strategies, regarding the problem of optimal system integration of renewable power sources or regarding the question if a more centralized or a consequently decentralized way of diffusion of the "renewables" should be preferred.

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Ethics vs. Innovation? The Impact of Embryo Research Laws on the Innovative Ability of National Economies

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Abstract

The article assesses the empirical veracity of the frequently heard thesis that strict embryo research laws can hinder innovation in embryo and stem cell research, and thereby impede the innovative ability of the medical biotech sector. Based on a comparative study of the OECD countries, and case-study material, the article argues that this thesis can only partly be confirmed. Strict embryo research laws are associated with a lower innovation quota in stem cell research. But this correlation mostly reflects stable structural differences between national innovation systems rather than dynamics triggered by policy measures. Permissive embryo research laws are not automatically associated with an innovative biotechnology sector, and the innovativeness sometimes is a partly unintended consequence, rather than the result of an active political strategy. The results of the analysis caution against undue simplified theses on the impact regulation can have on the innovative ability of national economies. If there are impacts of embryo research laws on the innovative ability of the biotech sector, they will be visible only in the long term. Short-term political steering efforts have to be judged very sceptically.

1 Introduction

Research institutions, politicians and representatives of the pharmaceutical industry alike claim that embryo and stem cell research are part of the most promising branch of medical biotechnology, and that exceedingly strict regulation of this research severely impedes innovation in the medical biotechnology sector (Standing Committee on Legal and Constitutional Affairs 2000; Deutsche Forschungsgemeinschaft 2001; Association of the British Pharmaceutical Industry (ABPI) 2004). On the other hand, opponents of stem cell research doubt the veracity of this claim. They argue that a ban of embryonic stem cell research is ethically necessary and does not inhibit innovation (Campbell 2001; Lilge 2001; Spaemann 2001).

The actors in this debate have mostly used abstract reasoning, hypothetical examples, or anecdotic evidence. Empirical studies on the consequences of permissive or strict embryo research laws on the innovative ability of national research systems are rare. This article tries to fill this gap, and analyzes empirically whose claims can be confirmed. Embryonic stem cell research is part of the scientific and political agenda since ten years (Gearhart 1998; Thomson 1998), and the first laws that explicitly deal with embryonic stem cell research date back to the same time. Laws regulating embryo research – the larger research field in which stem cell research is embedded – have been passed as early as 1987. Thus, it is not premature to conduct a first evaluation of the question whether strict embryo research laws do indeed impede innovation in stem cell research.

Methodologically, the article applies a quantitative approach and traces the relationship between the strictness of embryo research laws and innovations in the stem cell sector in the Western OECD countries from 1994 to 2006. The quantitative comparison is used to draw some general conclusions about the hypothesis, and to identify interesting country cases, which are studied in more detail. Thereby, the advantages of quantitative and qualitative approaches are combined and their weaknesses compensated (Lieberman 2005).

The article argues that the relationship between the embryo research law and the innovative ability of the medical biotech sector is complex and does not correspond to the views of either of the opponents in the debate. There is no systematic short-term effect, executed by the strictness of embryo research laws, on the innovativeness in the stem cell field. Neither do strict laws lead to a decline of innovations, nor do permissive laws automatically lead to an increase in innovations. The field is rather characterized by long-term structural differences. Case studies additionally lead to the conclusion that an increase of the innovativeness of the sector may in a few cases be the result of a political strategy, but coevally it often may be a concomitant phenomenon of regulatory inactivity. Thus, the argument that strict regulation instantly impedes the innovative ability, and permissive regulation leads to an increase in innovations is not supported. That does not exclude, however, that different embryo research laws in the long run and in a more subtle way may have such an effect.

The structure of the article is as follows. The second section outlines in short the controversy and the theoretical arguments, and additionally formulates the main hypothesis. In the third section the data and methods used to test the hypothesis will be focused on. The fourth section comprises the analysis. The fifth section summarizes the findings and hints at further venues of research.

2 The controversy: Are bioethics and innovative ability incommensurable?

Embryo and stem research are elusive notions, hence some basic definitions must be clear to get an overview of the field and to understand the major promises and ethical problems. Embryo research is here conceived as all techniques or scientific enterprises focusing on the human embryo. The embryo is the first stadium of human development, from the first division of the zygote (the fertilized egg) until it becomes a fetus (that is, major structures and organ systems begin to form).

Human embryos first came on the political agenda in 1978, when the first baby was born using in-vitro-fertilization (IVF). For IVF, eggs are fertilized – i.e. embryos created – and implanted into the womb of a woman in order to bypass certain forms of infertility. Additionally, the successful conduct of IVF showed that human embryos could be cultivated in a laboratory setting (Lauritzen 2001). For technical reasons, the number of embryos created for an IVF usually is larger than the number actually used for implantation. These surplus embryos are kept in a frozen state, but are almost never used for fertility treatment, as the donor couples have usually finished their family planning with one successful IVF treatment. Medical researchers demand to use these surplus embryos as an object of research. Another implication of IVF is that the embryos to be implanted may be screened beforehand to avoid hereditary diseases. The so-called pre-implantation diagnosis is still in its infancy. However, by the selection of the sex of the child it is possible to avoid hereditary diseases that are located on the sex-determining chromosomes. Nevertheless, screening is only a simple – and ethically contentious – selection procedure. Nobody is cured, only the "wrong" embryos are put away. If scientists would try to change the genetic endowment of the embryo, this would go under germline therapy (Stock/Campbell 2000).

The short sketch of these techniques already shows the gray area between reproductive medicine – the use of established techniques to cure diseases – and embryo research – the scientific enterprise of gaining new knowledge without immediate therapeutical implications. The line between cure and research is more clearly crossed with non therapeutic research, that is, research that uses the embryo as a raw material and without any intention of creating a child. The derivation of human embryonic stem cells is one form of such non therapeutic research. Stem cells are a very promising object for research, as they are still totipotent, which means that they can differentiate into any mature cell type. For example, they could in principle be used to create brain or nerve cells, as replacements for decayed ones (Gearhart 1998; Thomson 1998). The source for these stem cell lines can be the aforementioned surplus embryos, but scientist often demand that it should be allowed to create embryos for research purposes only, without any IVF treatment in mind. Particularly, the creation of embryos via therapeutic cloning is often seen as desirable. *Therapeutic cloning* is the creation of an embryo with the same genetic characteristics as a mature human being. This genetic identity is especially desirable for the creation of replacement tissue or organs, as the risk of rejection is much lower when the replacement tissue has the same genetic information as the recipient. If the same basic cloning technique is used to create a child, this is called *reproductive cloning*.

The ethical problems with the diverse techniques of embryo research are manifold and complex. The easiest judgment can be made about therapeutic research: there is nothing wrong with observing the development of an embryo. The other techniques are more contentious. The most obvious problems arise with all the techniques that lead to the destruction of the embryo. If one conceives of the embryo as a human being, all these techniques are fundamentally wrong and should not be carried out. The trouble here is the word "if". Some scientists and ethicists see the embryo as equivalent to a human being (Ryan 2001), others do not (Green 2001; Steinbock 2001). Different, but similarly complex, issues arise with germline therapy and reproductive cloning – no human being is killed here. But as Habermas (2001) argues, these techniques violate the bodily and moral integrity of the cloned and/or genetically modified child (Mendieta 2004).

One of the major tenets in the debate is the question whether there is an insurmountable tension between the promises of therapeutic innovations and the ethical considerations. Can we reap the benefits of biomedical innovations, and at the same time uphold strict bioethical principles (Salter 2007)? Proponents of stem cell research claim that innovation and strict bioethical principles are incommensurable. According to them, the imposition of strict embryo research laws severely impedes the innovative ability of the medical biotech sector (Jones/Towns 2006). The argument follows two lines: First, certain research venues – e.g. research on human embryonic stem cell lines – are positively forbidden, and thus impossible to carry out in a given jurisdiction. Second, even scientists that currently do not work with embryonic stem cells might be afraid to „cross the red line", and precautiously move to another jurisdiction, where the laws are more permissive. This is all the more important, as scientific progress in the sector is rapid, and laws could be considered to be too rigid to keep pace with the scientific developments. Thus, restrictive embryo research laws should dispel researchers and therefore lower the innovative ability of a national economy. The ramifications are clear: a decline of innovative ability in biotechnology leads to economic decline of the sector, and, ultimately, to the loss of jobs. On the other hand, permissive embryo research laws should attract researchers, and, in turn, generate more innovations in medical biotechnology.

These arguments can be found in public debate all around the world. For example, the Australian parliament conducted a public hearing on the regulation of stem cell research (Standing Committee on Legal and Constitutional Affairs 2000). Sue Serjeantson, as representative of the Australian Academy of Science stated clearly „if Australia is to capitalise on its undoubted strength in medical research then it is important that research on human therapeutic cloning is not inhibited by [...] unduly restrictive legislation in some states." (ibid.: 63) And: „The academy believes that scientific progress is proceeding at such a rapid rate that, if we put in place restrictive legislation, it is quite possible that [...] we are left in an environment where we have inadvertently hindered some of the research that might go forward." (ibid.: 79) In line with this, Australian scientists threatened more or less openly to leave the country if a restrictive law would be passed. Similar arguments from scientists, industry representatives, and high-ranking politicians can be found in the French (Hénard 2001; Viville/Ménézo 2002), German (Schröder 2000; Dams 2001; Winnacker 2001), Italian (Lorenzi 2003), Norwegian (Hazekamp/Hamberger 2005), Swiss (Interpharma 2001; Interpharma 2002), or British debate (Mulkay 1997; Blair 2000; Sleator 2000), and in the debates about European Union research funding (Salter 2005).

Opponents of stem cell research, on the other hand, claim that the promises of embryonic stem cell research are widely exaggerated by the researchers. According to them, the promises of stem cell research do not justify the destruction of human embryos. Besides this, they claim that other lines of research, like the use of stem cells taken from umbilical cord blood, bone marrow or fetuses are ethically less contentious and scientifically as promising or even more promising than the use of embryonic stem cells. Thus, from the opponents' point of view, passing strict laws on stem cell research is ethically necessary. Furthermore, it does not inhibit the innovative ability, because enough other lines of research are still open for ambitious researchers.

These arguments appear in public debates frequently – though not as frequently as their counterparts, because often more basic religious arguments are submitted and the innovative ability is thought to be clearly secondary to religious reasoning. Nevertheless, many opponents of stem cell research explicitly consider the question of innovative ability, and put forward the argument sketched above, that strict ethical standards and innovative ability can be reconciled. The argument is headed by scientists (Höffe 2001; Kollek 2001; Spaemann 2001; Fukuyama 2002), religious actors (Australian Catholic Bishops Conference 2000), politicians (Lindner 2001), and even by representatives of the pharmaceutical industry (Geyer 2001).

Thus, we have two countervailing claims about the impact of strict embryo research laws on the innovative ability of the biotech sector. The purpose of the remainder of this article is to test the hypothesis brought forward by the proponents of stem cell research: „Strict embryo research laws have a negative effect on the innovative ability of the medical biotech sector; permissive embryo research laws have a positive effect on the innovative ability of the medical biotech sector."

3 The concepts: How can we operationalize embryo research laws and innovative ability?

The hypothesis stated in the last section includes two main elements: the strictness of embryo research laws as the independent variable, and the innovative ability of national economies in the biotech sector as the dependent variable. These two concepts must be operationalized in order to test the hypothesis.

For the independent variable, this article proposes a measure of the strictness of embryo research laws based on the various techniques of embryo research, that may or may not be allowed. Nine basic techniques have been identified. Data on embryo research laws of 21 OECD countries have been gathered, indicating whether these basic techniques are allowed (coded 0) or forbidden (coded 1). The techniques and their coding can be seen in Table 1. Added up, these binary variables constitute the Embryo Research Index (ERINDEX).[1] Main source for the data is the survey on the legal situation in the EU countries done by Gratton (2002) for the European Group on Ethics and new Technologies and the surveys of the Council of Europe (1998) and the UNESCO (2004). These data have been cross-checked and complemented using legal studies (Eser et al. 1990; Koch 2001), case studies (Bleiklie et al. 2004) and e-mail correspondence with the relevant ethics councils and ministries.

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[1] To avoid concept stretching, only parliamentary laws that target both the private and public sector were coded. Constitutional provisions, funding guidelines etc. were not coded.

Table 1: Composition of the embryo research index *

Variable	Description of Procedure	Coding
THR	Therapeutic research: non-harming research.	0 (allowed) / 1 (forbidden)
TSS	Therapeutic sex selection: the selection of the child's sex after genetic testing in order to avoid hereditary diseases.	0/1
GLTH	Germ line therapy: the manipulation of the human germ line in order to influence genetically determined characteristics.	0/1
NTHR	Non-therapeutic research: research that destroys the embryo	0/1
NTHRAGE	The age or stage of development until which non-therapeutic research may be done.	0 (no time limit) 0.5 (up to 14 days after fertilization) 1 (forbidden in principle)
EPRES	Embryo production for research purposes: the production of embryos solely for the purpose of research.	0/1
ESCR	Embryonic stem cell research: research on human embryonic stem cells (which must necessarily have been created using human embryos).	0 (use and production of stem cells allowed) 0.5 (use of imported stem cell lines allowed, but no production) 1 (completely forbidden)

* The aim of the index is to map the abstract "possibility space" of embryo research. All of these techniques are theoretically possible, whether they are allowed or forbidden is an empirical question. The elements of the index are mostly, but not completely, logically independent from each other: if stem cell research is allowed, then, logically, non-therapeutic research has to be allowed (but not vice versa); if non-therapeutic research is allowed, then NTHRAGE cannot be 1; and if therapeutic cloning is allowed, embryo production for research purposes has to be allowed (but not vice versa, as embryos may be produced by other means).

The dependent variable is the innovative ability of a national economy in the medical biotech sector. This article proposes to operationalize the innovative ability of the medical biotech sector using the proportion of patents in microbiology[2] of the total patents; a measurement that could be loosely termed „biotech innovation quota".

There are some disadvantages of this operationalization. The time lag between patent application and the granting of a patent is sometimes

[2] EPO classification C12N („Micro organisms or enzymes, compositions thereof"), the same category that the original stem cell patents fall in. Source for the data: http://ep.espacenet.com/

very long. Combined with the relatively short time frame of the analysis, this means that at the moment long-term developments can not be analyzed adequately. The proportion of biotechnology patents does not testify anything about the importance, let alone quality, of the innovations. Neither does it tell us something about the economic importance of the innovations. And it does not distinguish between patents in "red" and "green" biotechnology. A more precise indicator would be desirable, but is at the moment not available.

However, there are reasons to believe that the indicator can serve as a good proxy measure for the innovativeness of the medical biotech sector. A growing number of patents in microbiology and genetic engineering should be the first detectable sign of an improved research environment due to permissive embryo research laws. Besides this, to measure the proportion of patents in the sector offers an intersubjective measurement, which allows to compare between countries and over time. Additionally, taking a policymakers perspective, if one would consider the biotech sector to be strategically important, the quota of biotech patents should be a good benchmark to assess whether the sector prospers, or not. In conclusion, given the scarce supply of cross-country and time series data about biotechnology research performance (Van Beuzekom 2001; Arundel 2003), using the proportion of medical biotech patents is a reasonable proxy for the innovative ability of the sector.

4 The analysis: A complex relationship

A first descriptive analysis of the data reveals a considerable variation of the independent variable, the strictness of embryo research laws. Table 2 shows that, so far, no regulatory model has become universally accepted. Instead, we observe a variety

Table 2: Regulatory situation in the OECD countries in 2007**

Country	THR	TSS	GLTH	NTHR	NTH-RAGE	EP-RES	ESCR	REP-CLON	THER CLON	ERIN-DEX
BEL	0	0	0	0	0,5	0	0	1	0	1,5
GBR	0	0	1	0	0,5	0	0	1	0	2,5
SWE	0	0	1	0	0,5	0	0	1	0	2,5
NZL	0	1	1	0	0	0	0	1	0	3
AUS	0	0	0	0	0	1	0	1	1	3
DEN	0	0	0	0	0,5	1	0	1	1	3,5
FIN	0	0	0	0	0,5	1	0	1	1	3,5
GRC	0	0	0	0	0,5	1	0	1	1	3,5
NEL	0	0	1	0	0,5	0	0	1	1	3,5
CAN	0	0	1	0	0,5	1	0	1	1	4,5
FRA	0	0	1	0	0,5	1	0	1	1	4,5
SPA	0	0	1	0	0,5	1	0	1	1	4,5
SUI	0	1	1	0	0,5	1	0	1	1	5,5
AUT	0	1	1	1	1	1	0,5	1	1	7,5
GER	0	1	1	1	1	1	0,5	1	1	7,5
ITA	0	1	1	1	1	1	1	1	1	8
NOR	1	0	1	1	1	1	1	1	1	8

**The USA, Ireland, Luxemburg and Portugal are missing, as they have no law regulating the public as well as the private sector as of 2007.

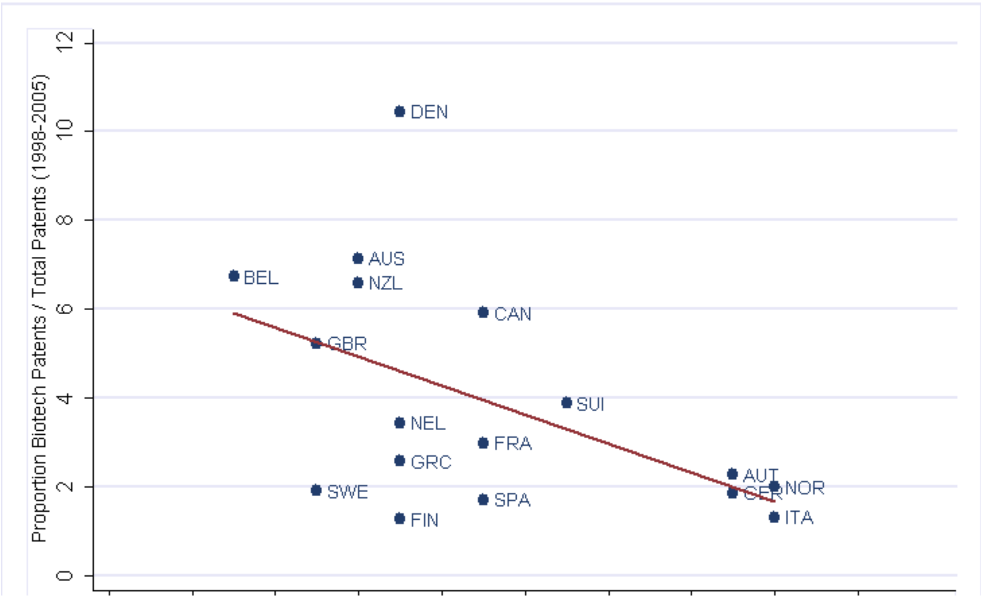
of embryo research laws. Using a rough classification, one may distinguish three categories of countries. First, a group of *permissive regulators*, comprising Belgium, the United Kingdom, Sweden and New Zealand. This group is characterized by the fact that all members allow the so-called therapeutic cloning.[3] Second, a group of *restrictive regulators*, comprising Austria, Germany, Italy and Norway. This group is characterized by its ban on non-therapeutic research. All the other countries are *intermediate regulators* that try to find a middle way between the two extreme groups.

The question posed in the theoretical part is: does the considerable variety of embryo research laws translate into a systematic variety of the innovative ability of the respective countries? An analysis of this question may start with the most simple form of cross-sectional plot. Figure 1 plots the average proportion of biotech patents (1998-2005) against the strictness of national embryo research laws (2007).

Figure 1 shows that restrictive embryo research laws are indeed interrelated to a lower innovative quota in stem cell research. The cross-sectional graph clearly shows that the countries with the most restrictive embryo research laws – Austria, Germany, Norway and Italy – have the lowest biotech innovation quota. This finding resonates with the available case studies in the field (Körtner 2002; Burrell 2005: 22). On the other hand, a permissive law does not guarantee innovations in the medical biotech sector. A comparison of Denmark and Finland shows that even countries with very similar embryo research laws exhibit considerable differences in their biotech innovation quota.

However, a cross-sectional perspective may obscure more than it reveals. A comparison of average values may simply reflect stable long-term level differences.

Figure 1: Relationship between strictness of embryo research laws and innovative ability



[3] In terms of overall strictness, the Australian law is similar to the law of New Zealand. However, as therapeutic cloning is scientifically and politically of supreme importance I use the admission or non-admission of this technique in order to differentiate between permissive and intermediate regulators.

From a political and strategic – as well as scientific – point of view, the more intriguing question is whether a correlation between permissive embryo research laws and a high innovative ability can also be shown *over time*. If the introduction of a liberal embryo research law is followed by an increase in the biotech innovation quota – or vice versa, the introduction of a restrictive law is followed by a decline of the biotech innovation quota – the case for the strategic importance of embryo research laws – and the incommensurability of innovation and ethics – would be strengthened.

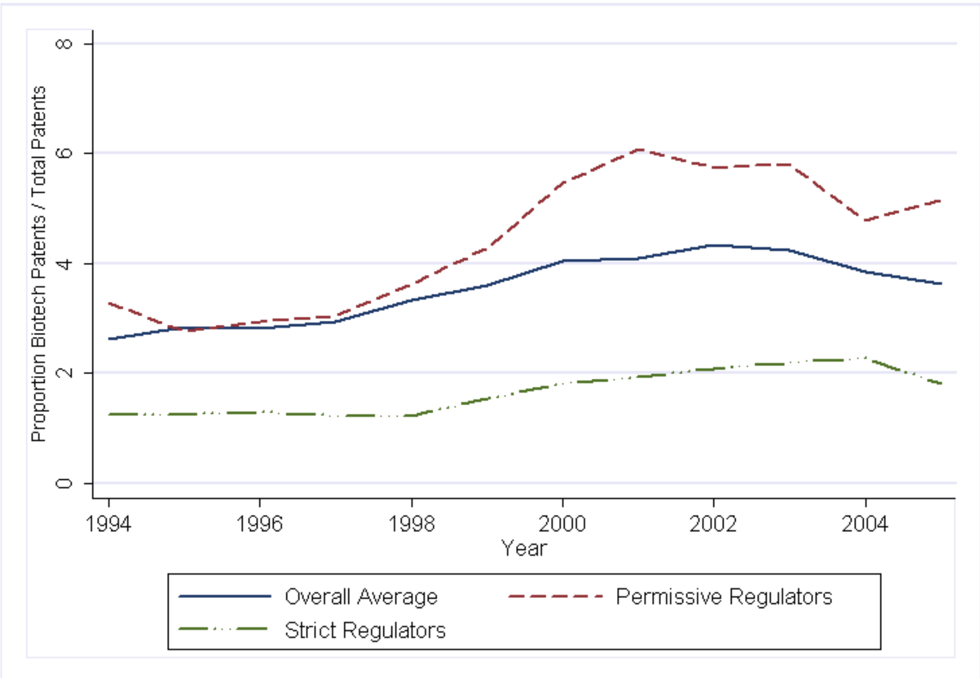
Thus, a longitudinal analysis is needed to complement the cross-sectional picture. Figure 2 offers a longitudinal perspective, disaggregated to show the development of the biotech innovation quota in different country groups.

Figure 2 allows some further conclusions. On the one hand, the data underline that Figure 1 does partly reflect stable structural differences. The group of restrictive regulators has a lower biotech innovation quota than the group of permissive regulators from the outset. On the other hand, the data show that these level differences have increased. After 1998 – after the breakthroughs in stem cell research – the biotech innovation quota increased in all countries, but most markedly in the group of permissive regulators.

In conjunction, Figure 1 and Figure 2 thus suggest that permissive embryo research laws indeed contribute to a higher innovative ability in the medical biotech sector.

Or, to interpret the data more cautiously: Permissive embryo research laws might be a necessary condition for a high biotech innovation quota, but no sufficient condition (see for example Sweden or Finland in Figure 1).

Figure 2: Development of the biotech innovation quota over time for permissive and strict regulators, compared to the overall mean.***



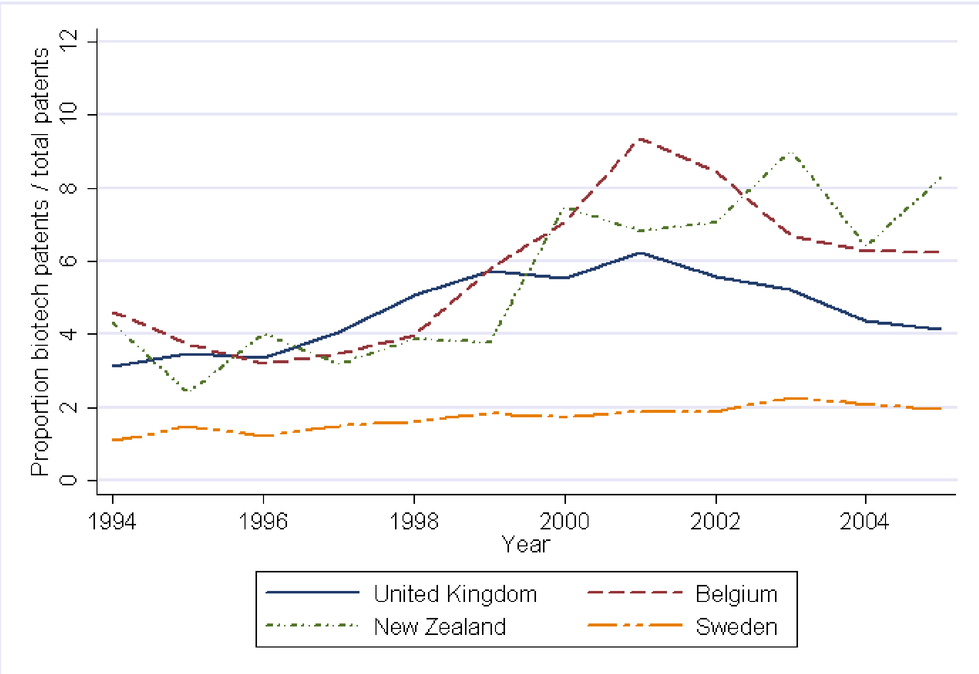
*** As outlined in the text, the United Kingdom, Sweden, New Zealand and Belgium can be considered permissive regulators, while Austria, Germany, Italy and Norway are strict regulators.

A further step of disaggregation plots the biotech quota for single countries against the time dimension, thus allowing conclusions about which countries might deliver further evidence for or against the hypothesis.

Figure 3 plots the biotech quota for the group of permissive regulators: Belgium, New Zealand, the United Kingdom, and Sweden. In all other countries under study, the quota remains more or less stable. This implies that there is no sharp decline in the biotech innovation quota in the countries that have passed strict laws on embryo research.[4] These findings further caution against the hypothesis that permissive embryo research laws have an short-term effect on the innovative ability of the sector.

The disaggregation into country trajectories cautions our interpretation even further, especially concerning the active political intervention and steering abilities governments can have. There are only three possible examples for "heroic innovation policy" that can be found in the country sample studied: Belgium and New Zealand have passed very liberal laws on stem cell research (see Table 2), and both countries have seen a considerable rise of their biotech innovation quota (see Figure 3). Furthermore, the United Kingdom has passed a very liberal law, but its increase in biotech innovation quota is not as marked as in Belgium or New Zealand.[5] The fourth country in the permissive group, Sweden, has not

Figure 3: Development of the biotech quota in the group of permissive regulators



[4] One might argue that the quota was so low from the outset that there was no room for a sharp decline. Another implication of this finding is that Denmark, which outstands in Figure 1, has always been strong in biotechnology patents, with no major impact of the embryo research laws.

[5] A possible explanation for this example is the fact that the United Kingdom's research profile is more heterogeneous, with more innovative sectors than in Belgium or New Zealand. Thus, changes in the proportion of biotech patents are harder to achieve.

experienced a change in the biotech innovation quota.

These results of the quantitative overview allow us to identify interesting country cases and pose more specific research questions. Especially the four cases presented in Figure 3 merit our attention. The sharp increase of the biotech innovation quota in Belgium and New Zealand (and the more smooth increase in the United Kingdom) raises the question whether these cases can be characterized as evidence for the thesis that permissive embryo research laws lead to innovations, or if we see only statistical artifacts. Additionally it will be to discuss, if these countries prove to be evidence for the thesis, what are the mechanisms and policy measures that lead to the success? On the other hand, the case of Sweden raises the question why the country was not able to capitalize on its permissive embryo research law. A closer investigation of these cases will allow more nuanced conclusions about the *conditions* under which liberal embryo research laws lead to a higher innovation quota in the medical biotech sector.

Belgium is a difficult case to interpret. On the one hand, Belgium confirms the thesis; it has been one of the leading countries in artificial reproductive technology. Thus, when the stem cell research breakthroughs occurred, Belgium already had an established research base in applied medical biotechnology (Varone /Schiffino 2004). As it had no special law regulating embryo research up to 2003, it was considered a "bioethical paradise" (Varone/Schiffino 2004: 85). Public opinion was very positive towards biotechnology (Schiffino /Varone 2004). Together with the United Kingdom, Belgium is considered to be one of the most research-friendly environments for stem cell research in Europe, and is either co-coordinator or project partner in a large share of EU-funded research projects involving stem cells (European Commission 2005). On the other hand, this Belgian success story is rather a by-product of political struggle and not the result of an active political strategy to promote life sciences. The boom in biotech patents in Belgium occurred from 1998 to 2001. However, the very permissive *Loi relative à la recherche sur les embryons in vitro* was passed only in 2003. Up to this time, the lack of a law in Belgium cannot be considered a part of a coherent political strategy. Rather, intense political struggle within a coalition comprising Christian democrats prevented the passage of a law on embryo research. The secular parties in government preferred a liberal law; Christian democrats preferred a strict law, the result was a deadlock situation in which no law could be passed (Schiffino/Varone 2004; Varone/Schiffino 2007). The secular parties could accept this deadlock as a second-best solution, because the lack of a law partly coincided with their preferences. However, they preferred the passage of a law to a lawless space, and when the Christian democrats left the coalition due to electoral defeat, a law was quickly passed. Thus, the biotech boom in the lawless space from 1998 to 2001 occurred to some extent "behind the backs" of the political actors.

Thus, Belgium confirms the thesis that liberal embryo research laws are associated with a prospering and innovative medical biotech research sector, although this cannot be attributed to an active political strategy, and is rather the (partly) unintended consequence of policy deadlock.

New Zealand's success story is similarly equivocal. New Zealand has an ethics committee regulating embryo research since 1993.[6] As early as

[6] The National Ethics Committee on Assisted Human Reproduction (NECAHR).

1996, a bill regulating embryo research – the Human Assisted Reproductive Technology (HART) bill – came into the parliamentary arena, but lay dormant for a long time in the Health Committee (Barr 2003b). Under the impression of the stem cell research breakthroughs, the Labour government re-animated the bill in 2003. Due to the Westminster system with few veto points, the government was able to push through the liberal bill (Barr 2003a), and the HART act was passed in 2004. Public opinion towards medical biotechnology and stem cell research is generally positive (Warren/Osborne 2006), supported with headlines like "Stem cells could end need for heart transplants" or "Blind could see again with new medical breakthrough", "'Incurable' illness falls to gene therapy", or "World on the edge of a new era of drug discovery" in the New Zealand Herald.[7] New Zealand Universities are amongst the leading research institutions in stem cell research, with a particular record in neurological research (Futurewatch 2006). What makes the increase in stem cell related patents even more intriguing is that the amount of state funding is comparatively low. Only NZ$2.3 million per annum are allocated to stem cell projects (Futurewatch 2006: 53).[8] However, similar to the Belgian case, the increase in innovations in stem cell research occurred *before* the permissive law was passed in 2004. In the New Zealand case, the delay of the law was not due to coalition struggles, but rather to conflicts and hesitation within the governing party. However, the conclusion remains the same: the success of the sector seems to have been a partly unintended consequence rather than the result of a political strategy.

Thus, the case of New Zealand leads to a similar conclusion as in the Belgian case. On the one hand, the liberal regulative situation seems to have been supportive for the increase in innovations in the stem cell field. On the other hand, this does not entirely reflect the intended consequence of a political strategy.

The United Kingdom was the first country to liberalize its embryo research law after the breakthroughs in stem cell research. The Human Fertilisation and Embryology Regulations from 2001 allowed therapeutic cloning, and were part of an explicit strategy to promote biotechnology as an integral element of the knowledge society (Blair 2000; Banchoff 2005). As a traditional leader in biotechnology (Gottweis 1998), with a strong role of the Royal Society as a policy advisor (Krönig 2001), and an already established overview and licensing system (the Human Fertilisation and Embryology Authority HFEA), the United Kingdom was in an ideal position to build on its experience and strengthen its innovativeness in the biotech sector. However, as Figure 3 shows, the bulk of the increase in biotech innovations occurred from 1996 to 2001, under the old Human Fertilisation and Embryology Act, dating from 1990. This act was permissive from the outset[9], and, at its time, introduced with the explicit aim to strengthen the United Kingdom's research base in biotechnology (Mulkay 1997). Hence, the United Kingdom could capitalize on the stem cell research breakthroughs because the regulatory framework that was already in place was liberal enough to keep researchers in the country.

Thus, the case of the United Kingdom fully confirms the thesis that permissive embryo research laws lead to an increase in the innovative ability of

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7 http://www.nzherald.co.nz

8 This is about €1.2 million. The state of California alone spends $300 million a year on stem cell research (Schwägerl, 2004).

9 Though not as permissive as its successor, with an ERINDEX of 4.

the biotech sector; although the case suggests that the effects are to be assessed on a more long-term time frame.

Sweden at first contradicts the thesis. Sweden had a relatively liberal embryo research law since 1991[10], that was changed in 2005 to allow therapeutic cloning, and with the explicit aim to strengthen the Swedish research position in biomedical applications (Kulawik 2003). However, as exemplified in Figure 3, the relatively liberal law of 1991 was not accompanied by an increase in the biotech innovation quota. But the Swedish case may illuminate the limits of a quantitative approach to innovativeness. The quota of patents may not have increased, but according to all observers, Sweden is a world leader in stem cell research (Torgersen et al. 2002; Kulawik 2003; Burrell 2005). The funding of 257.3 Mio SKR (27 Mio €) from 2003 to 2008 expresses the high priority that stem cell research has in the Swedish innovation system (Hague 2006), and the Karolinska Institute in Stockholm and the Sahlgrenska Academy in Gothenburg are amongst the leading suppliers of stem cell lines. Thus, the quality of the Swedish innovations in the biomedical sector is high, though its proportion compared to total patents is low. This may reflect a distinct "patenting culture" (Packer/Webster 1996), focusing more on quality than on quantity.

Thus, the case of Sweden is illustrative for two reasons. First, it confirms the thesis that permissive embryo research laws can lead to innovations. Second, it illustrates the limits of a quantitative approach to the field and the usefulness of qualitative in-depth material.

To sum up the conclusions of this analysis: There seems to be an interconnection between strict embryo research laws and a low innovation quota in stem cell research in cross-country comparison, which would confirm the thesis outlined in the theoretical section. However, this statistical interconnection has to be interpreted very cautiously. First, the same does not apply vice versa. Permissive embryo research laws are not consistently associated with a high innovation quota in stem cell research. The variation of the innovation quota increases as the embryo research laws get more permissive, but there are countries with permissive or intermediate embryo research laws and a low innovation quota in stem cell research. Second, the disaggregation of the data and the study of country trajectories reveals that there are only very few countries in which the innovation quota in stem cell research has changed substantially in the last 13 years. This illustrates as well that the countries, which have passed strict laws, have not experienced a decline of their innovation quota. Third, in the countries that did experience a sharp increase of the innovation quota in the stem cell area, there is some evidence that this increase is causally linked to a permissive regulatory situation. However, there is less evidence that this is due to a conscious political strategy. If one considers the temporal dimension, the increase of innovations in the medical biotech sector did often occur *before* political actors had decided on how to regulate the sector. Only in two countries of the examined – Sweden and the United Kingdom –the prospering of the biotech sector can be attributed to a distinct political strategy. Fourth, the time frame of the analysis is still rather short. At this moment, all we can safely conclude is that embryo research laws have no large systematic effect in the short term. What the long-term effects are – possibly in the form of path-dependent or self-reinforcing dynamics (Pierson 2000) – is open to speculation. Finally, all

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[10] ERINDEX of 4.5.

the results must be interpreted in light of the used indicator. The quota of microbiology/stem cell patents is only a proxy measure for the innovativeness of the sector. It does not say anything about the *total* number of patents in the sector – here, e.g. Germany can easily outshine Belgium. And it does not say anything about the importance or the quality of the patents (as the case of Sweden indicates). Thus, all the conclusions from this analysis must be read with some caveats as to their generalizability.

5 Conclusion

Taking together the results of the analysis and all the caveats, this article depicts a sector in which stable-long term differences in the innovativeness are dominant, and government interventions in the form of permissive laws do not have a predictable and stable effect in the short term. The cases of Sweden and the United Kingdom, where such a strategy did succeed, must be weighed against the large number of other cases, in which the biotech innovation quota remained stable, or cannot be causally linked to the strictness of the embryo research law. Innovativeness of the medical biotech sector seems to be in considerable parts determined by stable structural differences. Policy measures, like permissive or strict embryo research laws, seldom have a short-term impact on the innovativeness of the sector.

This finding cautions the hopes – and promises – of many actors that claim to introduce permissive embryo research policies in order to reap short-term gains in innovative ability. This strategy may work, but more often, changes in the innovativeness of the sector cannot be attributed to strategic political decisions. This finding also casts doubts on the ability of states to steer scientific developments and sectors and to force innovations by policy measures.

However, proponents of strict laws on bioethics should not draw the conclusion that embryo research laws do not matter at all for the innovative ability of a national economy. First, the analysis has revealed that none of the countries that have passed strict regulation was able to raise its biotechnology innovation quota, while at least some of the permissive regulators were able to increase their biotech innovation quota. Second, due to the relative youth of the research and policy field, this article could only illuminate a relatively short time frame. What the long-term consequences of different embryo research laws will be is an open question. Recent theorizing about the self-reinforcing nature and nonlinear dynamics of social processes (Mayntz/Nedelmann 1987; Pierson 2004) suggests that small differences in innovative ability may add up at an increasing rate, thereby generating path-dependent developments. Maybe the question of how to regulate stem cell research proves to be a critical juncture, and 20 years from now, the countries that chose a permissive law today will have a lead in the sector the other countries are unable to catch up with.

A final caveat is that all conclusions must be seen in the light of the limitations of the indicator used for innovative ability. As discussed in the methodological section, the proportion of biotech patents cannot precisely represent the quality or economic importance of the innovations, the time lag between patent application and patent grant means that long-term developments may not appear in the data, and the indicator does not distinguish between “red” and “green” microbiology. Thus, the picture painted in the quantitative analyses is not – and cannot be – as fine-grained as the picture from in-depth case studies. More detailed case studies are needed to uncover the social mechanisms that link the regulatory framework and the innovative ability of the biotech sector. But the conclusions from the quantitative analyses are a rough map of the relationship between the regulatory situation and the innovativeness of the biotech sector. They can serve as a starting point for case selection, and can be useful to embed the insights from case studies in a larger context.

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