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Shifting and Deepening Engagements

Experimental Normativity in Public Participation in Science and Technology

Michiel van Oudheusden (Université de Liège, michiel.vanoudheusden@ulg.ac.be)

Brice Laurent (MINES ParisTech, brice.laurent@mines-paristech.fr)

Abstract

Public participation in science, technology, and innovation is a significant trend in contemporary western democracies, which increasingly implicates the social scientist in diverse ways. Yet, the question as to how social scientists actually engage in public participation, and how their engagements may be normatively justified, is not the object of systematic consideration in participatory frameworks and in action-oriented social science. In this article, we ask how social scientists can take responsibility for their normative choices when engaging in participatory practice. Drawing on our experiences as researchers of public participation in nanotechnologies in Flanders (Belgium) and France, respectively, we reflectively consider our relationship with research subjects, the political relevance of our work, and the research problems we deal with. This leads us to articulate three modes of normativity that inform our commitments: a process mode, a critical mode, and a mode inspired by Actor Network Theory. Differentiating between these modes and garnering sensitivity towards each mode's characteristics opens the way to experimentation with different types of normativity through which the social scientist accounts for his commitments and shifts or deepens his engagements in response to conflicting demands and real-world circumstances. Thus, rather than endorsing one approach to participation, we recommend a pragmatic attitude that implies systematic probing of the roles the social scientist assumes vis-à-vis other participants, interests, and objectives, and that enables him to continually adjust his position in view of the particularities of his situation.

1 Introduction

"The integration of ethical concerns, innovation research and social sciences into nanosciences and nanotechnologies Research and Development will help build confidence in decision-making related to the governance of nanosciences and nanotechnologies." (CEC 2005: 9)

Public participation in science and technology (S&T) is a significant trend in contemporary western democracies, which engenders new research collaborations and the building of new relationships between science and society. Yet, despite the widespread adoption of participatory discourses and practices, the terms and uses of "participation" are manifold and contested. In this article, we reflect on our engagements as social scientists in ongoing processes of public involvement in new and emerging technologies. The questions we raise concern the shifting nature of roles (expert-non-expert, observer-participant), the interplay of different "knowledges" (scientific, sociological, lay) in participatory processes, and social researchers' contributions to innovation and research and development more broadly, as policy makers, natural scientists, and citizens call on us to take on responsibilities beyond the traditional confines of academia. The quote above from the European Commission's nanotechnology Action Plan is a case in point, as it proposes integrating social sciences into nanotechnology research and development in order to build public confidence in nano-related decision-making. Yet, the extent to which social science can contribute to this aim, and whether or not it should, is debatable. More challengingly still, assuming that social scientists accept the invitation to play a role in the governance of emerging technologies, how are they to proceed?

These questions are further complicated by the fact that social scientists themselves increasingly instigate and coordinate participatory activities in S&T, for instance through consensus conferences and scenario workshops. This is distinctively the case with new and emerging technologies, where social researchers mobilize citizens and natural scientists in experiments with "anticipatory governance" (Barben et al. 2008) and provide participatory expertise in potentially controversial contexts (Joly and Kaufman 2008). Often, these initiatives assume a scope, reach, and aims that differ from policy rationales. They can also differ considerably from one another.

The multiplicity of engagement formats and the variety of expectations and demands they entail, produces contradictions and uncertainties that are normative and political in character, as actors seek both to justify and prescribe particular lines of action for others to follow, and organize themselves for mutual support. As these processes invariably implicate the social scientist in various ways, there is a need to empirically examine and conceptually frame the forms of engagement he enacts (Macnaghten et al. 2005, Bennett and Sarewitz 2006). Thence, we ask ourselves how we relate to policy makers, citizens, natural scientists, and other social scientists in public participation. How should we engage with these actors and how should we study them? Under which conditions and on which grounds do we act? More broadly, how do we understand the political and normative significance of our work?

In the field of Science and Technology Studies (STS), in which our research is situated, the questions posed above prove contentious. Critics argue that STS research fails to transform the ways in which science is done (Fuller 2000) and that it cannot help us in answering the pressing political question, What to do? (Radder 1998). While prominent STS scholars respond that their work is "political in the deepest sense" (Jasanoff 1996) as well as critically engaged, for instance because it renders explicit competing claims in the production of rationality (Wynne 1996), these responses by and large leave open the question of how the social scientist is to articulate normative positions or state claims vis-à-vis the actors he engages with.

Recently, advances in addressing questions of this more explorative nature have been made, as STS analysts reflexively attend to the multiple and potentially conflicting roles they assume in technoscientific collaborations (see e.g. Abels 2009, Doubleday 2007, Burchell 2009, Robinson 2010) and ask what it means to intervene in practice as an STS researcher (Zuiderent-Jerak and Jensen 2007). Increased attention is also given to the different ways in which STS scholars conceptualize technology, politics and participation, and to the political implications of using these concepts in particular ways (Wynne 2007, Nahuis and Van Lente 2008). Acknowledging, and responsive to, these tendencies in STS, this article is meant as a contribution to the growing body of literature that develops critically reflexive analyses of STS, often with the benefit of ethnographic data, and questions the roles of social scientists in relation to public participation in S&T in particular.

Our questions and concerns lead us to interrogate the reflexivity of the social scientist. Reflexivity, as it is deployed in this article, implies calling attention to the social scientist's research and the practices he engages in. As we seek to illuminate normative aspects of social science research in particular, we ask how the researcher relates to the actors he studies, how his work is politically relevant, and what kinds of research problems he deals with. Our use of the term is not to be confused with calls for reflexive analysis in anthropological and sociological literature, which demand that social scientists make explicit their normative commitments by accounting for the funding they receive and how their work is mobilized, for instance.[1] While such questions can be normatively and politically relevant, they are often asked with the aim of ensuring both the neutrality of the social scientist and the accuracy of his descriptions. Consequently, they fail to consider how representation and object of study are interdependent (Woolgar 1988).

Nor do we propose continuous questioning of the social scientist's position and interpretations to the extent that he becomes an ethnographer of his own involvement practice. While "constitutive reflexivity," as this kind of reflexivity is called (Woolgar 1988), can help to render explicit what social scientists take for granted about their experiences and interpretative practices, it provides them with little in the way of practical resources. We concur with Latour (1988a) that relentless probing of one's own interpretations, knowledges and positions comes with the risk of being trapped in a "reflexivity loop" that restricts opportunities of becoming politically engaged. Thus, rather than disengaging from our research in order to interpretatively account for it, we seek to develop a strong capacity for practical action, which is nonetheless steeped in reflection.

In order to account for the different features of normativity that confront us, we distinguish three different modes of normative engagement that inform our researcher commitments: a process mode, a critical mode, and a mode inspired by Actor-Network Theory. Each of these modes constitutes a coherent expression of three dimensions that define social scientific activity: (1) the relationship of the social scientist with the actors he studies, (2) the political relevance of his work, and (3) the problem the social scientist

[1] For anthropology, see e.g. (Clifford and Marcus 1986). In sociology, Bourdieu (1980) has called for "objectifying the objectification."

deals with. Upon comparing our responses along each of these dimensions, we contend that it is the ever-changing and fluid interplay among modes that may fruitfully inform our future actions, as we shift between modes or deepen a particular approach with respect to a given context. In an attempt to offer ways to think about and handle the multiplicity of normative commitments, we propose the notion of experimental normativity, which we ground in classical pragmatism. More than a mode, experimental normativity is a pragmatic attitude towards engagement that implies systematic probing of the roles and contributions social scientists assume throughout their engagements. As such, it is an attempt at empirical exploration of how the social scientist may articulate various normative positions or state claims vis-à-vis the actors he studies whilst he engages with them in ways that he believes are meaningful and responsible, and thus sufficiently reliable to inform his future actions.

2 Two trajectories through participation

As our accounts suggest, public participation in nanotechnologies is particularly instructive to examine and rethink social researchers' roles and commitments, as these technologies are still at an early, undetermined stage of development. Hence, they open a space for collective exploration and enactment, which implicates diverse actors (citizens, scientists, and social researchers) and topics (ranging from safety and risk concerns to governance issues) in unprecedented ways. In the two cases described in this article, collective exploration is made possible by means of formal, well-structured group dialogue, such as a citizens' panel or a "Nanoforum" involving innovation actors and societal groups. The two cases also have in common that participatory initiatives often receive financial support from state bodies, or are at the very least lauded by policy makers in Flanders and France, respectively, as a means of furthering socially responsible innovation. Yet, despite this shared public endorsement of participatory mechanisms and despite significant overlap as to whom these mechanisms engage and how they are structured along participatory lines of inquiry, different problems and challenges surface in the interactions between participants and different kinds of discussion ensue. Accordingly, our responses as social scientists to the situations we encounter differ, and in fact lead us to ponder the kinds of questions participants are asked in the first place, to which ends they are asked these questions, and whether and how we can develop other framings of the issues, questions, and relationships at hand.

2.1 Author 1: From process to critique

I became involved in public participation in S&T as a social science researcher to the Flemish participatory Technology Assessment (pTA) project "Nanotechnologies for Tomorrow's Society" (NanoSoc). Although I had little knowledge of pTA at the time, I was intrigued by the idea of inviting outsiders to nanotechnology to participate in its development and sympathetic to the project's aim of initiating dialogue events between scientists and publics (I was also looking for a job). Initially, I engaged in the project as an "observing participant"; i.e. as one of the social scientists who contributes directly to the endeavor by initiating participatory workshops, conducting interviews with experts, collecting and analyzing data, and writing up reports. In a later stage however, I switched to the role of "participant observer," leading me first and foremost to observe and analyze actors' interactions in the project without actively bringing in my own perspective. This was shortly after I obtained a research grant that permitted me to do research more or less independently from NanoSoc.

My reasons for tentatively moving away from the project and the implications of doing so are elucidated below. Before turning to my experiences however, I should further qualify my understanding of "participant observer" as opposed to "observing participant," as the duality between the two positions informs my commitments. Participant observation, as I intend it, signifies an inclination towards detached analysis that emphasizes observation rather than participation, albeit without denying that the two are inextricably intertwined, as the observer cannot remove his observational traces. Similarly, detachment does not imply that the researcher has no normative commitments or social location; rather, it signifies an intention to a posture of non-alignment that brings "serious, sympathetic and critical attention to claims" as these are described into reality (Taves 2003). The distinction is an important one to make, as my intention to restore a distance with participants is largely at odds with the role many participatory approaches designate to the social scientist, particularly those that conceive of data generation and data interpretation as a joint enterprise to which all contribute through "co-operative inquiry" (Heron 1996, Reason and Bradbury 2001). NanoSoc is but one of many pTA formats that draw on this cooperative, action-oriented research paradigm. The language of "co-construction" that it speaks suggests that each actor has a stake in shaping technology and that everyone may be engaged in its crafting through a process of mutual learning. This also includes the social scientist, who is attributed the multiple responsibilities of initiating, facilitating, and analyzing participatory processes towards "socially robust" outcomes (Goorden et al. 2008a). Yet, one of the most obstinate problems I have faced is precisely how to combine these different roles, especially in instances where they tend to rule each other out. Hence, I have sought to come to terms with the methodological, political, and relational struggles I have experienced through the language of co-construction and questioned the feasibility of aligning initiation, facilitation, and analysis.

Questioning the smart environment

In 2007, social scientists in NanoSoc initiated a three-round Delphi study to which nanoscientists, "social experts,"[2] and citizens were asked to contribute short stories on the future of a smart environment with nanotechnologies. The aim of the study was to incite reflection on potential futures with "nano" in Flanders, taking participants' visions and expectations as a starting point. Social scientists initiated and facilitated the rounds and also analyzed participants' contributions by drawing out recurrent themes in the stories, assessed which actors and institutions were attributed which responsibilities, etc., but did not contribute narratives themselves. What struck me was how the vast majority of contributions depicted technology users as highly autonomous and responsible consumers who are free to choose. Respondents envisaged consumers using smart gadgets such as intelligent fridges, "personal digital assistants," intelligent underwear, and electronic labels on luggage in order to save themselves time, money, and frustration. Questions as to what causes time stress and frustration and how technology may incite anxiety were overlooked. Hence, I raised these questions in a popular science magazine editorial (Van Oudheusden 2007).

My urge here was to unearth assumptions about human needs and psychology that are built into actors' views on technologies, as well as to bring in voices not easily heard that

[2] This category comprised social scientists from other departments and universities than ours, scientists in the liberal arts, in philosophy and the humanities, and various types of professions, such as journalists, politicians, and contemporary artists.

question common sociotechnical presentations. I saw a role for the social scientist in discerning forms of critique not readily provided and that were therefore not taken into account. As such, I also implicitly questioned the disposition of the social scientist in NanoSoc towards facilitation and analysis rather than (direct) engagement. In a report that followed the Delphi study, I argued that we were to give more consideration to questions about assumptions, norms, and expectations in the ensuing phases of the project, specifically given the aim of interactive TA (as I labeled the project at that time) of "moving beyond self-containing perspectives and recursive practices that characterize a certain policy field or technology domain" (Loeber 2004) (Van Oudheusden et al. 2007).

Principlism versus narrative ethics

To some extent, deeper issues about the smart environment surfaced in the following NanoSoc phase, which consisted of three citizens' panels of fifteen participants each.[3] Panelists were asked to reflect on the nanotechnology futures that emerged in the first NanoSoc round, with the aim of inciting debate about potential developments, whether positive or negative. To make the workshop as concrete as possible, the NanoSoc research team had selected two scenes from the "nanofutures" in advance. These scenes were acted out by a professional actor and by participants themselves through role-playing. Questions laid out to the panelists included the following: How do the future worlds enacted in these plays differ from the ways in which you live and work today? How are they similar? What role does technology play in these future worlds? Which values are at play in these future worlds? Hence, the aim of the citizens' panels was to engage citizens in fictive worlds to make explicit the values depicted therein and to have participants reflect on the changing nature of values over time.

Shortly after the panel workshops, an issue of contention arose between social scientists as to how to analyze participants' contributions. As the aim was to draw out citizens' values in relation to nanotechnologies, a discussion ensued on whether to adopt a "principlist" approach, which assumes that four overarching principles are central to moral life and which organizes all values in relation to those principles, or a narrative ethics, which stresses the relational and communicative dimensions of moral situations (McCarthy 2003).[4]

As with the Delphi study, I felt more inclined towards exploring citizens' argumentations and challenging their views and norms, rather than attempting to organize moral beliefs and commitments according to predetermined principles. In a paper I wrote with a colleague shortly after this research phase, I argued that a narrative approach would provide a richer appreciation of citizen values, as it has the potential to reveal the framings that produce claims rather than only considering whether there is agreement or disagreement between them. To give an example, participants in the citizens' panel on smart environment defined the overarching principle of autonomy both as a value and a disvalue, depending on the situation at hand. One respondent argued that our increasing dependency on technology *enables* us to act independently (i.e. as free agents), as well as *disables* us to make decisions consciously and willfully without reliance on technology. Another respondent suggested that technology drives our need to become autonomous. Yet, the social situatedness of autonomy/dependency and the

[3] Criteria for selection included gender, age, socioeconomic status, work and educational background.

[4] More specifically, social scientists in NanoSoc deployed an ethical matrix, adapted to nanotechnologies.

extent to which it generates ambiguous responses to technology, received scarce attention in the initial principlist organization of the data.

Furthermore, principlism itself performs certain assumptions of what a citizen is, makes a distinction between the social and the personal, and between the human and the technological. While these distinctions may well be necessary for participants to make sense of nanotechnology, I felt they ought to be debated. So my aim was not simply to discern values as if these corresponded directly with the data citizens provided us with, but to reveal some of the process of gathering and analyzing data itself by showing that a principlist approach purifies away instructive nuances. However, I also wondered whether a participatory framework that seeks to instigate harmonious co-construction permits delving into potentially controversial issues and differences between participants.

Disrupting participation: critical normativity

One may discern from the examples above a principle of inquiry in NanoSoc that orients actors' contributions towards common action and solutions (e.g. an assumed common morality). Like pTA formats in general, procedures in NanoSoc are normatively grounded in a commitment to deliberation and consensus seeking (e.g. Sclove 1995, Hamlett 2003). More specifically, pTA formats seek to initiate a process of co-management (or co-construction) of technology to which various actors contribute their views and concerns so that widely supported outcomes may be obtained. Within this perspective, instigating an inclusive, accountable, and transparent procedure matters as much as, or more than, the technological outcomes themselves (Nahuis and Van Lente 2008).[5]

Hence, the political relevance of the social scientist in pTA lies in elucidating processes that meet these criteria, which he sees as a prerequisite to producing more robust sociotechnical systems. The core problem he deals with is evaluating the processes or design mechanisms that produce systems on those terms, usually with the intention of transferring the acquired knowledge to other settings and contexts.[6] Table 1 summarizes this process mode of normative engagement.

Table 1: A process mode of normative engagement

Relationship of the social scientist with the actors he studies	Co-researcher or co-practitioner
Political relevance of social scientific work	Elucidating processes that produce more robust sociotechnical systems
What is the problem the social scientist deals with	Evaluating process or design mechanisms

Without denying the importance of devising more inclusive procedures for sociotechnical decision-making, my

[5] This emphasis on procedure does not imply that the substantive results of TA practice are irrelevant. Schot (2001) for instance argues that Constructive TA (CTA), which is linked to pTA, "is based on the assumption that CTA practices will eventually … produce outcomes more widely acceptable, with fewer adverse effects." Nonetheless, pTA formats foreground the interaction between actors and the mutual exchange of viewpoints.

[6] In NanoSoc, the attempt to transfer procedural knowledge is implied in its mission: "The main objective of the research project Nanotechnologies for tomorrow's society (NanoSoc) is to develop and try out an interactive process as a methodology in support of (nano)scientists and technologists when trying to incorporate societal expectations and issues as regards strategic research decision making" (Goorden et al. 2008b).

experiences in NanoSoc lead me to say that a firm commitment to co-inquiry has far-reaching political and epistemological implications that remain unaccounted for. For one, "pTA researchers may be too preoccupied with accommodating various perspectives into a shared framework of action (...), thence leaving alternative and new understandings of notions unexplored" (Van Oudheusden 2011). In the first example above, dominant notions of smart environment remained unchallenged in the interactions between participants. Moreover, when all actors are involved in decisions about content and method, as the co-inquiry paradigm in its fullest form insists, critical questions as to whose assumptions define the smart environment and how it is deliberatively established remain not just to be answered, but need first to be recognized as significant. Complementary to this political argument, one could argue that a critical assessment of actors' assumptions is a necessary (albeit far from sufficient) condition to incite a collective learning dynamic, as it requires actors to recognize and articulate their interests, concerns, and identities in view of competing understandings, possibly even moving them to revise their assumptions in the process (Wilhelmson 2002, Rip 1986). Lastly, one may question the disposition of the social scientist in NanoSoc in that he inevitably does set himself apart from participants, not just by abstaining from debate in participatory events (as in the Delphi exercise), but also upon designing the project's data-gathering methods and extracting interpretations through them. My contention here is not that this disconnection sits uneasily with the principle of inclusiveness that is central to co-inquiry as such, but that it brings problems of ownership, control, and power that remain unaddressed if the distinction is not acknowledged.

The ramifications and inconsistencies I discern in the participatory approach explain my shift towards a critical mode of normative engagement that interrogates the assumptions, procedures, and techniques that sustain NanoSoc and pTA at large, and that is more detached than participatory in character. Interrogation, as I see it, may be achieved by setting up contradictions (principlism versus narrative ethics) and creating differences (searching for differentiation rather than agreement) that disrupt conventions, codes, and principles. At best, critical analyses of this type produce translations between different registers that allow interruptions to the norm, for instance by taking the form of a principlist value assessment that is reflectively considerate of the discriminating work it necessarily performs, and to some degree even inclines towards narrative ethics. Hence, these interruptions may generate alternatives alongside dominant practices. They become discourses that do not favor one account over another, but open up the possibility of difference.

Table 2: A critical mode of normative engagement

Relationship of the social scientist with the actors he studies	Critical distance (detachment)
Political relevance of social scientific work	Disrupting disciplines so as to open up spaces for alternative configurations
What is the problem the social scientist deals with	Providing criticism based on an interrogation of received views and commitments

The critical mode I have sketched out is summarized in table 2. Although it is not new in terms of the methodologies it deploys and the normative commitments it implies (in both respects it draws on the writings of Foucault and certain strands of STS itself; see e.g. Law 2004, Stirling 2008), I would argue that it remains to be fully enacted in relation to pTA practices and techniques. In the case of NanoSoc my interventions have incited debate among social scientists on questions of method and data gathering, on the relationships between project initiators and other parties, as well as on how to imagine and articulate the desired ends of the project. One nanotechnologist has repeatedly debated these questions with me as well, suggesting that in the interest of collaboration more time should be devoted to discussing with all participants the various theoretical frameworks and operational terms upon which a pTA rests.

It is important to recognize that the process mode and critical mode enact different concerns and interests that are by their very character difficult to draw together (e.g. the first is distinctively problem oriented, whereas the second values critique of modes and actions). It is therefore probably inevitable that deconstructing participation in the manners described weighs on my relationships with colleagues and with project participants who assume shared problem definitions, or are eager to establish them in the interest of moving the project forward without delving into normative concerns. The bigger question to my mind, however, is whether and how the tensions and conflicts between social scientists and their "normativities" can somehow be productive. This point is addressed in the following section by way of other empirical examples, and picked up again in the conclusion.

2.2 Author 2: Experimenting with mediation

Over the past few years, I have been studying a French civil society organization by the name of Vivagora, which campaigns for the "democratization of science and technologies." Created by science journalists in 2003, Vivagora has been particularly active in the field of nanotechnology. The association has organized public debates on nanotechnology, as well as intervened in public events organized or commissioned by the French government. Due to its alignment with civil society and the expertise its members bring to the table, Vivagora is a relevant case to examine –one that opens a third mode of normative engagement.

Vivagora's initial initiatives included two series of public nanotechnology meetings (in Paris in 2005 and Grenoble in 2006). As my research focused on sociotechnical controversies and public participation, the organization quickly became one of my objects of study. In one of several papers, I describe how Vivagora articulates a vision of public participation that calls for the collective production of robust sociotechnical systems (Laurent 2007). Vivagora equally took an interest in my research and came to contact me on a more regular basis. However, as I gradually became more implicated in Vivagora activities, I was led to question the nature of my engagement with the organization. I consider here some examples to illustrate different ways in which I negotiated relationships with Vivagora members, and thus the political relevance of my work as a social scientist.

Part of my research relates to the study of technological controversies in the field of ethics and the extent to which different forms of ethics produce different political arrangements. In a 2010 article, I describe a pragmatist ethics that does not accept stabilized boundaries between a factual reality that can be assessed and values that are then mobilized to judge it normatively (Laurent 2010). I argued that Vivagora articulates such a pragmatist ethics; a point the organization's administrator took note of and subsequently used to articulate her own position in a roundtable she was invited to. So in this instance, although the civil society organization was clearly an actor I was studying, my academic work enabled one of its members to more clearly state her position. My research thus contributed to "giving voice," so to speak, to one of the actors under study.

Giving voice is a long-term concern of feminist studies that seek to expose the oppression of women in politics, science, art, etc. and do away with gender discrimination (Gorelick 1991). The use of this expression in terms of empowering dominated social groups has led to a somewhat romantic understanding of what it means (Rip 2000). Yet my interactions with Vivagora imply more than a desire to make heard the voices of those with fewer resources, be they financial, organizational, cognitive, etc. First, Vivagora does not need me to be heard – even if I occasionally manage to help the organization. Second, giving voice in this case is not just a matter of circulating existing positions that actors are supposedly not aware of themselves, as another example may illustrate. The Citizen Alliance on Nanotechnology Issues (ACEN), which was launched in 2010 following an initiative by Vivagora, was expected to coordinate the work of several civil society organizations in nanotechnology and gather information about risk research and governance formats. As the project constituted an empirical site in the production of the public of nanotechnology, I professed my interest in ACEN in my conversations with Vivagora members, who then called for my help as a "content expert" in the field of nanotechnology. As part of the work of the alliance was to gather information, content expertise amounted to advising what sort of information is to be acquired. The project could therefore be seen as an emerging collective exploration: of the social to be enacted, of the identity of the civil society organization itself, of my own position in the process, of what it means to have knowledge of nanotechnology. Giving voice here thus implies collective experimentation with the concerned actors.

A third reason why giving voice, in the sense of empowering actors, is insufficient to account for my work with Vivagora, is that the relationships are less one-way processes than constant interactions and adjustments, which require work from both sides. In some instances, these adjustments went smoothly so that empirical research and political involvement could come together in the same movement. A case in example is the Nanoforum, a participatory mechanism supported by the French Ministry of Health in which Vivagora also participated. In this instance, I was asked to stand in the organizing committee on behalf of Vivagora when the administrator felt she needed someone to accompany her to meetings. I agreed to do so and explained to her that I wanted to consider this site as an empirical object of study. Yet, in the course of my involvement, I gradually engaged in discussions about potential topics for the forum. For instance, I insisted on political instruments like nanoparticle labeling, as I believed such instruments to be good entry points through which pluralist political processes gain footing. In the somewhat informal organizing committee (in which other academics were also present and which did not have the rigid nature of a long-standing administrative body) I could negotiate the specificities of my position as both a member of Vivagora and as an academic and feel comfortable with the research setting I was a part of.[7] Through my involvement, the forum evolved, as did Vivagora, which now focused less on organizing public meetings than on the collective monitoring of nanotech research. To give an example, in early 2010 Vivagora launched a project on collective expertise, which drew in several civil society associations to jointly examine existing scientific literature and regulation on the use of nano titanium dioxide

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[7] I appear as co-author in a paper written by the members of the organizing committee of the Nanoforum (Dab et al. 2009). I also use this example in my academic work.

and nano silver coatings. Initiatives as these in turn shaped the research I was doing. In taking a more explicit interest in how participatory mechanisms and devices are experimented with to answer complex, controversial or elusive public issues, I sought to answer how through experimentation "the citizen," for instance, is redefined or potentially transformed.

The relative ease with which I spoke with/for actors in Vivagora does not necessarily translate to other situations, however, especially when more traditional forms of representation are expected. Consider the following exchange between Vivagora's administrator, M, and myself:

M: We're looking for someone to represent Vivagora at the meeting with DGCCRF (a French administrative office).
L: I don't know if I feel comfortable doing this… I don't think I can advocate for Vivagora's positions.
M: That's always the problem with you academics… you know, we want to be in action. (...) You should take more responsibility in the association.
L: As I see it, I can contribute in my own way…[8]

In this instance I refused to participate on the official terms set by the administrator. The example indicates that the nature of the relationship is permanently at stake and needs to be explored through constant negotiations in which what is negotiated is itself in question. One can use the term "trial" here to describe the multiple situations in which uncertainty about the relative identities of the analyst and the actors is collectively explored (Latour 1988b). These relationships cannot be defined ex ante, as it is only through successive trials that they can be enacted. Hence, I cannot say in advance how I will position myself.

Giving voice and negotiating a position

In the work I do with Vivagora, giving voice is thus part of the job, in the sense that I believe my work contributes to making the actions of the organization more visible. As stated earlier, making the work of actors visible is not just a matter of rendering explicit existing positions. Rather, it implies using my own repertoires to bring new, previously non-existent realities to life.

To further elaborate this point, I turn to Actor-Network Theory (ANT). In an ANT perspective, enactment is a central issue and concern to the sociologist. Callon uses the example of his work with the Association Française contre les Myopathies (AFM) to demonstrate how his involvement contributed to the organizational evolution of the AFM through its explicit recognition that it could make a relevant contribution to scientific research (Callon 1999). As this example indicates, the nature of the social scientific contribution is to be found in the collective formation of social and technical identities, which entails articulating social identities not previously considered or clearly formulated beforehand, as well as participating in the construction of sociotechnical concerns (e.g. genetic treatment of a rare disease). The social scientist is attached to specific actors in this process, through which he enacts the social (Law and Urry 2004) and produces his own subjectivity (Gomart and Hennion 1998). He contributes to the stabilization of heterogeneous arrangements, which consist of political commitments (e.g. the definition of a public concern), value judgments (e.g. the choice to mobilize for a particular issue), and material devices (e.g. the layout of a participatory format). The collective exploration in my study of Vivagora and my interactions with the organization can be described as an ongoing process of enactment: both the members of Vivagora and I experiment with our social identities. Concretely, enactment comes about through the organization of participatory activities such as the Nanoforum,

[8] Phone conversation, October 16, 2008 (my translation).

and mutual attempts to transform sociotechnical concerns (such as nanoparticle labeling) into public issues. Practicing sociology then, is considered both a methodology for the social scientist and a form of action in the world that is always relational and process-oriented. Callon (1999), for instance, speaks of successive attachments and detachments to describe his work with actors, thus implying that there is not one, fixed relationship between the researcher and his research subjects. On the contrary, moments of proximity should alternate with distancing episodes. Yet, articulating attachments and detachments is clearly not easy or straightforward. My own experience with Vivagora demonstrates some of the difficulties it entails. The dialogue quoted above can be read as an example where my attempt to detach myself from certain actors is met with reluctance on both sides, as I am pressured into an engagement that I do not believe in or wish to advocate. It demonstrates that remaining attached and detached requires permanent adjustments with the actors in question and has to be tested and made more robust each time it is subjected to trials.

In this perspective, the difference the social scientist seeks to make in the world is interwoven with the forms of the links with the actors he studies. In the process of enacting associations, social scientists ideally act as mediators between different worlds. Contrary to intermediaries, mediators transform the social while they circulate among actors (Latour 2005: 39). The methodological position of the mediator as described by ANT goes with individual choices the social scientist makes as an academic researcher. His choices lead him to follow certain associations rather than others, providing resources to certain actors (those he studies), as much as they provide resources to him (Callon 1999).

An ANT derived mode of normative engagement

One can thus identify a mode of normative engagement derived from ANT, which appears relevant to account for some of the interactions with the actors I study and the form of normativity I articulate. The political relevance of this mode is to be found in the process of making associations visible and explicit, in ways that also render visible to the world his own descriptions and analyses. The problem the scholar addresses is which association he wants to study, and thereby enact. In this mode, the social scientist acts as a successively attached and detached mediator. Table 3 summarizes the mode of normative engagement as derived from ANT.

Table 3: An ANT derived mode of normative engagement

Relationship of the social scientist with the actors he studies	A mediator successively attached and detached
Political relevance of social scientific work	Making associations visible, thereby enacting them
What is the problem the social scientist deals with	Choosing emerging associations to study

As my above experiences in the field of nanotechnologies suggest, it is not clear what the issues are and how they are to be dealt with, or what the roles are of social movements like Vivagora and those of researchers like me. Clearly, while public participation in nanotechnologies is still in the making, there is room for exploration and collective enactment. Accordingly, as it is at times difficult to ensure the necessary openness in the relationships with the actors under study, there is a need to refine understandings of experimentation, enactment, and mediation based on everyday practice and struggles with normativity.

Accounting for trajectories across modes

Based on our experiences as social scientists with participation in S&T, we encountered a process mode, a critical mode, and an ANT-derived mode. Although these modes are prominent in our research field, we do not contend to have described the entire landscape of normative positions. Rather, we have sought to account for a variety of positions the social scientist adopts when he circulates among the actors he studies or "moves about" (Rip 2000).

The two previous cases therefore describe trajectories, which the social scientist enacts. In the first example, the analyst is involved in a participatory project to which he adopts a mode of normative engagement based on knowledge he acquires in the process. He shifts to a critical mode that allows him to make explicit issues not articulated by the involved actors, specifically the politics embedded in the conduct of a pTA exercise. The second example illustrates the continuous adjustment and negotiation that is needed to articulate a position that "gives voice" and at the same time contributes to enacting the social. We believe it is important to account for these processes of trajectory making to enable a better understanding of the theoretical value of the position of social scientist, as well as the political relevance of his work.

3 Experimental normativity

In *Reconstruction in philosophy*, Dewey (1920: 28-53) develops his analogy between the natural sciences and the human sciences. He argues that the natural sciences have learned to go beyond the hierarchy that privileges contemplative knowledge over practical knowledge. Scientists, argues Dewey, do not passively observe nature to see if their ideas correspond to reality. Rather, they engage in an active experimental process by controlling conditions and manipulating the environment to test hypotheses and solve real-life problems. With this view as his starting point, Dewey argues that the human sciences can gain relevant knowledge of the social by testing ideas and intuitions and also revising them in the light of new experiences, thus enabling humans and their environments to continuously adjust to one another. He proposes an experimental ethics that refuses general perspectives based on theoretical certainties, instead advocating an ethics in "which the needs and conditions, the obstacles and resources, of situations are scrutinized in detail" (Dewey, 1920: 174). Dewey's position is close to James's, for whom "ethical science just, like physical science, and instead of being deducible all at once from abstract principles, must simply bide its time, and be ready to revise its conclusions from day to day" (James 1897: 208).

Research in ethics, then, is research about methodologies and generating "effective methods of inquiry" (Dewey 1920: 170). These methods produce knowledge about the world, as well as enable researchers to deal with situations that are potentially problematic for scholars and non-scholars alike. Dewey thus refuses the dualist perspective that separates a supposedly theoretical position from a politically relevant one, as it is through the intervention of the object under study that an "amelioration" of the current situation can be reached. In fact, plans for improvement have to be worked out; a point to which we turn shortly.

In further developing his experimental ethics, Dewey grounds research inquiry in experience, which for him encompasses both intellectual reflection and practical intervention. To convey this connectedness between reflection and action, he describes experience as "double-barreled" in that "it recognizes in its primary integrity no division between act and material, subject and object, but contains them both in an unanalyzed totality" (Dewey 1958: 8). Accordingly, experimental ethics refuses rigid categorizations and a priori dichotomies (subject/object, insider/outsider, description/intervention) in so far that these arbitrarily reduce a set of multiple possibilities to one or two outcomes that are removed from actual human experience. For Dewey, philosophical intervention is thus best understood as an experimental process rather than as a mobilization of a set of ready-made instruments. While the conclusions it produces can be more or less stable, these are always "liable to modification in the course of future experience" (James 1897: vii).

In short, for pragmatists like Dewey and James, experience is a source for the constitution of knowledge and the construction of the social (Dewey 1958, Dewey 1988). It is embodied in a process that gradually stabilizes realities, allowing once again for human action to proceed. The analogy with natural science is useful. For one, Dewey and James insist on the practical character of intervention in the human sciences, including ethics. Second, pragmatism does not conceive of truth as a stable property, but sees it as a process through which a reality acquires validity (James 1978). Science studies, in turn, have demonstrated that scientific knowledge is based on successive trials (Latour 1988b). The notion of trial is also useful to account for the stabilization of the criteria that define what is morally good or bad (Boltanski and Thévenot 1991). Upon drawing together these lines of thought, experience emerges as a constituent part of the processes that stabilize technical and social realities. These processes, which comprise material and moral trials, can therefore be labeled experimental.

3.1 Reflection-in-action

Upon considering our own research in the light of classical pragmatism, both James and Dewey direct our attention to the processes we engage in as researchers of public participation. In insisting on the experimental character of these processes, and on the understanding that analysis and political intervention intertwine, they urge us not just to account for our research trajectories, but also to take seriously the challenge of defining the different forms under which intervention is possible. As our experiences with participation suggest, a variety of such forms are possible. For instance, the analyst may be too close to the actors he studies and may therefore want to restore a distance. Such action results from constant work and adjustments with the actors we study and cannot be described in terms of an epistemological distance between the subject and the object of his inquiry. Instead, one has to consider a plurality of modes of engagement across which the analyst circulates.

Accordingly, through experimentation the social scientist instigates relatively stable arrangements with the human and non-human actors he studies and works with, albeit in ways that lead to different answers for the researchers involved, as there is no unique way to "be normative." Rather than choosing from a list of existing modes of normative engagement, the research process leads the social scientist to articulate specific modes that are more or less stable, in the sense that they allow him to both account for his empirical exploration, and take into account his expectations vis-à-vis those of the actors he studies.

In this article the two empirical examples typified modes of normative engagement that help characterize the type of intervention we see fit for our own case. They were not given to us in advance. Nor will they remain fixed or stagnant, but develop according to the particulars of situation. Accounting for these evolutions is part of the research process, and implies that we include in our future descriptions explanations as to how relationships were established, roles assumed and alliances developed, as well as pinpoint the effects of our interventions on the actors and processes we engage with.

Experimental normativity then, is the work that is needed to articulate for ourselves modes of normative engagement based on continuous "reflection-in-action" (Schön 1987). We stress that reflection and action are interdependent to clarify a key difference between experimental normativity and "constitutive reflexivity" presented at the outset of this article. While the latter requires that the analyst detaches from himself and from his actions in order to identify what his underlying presuppositions and values are, we contend that values and relationships are constructed with the actors under modalities that are not given beforehand but need to be continually accounted for in the research process.[9]

3.2 Against relativism

Does our grounding of normativity in experimentation leave us with an extreme relativism that consents to any form of intervention? Dewey sees amelioration of the present situation as one of the aims of any work in ethics, yet he does not further develop the notion in *Reconstruction in philosophy.* For our purposes, we again invoke the concept of trial. Although it is conceivable that certain modes of normative engagement incite instability, we emphasize that neither the type of relationship, nor the distance between analyst and research subjects, is a pre, but has to be experimented with in practice. This means that the analyst's commitments and values (for instance, a desire to democratize technology) are not fixed, but constructed in a process that simultaneously produces knowledge and normative engagement. Seen in this way, the researcher's individual responsibility extends to the kinds of relations he manages with actors and to how he accounts in epistemological and normative terms for the particularities of his situation. Trials thus lead to question more than relationships with individuals: they are "problematic situations," as Dewey would say, in which public issues and social identities are interrogated at once, rather than separately.

A second reason to distinguish experimental normativity from relativism is that we conceive of knowledge accumulation as learning processes. Revising the conclusions from day to day, as is necessary with experimental normativity, does not mean that research happens in a state of permanent instability. The two trajectories we described are processes in which the analyst gradually learns about the object he studies and acquires a social understanding of his relationships with involved actors. Hence, learning occurs about the situation the analyst studies and the type of normativity he articulates. In addition, from the viewpoint of experimental normativity, learning again occurs through trials: of our relationships with the actors we study, of our positions with regards to our colleagues. Such knowledge accumulation supposes that it is both possible and necessary to experiment, that the researcher accepts to put himself at risk. The notion of trial also suggests that learning is not necessarily a collaborative or harmonious enterprise, as the relationships between actors are not given from the start and often evoke resistance to social scientific intervention (Callon and Rabeharisoa 2004, Vikkelsø 2007). In fact, learning may well agonize relations between actors (temporarily or even more permanently), for instance when the analyst distances himself from a certain kind of participation (trajectory 1) or refutes commitments that other actors

[9] To further clarify this difference: the reflexivity answer would imply that the analyst isolates punctual decisions and weighs the pros and cons of a given form of engagement, while experimental normativity seeks to account for the continuous production of particular forms of arrangements.

confer upon him (trajectory 2). Hence, experimental normativity is not about making purely subjective choices, but about ensuring the stability of a particular arrangement between the analyst and the actors he studies. As the two examples show, stability is not a permanent feature. As he faces new demands from the actors he studies, or attempts to articulate an explicitly critical stance, the social scientist may be led to enact other modes of normative engagement. "Stability" thus denotes an arrangement that is sufficiently reliable to inform our future actions. Having terminated a sequence of inquiry, we depend on "evidence already marshaled and constructive work already done" to experiment anew (Hickman 2009: 147).

3.3 The political value of experimental normativity

It should be clear from the emphasis we place on ongoing reflection-in-action, flexibility, and the open-endedness of social scientific engagement that experimental normativity conveys the significance and usefulness of ambivalence in experimentation; that is, of situations where the social scientist has the possibility to navigate across different modes of normative engagement. In the two cases described in this article, the researcher is caught up in existing expectations and forms of action, as we are both invited to engage as insiders on terms set by participation initiators, or assume a more descriptive role as outsiders. While the extent to which it is possible for us to work around these expectations (or even decline them) differs, our experimentations with normativity each suggest ways of moving beyond this implied insider/outsider dichotomy and of thinking through individual and collective identities.

Consequently, although we recognize the plurality of modes and their potentially conflicting nature (as well as potential overlaps between them), we first and foremost stress the need to explore with actors the types of engagement that demand articulation in a given situation without prescribing which mode is more appropriate. Experimental normativity should be distinguished from a meta-mode that provides tools and rules for the management of the analyst's normative engagement. It is best understood as an *attitude* that seeks to multiply experiments, thereby displaying the normative modes at play and proposing new forms of arrangements with the actors in question. While experimental normativity does not provide a rationale to guide the social scientist in every circumstance, it does insist on the connections that he can draw between different empirical sites. Upon drawing these connections the social scientist can shape alternative forms of political action.

What should be avoided is the a priori establishment of a distance between the analyst and the actors he studies. Rather, the social scientist must attend to the multiplicity of distances and critiques that arise from the particularities of a problematic situation. As such, critique, whether distanced or of a more intimate kind, exemplifies a "mode of responding" to the concrete activities and challenges that emerge in research practice (Zuiderent-Jerak and Jensen 2007). It also recognizes the deeply political dimension of the engagement process: through negotiations a relatively stable mode of normative engagement may emerge, which encapsulates the various roles and identities that both the analyst and the actors he studies assume in a particular situation. It is therefore crucial that the experimentalist in normativity is able to connect different sites and, through his scholarly production, shed light on multiple modalities, for instance in the realm of public discussions of science. And although these acts of connecting and describing may in some cases hold claims that are similar to the rationales that underpin public participation in the first place (e.g. through the notions of collective experimentation and social learning encountered in pTA), the value of his social scientific work and significance of his political intervention lies in his capacity to account for this multiplicity, as well as to decisively move across various modes of normative engagement as he meets challenges on the way.

4 Conclusion

This article describes various forms of normative engagement the social scientist enacts in public participation in science and technology. It discerns a process mode, a critical mode, and an Actor Network Theory inspired form of engagement, which we extract from our experiences as social scientists with public participation in nanotechnologies. With the aim of accounting for our normative commitments in research practice, we propose an experimental approach that negotiates between the various normativity repertoires starting from the particularities of our situations. Hence, we seek to come to grips with the issue of how the social scientist is to interact with the actors he studies, given the normative questions that arise through his engagements. Taking inspiration from classical pragmatists, we argue that these questions cannot be answered in the abstract, but require that the social researcher empirically explores his potential roles and contributions in a given setting and continuously accounts for his experiments.

We ground our normative reflections in our experiences with participatory initiatives in nanotechnologies. The multiplicity and variety of participatory initiatives in "nano," and the uncertainties related to the construction of "nano" publics and objects, enable, and compel, us to describe different forms of scholarly involvement. While we do not claim to have mapped out all the forms of social research involvement, we do believe our analysis elucidates a variety of participation postures and suggests their potential. If the social scientist intends to experiment with mediation for instance, as from an ANT perspective, empirical explorations of the diverse translation processes through which he enacts the social will be of much interest to him. They will also be necessary to account for the scholarly and political relevance of his work. Researchers in participatory technology assessment may in turn consider "mediation" as a means of reflexively attending to the roles they assume, and do not assume, in participatory spaces.

For scholars of reflexivity more generally, our experiences open a "window on the world" (Rip 2003: 361) as they enable a wider debate on the values and interests that inform social inquiry. In the context of public participation in science and technology, where the roles of academic scholars vis-à-vis non-academic researchers and practitioners are not clearly demarcated, our reflections may be of use in that they help specify the character of scholarly contributions to the field. This specificity consists in accounting for actions (e.g. shifting and deepening engagements) and situations in epistemological and normative terms without therefore dismissing the political alignments of the actors we study. While in the cases described above some professionals disproved of how we each problematized participation in our respective contexts, we contend that the modes we outline in this article, and how one negotiates between them, can serve action-oriented actors as resources. For one, public engagement inevitably implies a blurring of different roles in practice (as we have seen), which renders the conventional distinction between practitioner and analyst simply untenable (see also: Chilvers 2012). Second, given the political-economic significance of nanotechnology research, there is a real risk that *all* social sciences are trivialized or instrumentalized through, or despite, participatory processes. Practitioners, as well as analysts, must therefore consider what is at stake for them. Drawing out normative differences between actors, programs, and instruments can contribute to this aim of mutually informed positioning and articulation. At the very least, such articulation would render participatory social science more socially accountable and politically resilient, analogous to how social scientific interventions in technology can render "scientific cultures more self-aware of their own taken-for-granted expectations, visions, and imaginations" (Macnaghten et al. 2005). More importantly, it can enable social researchers to reflectively readjust and reposition themselves in the face of real-world challenges and concerns. Even if readjustments of this kind may not appear feasible, for instance because the social scientist is obliged to play a *particular* role, it would be naïve to assume that his disposition will go uncontested in practice. As Abels (2009) contends in answer to the question What role for social scientists in participation?, social scientists can, and already *do*, experiment with different commitments and orientations because they must. It would therefore be a mistake to leave the practical and political implications of their commitments unexamined and unaccounted for.

That being said, and having touched upon the weighty issues of normativity and politics in research, it is important to be modest about what our analyses and reflections may achieve, particularly as the situations we describe are still in the making. Secondly, as experimental normativity underscores the multiplicity of modes of knowledge production and engagements, experimentation need not, and should not, be limited to the individual researcher or to our cases. One can hope that for one scholar who organizes public discussions, there will be another one providing a critique of them. For one social scientist calling for institutional reflexivity (Wynne 1993), another one will propose empirically based examinations of social scientists who engage with natural scientists on the lab floor (e.g. Fisher 2007). Thus, as we describe the interventions of social scientists in participatory activities in nanotechnology, we welcome others to examine, engage with, and question our involvement practices and the experimentation with modes that we find compelling and seek to articulate.

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Scenarios as Patterns of Orientation in Technology Development and Technology Assessment

Outline of a Research Program

Ingo Schulz-Schaeffer (University of Duisburg-Essen, schulz-schaeffer@uni-due.de)

Abstract

It is widely recognized that technological future concepts play an important part in technology development. However, there is a lack of knowledge about how technological future concepts actually influence innovation processes and how they might be successfully employed to prospectively assess and shape new technologies. The research program presented in this paper addresses this research gap. It does so by focusing on the more detailed ways of envisioning the technological future, such as situational scenarios, and their capacity to provide epistemic orientation for technology development and technology assessment.

1 Introduction

"Sal awakens; she smells coffee. A few minutes ago her alarm clock, alerted by her restless rolling before waking, had quietly asked, 'Coffee?' and she had mumbled, 'Yes.' 'Yes' and 'no' are the only words it knows. […] At breakfast Sal reads the news. She still prefers the paper form, as do most people. She spots an interesting quote from a columnist in the business section. She wipes her pen over the newspaper's name, date, section and page number and then circles the quote. The pen sends a message to the paper, which transmits the quote to her office. Electronic mail arrives from the company that made her garage door opener. She had lost the instruction manual and asked them for help. They have sent her a new manual and also something unexpected – a way to find the old one. According to the note, she can press a code into the opener and the missing manual will find itself. In the garage, she tracks a beeping noise to where the oil-stained manual had fallen behind some boxes. Sure enough, there is the tiny tab the manufacturer had affixed in the cover to try to avoid Email requests like her own. On the way to work Sal glances in the foreview mirror to check the traffic. […] Once Sal arrives at work, the foreview helps her find a parking spot quickly. As she walks into the building, the machines in her office prepare to log her in but do not complete the sequence until she actually enters her office. […] Sal picks up a tab and 'waves' it to her friend Jo in the design group, with whom she has a joint assignment. They are sharing a virtual office for a few weeks. The sharing can take many forms – in this case, the two have given each other access to their location detectors and to each other's screen contents and location. […] A blank tab on Sal's desk beeps and displays the word 'Joe' on it. She picks it up and gestures with it toward her live board. Joe wants to discuss a document with her; and now it shows up on the wall as she hears Joe's voice: 'I've been wrestling with this third paragraph all morning; and it still has the wrong tone. Would you mind reading it?'" (Weiser 1991: 74f.)

The preceding paragraph is neither part of a science fiction novel nor is its author a writer. In fact, it stems from a scientific article published in a major popular science magazine and its author is a scientist: Mark Weiser, at that time head of the Computer Science Laboratory at the Xerox Palo Alto Research Center, presenting his research group's ideas about a new and revolutionary way of computing. Additionally, it is a rather significant article. It has become to be considered as the foundational paper of a key future technology, called "ubiquitous computing", which has attracted a large amount of research money and research activities within the last decade.

Imaginations of the future are essential for all future-directed activities. Without people thinking about how the future might or should differ from the present, innovations would never or only incidentally occur. The importance of technological future concepts for technology development and prospective technology assessment has become widely recognized in the relevant literature. However, there is a lack of secure knowledge about how technological future concepts influence innovation processes. This paper outlines a research program which addresses this research gap. Generally speaking, it is based on two suggestions: (1) to study not only the technological visions, that is the general and far-reaching pictures of the future, but the more detailed ways to depict the technological future, such as the Sal scenario presented above, as well; (2) to take into account not only the social and rhetorical effects and uses of technological future concepts but their factual and epistemic effects and uses as well.

2 Visions: the future concepts of radical innovations

Processes of technological innovation strive to bring about a reality, which for now exists only in imagination: the reality of future technology. Hence, innovation efforts rely on conceptions of the future. The future concepts of radical innovations are different from those that govern incremental innovations. The different character of the respective conceptions of future technology distinguishes incremental from radical innovation. Incremental innovations are efforts to improve and advance existing technology. Thus, in the case of incremental innovation the characteristics and features of the envisioned future technology are to a large part derived from the past: as solutions for the shortcomings and weaknesses existing technology has shown (cf. Rosenberg 1976: 125; Nelson/Winter 1977: 57; Dosi 1982: 152; Hughes 1987: 73f.). In this way, it is possible to arrive at detailed and highly concrete conceptions of the technological future. To extrapolate future technology from past developments thus has the effect to narrow down the considered paths of technology development (cf. David 1986; Arthur 1989).[1]

In contrast, radical innovation is characterized by discontinuity (cf. Freeman/Perez 1988: 46; Van de Ven et al. 1999: 63). Processes of radical innovation aim at future technology (and/or future uses) for which the past and the present do not provide technological (and/or cultural) precursors that may serve as example. For this reason, the technological futures radical innovative activities try to bring about, cannot or only slightly be extrapolated from existing knowledge. Consequently, these future concepts typically are vague in their specifications of the technical features and the forms of use of the envisioned technology. It has become common use in technology-related discourses to call future concepts of this kind "visions".[2] Especially the fields of technology, which currently are (or lately have been) considered as key future technologies, are highly affected by visions. Often, the names of these technologies are already "vision statements": Artificial intelligence, genetic engineering, nanotechnology, ubiquitous computing etc.

3 Effects and uses of visions in the innovation process

Previous research indicates that visions may have specific effects in innovation processes and specific uses in processes of technology assessment. Research on technology development analyses visions with respect to their empirically observable impact on innovative efforts. Research on technology assessment, rather, is interested in possible uses of visions as tools for assessing and shaping technologies of the future. Above all, the literature highlights the following three aspects:

3.1 Mobilizing and coordinating actors, interests, and resources

Many studies confirm that visions act as a means of mobilizing and coordinating innovation-related actors, interests, and resources (cf. Dierkes et al. 1992: 100ff.; van Lente 1993: 93ff., 125ff.; van Lente/Rip 1998b; Van de Ven et al. 1999: 30ff., 82f., 203; Bender

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[1] The orientation of the semiconductor development at Moore's law and related past development trends exemplifies this point. From these past developments the semiconductor industry derives detailed roadmaps for future research and development. Cf. in particular the ITRS roadmaps (International Technology Roadmap for Semiconductors); www.itrs.net.

[2] There are some similar terms in use in innovation research like „guiding vision" („Leitbild"), expectation structure" or „promising technology" which – including additional conceptual connotations – also denote future concepts of radical innovations.

2005: 178ff.). Visions seem to have a specific "appeal" (Dierkes/Marz 1992: 52) and rhetorical power (Rammert 1994: 16f.; Schulz-Schaeffer 1996: 118). Being "expectations of potential" (van Lente/Rip 1998b: 222) they attract and thereby mobilize actors to invest time, money and career chances in efforts to realize them.

According to well-known considerations from the Constructive Technology Assessment approach, the mobilizing and coordinating effect relies on the "performative role" (Geels/Smit 2000: 867. 882) of technological visions: "expectations are *performative*: they do something" (van Lente 2012: 772). These authors argue that the promise of a "promising technology" (van Lente 1993) at first is not much more than rhetorics (cf. van Lente/Rip 1998b: 224, 246). But it may give rise to a social dynamic "from rhetorics to social reality" (van Lente/Rip 1998b: 221): Scientists, research funding institutions, and enterprises become attracted by the vision's promises. They bring their interests, competences, and preferences into play, and, on this ground, articulate their particular expectations with respect to the envisioned technology. In this way the vision as a rhetorical entity triggers a social process of "mutual positioning" (ibid.: 224), a process in which "actors take up positions and make linkages" (ibid.: 235). Mutual positioning necessarily implies that the expectations become more specific, allowing to derive more specific requirements for the development of the new technology (followed by again more specific expectations, and so on). This leads to a process of agenda building, and what has been mainly rhetorics at first, more and more becomes social reality (cf. van Lente/Rip 1998a; van Lente/Rip 1998b).

Some authors hold that not only rhetorics is responsible for the mobilizing and coordinating effect of visions but that additionally an epistemic dimension should be taken into account. Especially the guiding vision ("Leitbild") approach (cf. Dierkes et al. 1992) has stressed this aspect. The approach claims to explain the mobilizing and coordinating effect by the visions' character as patterns of orientation. The argument goes as follows: by serving as commonly shared vanishing points of thought and action visions shape the perceptions and assessments of the involved actors (cf. ibid.: 45ff., 100ff.). By influencing the actors in such a way, the visions have the effect of coordinating actors and guiding innovation-related decisions (cf. Marz/Dierkes 1992: 36f.). According to this strand of argument, decisions to pursue and to fund projects of technology development are influenced the more by visions, the less the result of the innovative activities can be anticipated. Thus, visions are of major influence especially in the case of radical innovations (cf. Dierkes 1993: 269).

3.2 Guiding research and development activities

As discussed in the previous section, there is little doubt that visions do have an impact on initiating programs and projects of technology development. A different question is whether visions act as patterns of orientation for the ongoing research and development activities of innovation processes. This is a controversial matter. The guiding vision approach argues in favor of this assumption (cf. e.g. Dierkes 1993: 268ff.). Referring to own historical reconstructive case studies, its proponents claim to have shown that visions influence the actual research and development activities of innovators and thus do have an impact on the features of new technologies and on the paths of their development (cf. Marz/Dierkes 1994: 42ff.; Dierkes et al. 1992: 59ff.). However, it is to be suspected that this finding is an artifact of retrospective analysis (cf. Grunwald 2004: 56), especially since other studies do not confirm such an immediate effect of visions on technology development (cf. Rammert et al. 1998; Berkhout et al. 2003: 12; Hellige 1996a: 25f.).

Yet, one should not easily dismiss the assumption that the content of technological future concepts exerts an influence on technological research and development. Social dynamics are not enough to explain how technological future concepts are transformed into research agendas. For the dynamic from rhetoric to social reality to occur, actors' need clues to evaluate whether or not it is of interest to them to engage in the development of the proposed technology. At least to some extent they need to know which competencies and resources might be useful for realizing the vision, which academic or economic aims and ambitions thereby might be pursued, etc. Otherwise, there is little reason why (and how) actors' should position themselves within such an endeavor. Since these questions refer to the imagined reality of technological future concepts the clues for answering them are not to be found anywhere else than in these future concepts. Consequently, the factual content of technological future concepts should play a part in the process of mutual positioning and agenda building. In line with this argument, van Lente and Rip agree that visions are not purely rhetorical: „expectation statements contain a ‚script', indicating promising lines of research and technical development to be undertaken by the enunciator of the statement and/or by others. Thus they mobilize support in specific ways." (van Lente/Rip 1998a: 218) It thus seems plausible to assume that future concepts provide orientation in innovation processes. Yet, this does not imply that visions have the capability to directly guide specific research and development activities (cf. Rammert 1994; Rammert et al. 1998).

3.3 Prospective technology assessment

Without sufficiently reliable assessments of the societal (i.e. economic, political, legal, social, and cultural) and ecological risks and benefits of future technologies there is little chance of influencing innovative activities with the objective to advance desirable technological developments and to discourage undesirable ones. In the case of radical innovations, the present knowledge about the future reality of the envisioned technology is more or less restricted to what can be derived from the future concepts. Thus, technology assessment in this case has little options but to refer to these concepts. Some authors take account of this fact by suggesting to develop methods for "guiding vision assessment" ("Leitbild-Assessment", cf. Dierkes 1991; Hellige 1996b) or "vision assessment" (Grunwald 2004; Grin/Grunwald 2000). The basic idea is to assess the technological future as envisioned by these future concepts, that is to assess the risks and benefits to be expected if the visions' future would come true.

The idea to employ visions as tool of prospective technology assessment plays an important part in the guiding vision approach (cf. Dierkes 1991; Dierkes 1993; Marz/Dierkes 1994). As mentioned before, the authors of this approach hold the view that visions are effective in guiding research and development activities. Accordingly, they assume that the future the researchers and engineers are about to realize will be not too different from the future as pictured by these visions. Consequently, it makes sense to use the visions employed in innovative activities for assessing these activities' future outcomes. Additionally, it becomes a promising idea to try to prospectively shape technological change by shaping the visions to which the researchers and engineers refer to in their innovative activities.

However, it has soon been criticized to be an exaggerated claim that by analyzing visions it would be possible to recognize the consequences of technologies while they are still under development (cf. Hellige 1993: 196; 1996a: 29). Such a concept of prospective technology assessment underestimates the fact that innovation, and especially radical innovation, "involves uncertainty in an essential way" (Nelson/Winter 1977: 47), so that the "outcomes of innovative efforts can hardly be known ex ante" (Dosi 1988: 222). Additionally, given the current state of research there is little support to the claim that visions exert an immediate influence on research and developmental activities. As Grunwald states, „their promised use for shaping technology in a prospective sense […] has not been realised" (Grunwald 2004: 56; cf. Grunwald 2002: 149f.). This opinion is shared by many other researchers (cf. e.g. Schot/Rip 1997: 260; Rammert 1994: 16f.).

Nevertheless, even the above-mentioned critics do not entirely dismiss the idea of using future concepts as means for prospective technology assessment. Hellige suggests an attenuated version of vision assessment (cf. Hellige 1996a: 29). Following his line of argument, Grunwald proposes an elaborated concept of vision assessment. The cornerstone of his argument is that technological future concepts because of their mobilizing effects actually influence innovative efforts (cf. Grunwald 2006: 69ff.; Grunwald 2004: 57). For visions to play a part in innovative efforts, it is not necessary that they are blueprints of future technologies, which they are not. It is enough that visions affect decisions concerning the establishment and funding of innovative efforts. Vision assessment, then, is the task to analyze the visions' influence on innovation-related decisions and to evaluate whether this influence leads to decisions that are desirable from the point of view of society (cf. Grunwald 2009; Karafyllis 2009; Ferrari et al. 2012).

The idea to prospectively shape future technology by establishing visions of desirable techno-social futures remains highly attractive as well – in spite of the above-mentioned objections. The technology policy approach of transition management may serve as an example. According to this approach, sustainability visions should be employed to formulate desirable objectives of technology development, such as "cleaner cars" or "clean coal", from which policies to attain the visions' goals systematically should be derived. „The long-term visions of sustainability should be used as a guide to formulate programmes and policies and the setting of short-term and long-term objectives." (Kemp/Rotmans 2004: 147; cf. Kemp/Loorbach 2005). Here again it is implied that visions may not only rhetorically but also factually structure technology development.

4 Integrative capacity and lack of concreteness

Several well-known concepts of technology assessment in one or another way adhere to the idea of employing visions as means of prospective technology assessment and of prospective shaping of technology. Given the rather discouraging performance visions according to many researchers have shown in this respect, this is quite remarkable. Scholars adhere to this idea because if visions could be used in this way, a crucial problem of technology assessment could be solved: the problem of overcoming the „dichotomy between promotion and control of new technology" (Rip 2002: 14; cf. Schot/Rip 1997: 264). Most distinctly, the guiding vision approach embodies this hope. According to this approach, the visions on the one hand significantly govern technology development efforts ("Leitbildprägung"). On the other hand, they can be used to prospectively control technology development by taking care that innovation processes are based on desirable visions ("Leitbildgestaltung") (cf. Marz/Dierkes 1994: 35).

The main obstacle for using this integrative potential of visions lies in the fact that, though visions undoubtedly affect public and private decisions to engage in technology development, they do not provide pictures of the future detailed enough to guide specific research and development activities. Visions are rough sketches rather than detailed drawings of the technological future they focus on. They do not elaborate on the complexity of the future reality in sufficient detail to determine definite steps for realizing this future. For the same reason they do not provide a sound basis for evaluating the risks and benefits of the envisioned technological future. Thus, shaping technology by shaping visions does maybe work in the context of research and technology policy but not in the context of actual research and development activities. The question, then, is whether there are forms to express concepts of technological future, which may compensate for the visions' lack of concreteness.

5 Scenarios: specified conceptions of technological future

The scenario as a tool for future research, from the outset has been a means of concretizing and specifying future concepts. Scenarios created for this purpose try to take into account a plurality of factors and circumstances, which might affect the reality of the future technology and its forms of use, in order to describe this possible future as a complex of specified cause-effect-relationships. Scenarios concretize visions by focusing on the interdependences that are (or might be) constitutive for the actual reality of the envisioned future. This does not mean that scenarios are or that they could claim to be forecasts. Just as visions, they are not. Scenarios no more than visions provide a solution to the problem of fundamental uncertainty of innovative activities. Like visions, scenarios rely on assumptions about the future, which result at best from informed guess. Rather, scenarios concretize visions by spelling out the implications of the visions' assumptions. Scenarios exemplify how the envisioned future actually might look like by specifying for certain situations the relevant entities and events involved, the relations and interactions between them, the relevant circumstances, and so on. According to Herman Kahn and Anthony J. Wiener, the pioneers of scenario research, scenarios "are hypothetical sequences of events constructed for the purpose of focusing attention to causal processes and decision points" (Kahn/Wiener 1967: 6). In a more encompassing sense they consider the scenario to be an "aid to thinking" (ibid.: 262) because the scenario is a means to go ahead from the visions' overall pictures of the future to descriptions of the specific reality of possible futures.

For scenarios to become useful tools for describing hypothetic future realities in a most realistic and plausible way, the scholarly literature stresses the importance of the following quality criteria: First, scenarios should be credible (cf. Wilson 1978) and consistent (cf. Godet 1986: 135). They should provide a coherent and consistent picture and derive it plausibly from the underlying assumptions about the imagined future. Second, the scenarios should be exhaustive (cf. Steinmüller 2003: 15f.) or holistic (cf. ibid.: 7; Steinmüller 1997: 52), meaning that they should include all the aspects of the imagined future reality that might be of importance. And third, the underlying assumptions from which the scenarios are derived should be made explicit (cf. Amara 1991).

6 Types of scenarios

One type of scenarios can be expected to be especially suited to serve as a means of concretizing visions: the qualitative normative situational scenario. While there are scenario typologies that include more than ten dimensions (cf. e.g. van Notten et al. 2003) it is enough to include the following three dimensions in order to characterize this type of scenario:

Projective vs. normative scenarios: Scenarios that are obtained by extrapolating the future from the past and the present are called projective or explorative scenarios. Normative scenarios, in contrast, are based on assumptions, which are not derived from current trends. Normative scenarios focus on change and not on continuation. They are conceptions of desirable or undesirable future states. Since visions also focus on discontinuity, scenarios that concretize technological visions basically are normative scenarios. However, it should not be neglected that even radical innovations are discontinuous developments only in certain respects and in other respects (as in the case of incremental innovation) recombinations of already existing elements (cf. Edquist 1997: 1; Van de Ven et al. 1999: 9). This means that visions – and the corresponding scenarios – usually include projective components as well (cf. Steinmüller 1997: 53f.; Steinmüller 2003: 9f.).

Situational vs. developmental scenarios: A scenario's description of the interdependencies between components and relations may either address a possible future state of affairs or a possible future development. Scenarios of the first kind are called situational scenarios or snapshot scenarios, those of the second kind are called developmental scenarios or chain scenarios (cf. Steinmüller 2003: 11; van Asselt et al. 2010: 26f.). Technological visions are conceptions of desirable (or undesirable) future states of affairs. The scenarios putting these visions into concrete thus are situational scenarios. Both types of scenarios refer to each other. In a kind of forecasting, it is possible to derive situational scenarios from developmental scenarios. Vice versa, in a kind of backcasting, it is possible to derive developmental scenarios from situational scenarios. This can be done by asking which steps of development are necessary to realize (or to prevent) the future reality as described by a situational scenario (cf. Steinmüller 1997: 55). The pictures-of-the-future process as developed by Siemens AG calls this strategy "retropolation" (cf. Eberl 2001: 5).

Quantitative vs. qualitative scenarios: To describe in quantitative terms the elements and relations to be taken into account within a scenario, it is necessary to derive the assumed figures from actual trends, which already have been measured quantitatively. Purely quantitative scenario, thus, tend to be mere extrapolations. To a certain degree all assumptions about technological future states are affected by uncertainty and the possible ways there are characterized by discontinuity. To deal with such complexities, scenario construction has to rely on qualitative processes of reasoning about more or less probable, feasible and desirable (or undesirable) future developments and future states and on verbal descriptions thereof (cf. Schwartz 1993: 34; Steinmüller 2003: 45f.). For this reason, scenarios differ from forecasts by a certain amount of qualitative argumentation (cf. Ropohl 1997: 193). It is the proportion of projective or normative components that gives a scenario a more quantitative or a more qualitative character. Scenarios with a predominantly qualitative orientation usually take the form of narratives, in most cases in textual form but sometimes as cartoons or film sequences. A way to further increase the concreteness and the realism of qualitative scenarios is the so-called narrative scenario, a form of narration that introduces fictional persons as the story's protagonists (cf. Steinmüller 2003: 36). The above quoted Sal scenario (cf. Weiser 1991: 74f.) is an example of a narrative scenario.

Considering all three dimensions, it can be theorized that the qualitative normative situational scenario should be empirically observable as the most appropriate type of scenarios for concretizing and specifying the technological visions of radical innovations. Furthermore, it is to expect that scenarios of this kind that additionally take the form of narrative episodes – should serve this purpose especially well.

7 Visions und Scenarios in Ubiquitous Computing and Nanotechnology

In his foundational paper Weiser envisions a technological future in which computers become "an integral, invisible part of people's lives" (Weiser 1991: 66). According to this vision, a myriad of interconnected computing units embedded within the users' everyday environment will constitute a constant background presence, a ubiquitous informational infrastructure that is intuitively usable based on everyday knowledge. In this paper, Weiser coins the term "ubiquitous computing" to denote this vision.

As of the turn of the millennium, this vision has had a considerable impact on research policy (cf. Friedewald/ Raabe 2011: 56). In 2001, the U.S. National Research Council publishes a research policy paper, which proposes the vision of embedded computer-networks. It states the aim "to develop a research agenda that could guide federal programs related to computing research and inform the research community (in industry, universities, and government) about the challenging needs of this emerging research area" (NRC 2001: VIII). At the same time, the Nomura Research Institute, that is influential in the Japanese research policy, publishes a series of research reports proclaiming "Ubiquitous Networking" as the new paradigm of information technology (cf. Murakami/Fujinuma 2000; Murakami 2001; 2003). The Japanese national research policy soon adopted this idea. In a White Paper of the Ministry of Telecommunications a strategy for realizing a „Ubiquitous Network Society" (cf. MPMHAPT 2004) is suggested. Similar research policy activities are taking place in Europe. Already in 1999, the Information Society Technologies Advisory Group (ISTAG) – a panel of experts providing advice for the European research policy in the field of information technology – proposes the vision of ambient intelligence (cf. ISTAG 1999: 2), thus creating an own label for research policy in the emerging field of ubiquitous computing. In a subsequent report this vision is characterized as follows: „People are surrounded by intelligent intuitive interfaces that are embedded in all kinds of objects and an environment that is capable of recognising and responding to the presence of different individuals in a seamless, unobtrusive and often invisible way." (ISTAG 2001: 1).

It is noticeable that these "vision statements" nearly always are accompanied by scenarios, which in more or less detail spell out for a variety of domains of application how the future reality of ubiquitous computing[3] possibly will look like. Weiser's Sal scenario describes the use of ubicomp technologies at home, during commuting, and at work in the bureau. The ISTAG report „Scenarios for Ambient Intelligence in 2010" provides four narrative scenarios covering the domains of shopping, traveling, health care, mobile communication, recreational activities, and education (cf. ISTAG 2001: 4ff., 26ff.). The respective Japanese research policy papers include scenarios with similar topics. They are often presented as cartoons (cf. Mobile IT Forum 2003: 1ff.; MPMHAPT 2004: 19). The U.S. research agenda "Embedded, everywhere" also provides scenarios, though with a different thematic focus: mobility, warfare, and agriculture (cf. NRC 2001: 16ff.)

[3] The different terms „ubiquitous computing", ubiquitous networking", „embedded systems", „ambient intelligence", or „pervasive computing" are basically referring to the same technological vision. They differ from each other only slightly. To simplify matters I am using only the term ubiquitous computing and it's often used abbreviation "ubicomp".

Technology assessment studies of ubiquitous computing also rely heavily on scenarios. The EU project "SWAMI – Safeguards in a World of Ambient Intelligence" has set standards for the use of scenarios for assessing ubicomp technology. Here, four so-called "dark scenarios" build the basis for assessing the new technology – narrative worst-case scenarios devised to shed light on social and societal risks of future ubiquitous technology applications (cf. Punie et al. 2006).

With respect to the visions of nanotechnology, it is useful to distinguish between so-called futuristic or utopian visions and so-called realistic visions. K. Eric Drexler, to whom the authorship of the term "nanotechnology" usually is credited,[4] is the most outstanding proponent of the futuristic-utopian discourse. His pivotal vision is the future existence of molecular assemblers: nanoscale machines able to assemble designated structures from individual molecules or atoms. Thus being able to assemble the structure they themselves consist of, molecular assemblers additionally are self-replicative machines. Drexler affiliates far-reaching expectations for the future to this basic vision, which are quite futuristic visions as well: the colonization of the universe; the prolongation of the human life span, even up to immortality; a revolution of industrial production resulting in an extremely cost-efficient and resource-saving mode of production (cf. Drexler 1986; Drexler/Peterson 1991).

Futuristic visions play an important part in the public debate on nanotechnology, as for example the Bill Joy debate[5] has shown (cf. Schirrmacher 2001). Within the scientific discourse, however, the prevailing opinion is that popular visions of this kind are mere science fiction while it should be the task of serious scientific endeavor to elaborate more realistic and less fanciful future conceptions. The research policy papers concerned with nanotechnology largely express a very similar view towards nanotechnological visions (cf. NSTC 1999: 8; Royal Society 2004: 5). Nevertheless, the expectations regarding nanotechnology are not necessarily more modest within this discourse and the conceptions that count as realistic visions are not always less far-reaching than those within the futuristic discourse.

Most influential for nanotechnology to be set on the agenda of research funding agencies and policymakers are the research policy papers that have been worked out in the context of the emerging U.S. National Nanotechnology Initiative. According to an expectation prominent in these papers, "nanotechnology will have a major impact on the health, wealth and security of the world's people that will be at least as significant in this century [the 21st century; ISS] as antibiotics, the integrated circuit, and manmade polymers" (NSTC 1999: 2) have been for the 20th century. The overall vision of the National Nanotechnology Initiative pictures a future, „in which the ability to understand and control matter on the nanoscale leads to a revolution in technology and industry" (NSTC 2004: 1). This overall vision includes a multitude of visions for different domains of application: lighter and more durable materials, which will make production and transportation more energy-efficient; improved healthcare that will prolong life and improve its quality; dramatic reduction of waste and pollution through nanotechnological means, to name only a few of them (cf. NSF 2001: 3-10).

In contrast to ubiquitous computing, the use of normative situational scenarios is rather seldom in nanotechnology. While there is a constant and systematic use of scenarios as means to substantiate visions in research

[4] However, he was not the first to use this term to describe nanoscale production technology (cf. Schaper-Rinkel 2006: 475).

[5] Cf. http://www.wired.com/wired/archive/8.04/joy.html (last access: 2011/11/01).

policy as well as in technology assessment activities concerned with ubiquitous computing, a similar use of scenarios in nanotechnology occurs only occasional and if so mostly in a less elaborated manner (cf. Aschenbrenner 2003; BMBF 2006: 28). Some nanotechnology studies employ developmental scenarios for purposes of prospective technology assessment, but the parameter structuring these scenarios often remain rather abstract (cf. High Level Expert Group "Foresighting the New Technology Wave" 2004; Nanologue 2006; 11ff.; Renn/Roco 2006: 52ff.). Overall, in the field of nanotechnology neither the research policy papers nor the technology assessment systematically uses normative situational scenarios or scenarios at all. Most times, when the term "scenario" is used, it is used to designate visions (cf. Roco/Bainbridge 2002: 4-6; Brune et al. 2006: 382ff.; Grunwald 2006: 51ff.).

8 Effects and uses of scenarios in the innovation process

8.1 Mobilizing and coordinating actors, interests, and resources

To understand the relevance of scenarios as means of mobilizing and coordinating actors, interests, and resources, the comparison with the respective relevance of visions is helpful. This comparison reveals remarkable differences in how future conceptions are used in ubicomp and in nanotechnology research policy. As described above, there is considerable empirical evidence that the relevance of technological visions largely results from their rhetorical power. According to these findings, visions are especially well suited to attract the attention and to mobilize the support of research policy bodies, policy-makers, and organizational decision-makers, which is necessary to set up the respective research programs and research projects. The relevant literature largely agrees that technological visions may and do exercise this rhetorical power even when they are of no use as means of orienting and guiding the actual research and development of the envisioned technologies. The visions of nanotechnology confirm this (cf. Fiedeler 2010). Quite a few of them propose ideas far away (if not principally distinct) from what will be technically feasible for decades to come, and thus are completely unsuitable for orienting specific research activities (cf. Lösch 2006a; 2006b). Nevertheless, many studies observe a considerable actual significance of futuristic visions at the interface between science on the one hand and politics and the public on the other hand (cf. Grunwald 2006: 70). This holds especially in the field of nanotechnology (cf. Deutscher Bundestag 2004: 145, 153; Coenen 2003: 8f.; 2010; Brune et al. 2006: 388f.; Salin 2007; Rip/Van Amerom 2010: 136ff.). The visions that have been influential for establishing nanotechnology as a key future technology seem to differ from those of other new technologies in that they are only loosely coupled with the emerging scientific foundations of nanotechnology or with questions concerning the technical feasibility and usefulness of possible applications (cf. Woyke 2010: 53). It is in line with this observation that the use of situational scenarios – that is the use of more concrete and application-oriented future concepts – as means of attracting attention and mobilizing resources is rather seldom in the context of nanotechnology.

In the field of ubiquitous computing this is markedly different. As mentioned above, from the outset the visions of ubiquitous computing are accompanied by scenarios as a means of specifying the overall future concepts of the new technology and its possible uses. In itself, this finding of course does not imply that these scenarios are employed as means of mobilizing resources and support for technology development. However, there is evidence that ubicomp scenarios indeed serve as rhetorical means to this end. Qualitative normative situational scenarios are prominently placed within the research policy papers, which are written to promote and to initiate ubicomp-related research programs. Additionally, it is obvious that these scenarios are deliberately designed to emphasize the benefits of a future reality of ubiquitous computing (cf. Friedewald et al. 2005: 23; Punie et al. 2006: 7). It is hard to imagine that this scenarios' rhetorical presentation is without the intention to win over the policy papers' addressees.

What might explain the different use of scenarios as rhetorical means in these both fields of technology? The above considerations suggest that scenarios – due do their character as more application-oriented forms of future concepts – occur only in the context of sufficiently realistic visions while futuristic visions do not provide enough of a basis to deduce scenarios of this kind. An additional hypothesis is that the rhetorical use of scenarios in the context of research policy serves to mobilize actors more directly involved in technology development – and thus more application-oriented – than the visions' addressees. It fits into this picture that the debate on nanotechnology in which visions play a major part is mainly a public debate. It is a debate on the more fundamental issues concerning the promises and risks of nanotechnology. In this debate, the visions serve to attain public attention for the more fundamental research policy positions concerning nanotechnology rather than to promote specific research and develoment programs. However, these are only preliminary explanations, which remain to be substantiated empirically.

8.2 Guiding research and development activities

One of the position papers aimed at establishing and institutionalizing ubiquitous computing explicitly states that scenarios provide an opportunity to concretize ubicomp visions with respect to future technological applications. The Embedded Systems Roadmap 2002 (cf. Eggermont 2002) presents the following multistage development model: An overarching vision of a desirable technology constitutes the starting point of the process. From this vision, domain-specific scenarios of promising applications are derived. Subsequently, roadmaps are worked out, which define the steps of development necessary to realize the technological components of the arrangements described by the scenarios (cf. ibid.: Eggermont 2002f.). In a similar way, the Information Society Technologies Advisory Group characterizes the ubicomp scenarios they employ as "ways to uncover the specific steps and challenges in technology […] that have to be taken into account when anticipating the future. To put it another way, scenario planning is a tool to help us invent our future." (ISTAG 2001: 1)

Statements of this kind suggest that scenarios may be effective as patterns of orientation in the process of transforming technological visions into research agendas (see also Friedewald et al. 2005: 8). This is a rather interesting point, especially since the Constructive Technology Assessment approach, which at present is the probably most well-known concept for analyzing technological future concepts, considers the transformation process from visions to agendas to be mainly a social dynamic in which epistemic orientation plays a minor part (cf. above 3.1 and 3.2). There is some evidence that this view applies more to agenda building in nanotechnology than in the field of ubiquitous computing. However, this question is also open to further research.

Whether or not scenarios provide patterns of orientation that are guiding actual research and development activities is another research question that to my knowledge has yet not been explored in much detail. Kornelia Konrad (2004: 10, 24, 33, 135, 147; 2006) assumes that scenarios are indeed effective in such a way. However, neither her own research nor the actor-network theory studies she refers to, really confirm this assumption. Nevertheless, actor-network theory is a useful reference since it provides a consideration from which it is highly plausible that scenarios should have such a capacity: Every successful innovation is a new arrangement of coordinated roles. The performance of the technical components, the behavior of the users, the technology-related services of providers etc. must fit together sufficiently well to make a useful and usable technology (cf. Akrich 1992a; 1992b; Callon 1986; 1993). Thus, the technical components – just as all the other components of an innovation – occupy specific roles within the network of complementary interrelated roles the innovation consists of. To specify the possible roles a new technology may and should (or should not) adopt within future contexts of application is exactly what qualitative normative situational scenarios are about. Consequently, scenarios of this kind indeed should have the capacity to provide guidance for innovation-related research and development activities.

8.3 Prospective technology assessment

It is not clear how important the use of scenarios for purposes of technology assessment (TA) really is. Some TA experts appraise scenarios to have become the main device for technology-related future assessment (cf. Grunwald 2002: 226). Others see them as being rather marginal in their use for purposes of technology assessment (cf. Konrad 2004: 20ff., 259ff.; Steinmüller 1999: 670). For prospective technology assessment in the field of ubiquitous computing, however, scenarios definitely are the method of choice, whereas in the field of nanotechnology the vision assessment approach has become important for some years.

Technology assessment meant to produce knowledge useful for taking advantage of the benefits of new technologies and for avoiding the possible risks associated with them. Thus, technology assessment aims at shaping technology. According to the well-known anticipation and control dilemma of technology assessment it is easier adequately to anticipate the consequences of a new technology if it is already developed to a certain degree, it is easier to influence the direction of the development process in the beginning than in later phases (cf. Collingridge 1980: 16ff.). If to shape technology, it is thus necessary to assess emerging technologies at an early time when it is hardly possible to acquire sound knowledge of the possible effects that might be associated with them. Some approaches like the Constructive Technology Assessment approach deal with this problem by redefining what technology assessment can and should accomplish. Accordingly, technology assessment should be viewed as a method to enhance reflexivity within the ongoing process of technology development rather than as an instrument of anticipation and forecasting. In this context, Arie Rip explicitely refers to scenarios: „if paths are created while walking (Garud/Karnøe 2001), emerging paths can be mapped, and the way they emerge can be analysed […]. Basically, what happens is that scenarios are created in which impacts can be (speculatively) identified and assessed […]. Actors always work with partial and diffuse versions of such scenarios to orient themselves – and others. A social-science supported TA might improve the quality of their scenarios." (Rip 2002: 38)

Thus, the scenarios used by innovating actors as tools to invent the future should be employed by TA actors to assess the future as envisioned by these scenarios and to participate in inventing the future by improving them. In the field of ubiquitous computing this is a realistic option because there is a considerable similarity between the scenarios to be found in the context of research policy and of research and development and those used in TA studies. In contrast, prospective technology assessment in the field of nanotechnology cannot rely on such a link. Instead, it is largely dependent on visions if to derive assessments from conceptions of the technological future. These visions, however, are primarily rhetorical means for policy processes and do not provide much factual guidance for technology development. For this reason, the analysis of visions as provided by the vision assessment approach is rather a method of analyzing and assessing policy processes than a way to concomitantly assess emerging ideas about emerging technologies.

9 Outline of a research program

Technological innovation processes aim at inventing a future that for now exists only in imagination. This constitutes – especially in the case of radical innovations – the relevance of technological future concepts. Previous research on the impact of technological future concepts on innovation processes mainly focuses on visions: (1) The Constructive Technology Assessment approach views visions as triggers of a social dynamic of mutual positioning of innovating actors. Through this social process, the ideas about the envisioned future technology successively become more and more specific. The approach highlights the rhetorical function of visions but is not very elaborate on epistemic aspects of technological future concepts. (2) The guiding vision approach as well assumes that visions possess a rhetorical power to mobilize actors and resources. Additionally, the proponents of this approach are strongly convinced that visions provide guidance for research and development activities. However, the prevailing opinion within the relevant literature is that the related studies do not give sufficient evidence to confirm this point. (3) According to the vision assessment approach, visions are important because of their impact on research and technology policy discourses. Thus, the task of vision assessment is to support the development of policies and public opinion by reflecting on what these visions say and imply. Previous research provides only few considerations on more specific forms of technological future concepts and there is little empirical work concerning the question if and how future concepts provide epistemic orientation in innovation processes.

There is a research gap regarding this question. While former research dealt with it but could not answer it satisfactorily with respect to visions, the more recent research is primarily interested in the rhetorical and political use of visions and does not pay much attention to the epistemic dimension of future concepts. As I have argued above, there are reasons to believe that situational scenarios rather than visions include information about the components of the envisioned new technology, their features, performance, and interrelatedness, which all can be used to orient research and development activities. Against this background, the most promising way to close the research gap is to study the uses and effects of these (and other) more specific future concepts in innovation processes.

Exploring the epistemic dimension of future concepts in innovation processes is part of the more general objective of developing an approach that conceptually integrates technology and innovation studies with prospective technology assessment. From the descriptive analytical perspective of technology and innovation studies, technological future concepts are factors that do or may influence innovation processes. From the normative perspective of technology assessment, technological future concepts are tools for prospective technology assessment. If future concepts serve as a common point of reference for both perspectives this could be used to integrate both perspectives. This integration would require (a) that future concepts do indeed exert influence on technology development, (b) that the same future concepts are used as tools for prospective technology assessment, and (c) that the recommendations resulting from the assessment process find their way back into the domain of technology development – for example in form of future concepts with more desirable or less risk-laden features. As argued above, visions are unsuitable to bridge the gap between technology development and technology assessment but scenarios have this integrative capacity.

Both objectives – to explore the epistemic dimension of scenarios and to assess their potential for integrating technology development and technology assessment – require studying the respective uses and effects of scenarios in different innovation-related contexts: (a) in the research and technology policy context of mobilizing actors and resources, of mutual positioning of the actors involved, of the transformation of general ideas about the technological future into research agendas and research programs, and of establishing programs supporting research and development of the envisioned new technologies, (b) in the context of research and development of the new technologies, and (c) in the context of prospective technology assessment.

Where situational scenarios occur such as in the field of ubiquitous computing, they do not completely replace visions. Rather they complement them by spelling out the visions' overall ideas in specific ways. Thus, with the occurrence of scenarios visions do not become redundant. This implies that visions may remain to be relevant for innovation processes in certain respects even when there are more specific ways to express ideas about the technological future. Consequently, for each of the three contexts just mentioned the respective uses and effects of scenarios should be analyzed in comparison with corresponding uses and effects of visions. It should be added that the scenarios' and visions' uses and effects in question not necessarily are intentional ones. Obviously, an intentional use should be expected when visions are deliberately employed as rhetorical means or scenarios as technology assessment techniques. Yet the ways in which future concepts influence processes of research and development are less unambiguous and rhetorical effects do not necessarily presuppose corresponding intentions. Thus, research on these issues should take in mind that unintentional effects of future concepts on innovation processes might be as important as those resulting from their intentional use.

The following hypotheses about the uses and effects of scenarios in comparison to visions within the different contexts of the innovation process are the main guidelines for the research program outlined here. The first and second hypotheses address the research and technology policy context:

H1: Like visions, scenarios are means of mobilizing actors and resources. In contrast to visions, scenarios attract the more application-oriented actors in innovation processes.

H2: Scenarios provide epistemic guidance for the transformation of visions into research agendas and research programs, while visions in this process act as triggers of social dynamics.

Recent innovation research tends to view the formation of research agendas and the establishment research programs mainly as a social, political, and rhetorical process while paying less attention to epistemic factors. However, the institutionalization of a new field of technology is an epistemic as well as a social process and thus it should be regarded as including a social and a factual dimension. Establishing a new field of technology, a new research agenda, or a new research program requires to define the subject of the research activities to be established. It requires to specify the characteristics, features, and problem-solving capacities of the new technology and to identify the respective requirements for research and development. This is the factual dimension. Mobilizing and mutual positioning of actors constitutes social dimension of the process. The presupposition of the first hypothesis is that visions are of major importance with respect to the social dynamics of establishing research agendas and research programs. Additionally, the hypothesis assumes that scenarios by mobilizing application-oriented actors also act on the social dimension of this process. The presupposition of second hypothesis is that visions possess little potential for epistemic guidance in the context of research policy. According to the second hypothesis, this is what should be expected from scenarios.

H3: In contrast to visions, scenarios provide epistemic guidance for actual research and development activities. Scenarios can be used as tools to invent the future.

The third hypothesis addresses the context of research and development. Gaining better knowledge about the connections between technological future concepts and actual research and development of new technologies would substantially advance innovation research. Van Lente and Rip characterize the process through which the promises of technological visions result in new technologies as a "promise-requirement spiral" (van Lente/Rip 1998a: 223). To realize a technological vision it is necessary to translate its promises into developmental requirements: Which technological problems have to be dealt with? Which competencies and resources are needed? Which actors with which competencies and resources are already aboard or have to be mobilized? etc. According to the authors, the promises of a technological vision become more specific through this translation process. For example, the actors involved will focus on certain domains of application and on certain strategies of research and development while other possible paths will be postponed or remain unnoticed. The more specific promises allow to define even more specific requirements which in turn lead to even more specific promises and so on.

With scenarios, it would be more appropriate to speak of an expectation-requirement spiral, because scenarios concretize visions by translating their overall promises into specific expectations about the technological future. If scenarios act as patterns of orientation for research and development activities, expectation-requirement spirals of the following kind should be observable: Requirements for research and development are derived from the scenarios' expectations about the new technology's performance within specific domains of application. The definition of these requirements allows to further specify the scenarios and in turn to define even more specific requirements, etc. The empirical existence of such expectation-requirement spirals would strongly support the assumption of the scenarios' capacity to guide actual research and development activities. Such a capacity is to be expected because scenarios are (if they are well-crafted) complexes of consistently specified cause-effect relationships thus providing a particularly good basis for translating ideas about the technological futures into instructions about how to reach there. The third hypothesis leaves it open whether the transformation of technological future concepts into actual research and development activities necessarily includes a epistemic dynamic. It is open to empirical research to which degree social and epistemic dynamics might substitute each other in this respect and different kinds and uses of future concepts such as those in ubiquitous computing in contrast to those in nanotechnology might provide different answers.

The fourth and fifth hypotheses address the context of prospective technology assessment:

H4: Scenarios are a way to spell out the possible future reality of a new technology coherently and in much detail for each domain of application that might be promising or that is expected or suspected to emerge. Scenarios are useful tools for prospective technology assessment because they provide realistic descriptions as a basis for assessing the future technology's possible risks and benefits.

H5: If scenarios have the capacity to orient research and development, they can become useful tools for shaping technology. This requires that the scenarios used for purposes of prospective technology assessment are sufficiently similar to the scenarios, which are influential in the context of research and development

When technological future concepts are the basis for assessing the risks and benefits of new technologies, the subject of such prospective technology assessment is not the future reality (which is unpredictable) but the present ideas and assumption about the future. In line with considerations of the vision assessment approach (see 3.3), it can be argued that there are circumstances under which these present ideas about the future nevertheless are important for innovation processes: If they influence the perceptions, thoughts, and actions of the actors involved. The fourth hypothesis presupposes that the scenarios' influence on innovative actors results from the realism of their descriptions of possible future realities and assumes that this realism makes them useful for prospective technology assessment. It sounds contradictory, at first, that realistic descriptions (plural!) of an unpredictable future could be given. Yet this is exactly what scenario design aims at. It becomes an attainable goal by starting with hypothetical basic assumptions about the future and limiting the task of giving realistic descriptions to the description of the consequences following from these assumptions. The above mentioned quality criteria for scenario design: credibility, consistency, coherence, completeness, and plausibility with reference to the underlying assumptions (see 5) all serve this purpose. Designed this way, scenarios are realistic only in relation to their underlying assumptions. Obviously, scenarios then can become the more realistic the more plausible these basic assumptions are.

Accordingly, with respect to the fourth hypothesis there are two main questions open for empirical research: The first question concerns the role of scenarios for generating realistic descriptions of the complexes of cause-effect relationships of which the alternate possible future realities of a new technology might consist. However, the scenarios' descriptions – even if they internally are highly realistic – might remain an intellectual game as long as their underlying assumptions are deemed unrealistic or unsubstantiated. Since scenarios by focusing on specific future technological applications are down-to-earth versions of future concepts this should be helpful for staying realistic also with respect to the scenarios' underlying assumptions. Thus, the second question concerns the suitability of scenario design for supporting the development of well-grounded basic assumptions.

In the case of prospective technology assessment, all recommendations for shaping technology have to be derived from the assessment of the new technologies as they are pictured by technological future concepts. Consequently, the quality of the recommendations depends on the quality of the future concepts used to develop them. Since scenarios allow for realistic and coherent descriptions, the fifth hypothesis assumes that this form of future concepts is especially suitable as a basis for arriving at well-founded recommendations on the shaping of future technology. However, actually to shape technology on the basis of scenarios is a demanding endeavor. It requires not only well-crafted scenarios for well-reasoned deliberation. Additionally, the relevance of the conclusions drawn from the scenario assessment depends on effectiveness of the underlying scenarios as patterns of orientation within the context of research and development. As argued above, only by influencing the thoughts and actions of the actors involved technological future concepts are of any relevance for innovation processes. Consequently, only the assessments of scenarios which are influential in this way allow to generate recommendations of relevance, if the aim is to shape technology. Thus, a further prerequisite of assessing scenarios with the aim of shaping technology is, as stated in the fifth hypothesis, that there is sufficient similarity between the TA scenarios and the scenarios of the researchers and engineers. It has to be explored empirically under which circumstances scenarios or other specific forms of technological future concepts provide epistemic orientation both in the context of research and development and in the context of prospective technology assessment. The resulting findings might show if and how such future concepts provide the means to bridge the gap between technology development and technology assessment.

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A Micro-theoretical Perspective of Multi-Level Systems of Innovation

Julian Kahl (Ruhr University Bochum, julian.kahl@rub.de)

Abstract

Comparative institutional analysis focuses on the impact of cross-national variation of institutional structures on economic growth and innovation. A fundamental concern of this literature is that national institutional arrangements are the foundation from which comparative advantage and innovative performance is derived. However, these analyses have tended to disregard the ample scope for heterogeneity at the regional, sectoral and micro-level within economic systems. In view of this lack of theoretical and empirical treatment of micro-diversity which is increasingly recognized as one of the key growth drivers and sources of evolutionary change of economic systems across a broad range of disciplines, comparative institutional analysis fails to provide a convincing explanation for the processes by which these institutional structures emerge and evolve. Taking issue with the institutional determinism as well as the static conception of economic systems underlying the varieties of capitalism framework, this paper argues that a micro-theoretical perspective on multi-level systems of innovation may provide a more nuanced view on the processes underpinning innovative activity. In this framework economic systems are conceptualized as inherently multi-level and co-evolutionary entities. That is, their structure emerges from continuous interactions of heterogeneous micro-agents embedded in innovation networks generating varied sets of resources on the one hand. On the other hand, institutional structure provides micro-agents with variegated resources that in turn may be exploited, recombined or modified at the micro-level. The main research interest in the proposed micro-theoretical framework lies in unpacking the co-evolution of micro-diversity embodied in organizational capabilities as well as institutional structure at multiple levels of innovation systems.

1 Introduction

Comparative institutional analysis and the literature on the varieties of capitalism (VoC) (Hall/Soskice 2001, Hollingsworth 2000) investigate the impact of cross-national variation of institutional structures on economic growth and innovation. The fundamental point of departure in this body of literature is that innovative performance is the result of the interplay of different national institutional arrangements. Even though micro-agents take a central position in the VoC framework, it has tended to disregard the ample scope for heterogeneity at the micro-level. In particular, patterns of economic behaviour at the micro-level are frequently conceptualized as a result of institutional logics at the macro-level. It is argued here that this takes a rather narrow view of agency and variation at the micro-level denying any strategic leeway micro-agents have to circumvent institutionally impoverished environments by drawing on different combinations of institutions (Lange 2009) available at the regional, sectoral, national or international level. The VoC's conception of economic systems also neglects the endogenous potential of micro-agents to alter macro-structures. This is unsatisfactory as micro-diversity and its transformation into novelty is recognized as the key growth driver as well as the fundamental source of the evolution of economic systems across a wide range of theoretical frameworks including complex adaptive systems approaches (Cooke 2012), evolutionary economic geography (Boschma/Martin 2010) and complex systems theory (Kauffmann 2008). Therefore, it is argued here that one of the most important issues an evolutionary theory of innovation needs to elucidate relates to the co-evolution of micro-diversity on the one hand and institutional structure on the other (Ahrweiler 2010; Cooke 2012; Saviotti 2009).

While theoretical frameworks from evolutionary economics (Lundvall 1992; Nelson 1993) initially focused on national systems of innovation (Freeman 1987; Lundvall 1992; Nelson 1993), economic systems have been shown to display considerable heterogeneity at the regional (Cooke 1992; Braczyk/Cooke/Heidenreich 1998), sectoral (Breschi/Malerba 1997; Malerba 2004) as well as the micro-level (Butzin/Rehfeld/Widmaier 2012; Cooke 2012). Moreover, innovation networks represent the central form of organization by which increasingly complex innovation processes unfold (Ahrweiler 2010; Pyka/Scharnhorst 2009; Powell 1990). These networks, shaped by geographical (Glückler 2007) as well as sectoral specificities (Kogut 2000), link heterogeneous micro-agents including firms, universities, research institutes and government agencies with varied organizational capabilities in the generation of innovation. Moreover, micro-agents' organizational capabilities are institutionally embedded (DiMaggio 2001; Granovetter 1985), that is, these agents do not innovate in isolation and depend on specific institutions – defined as "sets of common habits, routines, established practices, rules, or laws that regulate the relations and interactions between individuals, groups and organizations" (Edquist/Johnson 1997: 46). Innovation thus emerges from multiple levels of innovation systems including micro-processes that are endogenous to innovation networks as well as institutional structure (Whitley 2007) that is exogenous to these networks. A current frontier in the field of innovation studies relates to the integrated analysis of these levels as well as their impact on the evolution of innovation networks (Kudic/Pyka/Günther 2012; Parkhe/Wasserman/Ralston 2006). This paper seeks to make a contribution to this body of literature by proposing a micro-theoretical perspective on multi-level systems of innovation (MMLS) that provides a framework for the integrated analysis of micro-level change processes on the one hand and institutional selection environments at multiple levels on the other (DiMaggio 2001; Padgett/Powell 2012; Kudic/Pyka/Günther 2012).

By unpacking the fine-granulation of innovation processes (e.g. Butzin/Rehfeld/Widmaier 2012; Cooke 2012), the proposed MMLS seeks to shed light on the co-evolution of actors, networks and institutions. In contradistinction to the VoC approach that places its main emphasis on the institutional structure of innovation systems to explain innovative activity and in reference to (Ahrweiler 2010; Cooke 2012; Pyka/Scharnhorst 2009) it is argued here that innovation emerges from ongoing interactions at the micro-level. Therefore, this MMLS framework takes as a starting point that in order to understand outcomes at the macro-level, a more nuanced perspective of the micro-mechanisms and their interrelations with institutional structure that jointly produce micro-diversity is needed. Such a framework may provide important insights into the extent of the institutional structuring of firms' strategies as well as the factors that impact the evolution of micro-agents' organizational capabilities which in turn forms the basis for understanding the drivers of evolutionary change of economic systems. While acknowledging the impact of institutional forces on micro-agents, the MMLS accommodates the notion of heterogeneous actors and agent autonomy relaxing the structuralist determinism of the varieties of capitalism approach. Departing from this monolithic conception, innovative activity is conceptualized as a process embedded in multi-level systems relating to the micro-level (e.g. organizations), meso-level (regional and sectoral systems of innovation) and macro-level (national institutional settings).

This paper proceeds as follows. First, by reviewing the varieties of capitalism literature, the rationale for a multi-level analysis of innovation systems is provided. Second, an overview of the multi-level characteristics of innovation is given by addressing various theoretical frameworks that deal with innovation from different perspectives. Third, to elucidate the interrelations between the different levels of innovation systems, the co-evolution of micro-diversity and institutional structure is addressed. Ultimately, central pillars of the proposed MMLS framework are explored.

2 Varieties of capitalism

The varieties of capitalism (Hall/Soskice 2001) framework remains highly influential in comparative institutional analysis, economic sociology and institutional economics (Hancké et al. 2009). One major theoretical assumption underlying the VoC-framework is that national economies differ with regard to their institutional foundations, which has a considerable impact on behavioral patterns of micro-agents, sectoral specialization and economic output of economic systems. The interplay of different institutions provides national economies with specific comparative advantages and gives rise to distinct 'system logics' that generate particular behavioural patterns of micro-agents in terms of innovation strategies and routine problem solving approaches. The ways in which firms deal with coordination problems in specific institutional arrangements is at the heart of the VoC-approach. Hall and Soskice (2001) conceptualize firms as developing dynamic capabilities which provide them with competitive advantage. In order to develop these dynamic capabilities, firms need to coordinate relationships both internally, e.g. with their employees, as well as with their external environment, e.g. suppliers, stakeholders and trade unions. From a transaction cost theory perspective these relationships are problematic; therefore, the ways in which firms solve these coordination problems depends on their relational capabilities. A core assumption of the VoC-framework is that firms solve these coordination problems in system-specific ways relating to different spheres of the national institutional setting, i.e. industrial relations, vocational training and education systems, financial systems, corporate governance and inter-firm relations. The VoC-approach provides a supply-side theory of institutional arrangements with a view to explaining how these institutional configurations affect the supply of inputs (e.g. capital, trained personnel) available for micro-agents (Deeg/Jackson 2007). Moreover, a central starting point of the framework is the path-dependent development of economic systems. National economies are not converging on a superior model in the wake of intensified globalization. By contrast, it is assumed that these systems adhere to specific institutional trajectories which to some extent exhibit persistent characteristics.

The varieties approach identifies two different types of economic systems – coordinated (CME) and liberal market economies (LME) which, among other things, display system-specific corporate strategies, innovation patterns and inter-firm interactions. Liberal market economies such as the USA and UK are characterized by market-based institutions. In these economies, the interactions between micro-agents are based on formal contracting and competition. By contrast, in coordinated market economies such as Germany and Austria, the coordination of economic activity rests on strategic interactions, i.e. non-market-relations between economic actors. Due to their specific institutional set-up Hall and Soskice (2001) find that LMEs excel at radical innovation, while CMEs are found to specialize in incremental innovation.

2.1 National institutional domains

The following section turns to the national institutional domains and the stylized patterns of innovation of the two archetypical systems. Among the institutional domains briefly reviewed here are financial systems and corporate governance, labour markets as well as educational and training systems.

Corporate governance and financial systems represent important institutional domains in the VoC-framework. Acknowledging that there is considerable cross-country variation in the structure of these domains, different modes of coordination among micro-agents arise in light of the central coordination problem underpinning these institutional sectors, i.e. firms attempting to access finance on the one hand and investors looking to safeguard their returns on the other (Hall/Soskice 2001). Moreover, newer findings indicate that the breadth and depth of financial systems has a major impact on the output of the economy in terms of entrepreneurial activity (King/Levine 1993), technological progress (Dosi 1990), sectoral specialization (Tylecote/Conesa 1999) and macro-economic growth (Hirsch-Kreinsen 2011).

A fundamental distinction between financial systems in LMEs and CMEs refers to the type of finance provided. CMEs are characterized by bank-based and decentralized financial systems where credits are the dominant form of finance, whereas LMEs are marked by highly developed capital and equity markets. The 'insider' and 'outsider' models highlight further differences with regards to ownership, access to information and patterns of innovation. While the insider model pervasive in CMEs is particularly well-suited for sectors based on incremental innovation and patient capital, the outsider model dominant in LMEs is more conducive to the generation of radical innovation based on risky investments and in particular relating to the provision of venture capital for start-ups. The emergence of high technology sectors in liberal market economies is attributed to recent innovations in the financing of innovation (Mayer 2002) as well as institutional complementarities with other institutional domains. By contrast, financial systems in CMEs provide firms with access to credit-based patient capital that is less dependent on publicly available financial data or current profitability and more inclined to longer investment horizons. Investment decisions are frequently based on insider knowledge of firm competencies and profitability. This insider knowledge is harnessed in dense networks inside firms and with its stakeholders (suppliers, clients) providing opportunities for reputational monitoring (Hall/Soskice 2001). Moreover, the strategic mode of interaction in CMEs is also reflected in the two-tier board system, corporate constitution and employee representation within these firms wherein works councils have a strong position in strategic decisions (e.g. hiring of new employees, negotiation of severance payments), while managers have little scope for unilateral action (Vitols 2001). These institutional structures provide a fertile ground for long-term, yet low-risk investments in traditional sectors, whereas venture capital for risky ventures is scarce in these institutional environments.

National institutional frameworks also strongly influence the dynamics of labour markets which in turn impact the pattern of technological specialization and competitive advantage. A parsimonious distinction is made between internal and external labour markets. CMEs are characterized by internal labour markets which are based on long-term employment contracts and the internal creation of human capital. External labour markets refer to the practice of recruiting qualified personnel on markets. In industries where competitive advantage is achieved in high-product quality segments based on continuous product and process development, internal markets provide firms with a comparative institutional advantage. Whereas external markets are favourable in rapidly innovating science-based sectors based on short product life cycles and the reconstitution of teams of highly skilled personnel. Moreover, the highly developed equity markets also provide incentives for firms to acquire trained personnel or technologies on (external) markets. Highly qualified personnel is acquired and retained by high powered incentive systems. Due to the weak labour regulations recruiting personnel on highly fluid labour markets is pervasive which enables firms to react to developments on (equity) markets swiftly (Hall/Soskice 2001). By contrast, impoverished external markets in CMEs may substantially mitigate the capacity of firms to compete on these markets (Coriat/Weinstein 2004)

Finally, among educational and training systems there exists considerable cross-country variation. In broad terms, the inclination of these systems towards basic or vocational training has an impact on the type of skills readily available for firms in national economies (Hall/Soskice 2001). Moreover, national systems of innovation also differ markedly with regards to the commercialization of knowledge and technological transfer between basic science and business (Feldman et al. 2006).

2.2 Pitfalls of the varieties of capitalism framework

While the VoC-approach provides a simple, yet powerful way of comparing economic systems, it cannot explain the variation at the regional level, sectoral and micro-level. Furthermore, the approach cannot explain why and how economic systems change. Indeed, the varieties of capitalism approach has recently been subjected to intensive critique (Akkermanns et al. 2009; Allen 2004; Lange 2009; Peck/Theodore

2007; Taylor 2004). By way of conceptualizing economic systems as homogeneous entities, the varieties approach adopts a highly-stylized perspective of economic development falling short on some of the most fundamental aspects of economic activity. One central criticism levelled at the VoC-approach in this regard concerns the lack of heterogeneity afforded in this framework. Allen (2004) challenges the premise of a homogeneous mode of coordination within economic systems underlying the VoC-framework. From this perspective, although there may exist dominant sets of institutions, these institutions may not radiate across entire economic systems as readily as assumed in the VoC-framework. On the contrary, some sets of institutions may follow their own logic remaining largely unaffected by national institutional arrangements. Moreover, in contrast to the varieties literature Hollingsworth et al. (1994) find that within countries there is ample variation among sectors with regards to governance structures (e.g. level of state intervention or type of inter-organizational networks) which has a considerable impact on the performance of these sectors. While acknowledging the specificities of sectoral governance within economies, it is argued that these governance structures are also highly varied across countries as national institutions and sectoral governance regimes interact giving rise to varied economic performance and innovative output. By contrast, in a dynamic perspective, the second-order coordination argument holds that the increasing internationalization of some of the components of economic systems results in a structural alignment which gradually erodes national institutional arrangements (Ahrweiler/Gilbert/Pyka 2006). Collaborative activities within internationalized networks are identified as central drivers facilitating a harmonization of structures that increasingly displaces national institutional frameworks. For instance, the recent success of high technology sectors such as the biotechnology or the internet software industry in Germany or Sweden are indications of the erosion of structural differences between the CMEs and LMEs. In contradistinction to these findings, a wide range of studies emphasizes the persistence of cross-national differences in terms of strategy (Haeussler 2011), sectoral specialization (Casper 2006) and venture capital (Ahlstrom /Bruton 2006).

3 Rationales for a micro-theoretical perspective of multi-level systems

A key premise of the VoC-framework relates to the institutional structuring of agency. Institutional frameworks provide certain types of resources for micro-agents thereby supporting different innovation strategies, which is why firms in favourable environments outperform their counterparts in more institutionally impoverished environments. However, in doing so, the varieties framework theorizes economic actors as having uniform preferences endogenous to certain types of institutional environments (Allen 2004). By way of conceptualizing economic systems and micro-agents as homogeneous entities, the 'varieties' approach thus adopts a highly-stylized perspective of economic development 'reading-off' micro-level properties from macro-institutions. This view represents a structuralist determinism reducing the scope of individual manoeuvre drastically (Deeg/Jackson 2007). The lack of empirical treatment of the firm may be attributed to the aggregate perspective underlying the VoC approach. This perspective may explain why firms' strategies as well inter-firm networks have not been central aspects in this framework. Also, due to the preoccupation with aggregates, the interrelations between the micro-level and the macro-level have been underrepresented. In order to understand outcomes at the macro-level, however, it is argued that processes at the micro-level need to be taken into consideration as individual economic agents do not intentionally produce some sort of institutional or spatial structure.

The proposed MMLS may provide a more nuanced perspective on the institutional structuring and evolution of organizational capabilities by affording attention to the interplay of two superordinate dimensions, notably structure and agency (Giddens 1984). In line with the notion of the duality of structure underlying structuration theory, the MMLS is attentive to the structural properties of systems which "are both medium and outcome of the practices they recursively organise" (Giddens 1984: 25). A starting point is that the hierarchical structure of multi-level systems has a bearing on micro-agents in terms of providing latent institutional resources on the one hand and constraints on the other impacting micro-agents, for instance, in terms of innovative performance (DiMaggio 2001). Organizational capabilities and the processes by which firms exploit, recombine and modify latent institutional resources as well as their capacity to circumvent impoverished institutional environments are contended to vary considerably at the micro-level. The aggregate of these processes generate and incrementally change macro-structures. In contrast to the varieties of capitalism literature, the structuralist determinism is thus relaxed providing considerable scope for agency and variation. 'Structure' may be decomposed into three interrelated analytical components, notably the macro-level (national institutional settings), meso-level (regional and sectoral systems of innovation) as well as the micro-level ('agency') relating to the behavioural patterns of micro-agents at the firm and network level. Understanding the complex interplay between structure and agency may provide meaningful insights into the drivers of innovative performance and the evolution of these systems.

In the following sections the theoretical frameworks dealing with innovation on the different levels of innovation systems will be reviewed. Following this review, the outlines of a MMLS will be elucidated. A starting point relates to the question why firms should be conceptualized as heterogeneous entities.

4 Micro-theoretical foundations of MLS

4.1 Theory of the firm

An answer to the question posed above (Nelson 1991) is provided by the resource-based view of the firm (RBV) (Penrose 1959). Rather than industry structure and the static equilibrium framework of industrial organization (Porter/Caves 1977), the RBV argues that understanding differential firm behaviour and performance rests on the persistent heterogeneity of resource endowments and the creation of idiosyncratic firm-internal resources. While many resources can be bought and sold on factor markets, some assets remain non-appropriable as factor markets remain incomplete. Moreover, in many cases implementing certain firm strategies requires highly firm-specific assets, which are developed internally. In a standard static equilibrium perspective, these differential resource endowments would simply erode due to the perfect mobility of resources (Dierickx/Cool 1989). Therefore, resources are defined as those (tangible and intangible) assets which are tied semi-permanently to the firm (Wernerfelt 1984). Firm's competitive positions are therefore shaped by internal resources and capabilities which are also the main source of their profit[1].

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[1] More particularly, resources relate to the firm's capital consisting of physical, financial and immaterial capital. Physical capital

With a view to explaining the size and scope of firms, Penrose (1959) points to the type of resources firms utilize: it is the abundance or the scarcity of resources that impacts the choice of markets and profits. Constraining factors for firm growth include (1) limited supply of labour or physical inputs, (2) financial restrictions, (3) investment opportunities and (4) inadequate managerial competence – all of which may vary considerably across the multiple levels of innovation systems. It follows from this view that if all firms were endowed with the same stocks of resources, there would be no above-normal rents and first-mover advantages. Therefore, an industry must necessarily be made up of heterogeneous components for there to exist competitive advantage (Barney 1991). Drawing on Schumpeter (1942), Penrose (1959) conceptualizes the competitive process in which micro-agents vie for resources for survival as being shaped by uncertainty and disequilibrium. Moreover, in this process micro-agents may accumulate knowledge through learning and R&D investments thus fostering absorption capacities (Cohen/Levinthal 1990) which implies that this is an evolutionary and path-dependent process (Mahoney/Pandian 1992; Nelson/Winter 1982; Teece et al. 1997; Teece 1991).

4.2 Dyadic relations and networks

A main focus in strategy research has been on explaining differential firm performance viewing firms as autonomous entities. More recent studies expand on this view of firms in a world that is increasingly organized in networks of inter-organizational relations. Ibarra et al. (2005) note that the network literature has evolved along two distinct trajectories. One trajectory is concerned with the micro-level of networks (e.g. Dyer/Singh 1998; Gulatti et al. 2000; Hite/Hesterly 2001; Larson 1992), whereas the other deals with networks from a macro perspective (e.g. Barabási/Albert 1999; Watts/Strogatz 1998).

A starting point of micro-theoretical perspectives of networks is that that understanding differential firm strategies and performance necessitates the investigation of network ties encapsulating firms in multiple relationships (Gulatti et al. 2000). Acknowledging that any network may be disassembled into a given number of dyads, the basic unit of analysis is the dyad in these studies (e.g. Mowery 1998; Mytelka 1991; Teece 1997). One of the approaches dealing with this basic unit of network relations is the 'relational view' (Dyer/Singh 1998). A central assumption underpinning this approach is that a firm's competitive resources may be embedded in inter-organizational networks producing relational rents, i.e. rents created from pooling resources generating products or services that could not have been created by either firm in isolation (Dyer/Singh 1998). In this view, relational rents are strongly connected to firm-internal competencies. Therefore, the relational-view may be seen as a logical extension of the resource-based view.

Rather than focusing on dyads, social network theory (SNT) examines entire networks. Networks are conceptualized as "a set of actors connected by a set of ties" (Borgatti/Foster 2003). Actors are often referred to as nodes which are connected by shared endpoints that directly or indirectly link nodes producing a particular network structure with different topological characteristics (e.g. "centrality", "betweenness", "density", "homophily"). A fundamental concern of SNT relates to the topological characteristics of net-

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includes access to natural resources, raw materials, machinery, inventories etc. Financial capital comprises liquid capital, shares, bonds, securities and so on. Immaterial capital refers to both embodied and disembodied capital such as know-how, business ideas, licenses, designs and copyrights (Grant 1991).

work structure and nodes' positions within them in relation to outcomes at the node and network level of analysis (Borgatti 2011). While a rich body of literature has emerged in SNT (see Bergenholtz/Waldström 2011 for a literature review), three major perspectives will be considered briefly, that is, the structuralist and the institutional as well as an approach that will be referred to as technologist.

One of the earliest approaches of network analysis is the structuralist perspective (Burt 1992), in which a fundamental claim is that nodes that occupy similar network positions exhibit commonalities in terms of a defined outcome (e.g. innovative output). In the structuralist view individual nodes are by and large homogeneous entities – the only distinction being structural positions that provide opportunities (e.g. ability to innovate) and constraints. Structurally equivalent nodes are expected to display common attributes (e.g. behaviour) (Borgatti et al. 2009; Borgatti/Foster 2003). Moreover, Barabási and Albert (1999) make a seminal contribution to the structuralist perspective by showing that networks across a broad range of systems including genetic networks as well as socio-economic systems undergo constant expansion by adding new nodes. More precisely, new nodes are added by preferential attachment, that is, the new nodes enter into already well connected network regions.

However, the structuralist perspective of networks affords little attention to node properties and agency (Ahrweiler 2010). Thus from a MMLS perspective, this view of networks may be criticized in terms of its inherent structuralist determinism and the lack of agency treating central features of network nodes and ties as well as the processes by which networks evolve as blackboxes. That is, the growth dynamics of Barabási-type complex networks do not provide insights into the micro-mechanisms by which networks and individual nodes co-evolve. We argue here that due to various endogenous as well as exogenous factors, network evolution should rather be understood as a nonlinear process. Therefore, even though relational rents may arise from the position of firms within a network, network nodes' heterogeneous organizational capabilities should receive equal attention. To illustrate the point why it is important to conceptualize networks as consisting of heterogeneous agents, consider the following: The capability of building and occupying a certain position within a network vis-à-vis competitors or strategic partners depends on mobilizing internal resources. This implies that attaining a network position necessarily presupposes efforts by heterogeneous actors for any sort of order to emerge. Once these positions are captured, they may yield certain rents. However, it is argued here that understanding how network structures have developed and in which direction they are going to evolve requires a more nuanced perspective.

In this context Powell et al. (2005) argue that structuralist approaches focusing on topological characteristics of networks have neglected institutional underpinnings as well as the heterogeneous demography of nodes - all of which substantially impact the flow of information and evolution of networks. A starting point of this literature is that that formal structures of organizations are shaped by institutional environments (Meyer/Rowan 1977). Recognizing that organizations are embedded in relational and institutional contexts in organizational fields, networks are conceptualized as transmission channels of organizing principles. In organizational fields, particular patterns of information flows emerge from the status order of individual organizations, which engenders a core and periphery. In broad terms, agents in the periphery emulate the structure and behaviour of the most central ones by mimetic processes. In the process of structural convergence, institutional logics such as rules and conventions representing specific organizing principles play a major role (Powell et al. 2005). By contrast, rather than focusing on institutional principles of network structure a related strand of literature highlights the technological underpinnings of networks. The technologist view argues that technological generative rules give rise to network structure, which in turn influences firm' behaviour (Kogut 2000). In these approaches, network structure reflects different sets of operating principles ensconced in technologically specific knowledge bases underlying industries.

Taking technologies or institutions as a starting point, however, may considerably underestimate the scope for variation at the national and micro-level. Moreover, the question remains how technological and institutional organizing principles interact and impact the structure and dynamics of networks. Informing the construction of our MMLS framework, we draw from these analyses the differential impact of technological knowledge bases as well as institutional environments on network structure and the evolution of organizational capabilities. In addition, fundamental questions relating to the analysis of MMLS include: Why is there ample scope of variation among network structures in the same technological field? Does the structure and evolution of networks vary in different national and regional contexts? Are there indications of structural alignment or convergence among industries embedded in different national institutional settings? In what ways do networks and institutional environments co-evolve? The meso-level of innovation systems may shed light on a number of these issues.

5 Meso-level

The varieties of capitalism framework conceptualizes economic systems as flat and closed entities. Evolutionary economic geography, however, shows that economic and innovative activity are highly concentrated (e.g. Jaffe/Henderson/Trajtenberg 1993) within a variegated and evolving landscape of interconnected regional economies (Boschma/Martin 2010; Cooke 2001; Doloreux/Parto 2005; Martin/Sunley 2006), wherein various sectoral systems of innovation (Malerba 2004) with varied knowledge bases and heterogeneous micro-agents compete for resources within regionally as well as sectorally bounded selection environments. Jointly, these interacting components give rise to the meso-level of innovation systems which may vastly diverge from the national level and incrementally transform the latter thus generating novel macro-structures (Cooke 2012).

5.1 Sectoral systems of innovation

The concept of sectoral systems of innovation provides a basis for explaining and empirically investigating the question why different sectoral regimes emerge under one national institutional framework (Strambach 2010). This concept accommodates the notion that "innovation systems…tend to be sectorally specific" (Nelson 1992: 371). Malerba (2004: 16) defines sectoral systems of innovation as a "set of activities unified by some linked product groups for a given or emerging demand and characterized by a common knowledge base". Knowledge bases differ across sectors in terms of their specificity, tacitness, complexity and interdependence (Breschi et al. 2000). A central premise of the sectoral systems of innovation (SSI) framework is that innovation patterns tend to display commonalities across countries. These cross-national contingencies are attributed to sector-specific technological regimes, knowledge bases, actors, networks and institutions.

Drawing on the concept of technological regimes by Nelson and Winter (1982), the SSI approach emphasizes the importance of the technological environment for the organization and evolution of industries. Technological regimes are defined by the specific composition of opportunity, cumulativeness and appropriability of innovation, which represent central economic properties of technologies. These in turn greatly affect the incentives and requisite organizational capabilities in innovation processes. Technological opportunity conditions relate to the potential with respect to the likelihood of generating innovative activities for the invested amount of funds. These conditions are found to vary considerably across technological regimes. Moreover, the appropriability conditions, that is, the mechanisms by which firms safeguard their innovations from competitors as well as technological cumulativeness referring to the extent to which the generation of novel knowledge builds on extant knowledge may also strongly vary across technological regimes (Malerba 2002). These, in turn, give rise to specific learning processes, structural patterns of innovation (e.g. industrial concentration, the rate of entry and exit) as well as the transformation of sectoral systems of innovation (Breschi et al 2000). In the SSI-framework, technological regimes thus account for much of the cross-country invariance in terms of innovation patterns. The different elements of SSI, i.e. knowledge bases, actors, networks and institutions co-evolve giving rise to distinct patterns of innovation (Coriat et al. 2004). A parsimonious distinction of innovative activity across industries is made between Schumpeter Mark I and Schumpeter Mark II industries. This distinction focuses on the systematic distribution of innovative patterns among entrants and incumbents. The former constitute learning regimes in turbulent environments with great amounts of entries, entrepreneurial activity and processes of 'creative destruction' constantly challenging and eroding incumbent's positions. By contrast, a distinct feature of Schumpeter Mark II industries are processes of 'creative accumulation', by which dominant industry incumbents 'deepen' their competitive positions by way of accumulating capabilities over time in relative stabile environments with relatively high barriers to entry (Breschi et al. 2000; Malerba/Orsenigo 1997).

The SSI-framework holds that heterogeneous micro-agents in similar technological regimes display common behavioural characteristics and organizational forms (Malerba 2002). It is assumed that these regularities also apply to the transformation of industries. However, while some of the conditions underpinning technological regimes are held to be constant across countries, it is conceded in the SSI-framework that the capacity to exploit and create technological opportunities varies substantially across countries relating to national institutional frameworks. The SSI-framework is also attentive to the notion of heterogeneous micro-agents and sector-specific networks of innovators (Malerba 2004). However, the integrated analysis of actors, networks and institutions found in this framework has tended to underrepresent micro-diversity and the processes by which organizational capabilities and networks evolve. This is closely connected to the level of analysis of this framework: Although the SSI framework recognizes the impact of institutions and the heterogeneity of micro-agents, the focus of this framework has been on the relation between technological regimes, industrial structure and evolution in an aggregate perspective. In doing so, the specificities of national systems of innovation are frequently regarded as 'residuals'. It is argued here that understanding the interplay between the institutional features and sectoral patterns of innovation and their manifestation at the micro-level is key for understanding the factors inhibiting or driving industrial performance. More generally, little is known about the extent to which sectoral systems of innovation are shaped by national institutional settings such as financial systems, labour markets, science and education systems on the one hand and the evolution of organizational capabilities on the other. For instance, as entrant's requirements of finance also varies markedly across industries, nation-specific financial systems may impact the evolution of certain organizational capabilities which give rise to specific industries that in turn disproportionately contribute to aggregate economic growth (O'Sullivan 2005). In addition to heterogeneity at the sectoral-level, a growing literature points to the great scope of variety at the regional level.

5.2 Regional systems of innovation

An extensive of body of literature has highlighted the importance of the regional level for innovative performance (Asheim/Gertler 2005; Audretsch/Feldman 1996; Braczyk/Heidenreich/Cooke 1998; Camagni 1991; Porter 1990) and the scope for variation of economic systems at the regional level (Voelzkow 2007). Rather than eroding the importance of local proximity, globalisation forces as well as the shift towards the knowledge-based economy (OECD 1996) seem to accentuate the importance of localised production systems (Asheim/Gertler 2005; Porter 1990). Regional concentrations of "interconnected companies, specialized suppliers, service providers, firms in related industries, associated institutions in particular fields" (Porter 1998: 199) lay the geographical foundation from which innovation emerges. The driving forces that give rise to the spatial clustering of economic activity have been elicited by Marshall (1890) and more recently formalised by Krugman (1991), namely in terms of three different types of externalities, i.e. the development of a local pool of specialised labour, local provision of non-traded inputs specific to an industry in greater variety and at lower cost as well as the flow of information, ideas and technological spillovers in spatial proximity. Particularly the last type of localised externalities have been shown to facilitate the transmission of knowledge and the generation of innovation among interacting micro-agents embedded in regional systems of innovation (RSI) (Cooke 1992).

Recent approaches in economic geography have focused on evolutionary aspects of economic development (Boschma/Martin 2010) in general and cluster life cycles (Menzel/Fornahl 2010) in particular. One of the central points raised by these strands of literature is that economic development is affected by constant structural change and upheaval forces; throughout history new industries have emerged and mature industries have declined or relocated in non-predetermined path-dependent processes (Martin/Sunley 2006) which have in turn laid the foundation for upswings as well as the decline of regional economies. Audretsch and Feldman (1996) link the notion of industrial life cycles to the geography of innovation. That is, the propensity of innovative activity to cluster spatially is closely linked to the evolution of industry life cycles; while particularly in early industry life stages the share of tacit knowledge is highest (Audretsch/Feldman 1996), newer findings indicate that as industries mature an increasing codification of knowledge takes place which in turn leads to a dispersal of economic activity. In these mature stages of cluster life cycles, positive agglomeration effects are offset by congestion effects. Thus, micro-agents primarily benefit from co-location within clusters between two distinct junctures, namely after the emergence of clusters, that is, when the regional concentration has reached a critical mass and until the heterogeneity of a cluster is exhausted due to mutual learning processes and the subsequent convergence of regional competencies (Menzel/Fornahl 2010). Upon depletion of micro-diversity, maturity or stagnation of cluster growth may set in thus turning the benefits derived from clustering into liabilities locking regional economies into downward spirals of development.

Regional systems of innovation are thus faced with the challenge of constantly having to adapt to changing environments by generating micro-diversity and renewing their knowledge bases (Cooke 2012). RIS may facilitate localized learning processes by way of providing an institutional support infrastructure on the basis of which micro-agents may import, recombine, generate and diffuse highly complex tacit knowledge (Cooke 2008: 402; Polany 1966). The accumulation of these idiosyncratic resources may continuously deepen and widen the regional knowledge base (Asheim/Coenen 2005) and thus form the foundation for ''localized capabilities' (Maskell 1997) and 'competitiveness' (Porter 1990) at the firm and regional level. More particularly, localized learning processes are facilitated by regionally embedded subsystems (Cooke 1997). On the one hand, RIS are comprised of knowledge generation and diffusion subsystems engaged in the production and dissemination of knowledge and skills within regional institutions such as public research institutions, technology mediating organizations as well as education facilities. On the other hand, RIS are shaped by knowledge application and exploitation subsystems encompassing firms, clients, suppliers, competitors, financing institutions, industry associations and government agencies (Tödtling/Trippl 2011).

Although the literature on regional systems of innovation has made extensive progress on the factors underpinning the geography of innovation, the framework has only recently begun to shed light on the micro-processes by which RIS emerge and evolve (Boschma/Martin 2010; Cooke 2012). Similar to comparative institutional analysis, this shortcoming may be attributed to economic geography's concern for populations of firms. In most studies on the geography of innovation, geographical proximity among micro-agents is equated with different kinds of innovative outputs such as knowledge externalities and localized learning. More recently, geographical proximity as such has been proven to be insufficient for explaining innovative outcomes (Boschma 2005; Doloreux/Parto 2005). Moreover, the RIS literature has by and large contended that dense networks of inter-firm cooperation are favourable to regional economic performance. However, this notion neglects the processes and structure underpinning these networks (Giuliani 2010). In sum, the notion of proximity is increasingly deemed insufficient for understanding the complex interactions among micro-agents. That is, the notion of 'proximity' treats interactions among micro-agents as a black-box reading-off micro-actor's properties from meso-structures. Therefore, a framework that is attentive to the micro-mechanisms by which RIS emerge, adapt or fail to adapt to changing environments may elucidate a more nuanced view in this context.

6 Towards a micro-theoretical framework of multi-level systems

In the final chapter of this paper, the outlines of the MMLS will be elucidated. This model is informed by the fundamental finding of the literature review provided above relating to the insufficient treatment of the micro-mechanisms that underpin the co-evolution of actors, networks and institutions that produce the fluctuations of aggregate variables and institutional structure (see also Cooke 2012). Drawing on some of the major tenets of complexity-based approaches (Ahrweiler 2010; Kaufmann 1993; Prigogine/Nicolis 1989; Saviotti 2009; Pyka/Scharnhorst 2009), the co-evolution of structure and agency is afforded a central position in this framework. At the heart of this process is one of the most important evolutionary concepts, notably co-evolution. Co-evolution is one of the fundamental mechanisms driving evolutionary change of economic systems. It captures the interactions and feedback loops between two components within a given system over a certain period of time (e.g. Murman 2003). While co-evolution and multi-level theory have in common their concern for interaction effects among different interacting components and different levels respectively, co-*evolution* adds to this type of analysis the time dimension[2]. The last section will briefly sketch out some of the major dynamics of such interaction effects.

6.1 The co-evolution of structure and agency

Complexity theory (e.g. Kaufmann 1993) offers a fruitful starting point to address the co-evolution of structure and agency (Fuchs 2003). This relates to one of the fundamental explananda of evolutionary economic development, that is, the emergence and transformation of order. Even though in the course of economic development micro-diversity increases, economic systems do not tend to display higher levels of randomness. On the contrary, bifurcations, that is, discontinuous and radical changes to structure notwithstanding, economic systems display considerable stability with incremental, rather than radical variation (Saviotti 2009). Bifurcations are a consequence of the inherent propensity of socio-economic systems to transformation which has qualitative components giving rise to new types of entities and interactions as well as quantitative underpinnings, referring to growing efficiency and increasing micro-diversity, that is, an increasing number and heterogeneity of entities within economic systems (Saviotti 2010). Understanding how such micro-diversity is generated and how it co-evolves with its institutional selection environment is the central question a micro-theoretical perspective of multi-level systems of innovation (MMLS) seeks to address. Complexity theory offers at least two important processes by which such evolution takes place, that is, autocatalysis and the above described process of co-evolution.

Autocatalysis is a central concept from complexity theory that provides a meaningful explanation to processes by which small initial differences are scaled-up into macro-level phenomena (Padgett/Powell 2012). Autocatalysis refers to a cyclical concatenation of processes that engenders and stimulates growth of its constituent components until a certain threshold is reached (Ulanowicz 1997). In this process, autocatalysis promotes competition and selection in specific directions towards autocatalytic sets[3]. Originally, autocatalytic sets were used to describe chemical reaction networks that if provided with the required energy inputs would reproduce over time. These reproductions may be carried forward even in the event that some of its constituent components (e.g. network nodes) are removed by mechanisms of self-repair and resilience (Padgett/Powell 2012). Moreover, autocatalysis is not limited to a single loop, it "transfers its influence to the wider systemic environment via con-

[2] Co-evolution is itself a multi-level phenomenon (Cooke 2012); for instance, innovation system scholars have focused on the co-evolution of institutions and technologies (Nelson 1993), whereas business scholars have investigated the co-evolution of different levels of organizations (Klein/Kozlowski 2000). More recently, the co-evolutionary nature of network development (Doreian/Stokman 2005; Lewin/Volberda 1999; Volberda/Lewin 2003) and industries (Ter Wal/Boschma 2005; Kudic/Pyka/Günther 2012) as well as regional specificities of network evolution (Glückler 2007) have gained attention.

[3] Autocatalytic sets are defined as a "set of nodes and transformations in which all nodes are reconstructed through transformations among nodes in the set" (Padgett/Powell 2012: 8)

nections that exist among assemblages of autocatalytic loops" (Matutinovic 2005). Thus in economic systems autocatalytic sets refer to patterns at the micro-level (e.g. organizational capabilities) that by way of reproduction may become prolific over time thus generating and transforming meso- and macro-structures. With respect to the evolution of structure and agency, one of the principle problems emerging from this notion is connected to the processes by which micro-agents self-organize into self-replicating autocatalytic sets and how these sets co-evolve with institutional selection environments.

Evolutionary economic geography (e.g. Boschma/Martin) shows that variation at the meso-level plays an important intermediate role in generating and transforming institutional structure (Cooke 2012) by absorbing interregional knowledge spillovers (Giuliani 2005) and incrementally building regional knowledge bases as well as by disseminating novel combinations and endogenous resources (Bathelt/Malmberg/Maskell 2004) by the workings of a number of interacting heterogeneous micro-agents. Moreover, regional systems of innovation are conceptualized here as dynamic selection environments within and across which micro-agents engage in the competition for resources the outcome of which determines the creation and destruction of micro-diversity. In this process, the region's properties co-evolve with the deliberate attempts of micro-agents to modify meso-institutional environments (Essletzbichler/Rigby 2010). Indeed, these modifications must not be commensurate with incremental or radical transformations of structure, but may also relate to strategies of auto-protection locking regional economies into protracted periods of institutional stagnation (Grabher 1993). More generally, in the proposed framework, macro-institutional structure is thus conceptualized as an emergent property of autocatalytic micro-level processes which may be strongly mediated at the meso-level. This underscores the central position agency is afforded in the MMLS framework.

6.2 Central pillars of a micro-theoretical framework of MLS

We propose to conceptualize and empirically analyze agency as the highly varied organizational capabilities of micro-agents to generate and leverage resources and to adapt to evolving institutional selection environments. These capabilities are the outcome of micro-agents' knowledge bases and resources which may span organizational boundaries (networks) and may include higher-order latent institutional resources, that is, resources at the meso- and macro-level. Thus at the basis of the proposed model are micro-agents conceptualized as heterogeneous factors bundles with varying resources, strategies and absorptive capacities (Baum/Rowley 2008; Cohen/Levinthal 1990; Penrose 1959; March 1991) embedded into a direct environment comprising the ego-centered network of the focal firms as well as an intermediate meso-level shaped by sectoral (Malerba 2004) and regional systems of innovation (Cooke 1992) and a macro-level comprising the national institutional framework (Hall/Soskice 2001).

Rather than merely 'selecting' those kinds of organizational capabilities that fit a specific selection environment, institutional structure provides a specific set of what is here referred to as 'latent institutional resources' (cf. Murman 2003). 'Latent' denotes that these institutional resources are potentially available to micro-agents, that is, they are not accessible and interpretable to the same degree by all micro-agents as these exhibit heterogeneous capabilities in terms of transforming these resources into resource generating and leveraging mechanisms. Given the heterogeneity of organizational capabilities, micro-agents may engage in networks to access complementary stocks of resources (Pyka/Küppers 2002). In doing so, micro-agents are contended to display the capacity of circumventing and adapting to impoverished institutional environments by modifying latent institutional resources and creating endogenous resource bundles. In this process, networks play an important role. These networks may be extremely clustered generating localised externalities which are conducive to the formation of highly idiosyncratic resource bundles not supported by the macro-institutional environment (Voelzkow 2007). Firms may also engage in institutional arbitrage by way of internationalizing their activities in highly dispersed networks providing functional equivalents of institutions (Ahrweiler/Gilbert/Pyka 2006) or combine both institutional arbitrage and local clustering (Bathelt/Malmberg/Maskell 2004).

More particularly, organizational capabilities are conceptualized as an outcome of the configuration of activities and resources across the focal firm's internal value chain as well as the properties and the management of the focal firm's network relations embedded in a specific network structure. On the interior resources relate to financial assets and the technological knowledge base as well as organizational competence referring to e.g. recruitment of qualified personnel and management capability. To leverage these resources, firms may draw on their relational exterior. Firms also display varying relational capabilities, that is, the ability to build and sustain relations with other firms (Dyer/Singh 1998). Moreover, the focal firm as well as the network nodes may pursue complementary or non-complementary proprietary as well as network strategies. With respect to the types of proprietary strategies firms pursue, a parsimonious distinction is made between exploration and exploitation (Lavie/Rosenkopf 2006; Levinthal/March 1993; March 1991). Exploration refers to "search, variation, risk taking, experimentation, play, flexibility, discovery, innovation" (March 1991: 71), whereas exploitation may be described by "refinement choice, production, efficiency, selection, implementation, execution" (ebd.). To safeguard survival, firms need to balance these activities both internally and within their networks (Lavie/Rosenkopf 2006). That is, micro-agents are conceptualized here as primarily interested in attaining these proprietary strategies, while network nodes may facilitate or constrain these attempts by providing complementary resources.

Balancing these activities requires the focal firm to build and sustain appropriate portfolios of relational ties and to capture promising network positions. Relational ties between the focal firm and network nodes represent the channels through which various types of resources may be exchanged (Hite 2008). These ties may have multidimensional properties (Hite 2003), which in turn may increase competitive advantage (Dyer/Singh 1998). To leverage proprietary strategies, focal firms and nodes may pursue varied network strategies (Baum/Rowley 2008; Doreian 2008). Drawing on Kudic et al. (2012), these network strategies may relate to progressive, moderate and conservative relational orientations, where progressive strategies refer to the rapid expansion of network ties to gain access to resources, while moderate strategies relate to more gradual expansion and conservative strategies aim at retaining the existing stock of resources.

The interplay of the firm, relational, node and network level create a complex and evolving network structure with specific properties (e.g. density, homophily) which in turn give rise to network trajectories (Kilduff/Tsai 2003). These trajectories are the outcome of the strategic orientation of focal firms and network nodes at point t_0 which in turn impacts the type of cooperation options in the future at t_1 (Kudic/Pyka/Günther 2012). Jointly, behavioural patterns of focal firms and nodes give rise to specific patterns of network change[4] (Koka/Madhavan/Prescott 2006).

Moreover, organizational capabilities may be reproduced or modified over time via adapting firm-level, node- or network-level properties, that is, variables endogenous to networks. To illustrate this point consider for instance the evolution of a dyadic relation D_1 between a present (t_0) and future (t_1) point in time between the focal firm F_1 and the network node N_1 that provides specific sets of resources DR_1 to F_1 and DR_2 to network node N_1. While benefits derived from D_1 are distributed equally at the inception of the relation, for purposes of illustration, F_1 extracts larger relational rents as a result of F_1's superior absorptive capacity and relational capabilities. Moreover, although resources derived from DR_1 and DR_2 exhibit positive, albeit diminishing returns, upon reaching an inflection point IP_1 and IP_2 respectively the benefits obtained from DR_1 and DR_2 decline sharply in this exemplar. First, resource accumulation between t_0 and t_1 disproportionately increase resource stocks of F_1. However, upon reaching IP_1 it may be rational for F_1 to alter its relational tie to N_1, whereas N_1 may then still have an interest in the relation in view of the resource gained from DR_2. F_1 may decide to dissolve the relation. This in turn modifies network structure. Moreover, F_1 may not be aware of the changing nature of its relation to N_1 (Simon 1959) or deliberately choose to maintain its relation in view of switching costs. More generally, the focal firms' complex portfolio of discretely evolving relations impacts the amount of resources available for F_1, which in turn impacts network structure. These sets of resources must not necessarily be superior to the one at t_0. Indeed, it is widely accepted that network relations may become liabilities (Hagedoorn/Frankort 2008) and exhibit diminishing returns (Deeds/Hill 1996). However, the processes by which this takes place and how this relates to network structure remains less clear.

In the above described relation between F_1 and N_1, the changing quality of institutional selection environments may also play a central role as these changes may impact the level of latent institutional resources available for the focal firms' and network nodes' strategic action. For the sake of parsimony and in reference to Koka et al. (2006) as well as Hall and Soskice (2001), we distinguish between resource abundant and resource impoverished institutional environments (cf. Fig. 1). While resource abundance describes institutional environments that offer favourable bundles of latent institutional resource (e.g. access to finance, qualified labour) and thus hospitable conditions for growth, impoverished institutional environments provide limited amounts of resources and may thus inhibit growth. This raises the question whether and how micro-agents adapt their organizational capabilities and network relations to changing institutional selection environments (Saviotti 2009: 21) and how this affects network structure as well as performance (e.g. outputs such as innovation, revenues). The interrelation between institutional environments at multiple levels of innovation systems represents another central analytical dimension of the MMLS framework.

[4] These patterns of network change include expansion, churning, strengthening and shrinking.

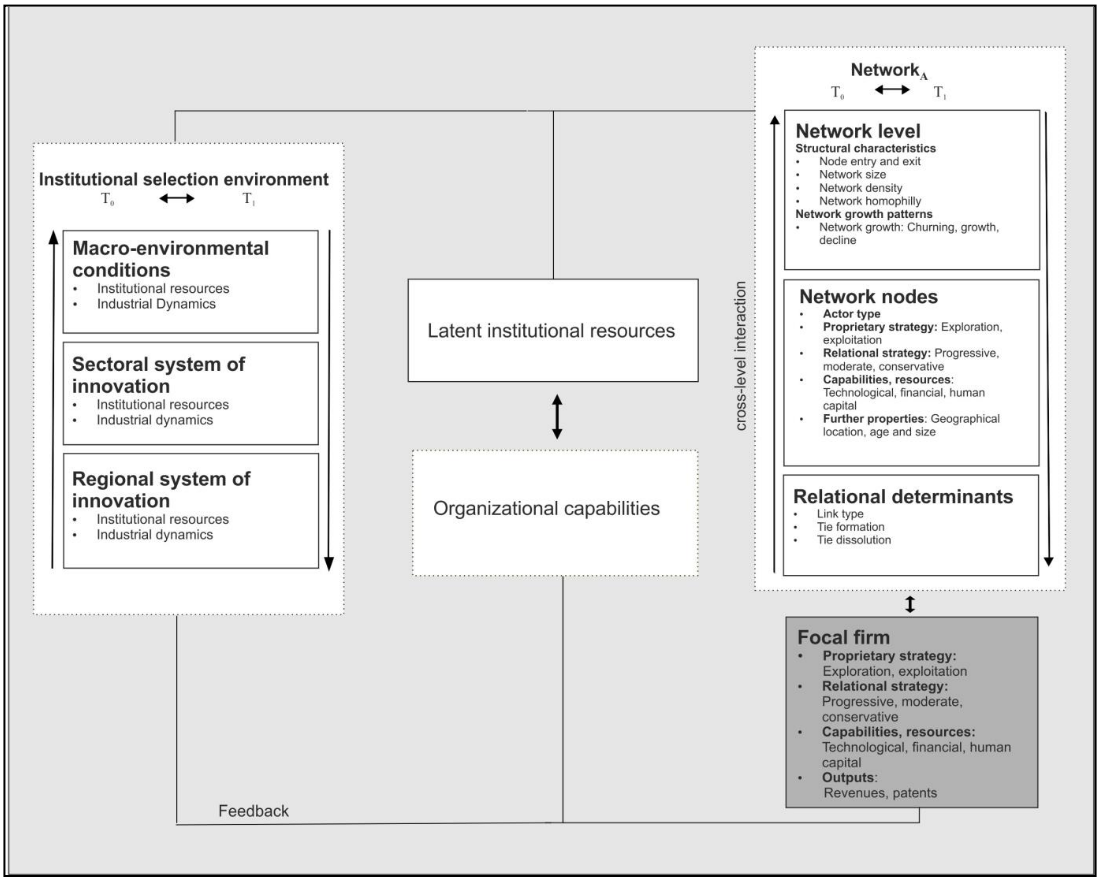

Figure 1: A framework for the analysis of the co-evolution of actors, networks and institutions

Drawing on Hite and Hesterly (2001) we thus seek to analyze the evolution of organizational capabilities embedded in inter-organizational networks as adaptation to changing resource requirements and resource acquisition challenges of the focal firm. Moreover, following these authors we conjecture here that resource challenges do not unidirectionally affect network evolution; network evolution also impacts the set of resources available to the firm in the future. That is, the relation between firms and their networks is co-evolutionary as is the relation between the focal firm and networks (Soda/Zaheer/Carlone 2008) as well as the institutional selection environment.

6.3 Cross-level effects

Having introduced some of the most relevant components of the proposed MMLS-perspective, the last section briefly turns to the expected cross-level effects that this framework seeks to address. One basic assumption underpinning multi-level theory is that understanding outcomes at one level of analysis requires researchers to account for the interrelations of this level with higher and lower levels of analysis (Kilduff/Tsai 2003). The directionality of interaction effects relates to top-down and bottom-up effects (e.g. Moliterno/Mahony 2011)[5]. Moreo-

[5] Due to space constraints, the notion of lateral interaction effects referring the interplay between entities within a single level, for instance, interaction effects

ver, these interaction effects may be self-reinforcing over time. For instance, Klein and Kozlowski (2000) argue that top-down effects at a certain point in time (t_0) may change the structure of lower levels, thus altering the magnitude of bottom-up effects at a later point in time (t_1). Over time this may cause self-reinforcing feedback loops (Arthur 1990) thus transforming small initial differences into macro-level transformations (Hite 2008: 136).

The most important cross-level effects are briefly sketched out here. Micro-level bottom-up effects refer to the interplay between the focal firm and network nodes. In this case, research may target the ways in which the focal firm leverages its resources across a dyadic tie to pursue its proprietary strategy addressing the question how this affects performance of both interacting parties as well as network structure. In turn, network structure and growth patterns emerge from the multitude of relational ties the focal firm builds and adapts. Conversely, a first-order top-down effect relates to the alterations to the network nodes' properties that may impact the focal firms' stock of resources. For instance, a change in the nodes' relational strategy from progressive to conservative may impact the amount of resources that are available for exchanges with the focal firm. The focal firm may then not be able to pursue its proprietary strategy requiring it to make a strategic decision in terms of amending its own relational strategy and acquiring new stocks of resources by way of changing its portfolio of network ties.

Higher-order top-down effects relate to meso- as well as macro-level top-down effects affecting F_1[6]. Both levels relate to the impact of industrial dynamics as well as the abundance or scarcity of latent institutional resources on F_1 and its $Network_{F1.}$ For instance, high levels of entry in turbulent sectoral environments may translate into a higher rate of network entries thus changing network properties such as size, density, homophily and growth patterns and ultimately the set of resources available for F_1. Moreover, an impoverished macro-institutional environment may have a bearing on the structure of $F_{1's}$ network, possibly causing pockets of network nodes in said network to atrophy. From a MMLS perspective, one of the fundamental questions in this context relates to the ability of the focal firm to adapt to these changing environments and reproduce its organizational capabilities embodied in its proprietary and network-based resource generating and exploiting mechanisms.

7 Conclusion

The starting point of this paper has been the insufficient treatment of micro-diversity and agency in the literature on the varieties of capitalism (Hall/Soskice 2001). The varieties framework theorizes economic actors as homogeneous entities thus adopting a highly-stylized and static perspective of economic development reducing the scope of individual manoeuvre as well as the inherent tendency towards change in socio-economic systems drastically (Prigogine/Nicolis 1989; Saviotti 2009). This is unsatisfactory inasmuch as innovative action, which may be seen as the "real expression and explanation of life force" (Cooke 2012: 5) as well as the central mechanism promoting adaptation and renewal of systemic structure, emerges from complex interactions of

among networks or among varied sectoral systems of innovation which are central to the notion of 'transversality' (Cooke 2012) cannot be addressed.

[6] For the sake of parsimony and to maintain coherence, this model does not refer to the interrelations between the macro- and meso-level. Moreover, questions concerning the bottom-up structuring of these respective levels cannot be taken into consideration here. These may be more adequately captured by simulation models.

heterogeneous agents at the micro-level embedded in innovation networks (Ahrweiler 2010; Pyka/Scharnhorst 2009). In search of an adequate analytical and conceptual framework that alleviates the tension between micro- and macro-analyses as well as static and evolutionary perspectives, networks were identified as the most promising candidate analytical device.

However, it has been argued that network approaches that focus primarily on structural elements to explain network evolution lack a convincing explanation of the mechanisms by which these structures come into existence and how they change. While these network analyses have engendered a variety of valuable insights, their constituent components have been analyzed as homogeneous entities thus replicating the above delineated structuralist determinism. For this reason, the analysis of agency in networks requires different analytical tools (Ahrweiler 2010). A recent review of some of the 'grand theories' of system change argues in a similar vein (Cooke 2012), that is, extant theoretical approaches including co-evolutionary transition theory (Geels 2004), resilience approaches (e.g. Folke 2006) as well as approaches in evolutionary economic geography (Boschma/Frenken 2003), lack explanatory power concerning the upward and downward causality of changing systemic properties as well as the micro-mechanisms that produce the fluctuations of aggregate variables and systemic structure.

This paper has sought to develop a tentative analytical framework that captures micro-diversity and agency on the one hand as well as incorporating processes at higher levels of aggregation on the other. It has been argued that agency and structure co-evolve generating as well as incrementally altering multi-level systems of innovation. While acknowledging the bearing of institutional forces on micro-agents, this framework relaxes the structuralist determinism of institutional analysis. Indeed, the main research interest of the proposed MMLS lies in unpacking the co-evolution of micro-diversity within multi-level systems of innovation. In this context, organizational capabilities play a central role. These capabilities may be embedded in network trajectories that are shaped by geographical factors (Glückler 2007) as well as institutional selection environments (Essletzbichler/Rigby 2010; Hall/Soskice 2001; Malerba 2004; Cooke 1992). This approach thus draws attention to the nonlinearity of the co-evolution of capabilities, networks and institutions, wherein organizational capabilities are emergent properties of firm-internal as well as latent resources available at the firms' exterior. The interplay between the firms' direct environment relating to its network relations and its more remote environment referring to the meso- (sectoral and regional systems of innovation) as well as the national institutional framework at the macro-level, is afforded an important position in this framework. To avoid deterministic interpretations of the resources provided by institutional structure, the notion of latent institutional resources directs the analytical focus towards the variegated sets of resources that are potentially available at different levels of innovation systems. In the competition for these resources, micro-agents exhibit heterogeneous capabilities. This in turn causes a considerable degree of heterogeneity at the micro-level. Moreover, as a means of survival micro-agents pursue varying proprietary and network strategies to build and sustain their resource generating and leveraging mechanisms in competitive environments. Micro-agents and their organizational capabilities as carriers of the competitive process (Saviotti/Noteboom 2000) thus co-evolve with institutional selection environments. The meso-level and in particular, regional systems of innovation, may play a central role as selection environments and resource facilitators by jointly fostering the emergence of micro-diversity. Moreover, autocatalytic processes may turn micro-level differences into meso-structures and promote the transformation of entire systems.

Clearly, the framework outlined here is at its inception. With regards to methodology, in-depth comparative case studies (Eisenhardt 1989) may supplement quantitative ego-centered network analyses by providing detailed analyses of individual components of the framework sketched out here. For instance, these systematic case studies could address the evolution of a focal firm's proprietary and network strategy and its resource generating and leveraging mechanisms and their impact on network structure across different environmental settings. These analyses may provide very detailed information on the behavioural patterns of specific micro-agents which may elucidate the ample scope of strategic manoeuvre feeding into actor-based simulation models (Ahrweiler 2010).

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