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Two Styles of Knowing and Knowledge Regimes: Between 'Explicitation' and 'Exploration' under Conditions of 'Functional Specialization' or 'Fragmental Distribution'

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Two Styles of Knowing and Knowledge Regimes: Between 'Explicitation' and 'Exploration' under Conditions of 'Functional Specialization' or 'Fragmental Distribution'[1]

Werner Rammert

1. Innovation and knowledge changes: knowledge regimes and styles of knowing

Knowledge changes can be seen as the dominant dynamics of modern innovation. Knowledge changes include the dynamics of scientific innovation, of industrial innovation, and of the institutional system of innovation. Knowledge changes are concerned with both, the regime of knowledge production and the style of knowing.

Innovation depends on many processes of knowledge production that are distributed over various institutional settings. The scientific innovation in the academic field is as important as the technological innovation in industry. New knowledge does not only matter when scientific discoveries are made or technological projects are pushed forward. It matters, too, when industrial products are improved, when services and markets are created, and when political funding programs are launched. These various processes of knowledge production which follow different rules and rely on different resources have to be coordinated in a system of innovation. A 'knowledge regime' is constituted by the specific way how the differentiation between the scientific, industrial and political dynamics of innovation is shaped and how the interplay between them is institutionalized. The emergence of a new knowledge regime besides an established one can be stated, if one can identify new patterns of coordination in the academic, industrial and political fields of knowledge production as well as between them and if these patterns can be condensed into a coherent set of 'rules of the game'.

Innovation also depends on the kinds of knowledge that are produced and on the 'styles of knowing' that are cultivated. Modern society is famous for its processes of formal rationalization, codification and scientification of traditional knowledge. New types of explicit, scientific and codified knowledge were preferred to diffuse and diverse kinds of knowing, like ascertained laws to observed regularities in science, like tested procedures to engineering routines in technology, like fixed patents to ascribed engineering capabilities in law, or like calculated business plans to diffuse commercial intuitions in economy. Digging deeper than traditional theories of science, one can detect the rising relevance of the ways how different kinds of knowledge are related with one another. Studies on scientific as well as on industrial innovation emphasize the critical role of tacit and non-explicit knowing, of knowledge that is incorporated in bodies, brains, and technologies, and of trans-disciplinary expertise. Consequently, they set the issue of knowledge styles on the agenda of innovation research.

In history, we have experienced some great knowledge changes, like the transition from oral to written knowledge in Greek Antiquity. This transition favored the rise of knowledge regimes that were based on religious doctrines instead of mythical narration and on theo-

1. The author thanks Jerry Hage, Martin Meister, Terry Shinn and Ingo Schulz-Schaeffer for critical comments and constructive propositions.

retical reasoning instead of magical skills. Similarly, the media revolution from written to printed knowledge turned secret and local knowing into public and universal knowledge. This change gave rise to modern knowledge regimes which substituted formal rationality for routine and tradition and scientific knowledge for experience. One can summarize that knowledge regimes differ from one another under the two aspects what kind of knowledge they privilege and how the production, distribution and use of knowledge is institutionalized.

Actually, we face again significant knowledge changes. Reviewing the science and technology studies literature, one can learn that the production of scientific knowledge seems to be in a process of fermentation. Since the 19th century, it was mainly institutionalized at the modern research and teaching universities as a relatively autonomous activity. Disciplines, scientific communities and faculties were differentiated according internal criteria which followed the idea of the 'unity of science'. This type of disciplinary institutionalization favored a complementary specialization and an enormous increase in scientific productivity. But it showed great resistance when it became challenged by external requirements, such as the cooperation with other disciplines in order to solve trans-disciplinary problems or to co-produce technological innovations with economic and political partners. New patterns of scientific knowledge production evolved inside and outside the academic field, like mixed epistemic cultures around laboratories, clustered networks of researchers around great problems of mankind, discipline-crossing communities around generic research technologies, and inter-organizational communities of practice. These kinds of "post-normal science" (Funtowics/Ravetz 1993) developed besides the canonical system of closed disciplines and universally oriented scientific communities. What is labeled sometimes as "fragmentation", sometimes as "disunity of science" and sometimes as trans-disciplinary "mode 2" of scientific knowledge production, that shall be analyzed in this paper under the aspect whether these patterns have a common denominator so that we can speak of the emergence of a new knowledge regime. It will be argued that a regime of fragmental distribution comes up in some fields of knowledge production as an institutional response to the problem of heterogeneity that is caused by over-specialization. The fragmental knowledge regime does not replace the dominant regime of functional specialization, but steps besides it.

Reading the socio-economics of innovation and organization sociology literature, one gets the impression that thorough knowledge changes are taking place in the field of industrial innovation. The specialization between economic and academic organizations is partly fading. Firms turn themselves into knowledge-producing units, and universities change towards knowledge-exploiting units. The concepts of functional division and sequential organization between discovery, invention, innovation, and diffusion that constitute a national system and a standard course of innovation are partly given up in favor of concepts of distributed innovative processes (see e.g. Coombs/Harvey/Tether 2003) between a greater variety of organizations that are dispersed in space and operating at the same time. It shall be argued that the increasing number of networks of innovation that are characterized by interactions between heterogeneous organizations can be seen as a particular mode of coordination and an adequate institutional answer to the problems of a fragmental distribution of innovative activities.

This contribution also refers to the macro-sociological debates on the changes of modern society insofar as it offers a modest conceptual solution to the problems and claims of 'grand theories', like 'post-modernism', 'knowledge society' or 'reflexive modernization'. It will be argued that we can distinguish between two knowledge regimes, a functional and a fragmental one. They differ in the way how they respond to the consequences of functional differentiation, the one by continuing specialization and standard integration, the

other by taking advantage of fragmentation and loose coupling. It will be also argued that we can distinguish between two styles of knowing, the one that relates explicit knowledge without regarding the tacit dimension and the other that explores the relations between the two kinds of knowledge. It is an open and empirical question in how far and in which fields of the innovation system both changes correspond with one another. The rise of a fragmental knowledge regime and of an explorative style of knowing that can be deduced from the patterns described in the literatures may signal critical macro-institutional changes (see Campbell in this book).

In the next chapter (2.), these three bodies of literature are reviewed under the aspect whether and where distinct patterns of knowledge production can be detected. It is the aim of this part to construct coherent patterns of rules that may indicate the existence of two knowledge regimes besides one another.

The following chapter (3.) focuses on the relation between explicit knowledge and tacit knowing. Referring to the distinctions between the "known" and the "knowing" (Dewey/Bentley 1949) and the "explicit" and "tacit" knowledge (Polanyi 1966) it will be analyzed how the attention of tacit knowledge constitutes different styles of knowing.

In the last chapter (4.), two lines of research are drawn from the conceptual considerations and the presented empirical studies. We need more comparisons between individual innovation biographies in different technological and industrial fields in order to identify distinct patterns of innovation paths and their changes. And we need finer grained analyses of innovative constellations that refer to scientific, technological, and institutional concepts. It is of great importance for science managers, funding institutions and politicians to know about the different patterns of knowledge production and the distinct styles of knowing and of knowledge regimes in order to choose particular and well-adapted styles of management and consistent strategies for institutional policies.

2. Changing patterns of knowledge production: between 'functional specialization' and 'fragmental distribution'

2.1 Relations between types of social differentiation and regimes of knowledge production

Societies and social systems can be analyzed under the two complementary aspects of diversity and coordination. Since the times of Karl Marx and Emil Durkheim, sociologists ask for the interrelationship between kinds of division of labor and mechanisms of social coordination, between types of social differentiation and regimes of social integration. If we want to examine the question of a fundamental knowledge change as supposed by adherents of post-modernism or by proponents of the coming of 'knowledge society', then we have to look for changes of the division of knowledge production and for changes of institutional and organizational patterns.

Modern society differs from traditional society by the emergence and pre-dominance of a new type of social differentiation, which is characterized by patterns of functional specialization of spheres, values and institutions. This type of differentiation splits society into complementary parts which are organized around different functions, but which have the same status. Spheres of action and sets of orientations are separated horizontally from each other, like the economic, the political and the scientific subsystems. They differ under the aspect of their specialized contribution to the reproduction of society. They increase their

efficiency by generating a self-referential orientation following its own code of orientation and purifying it from other influences. They achieve a relative autonomy from interventions from outside by establishing a system of self-organization. As the functions are indispensable and cannot be substituted by another subsystem, all functionally specialized systems are basically equally important. In modern society, a functionally specialized system of horizontal division outplays the vertical system of stratification as the dominant pattern of differentiation.

The production and use of economic, governmental, and scientific knowledge is institutionalized according to this type of division: the knowledge processes are concentrated in the particular specialized spheres of society. Scientific knowledge production is concentrated in the academic sphere of universities and research institutes. It gains high institutional autonomy and self-governance. It can be characterized by the focus on basic science. It is mainly organized along scientific disciplines. Industrial knowledge production, however, takes place in specialized research and development departments and in industrial research institutions. It is strongly oriented towards applied sciences and follows the lines of technological trajectories and industrial fields.

This kind of knowledge specialization brings up problems of coordination and coupling between the separate subsystems. Markets of patents and licenses and the establishment of research and development departments in the big corporations became the predominant means of coordination between science and industry. When the state aimed at the enforcement of military power or at the acceleration of economic innovation, then he recruited consultants from science and industry and established mission-oriented laboratories and domain-oriented governmental research in order to couple the separate knowledge processes. The patterns of coordination were strongly influenced by the strategy to maintain the lines of specialization between scientific disciplines, industrial branches, and policy domains. The whole system of specialized knowledge production was treated as if it were integrated by a standard model of sequential innovation. This often described model attributes the functional parts of the innovation process to the separate institutional fields. It functions as a productive fiction, because the different contributions can be combined by the actors who follow the sequential order of discovery, invention, and innovation. One can say that this regime of complementary and specialized knowledge production emerged as an institutional answer to the functional type of social differentiation.

But the ongoing knowledge specialization, the globalization of the knowledge production, and the acceleration of the innovation tempo lead to unexpected problems of synchronization and mutual adjustment. The lines of functional specialization between scientific, industrial and political institutions is sometimes crossed when a function or some rules are taken over from the other institution and combined with its own ones. The functional divisions between scientific disciplines, industrial branches, and political domains loose their exclusive character at some fields. The sequential order of the innovation processes gets more and more disturbed by parallel processes of scientific and technological innovation. The standard model of innovation is at some places broken into pieces. The dispersed fragments are then put together to something like a heterogeneous patchwork of innovation. All these changes – as shall be demonstrated in the next chapters - show a common pattern that indicate the emergence of a fragmental type of social differentiation and an affiliated fragmental regime of distributed knowledge production.

A fragmental type of social differentiation splits a heterogeneous whole into parts that are of the same kind, but of a different status or on a different level. Regional innovation networks e.g. always include nearly the same mixture of elements, like scientific, economic, and political actors and institutions. But some networks of innovation are setting the

bench marks, like the Silicon Valley network of microelectronics and software industry or the Baden-Württemberg network of mechanical engineering and car production, others are imitators and followers in the global competition. The differentiation of scientific disciplines is rooted in well-defined and theory-bound fields of research. Each of them enjoys the same highly regarded status as certain knowledge that we call scientific truth. But when the number of mission-oriented research projects and research programs increases, one cannot any longer follow the lines of disciplinary knowledge production, but one has to mix several pieces of disciplinary knowledge, many methods of scientific and technological knowledge production, and also different kinds of knowing, like building laboratories or patenting products and procedures. Then a new type of fragmented knowledge production is coming up that is rooted in the same combinations of heterogeneous knowledge fragments. The quality cannot any longer be reviewed by the peers of one discipline, but by heterogeneous expert groups and mixed epistemic cultures across the classical disciplines.

TYPES OF SOCIETAL DIFFERENTIATION	*functional*	*fragmental*
Type of division	separated + horizontal	combined + heterogeneous
Means of coordination	market; science	networks; mixed cultures
Regime of knowledge production	complementary + specialized	heterogeneous + distributed

This fragmental type of differentiation differs from the functional one radically under the aspect that the purified separation is given up in favor of heterogeneity and reflexivity. Functionally specialized institutions and purified scientific disciplines remain fundamental factors for the knowledge production though they stay sometimes in the background, but they are loosing their privilege to act as the dominant pattern or personnel on the stage of innovation where heterogeneous innovation networks, trans-disciplinary expert groups and mixed epistemic cultures also take over prominent roles. It shall be demonstrated that a new knowledge regime of fragmental distribution rises besides the regime of functional specialization and in close relation to the fragmental type of social differentiation.

2.1 Scientific innovation: Between disciplinary research and distributed knowledge production

The institutionalization of modern science can be seen as the establishment of scientific disciplines, affiliated scientific communities and academic organizations, like institutes, laboratories, faculties and universities. Each of them follows the same order of specialization. It was mainly the disciplinary division of knowledge production around theoretical core programs that laid the ground for scientific growth. The unity of disciplinary research and teaching enabled the accumulation and integration of scientific research results. This development can be seen as an epistemological emancipation. Disciplinary research was freed from the earlier dependence on theology and philosophy. The hierarchy of faculties

was dissolved. The stratificatory pattern of pre-modern science was replaced by a functional pattern of disciplinary specialization.

This process of knowledge specialization had not only augmented the number of disciplines, but it has multiplied the number of sub-disciplines and specialities. As a consequence, the limits of disciplines became frayed, and the over-all idea of the 'unity of science' decayed. Philosophers of science had developed this idea of the unity of science in times when the real unity became threatened. It was a philosophical program to keep the exploding scientific disciplines together. The more knowledge specialization progressed, the more new research fields emerged. They came up either at the periphery of traditional disciplines or between disciplines. But they advanced to new disciplines or could be integrated into an established one, very rarely. Computer sciences or informatics - how this interdisciplinary research field is called in France and Germany - derives from such different sub-disciplines like formal logics, applied mathematics, cognitive psychology, computer linguistics and automata construction, but it never gained the paradigmatic status of an integrated discipline like e.g. plasma physics as part of physics. If we look at the fields of artificial intelligence or robotics, we cannot any longer apply the category of a closed and unified discipline or a functionally specialized part of a discipline. They are neither parts of mathematics nor parts of mechanical engineering; they remain in the status of a loosely coupled trans-disciplinary field composed of specialties. The knowledge production is distributed over heterogeneous fields of research. These fields of distributed knowledge production gain stability, if they succeed in developing common practices of borderline-activities in so called "trading zones" between disciplines and if they share a "pidgin"-like kind of communication (Galison 1996; Meister 2002).

Scientific communities underlie the same patterns of change that result from the ongoing specialization and multiplication. Scientific communities are narrowly connected with the concept of scientific disciplines. Teaching, education and graduation usually follows the lines of the disciplines. Faculties, departments and universities are mainly organized under the aspect of disciplinary specialization. But when we actually look into some research laboratories, the disciplinary division of knowledge production is given up more and more in favor of mission-oriented projects and mixed research teams. We shall still find designations like physics or mathematics or chemistry or biology department as reminiscences of educational backgrounds. But all empirical descriptions of laboratories come to the congruent result that either the broader concept of "epistemological cultures" (Knorr Cetina 1999; Traweek 1988) or the narrower concept of "experimental cultures" (Rheinberger 1997) are now the more significant categories to catch the reality of distributed knowledge production than disciplinary scientific communities.

The modern university seems to transform itself in a similar way. The growth of disciplines can not any longer be organized under the roofs of faculties. Faculties have often turned into formal organizational units that hold together very heterogeneous departments and institutes. Universities are not any longer able to house all disciplines and faculties. They too follow the pattern of specialization: they strengthen particular profiles and core competences and seek for alliances with other universities. This trend started even earlier when teaching and research universities, business and medicine schools and Technological Institutes were established as distinct units of the academic system. But nowadays we observe a greater diversity, but a smaller number of disciplines which are bound together under a particular mission than in earlier ones, like the Hertie School of Governance with Political Science, Management Science, and Law at Berlin or the Keck School of Applied Life Sciences with Biology, Engineering, Innovation Management and Ethics at Los Angeles. The teaching starts to be separated from the disciplinary curricula. Modularization is the

beginning of breaking the traditional curriculum into exchangeable pieces. Multiple forms of re-integration get possible, like master studies of computer-aided façade design in architecture or special educational programs for the breeding of experimental animals in biology. Curricula often give up the idea of a specialization on the basis of a disciplinary identity in favor of a flexible combination of divergent knowledge pieces and competences. The unity of teaching gets fragmentized. The universities as units of teaching are gradually reduced to 'multiversities'(at first Kerr 1963) which form a selected set of disciplines instead of the whole universe of the sciences and humanities (see Schimank/Stölting 2001).

A further consequence of the multiplication and specialization of research fields is a change in the pattern of interdisciplinary cooperation. The traditional pattern of scientific cooperation was hierarchical. The research subject was primarily defined from the perspective of one leading discipline. The other disciplines got the roles of auxiliary sciences or maids, like statistics for biology or instrument-making for nuclear physics. This strong stratificatory pattern inside and between disciplines is now replaced by weaker forms of inner and interdisciplinary cooperation. Each field of a discipline contributes a well-defined part to a visible and shared objective. It is based on a functional division of knowledge production. Even established disciplines, like physics, chemistry or geology, develop a pattern of internal disciplinary specialization that shows little communication between the fields. High energy physics e.g. is internally subdivided into theoretical, experimental and instrumentation micro cultures with a low intensity of exchange between them, as Peter Galison (1997) has demonstrated. This functional division is sometimes dissolving, when such a clear object or aim is missing because the research subject is still in the making, or when these processes are situated between the engaged disciplines. In artificial intelligence e.g., one may always find leading ideas and concepts that coordinate the distributed research activities; but they change every five to ten years and with them also the dominating disciplinary fields, like the engineering sciences in the early cybernetic phase, cognitive sciences during the classical phase of the physical symbol systems approach, the brain sciences under the paradigm of non-symbolic artificial intelligence (see Gardner 1985). Artificial intelligence has developed beyond the functional pattern of specialized disciplinary contributions. The cooperation is more fluid and more heterogeneous than in the established disciplines. One can distinguish it as a particular pattern: It is the fragmental pattern of interdisciplinary cooperation in a patchwork-like organized field with changing poles.

For a long time, academic research has been seen mainly shaped by theoretical developments. One supposed that both, the cognitive and the organizational development of scientific disciplines, follow a congruent pattern (see Whitley 1984; Fuchs 1992). Even as the research instruments were obviously growing in size or complexity like in high energy physics or simulation techniques, one saw their development in line with the disciplinary pattern of theory-building. But we can observe many examples for the fact that scientific instruments are not only transferred from one to another field, but that they triggered new research fields across the established disciplinary boundaries, like the electronic microscope that pushed nanotechnology, or even created a new quasi-disciplinary research field, like the computer that enabled the computer sciences. If one looks under this aspect at the crossing of disciplinary boundaries, one detects many more examples of migrating instruments and trans-disciplinary communities. "Generic technologies" (Shinn/Joerges 2002) push patterns of disciplinary specialization into the direction of new combinations of disciplinary fragments. Nanotechnology can be defined as such a trans-disciplinary field of heterogeneous knowledge pieces and competencies that was constituted by the capacity of the new microscope to move tiny molecular particles. It is neither a sub-discipline or specialty of physics nor a mere part of mechanical or chemical engineering. It includes parts, proce-

dures and pieces from all these fields. They are not integrated like the branches of one disciplinary tree, but they follow the pattern of knots and roots of a rhizome that nourishes the distributed knowledge production.

This criss-crossing and re-combination seems also to open academic research to interdisciplinary and to external definitions of the research subjects. The complexity of research subjects is highly increasing in some fields because of the expansion of aspects many disciplinary and external actors are interested in. The physics of efficient energy production e.g. turns nowadays into a trans-disciplinary combined effort to design sustainable technical systems of energy circulation. The narrow perspective of weather forecasting that is a specialty of the physics of thermo-dynamics is now widened to the enlarged perspective of complex climate research that combines such heterogeneous fields like palaeo-climatology, computer simulation and others (Stehr/von Storch 1999).

The expansion of computerized work and computer-mediated communication changes the subjects of disciplinary research and, even more, also the conditions of scientific work and communication itself. Ergonomics e.g. proceeded by a complementary combination of physiological, psychological, and sociological aspects of work place design. With the rise of computerization and new technological media, they had not only to add another aspect of engineering named software engineering. Their subject, however, turned into a more hybrid subject that asks for a new trans-disciplinary approach, like human-computer-interaction studies that are based on both, activity theory and the theory of cognition (see Chaiklin/Lave 1998; Middleton/Engström 1996) or high tech workplace studies that follow an anthropological approach to frame all fragmented aspects (Button 1993; Star 1996) or like Socionics that uses sociological models to design software agents and architectures of intelligent information systems and that changes sociological theory-building by making technical agents and human actors to an hybrid subject (Malsch 1998; 2001; Burkhard/Rammert 2000). The influences of computerization and the Internet on the re-organization of scientific disciplines and communities are still an open research question (looking at some distinct aspects see Merz 2002). One can observe these change processes under the question whether they give rise to a new pattern of heterogeneous cooperation between diverse and distributed research fields and under what conditions they strengthen the functional specialization and integration of academic research.

We can summarize that at many research fields the subjects of research are becoming more *complex* under the aspects of elements and relations, more *heterogeneous* under the aspect of included disciplinary perspectives, and more *hybrid* under the aspect of kinds of focused objects. Critics could object that these developments are not a really new phenomenon. It seems to be the normal way how engineering and applied sciences proceed. Even if we accepted this objection, we could argue that obviously the complementary specialization between basic sciences and applied or technological sciences dissolves in many cases. Fundamental research can be found in technological fields, take e.g. the reward for the invention of the electronic microscope with a Nobel Prize, and technological and practical aspects are narrowly intermingled with basic scientific advances, like in molecular biology. The terms of “techno-sciences” and of “high technologies” (Latour 1987; Rammert 1992) were coined to grasp this crossing of two distinct knowledge styles and research cultures. It seems to me obvious that a new pattern of interdisciplinary distributed knowledge production has developed besides the established pattern of disciplinary and complementary interdisciplinary academic research. The crossing of disciplinary borders sometimes gains a new quality. The heterogeneous cooperation is beyond the usual interdisciplinary cooperation. The new knowledge situation can better be described to be in the state of a loosely coupled distribution rather than in the state of a functional or even hierarchical inte-

gration. It is far beyond the phase of “finalization” of completed and perfected disciplines (see Böhme/van den Daele/Weingart 1976). It looks more like a patchwork of disciplinary knowledge fragments.

2.3 Industrial innovation: Between complementary divisions and distributed innovation processes

The economic enterprise has been acknowledged since Schumpeter as the central locus of technological innovation. But the research on technological innovation has taught that the firm is only one important locus besides communities of practionners and technological systems (see Constant II 1987) and that the patterns of corporate innovation change in relation to technological regimes, industrial structures and supporting institutions (see Nelson 1998). Both, the socio-economics of innovation and the industrial organization literature, have produced a rich stock of knowledge about the interrelationships between technological, organizational, and institutional developments. I shall only review some results under the aspect whether they indicate significant changes of the patterns of knowledge production.

In the beginning, the scholars of the economics of innovation focused on the question in how far the technological innovation depends on scientific advances in the basic sciences. A controversy between adherents of the “technology-push” and the “demand-pull” approach came up which was later-on dissolved by making distinctions between radical and incremental innovations (Abernathy/Utterback 1978) and between traditional and “science-based” industries. The chemical and the electro-mechanical industry became the paradigms for the organization of science-based industrial innovation (Noble 1977). They introduced the industrial laboratory and the research and development department into the enterprise. Research and development were integrated in the divisional structure of the big corporation. Its function was to maintain a narrow relationship to scientific advances and the scientific community and to translate scientific discoveries and technological options into new products and production processes.

This ‘internalization’ of scientific knowledge production established typical patterns of functional specialization inside and outside the firms: the organizational structure of these firms was characterized by an internal differentiation between research & development, production, marketing and other departments that respond to the complex environment of the firm (see Lawrence/Lorsch 1967). The institutional structure of the environment was designed as a standard sequence of special innovation processes from basic scientific discoveries over technological innovation to broad diffusion of the product. The whole innovation process was organized as a sequence of separable stages linked by relatively minor transitions to favor adjustments between the stages. The predominant pattern between the specialized functions can be characterized as a “linear sequential coupling” (Van den Ven 1988: 111 pp.).

When the challenges of the knowledge production are growing and when the diversity of knowledge resources is increasing, then the firms change their dominant strategy. As they cannot afford to produce all the necessary knowledge themselves, they start a process of ‘externalization’ of the knowledge production. They concentrate their activities on their “core competencies”, a set of differentiated skills, complementary assets, and routines that provide the basis for a firm’s capacities and sustainable advantage in a particular business (see Prahalad/Hamel 1990).

The reduction of the sets of knowledge production inside the firm is compensated by the multiplication of relations with knowledge producers outside the firm. A first kind of relations is maintained with the externalized knowledge producers. They together build sometimes a kind of "virtual organization" which offers products and services as a combined system. A second kind is the punctual and temporarily cooperation with competitors in so called 'alliances'. A third kind of relation is the intensification of the user-producer-interaction (see Hakanson 1987; Lundvall 1988) in order to launch user induced innovations with success. All these changes of the patterns of innovation are systematically collected under the new term "networks of innovators" (Freeman 1991).

Since the 80ies of the last century, one can observe the quantitative growth of all kinds of networks, like "joint ventures", joint R&D agreements, technology exchange agreements, common licensing, research associations, and computer data bases. Fore-runners can be tracked back to the early research associations of the leather and color industries in the 90ies of the 19th century. Formal networks reach back to the time limited co-operations between the petrol corporations in the 30ies, in the chemical and in the synthetical rubber industry. The "network form of organization" (Powell 1990) gets a new quality when they change from a type of "strategical network" (Sydow 1992) between firms for keeping control towards a type of "idea-innovation-network" (Hage/Hollingsworth 2000) between firms and other organizations in order to share knowledge. The latter network has a more combinatory than a stratificatory character. It can be better compared with a "loosely coupled system" (see Weick 1976) than with a "tightly coupled" one. The pattern of "linear sequential coupling" is replaced in some industries by the pattern of "simultaneous coupling" (Van den Ven 1988). This second regime of a "distributed innovation process" (von Hippel 1988) can be mainly observed in the new industrial branches of high technologies, like electronics, information technologies, new materials, and bio technologies, where many small and medium-sized firms create networks of knowledge production with one another and with some big incumbent corporations.

The industrial innovation is not only distributed between the firms' own internal and other firms' external places of knowledge production. It is not only distributed between the user-firms and producer-firms or between small start-up firms and big incumbent corporations. It is moreover distributed between heterogeneous institutions, like science, economy and the state. It is pushed and pulled by a highly diverse spectrum of actors from university departments over governmental research institutes to risk capitalists. The boundaries between scientific innovation and industrial innovation are blurring, especially in the high technology and new economy sectors. That is why the next chapter deals with the change of the patterns on the higher (macro-) level of heterogeneous networks of innovation.

2.4 Regime innovation: Between a specialized and standardized system of coordination and a fragmented and fluid order of interactive networking

Crossing boundaries between the specialized systems, that is one signature of a new knowledge regime. The functional differentiation between scientific innovation and industrial innovation gets blurred. On the one side, it is not any longer sufficient to concentrate one's view on the change from disciplinary to interdisciplinary patterns of scientific innovation. Industrial laboratories and research firms have developed into an integral part of the "research system" that cannot be restricted to the academic sector of scientific knowledge production. The industry-university relations cross the boundaries between economy and science at some interfaces, and even more, a kind of a "triple-helix model" of relations be-

tween industry, university and government is claimed to evolve that interlocks science, economy and politics (Etzkowitz/Leydesdorff 1997).

On the other side, the analysis of industrial innovation demands a broader view than the firm and inter-firm view on organizational patterns and inter-organizational relations between firms and industries. It is a too narrow view to concentrate on "technical systems" that are defined as networks of agents in an economical industrial arena (Carlson/Stankiewicz 1996) or on exclusively "industrial networks" (Imai/Yamasaki 1994). The concept of "large technological systems" (Hughes 1997) crosses the borders of the industrial arena and interweaves scientific, industrial and political agents and artefacts. The concept of "user-producer-interactions" (Lundvall 1988) has been broadened to regional and "national systems of innovation" (Nelson 1983; Edquist 1993) that include actors and institutions from the educational, research, legal, administrative and economic sub-systems. A similar change can be stated for the change of network concepts: from strategical networks, industrial networks or functionally structured idea-innovation networks (see Hage/Hollingsworth 2000) to heterogeneous networks of innovation that include the really mixed spectrum of many and diverse academic, economic and governmental agencies (Powell/Koput/Smith-Doerr 1996; Rammert 1997).

Looking from such an enlarged perspective on the overall and distributed innovation processes, one can realize a growing diversity of academic, industrial and governmental organizations and a distinctive pattern how they are related with one another. The institutions of basic scientific research, like some Max-Planck-Institutes or the GMD-Institute of Mathematics and Data Processing in Germany, are transformed into more market-oriented institutions. Universities are influenced to develop and differentiate towards research universities, professional schools or regional higher education schools. The rise of the "entrepreneurial university" (Etzkowitz 2002) that follows the example of Harvard, MIT and Stanford, demonstrates the success of a hybrid type of institution that follows the logics of both, of the academic and of the economic system. A similar confluence of formerly separated systems can be observed in the sphere of industrial organizations. The organizational population does not only show a higher diversity of types, but some start-up firms and some big corporations turn into knowledge-creating companies (Nonaka/Takeuchi 1995) which take over some norms of academic research and innovative work (Hirschhorn 1988).

Building bridges between the separate systems is a second criterion that makes differences. When the parts of the innovation system are functionally differentiated, then the specific tasks and orientations are organized in homogeneous, but separate sets, e.g. scientific research in disciplinary communities with publications as particular product, and industrial innovation in enterprises and technological communities with patents or new products as output. Bridging the systems requires a differentiation of further transfer subsystems, the establishment of standardized interfaces and a long-term perspective of coordination. The coupling of the separate, but homogeneous units follows a linear and reverse linear mode. Such kind of a standardized coordination between the separate systems can be found in the fields of mechanical engineering and in chemistry which can look back on a long experience of institutionalization.

But one can also observe different developments in other fields, like microelectronics, software technology or biotechnology where the units are becoming more and more heterogeneous. Universities supplement their traditional research and teaching tasks with managerial competences in order to apply for patents, to found start-up firms and to sell educational programs. Business enterprises develop scientific education and research competences besides their management and venture competences. The innovation system then consists of fragmented parts which are coupled more opportunistically than systematically

and under a shorter temporal perspective. The interfaces are floating and look more like trading posts where exchanges are performed based on trust-relationships. The exchanges are neither punctual like on markets, nor strongly coupled like in corporations. They are loosely coupled like in interactive networks. The style of bridging between the heterogeneous units follows an interactive mode of innovation. The arm length relations between separate systems are now replaced by an enacted web of weak ties between heterogeneous units.

Breeding different regimes of knowledge production is the institutional answer at these processes of knowledge specialization and fragmentation. They are based on the two styles of functional integration and interactive coordination. How can the formation of different regimes be described? In the science and technology studies literature, the distinction between a "mode 1" and a "mode 2" of scientific knowledge production is heavily debated (Gibbons et al. 1994). "Disciplinary" and "trans-disciplinary" knowledge production, "decontextualized science" and "context-sensitive science" are distinguished. Some research fields are claimed to be shaped by segregated scientific communities, others by "integrated arenas" constituted by heterogeneous participants. The separation of scientific and public debates is in some fields replaced by a "hybrid agora" and by "transaction spaces" between science and politics. Homogeneous disciplinary advisers give way to "socially distributed expertise" (Nowotny/Scott/Gibbons 2001). If one does not interpret these changes of pattern as an linear transformation, but as two possible styles of knowledge regimes, then one can find both styles in some research fields of classical scientific disciplines, like nuclear physics or molecular biology, as well as in new interdisciplinary research fields, like environmental science or risk analysis. The attribution of a mode 2-type depends on the intensity and scale of heterogeneous contexts which are thrown into interaction with the scientific knowledge production.

Networking between homogeneous units and networking between heterogeneous parts are two distinct modes of coordination. From the industrial economy and organizational sociology literature, one can learn that strategical networks between firms, like in the road construction, assurance or film industry, are quite different from hybrid networks of innovation, that interweave agents from heterogeneous institutional fields, like university biology departments, the National Health Institute, patent lawyers and private companies. Especially in the new economy and high technology sector, the interaction between developers, producers and users is transformed from a highly standardized relation between separate systems of an academic and a commercial world into a "hybrid regime" where the different standards and values have been intermingled (Owen-Smith 2003: 1100). Networks of business groups and "authoritatively-grounded" networks, like in South Korea and Japan (Hamilton/Feenstra 1998), differ from heterogeneous networks of 'industrial districts' and "market-oriented voluntaristic" networks, like in Taiwan and China, in so far that they include more heterogeneity and offer more open access than corporate systems. "Hybrid networks" (Teubner 2002) constitute a third arena of allocation: It is neither the contract-relationship between agents on a market, nor the organizational relationship between members and the management of a hierarchy. It is a particular type of networking relations beyond both that is based mainly on trust relations (Powell 1998a).

Networks of innovation are built in order to do both, to exploit common, but distributed resources and at the same time to explore knowledge spaces with a common interest, but from diverse perspectives. 'Exploitation-focussed' networks tend to develop hierarchical, exclusive and corporate structures, whereas 'exploration-focussed' networks are always in the making, interactively learning and open to new agents. In chemistry or car production, the strategical networks are strongly controlled by big corporations and the whole system of innovation is integrated along the complementary functions of research, development, pat-

enting, testing, production and quality control. In biotechnology or information technologies, heterogeneous networks of innovation are coming up and show a high intensity of interaction and mutual learning between generally equal, but heterogeneous agents. The agents of knowledge production are multiplied; their specialized character is given up in favor of hybrid formations; the networking shows a more interactive, heterogeneous and heterarchical form than the corporate networks. It is an open question whether this change is restricted to the aging of industries and technologies, from young industries and technologies with ill-defined problems and low codification of knowledge to established ones with highly defined trajectories and knowledge stocks or whether this change is more general and also includes the whole social system of production and innovation.

The acceleration of the tempo of knowledge production is a significant general trend. It has limited the coordinative capacities of the linear-sequential mode of integration. The standard model produced certainty and coherence by connecting the stages of inception, invention and innovation, consecutively. But under the mode of parallel-interactive coordination, the different activities from the idea-creation to the marketing are fragmented and distributed over many different arenas (see Hage/Hollingsworth 2000; Coombs/Harvey/Tether 2003). That means that they are performed at the same time at dispersed places like in parallel computing processes. Problems of continuity and synchronization arise because of the different tempi. Innovation networks with permanent and parallel interactions are the institutional answer to these problems (Rammert 2000).

At the end, we can distinguish between two styles of knowledge regimes: a regime of further functional specialization and a regime of fragmental distribution. They shape the boundaries, linkages and units of the knowledge, industrial and innovation systems differently, as I have illustrated. In the debates about the changes of modern society, we can now re-discover some of the features. Adherents of post-modernism point at the “dissolving of boundaries”, at the “fragmentation” of social units (Baudrillard 2004) or at the “patchwork character” of institutions (Lyotard 1984), but analytical and empirical specifications are missing. The proponents of a theory of “reflexive modernization” (Beck/Giddens/Lash 1994) have been more successful in the identification of some processes of “de-differentiation” and “heterogenization” at many fields of modern society that is characterized by continuous functional specialization and the unintended reflexes on its problematical consequences. In this paper however, it is argued that one can distinguish a new style of knowledge regimes which is related to a fragmental mode of social differentiation. But an epochal change from one type of society to another is not generally supposed. It is only one possible hypothesis that the consequences of functional specialization generally lead to a new knowledge regime all over the society. Other hypotheses may state that it is the character of scientific disciplines or the nature of the technologies that make the difference. Even other hypotheses may emphasize the temporal differences between technologies in an early stage of ferment and variation and in a normal state of dominant design and stabilization (Tushman/Rosenkopf 1992). Another hypothesis could look for institutional paths of innovation in certain industries and in particular countries to explain different regimes (Hall/Soskice 2001). At the end, we shall be able to draw a map that shows at which areas and at what times one of the two styles of regimes is predominant.

REGIMES LEVELS	*functional specialization*	*fragmental distribution*
Interaction	disciplinary communities specialized disciplines + and sub-disciplines	communities of practice heterogeneous expert groups
Organization	formal, internally specialized org., e.g. faculties, divisions	interdisciplinary research institutes firm alliances, virtual enterprises
Society	strategical networks policy networks specialized + complementary institutional regimes	heterogeneous interactive network of collaboration and innovation experimental regimes of institutional learning

3. Between two styles of knowing: Processing explicit knowledge or exploring the relation between explicit and tacit knowing

3.1 Changing relations between explicit knowledge and tacit knowing: the ‘circle of explicitation’

When the modes of knowledge production are changing, then it is an obvious question whether also the kind of knowledge itself that is preferred in society undergoes a significant transformation. Following Max Weber and Werner Sombart, modern societies are characterized by a transformation of traditional into scientific-rational knowledge and of tacit into conscious knowledge. Modernization means to make more and more explicit the inherent relations between means and ends and to reorganize the activities under the imperatives of progress, accountancy and efficiency. Explicit knowledge, like written and codified laws, economic book-keeping or scientific explication, is privileged in comparison to all kinds of non-explicit knowledge, like traditions of jurisdiction, economic intuition, technical experience, and practical rules. Formalization, codification, and scientific explication marks modern society under the cognitive aspect as well as functional specialization does it under the institutional aspect.

When the digital computing revolutionizes all functions of information-processing, the production, the distribution and the reproduction of information, the processes of the explication and formalization of knowledge get even more intensified. All kinds of knowledge are now gradually transformed into formalized information, into electronic data bases and into expert systems. In the case of research knowledge, the formulas and the textbook knowledge are transformed into computerized data processing and electronic archives. In the case of production knowledge, all relevant data, like parts, prices and parameters of a product and the temporal and spatial position in the production process, are represented in information, construction and management systems. Computer programs coordinate thousands of operations and hundreds of variations in order to convey a car with exact those specifications which a particular buyer has asked for. All pieces of knowledge which can be made explicit by writing it down, or more narrowly by condensing it to a formal rule and by representing it by an algorithm, can be handled with the help of the computer.

The stock of the explicit knowledge pieces will be once more augmented during the digital revolution on the same scale as it was augmented after the print revolution. As we know, the print revolution increased the mass of explicit knowledge by the printing of books, circulation of periodicals and accumulation in archives and enabled the specialization of new genres of knowledge and of more scientific disciplines. Will the digital revolution only continue this process of explicitation and codification, or will it lead to comparable changes of the ways of knowing as the print revolution did?

Before we can answer this question, some terms have to be clarified. Usually, knowledge is seen as a substance, something that is embodied in books, brains, patent formulas or computer programs. In this book, we define knowledge as the capacity to reproduce or to replicate findings, products and processes (see the introduction to this book). This capacity is influenced by both, by people who know and by media which store and process information. We take the term of 'knowing' in order to relate to the fact that knowledge emerges out of the interaction between the knower and the known (see Dewey/Bentley 1949). Neither collecting books nor navigating through digital archives is a sufficient operation for really knowing something. When one wants to draw knowledge from a piece of explicit knowledge like a printed formula or a programmed expert system, then one always needs non-explicit knowledge. It is necessary to be able to read and understand, to translate it into effective action or to learn from the interaction. There exists no explicit knowledge without a rooting relationship in tacit knowing. "Hence all knowledge is either tacit or rooted in tacit knowledge. A wholly explicit knowledge is unthinkable."(Polanyi 1969: 144)

Usually, explicit knowledge and tacit knowledge are conceived as if they were two expressions of one and the same kind of knowledge and that one can be transformed into the other (e.g. by "externalization", see Nonaka/Takeuchi 1995). The relation between them then takes the form of a zero-sum game: the more knowledge is made explicit, the more tacit knowledge is diminishing. But this juxtaposition contradicts the logical argument of Polanyi and the empirical reality of knowledge differentiation. If each new piece of explicit knowledge implies a new tacit dimension of knowing, e.g. how to read the formal terms or how to interpret the program-processed results, then the dimensions of explicit knowledge and tacit knowing must be different. They are two kinds or modes of knowing that cannot be substituted one for the other. If the process of knowledge specialization creates more and more domains of knowledge, then at the same time it increases the realm of not knowing something explicitly. One aspect of this phenomenon is discussed under the concept of "Not-Knowing" ("Nicht-Wissen"), a kind of structural ignorance that emerges out of the up to now unknown relations that comes up with every new piece of knowledge (Luhmann 1992; Beck 1992; Smithson 1993). Another aspect is the realm of the unarticulated knowledge (see Cowan/David/Foray 2000). This special kind of tacit knowing is growing with knowledge specialization because more and more sectors of society and categories of people act on the basis of rules and routines the explicit knowledge of which only exists in the domains of highly specialized experts.

We see that the relevance of tacit knowing is increasing under conditions of knowledge differentiation in a double sense. On the one side, the production of new knowledge always produces new methods, machines and media the use of which requires tacit knowing how to handle and to interpret these means. It is a question of time and money whether some parts of this non-explicit knowledge will be articulated and even codified. But other parts of implicit experience cannot be made explicit. On the other side, the fragmentation between the different knowledge domains diminishes the parts of the population which explicitly know the particular code books. At the same time fragmentation augments the realm where people have to rely on tacit knowing. If we conceive tacit knowing and explicit knowledge

as distinct, but interdependent dimensions, then we discover a paradoxical relation between them: The more knowledge is made explicit by processes of codification and computing, the more increases the importance of non-explicit knowledge to appropriate and integrate it. This paradoxical relation constitutes what I call the 'circle of explicitation': Making explicit what was unarticulated before produces new tacit dimensions of knowing and at the same time increases the importance of non-explicit knowledge.

This fundamental circle of explicitation cannot be resolved, but societies have developed different styles of knowing to cope with the paradoxical relation. It is a misleading conception to distinguish societies only by the dominant kind of knowledge, like traditional and tacit knowledge in pre-modern societies and rational and explicit in modern societies. It is the relation between these kinds of knowledge that creates the style of knowing. Under the regime of functional specialization, we can observe a preference for the abstraction, formalization and universal codification of knowledge. Knowledge is liked to be transformed into standardized packages of information in order to facilitate the processing inside and the exchange between the different spheres of action. This style of knowing follows the mechanical and universal model of information-processing. Under the regime of fragmental distribution, the situational and associative knowledge gains higher importance in order to translate between the modularized and heterogeneous pieces of knowledge and to be able to learn. This style of knowing follows the organic model of cultivating knowledge and explores the fluid relations between explicit and tacit knowing. The explicit fundamental knowledge of molecular biologists e.g. can be only successfully transferred to bio-engineering and business, when it is combined with the tacit knowing how to organize a laboratory and how to evaluate the chances of different claims. Both styles have in common that they encompass both, the tacit and the explicit kind of knowledge. But they differ in the way how they relate the two: the *style of explicitation* is based on excessive explanation and exploitation of codified knowledge, whereas the *style of exploration* trusts more on the tacit circulation and informal integration of the implicit and explicit knowledge.

3.2 Unraveling the critical importance of tacit knowing and the technical roots of scientific innovation

Science is the most prominent endeavor that presupposes, produces and uses explicit knowledge. Premises and prerequisites have to be made explicit, propositions and conclusions have to be formulated in a precise and explicit way, and methods and instruments have to be operated according to explicit rules in order to receive methodically controlled knowledge that can be replicated universally. Science seems to be the holy empire of explicitness.

From the social studies of science literature we have, however, learnt that even scientific knowledge is based on non-explicit knowledge. It was the Polish physician and pioneer of science studies Ludwik Fleck (1935) who has demonstrated that scientific statements and interpretations of empirical observations as well as expected effects of instruments are deeply embedded in an unarticulated and shared frame of a 'thought collective' that he called 'thought style'. It is this group-bound, gestalt-oriented and incorporated kind of knowledge that the chemist and philosopher of science Michael Polanyi later defined as 'tacit knowledge' and with reference to that the physicist and historian of science Thomas Kuhn coined the famous term 'paradigm'. This statement about the rooting of scientific knowledge in tacit knowing does not mean that science has always remained an art, as some post-modern thinkers assume, but that the achievements of modern science are neces-

sarily interwoven with non-explicit knowledge. It is Polanyi who expresses the paradoxical relation between implicit and explicit knowledge more sharply. “Any attempt to gain control of thought by explicit rules is self-contradictory, systematically misleading and culturally destructive” (Polanyi 1969: 156). He states that the process of formalization of all knowledge that does not exclude any element of implicit knowledge destroys itself. As a consequence, one has to consider the relation between the two kinds of knowing, namely how it is organized and how it is changing over time.

Scientific innovation takes place via the interference of all kinds of knowledge, of formalized theoretical and implicit practical knowledge, of articulated, instrumentally incorporated and habitually embodied knowledge. It is not only a result of explicitation and information-processing. The sociologist of scientific knowledge Harry M. Collins (1974) has already demonstrated that the published physical and technological knowledge is not sufficient, if one wants to replicate a path-breaking experiment with success. At least one needs one person who has been a member of the scientific research group or who as a visitor has shared the practices of the group for a while. Collins’ TEA Laser Set study emphasizes the importance of shared collective experiences and of incorporated knowledge for the production and reproduction of scientific knowledge. Mathematics is surely the scientific discipline with the highest degree of explicitness. Even here, the proving of calculative procedures and the formal examination of proofs with and without the help of computers is based on different kinds of background knowledge that cannot be precisely articulated and made completely explicit (Heintz 2000: 175). After a kind of laboratory study in a mathematical research institute, the sociologist of science Bettina Heintz could demonstrate that distinct mathematical cultures or thought styles are existing which differ under the aspect whether they accept computer-based procedures of proving or not. Some mathematicians only accept human proving and deny the computer-based one because the latter is, however, based on an explicit computer program, but one cannot reconstruct and control all of its operations and instructions.

It is not only the computer that changes the knowledge style in science. Right from the beginning, modern sciences are closely connected with technical instruments. Usually, one separated the scientific disciplinary knowledge from the conditions of its production. It was purified from human and technical interferences, and it was made explicit as a disciplinary code. Historians of science have criticized this idealistic view of a merely cognitive and completely codified disciplinary knowledge that is based on the style of perfect explicitation. They, however, emphasize the whole system of knowledge production that also includes the material side of knowledge production and the social practices of closure and coherence-building. If we acknowledge that scientific knowledge is a mixture of both, of universal, calculative knowledge and of context-specific practical design, of codified design parameters and of implicit hands-on experience (Vincenti 1990), then a style of exploring the relations between the two can be distinguished from the style of establishing and exploiting the explicit. As the variety, size and complexity of technical instruments has been steadily increasing, - one may think of the complicated system of accelerators, detectors and calculation programs in High Energy Physics, or of the loosely coupled world-wide network of observation stations with various documentation techniques, simulation-models and the link between supercomputers in fields like climatology and oceanography - , classical disciplines turn into multidisciplinary fields of research. The more the scientific disciplines and sub-disciplines are fragmented and re-organized in this way, and the more they are interwoven with technical instruments, the more the above described explorative style of knowing shall favor innovation.

Some of these so-called research technologies develop towards ‘generic technologies’ (Joerges/Shinn 2001) that establish new fields of knowledge and innovation besides and between the established scientific disciplines. The spectrometer, the computer-simulation, the electronic microscope are examples of this type of generic technologies, around which particular communities of knowledge came up (see Shinn in this book and Shinn 1997). These communities circulated both, explicit and codified knowledge via special journals and tacit knowing via technical experience.

Another kind of exploration takes place when the experience of a research technology is combined with the highly explicit knowledge of scientific disciplines. I remind of the development of the computer sciences when such heterogeneous competencies as those of fundamental mathematics and formal logics on the one side were brought into close interaction with those of practical deciphering and telegraphy engineering on the other side (Heims 1980; Rammert 1992). In the case of the great human genome project, Craig Venter left the straight strategy to make explicit one genome structure after the other that gives an example of the style of explicitation. But he instead followed an intuitive strategy of searching patterns by a complicated computer program what can be seen as an example of the style of exploring the relations between the explicit and the tacit knowledge.

Two styles of knowing exist side by side. The style of explicitation characterizes the endeavor to establish a disciplinary code and to enlarge the core knowledge. Specialized knowledge will be aggregated and integrated into the fundamental scientific code of the discipline. When this explicit knowledge base has gained a particular grade of unification and perfection, then this knowledge can be applied for many practical uses during the so called phase of “finalization” (Böhme/Krohn/Weingart 1976). Nuclear physics, plasma physics, synthetical chemistry, molecular biology or neo-classical economy are research fields in which this style of knowledge production is dominant.

If we accept the description of the actual knowledge changes towards a more heterogeneous and distributed knowledge production and if we acknowledge the increasing use of a growing variety of technical instruments, then we may discover another style of knowing. It is more sensible for the relations between explicit and non-explicit aspects of knowing, but it does not only rely on the fundamental and formal processes of explicitation. It produces coherence between heterogeneous participants by processes of enculturation that constitute communities of knowing by interaction, learning and soft theorizing. That means that scenarios and simulation models enable a tacit integration instead of axiomatic theories that only allow a formal integration of knowledge pieces and follow a limited logic of algorithmic information-processing. There shall also remain a strong tendency to make explicit more and more of the unarticulated knowing and of codifying the heterogeneous knowledge fragments; but the explicitation shall be limited by time and costs (see Cowan/David/Foray 2000). The more fragmentation and instrumentation processes augment the spheres of non-explicit knowing, the more one shall restrict strong codification for only the most relevant cases and expand the search for heuristic strategies. The style of exploring the relations between the explicit and the tacit dimension of knowledge fosters a strategy of “satisficing” (Simon 1954) that concentrates on the tuning between the different kinds of knowing.

3.3 Overcoming the limits of explicit and rational knowledge by tacit knowing and trustful cooperation between firms in the industrial innovation

Modern economy is said to be based on rational choices between goods the values and costs of which can be made explicit. But especially in the field of innovation and techno-

logical choices it is evident that decisions are following more likely rules of thumb and organizational routines than explicit rational calculations (see Nelson/Winter 1982). Numbers are definitely the basis of book-keeping and controlling in the modern firm, but knowledge is more than number-crunching: It is the capacity to relate these numbers to other numbers and to interpret their relevance in relation to earlier experiences and future constellations.

Under the regime of fragmental distribution, the conditions of temporal planning and of clear cost calculation are worsening. The usual uncertainty of economic decision-making is multiplied. A complex "circle of uncertainties" (Rammert 2002: 177) is coming up that limits the explicit calculation of risks, returns and benefits. Firms which want to invest into an innovation do not know,

- whether they get access to the relevant scientific information about it,
- whether they are able to select the relevant technological information out of the flood of inflationary information,
- whether they have the capacity to process and convert it into useful knowledge,
- whether the innovation process comes up with a technologically feasible product,
- whether this product can be produced economically,
- whether a new market can be established,
- whether the users accept the product and tolerate its unintended consequences,
- whether the developer gets a fair return to its investments and risks,
- whether his property rights are sufficiently protected, and
- whether the product meets the compatibility requirements of technical standards and legal norms.

Fragmentation processes in the fields of scientific knowledge production limit the standard solutions how to cope with uncertainty, such like establishing close relationships with a faculty or a disciplinary research institute or hiring research and development people with a sound disciplinary background. If you are not sure which of the many diverse competences you shall need, then you have to install distributed connections to many different research fields and institutions. It is not any longer only a question of buying the knowledge and being the first to know, but the complexity of "distributed innovation processes" (Coombs/Harvey/Tether 2001) requires new strategies of building alliances with complementary or even with competitive firms to share the knowledge and the risks.

In the industrial economics literature, we can find two significant changes of this subject: from an information to a knowledge approach and from knowledge-using to knowledge- creation. The information approach conceives the firm as a "response to information-related problems" (Fransman 1998: 149). Information is defined as closed sets of data which can be appropriated and processed by firms. It is a common belief of the 'principal agent' and of the 'transaction costs' view that firms organize innovation on the basis of asymmetrical information and thereby economize on 'bounded rationality' and opportunism. The knowledge approach, however, emphasizes the problem of uncertainty and the fact that information is always incomplete and has to be interpreted. "The problem of innovation is to process and convert information from diverse sources into useful knowledge about designing, making and selling new products and processes"(Freeman 1991: 501). It conceptualizes the firm as a "repository of knowledge", that means a collection of routines, organizational experiences and dynamic capabilities, as the evolutionary and institutional economics have proposed. The dynamic capability of a firm consists of unique organization skills the replication of which is limited because they are tacit in nature, not codified, or embodied (Teece/Pisano 1998: 206). They must be built because they cannot be bought. One can distinguish between weak, moderate, and strong "approbability regimes" of firms,

if one crosses the dimension “ease of replication” (easy – hard) with the dimension of “intellectual property rights” (loose – tight) (Teece/Pisano 1998: 207). Weak appropriabilty regimes favor the augmentation of small start up firms, whereas strong regimes enable the establishment of big dominating and incumbent firms.

The second shift - from the concept of knowledge-using firms to the concept of knowledge-creating firms (Nonaka/Takeuchi 1995) - seems to be more radical and relevant as the first one. It theorizes on the difference of tacit and explicit knowledge and on the spiral processes of knowledge changes. It emphasizes the relations and interactions to produce and to reproduce different kinds of knowledge sets. “Systemic knowledge assets” develop out of the connection of packaged explicit knowledge (Nonaka/Toyama/Nagata 2000: 15). This process of “combination” belongs with no doubt to the knowledge style of ‘explicitation’. “Experiential knowledge assets” rise, if tacit knowledge is shared by common experience what is called “socialization”. “Conceptual knowledge assets” are articulated in the process of “externalization”, and “routine knowledge sets” mark the opposite process of “internalization” when explicit knowledge is turned into embedded and embodied routines. One can criticize that the externalization of tacit knowledge is not so easy and that not all modes of tacit knowing can be made explicit (Clegg/Ray 2003), but the shift from a concept of the firm as an “information-processing entity” to a “dynamic configuration of knowledge creation”(Nonaka/Toyama/Nagata 2000: 17) is path-breaking.

This concept can be expanded to inter-organizational relations between firms. Under conditions of fragmental knowledge production, firms have to incorporate a diversity of sources of learning to raise their potential rate of innovation. The traditional strategy of firms to innovate aimed at the integration of diverse technologies by building large-scale plants and big corporations. This diversification and integration strategy that was successful during the inter-war and early post-war period became exhausted in the 70ies. Up-scaling the corporation was substituted by building corporate international networks. Since the late 80ies, the formation of “a more complex integrated and interactive network for the generation of new competence” could be observed at 166 firms in US and Europe (Cantwell/Piscitello 2000: 26). These international networks resemble more heterarchies of learning than hierarchies of power. As knowledge and learning processes are distributed, new bodies of knowledge are generated mainly by the encounter and interaction of two or more previously existing bodies of organizational knowledge. They are assured by inter-firm technological agreements as it is demonstrated by an analysis of the automobile robotics sector (Lazaric/Marengo 2000: 56).

There are many ways how the different modes of tacit knowing and technological learning take place. A first way is the continual exchange of knowledge within “technological communities” (Constant 1987; Rosenkopf/Tushman 1998). Technological communities are parts of a professional community, like the society of electrical engineering or of chemistry. They communicate explicit knowledge by influencing the educational programs and non-explicit knowledge on meetings and committees. A second way can be seen in the informal help between particular “communities of practice” (Wenger 1998; 2000). Communities of practice are usually bound to a local community and its practices. These “networks of practice” (Brown/Duguid 2000: 28) are not working together at one place, but they build a virtual guild that shares similar practices and indirect communications. A third and more general way is the organizational or inter-organizational practice of doing something together, a kind of coordinated activities without explicit communication. The firm, the organization or the inter-organizational network are made up of diverse communities with different practices and interpretative systems that share collaborative practices in addition to their local practices. Innovation is then a systemic process that involves linking the inventive knowl-

edge of diverse communities into something robust and rounded enough to enter the market place (Brown/Duguid 2000: 26).

At the end, one can relate different grades of explicitation and of explorative experience to different kinds of organizations and different types of technology or phases of technology development. Since Max Weber, bureaucratic organizations are defined as a prototype of formal organizations by written rules and explicit procedures of rational action, especially by the criterion of formal membership. They have the highest degree of explicitation and the lowest degree of tolerating informal knowledge and practical experiences. They are well designed for the processing of clear cut information and homogenous knowledge domains, like financial control or mass production of a not too complex and stable technological product or service. Incumbent big corporations have developed a divisional structure and an internal differentiation between domains of routine and domains of innovation. They still show a high degree of explicitation, but the differentiation and dynamics of the environment enforces lateral communication and informal knowledge processes (see Hage 1999). In the 'low tech' industries, the central focus of knowledge generation is laid on the organization of practical knowledge (Hirsch-Kreinsen et al 2003); in 'high tech' industries, other strategies gain importance, like coordinating the diverse sources of knowledge and balancing the relation between explicitation and explorative experience.

Networks of cooperation between firms come up, when the share and the diversity of non-explicit knowledge is increasing in comparison to homogenous and explicit knowledge. We distinguish three types of networks. Networks of small firms are formed in order to offer a more complex technology or service on the global market; they concert their particular organizational knowledge, explicit and non-explicit, with the other firms which have a complementary capability. Supplier firms in the car industry which join to build a "virtual organization" (Davidow/Malone 1992) are an example. Networks of small firms, like start-ups, and big firms develop, when small firms need more structured knowledge for the production and distribution of a new product on the one side and when the big incumbent firms want to appropriate the explorative capacity and the tacit knowledge of start-ups on the other side. Co-operations between small biotech firms with big pharmaceutical corporations are fine examples. Networks between big corporations take the form of a time-limited and product-oriented alliance in order to share their knowledge bases and to develop a particular new product. These projects are motivated by the limitation of the risk and the costs of a radical innovation that requires a high rate of non-explicit knowing. Joint ventures in the telecommunication sector, e.g. for the appliance of the UMTS-technology, follow this strategy of combining the diverse technological capabilities.

At the end, we can see that the different kinds of non-explicit knowledge are growing under the regime of fragmental distribution (see also Rammert 2004). One needs additional practical knowledge to embody heterogeneous knowledge in functioning technology and to combine different products and services towards a complex technological system. One also needs more time, money and personnel to span the boundaries between technological domains and diverse industrial traditions. One needs also a greater space for the explorative combination of explicit and non-explicit knowledge and for the "generative dance between organizational knowledge and organizational knowing" (Cook/Brown 1999: 381).

3.4 The rising relevance of tacit rules and trust-relationships in heterogeneous networks of organization and under conditions of distributed governance

Modern states are based on explicit constitutional rules and administrative laws. For a long time, they were conceived as the central agency of regulation. Governments developed specialized ministerial administrations who defined the explicit legal frameworks of financial, economic or science and technology policies. But policy studies could demonstrate that a formulated political program or a legal regulatory framework could only gain the intended results, if the conditions of its implementation, especially the interests, the knowledge and experiences of the heterogeneous collective actors in the field, are known and acknowledged (Mayntz 1993). New forms of governance were tested, like corporate governance, that divided governance between state authorities and private associations (see Hollingsworth, Schmitter, Streeck 1994). Under a regime of functional specialization, this kind of oligopoly between the relevant collective actors allowed concerted actions and regulations because the different stocks of domain knowledge were communicated.

The knowledge condition becomes much more difficult, when we move towards a regime of fragmented distribution. The diversity of actors who participate in the innovation process is growing, not only the number of actors. The knowledge that is needed to formulate effective and consented regulations is more radically distributed over many fields of expertise and over many levels of action. The knowledge base that was certain up to that time becomes quickly obsolete in high technology fields. The creation and diffusion of new knowledge that cannot be transformed easily into packaged and portable information passes many loci and crosses a variety of communities and organizations. Under these fragmented conditions, a kind of co-ordination mechanism is required that achieves both: It must maintain the diversity of actors and their knowledge perspectives, and at the same time, it has to create a culture of trust and co-operation. A kind of distributed governance between heterogeneous actors rises that refers to both, to explicit rules that frame the collaboration and to an implicit cultural model or "hidden curriculum" (Rammert 2002: 180) that constitutes an informal platform of collective learning. The new institutional answers to this question are procedures of mediation that confront and concert actors with different and even dissenting knowledge perspectives and interactive networks of innovation that pool the heterogeneous knowledge capabilities and follow a mixed model of formal contracts and tacitly confirmed routines.

This model of mixed kinds of knowing and of distributed governance can be observed under the condition of a fragmented knowledge regime on each level: on the micro level, new situations of "distributed co-operation" between heterogeneous people (see Hutchins 1996; 1998, Strübing et al. 2004) and situations of "distributed action" between hybrid agencies, like machines, programs and people (see Rammert 2003; Rammert/Schulz-Schaeffer 2002), rise especially in high tech work places and replace the Fordist model of work organization that is mainly shaped by a sequential and over-specialized functional division of work planning and performance. Governance is on this level assured by an overlapping of the diversity of skills and a low grade of formalization of knowledge, by a balanced mixture of explicit standards and tacit routines, by explicit "boundary objects" and other more implicit borderline activities which mediate and translate between the different knowledge cultures (Galison 1997; Star/Griesemer 1989).

On the meso level of organization, mechanical and divisional forms of organization that rely on a high grade of explicitation and formalization dissolve and change towards organic, design-, process- and project-oriented modes of organizing (see Hage 1999), when the knowledge conditions get more fragmented and when knowledge changes raise the

level of uncertainty. When the knowledge acquisition by purchase, license, or internal research is restricted, then firms as well as governmental agencies have to join heterogeneous networks of innovation in order to participate at the collective knowledge creation and diffusion processes.

On the macro level of society and its sub-systems, these heterogeneous networks of collaboration and innovation take over the role of distributed governance (Powell 1998b; Callon 1992; Hage/Hollingsworth 2000). They unite scientific, economic and political actors and their different codes of action and knowing, such as research universities and start-up firms, nonprofit organizations and venture capitalists, law firms and consultants and so on. "…heterogeneity and interdependence are greater spurs to collective action than homogeneity and discipline" (Powell 1998b: 231). When collaboration and collective learning across institutional boundaries seem to become the critical factor in the competition, then it is ineffective to formalize all decisions and approvals and to make all kinds of knowledge explicit. In many fields it is sufficient to develop routines of cooperation and informal channels of communication. These forms of collective learning can evolve to formal and "hybrid networks" (Teubner 2000) where the multiplicity of independent actors is blended towards the unity of a collective actor. Or they can develop as "informal networks" (OECD 2001: 8) that are especially capable of incorporating tacit knowledge into their learning processes. They need not so much formal procedures and explicit treaties, but they are built on informal meetings and relations of mutual trust.

Finally, the considerations and findings of this part demonstrate neither that explicit knowledge will loose its relevance or even diminish under the fragmental knowledge regime, nor that all kinds of tacit knowledge can and will be made explicit. There is no zero-sum game between the two kinds of knowledge. Both can grow and gain more relevance at the same time. It is a question of relating the two kinds of knowledge that shapes two styles of knowledge regimes.

STYLES	*'Explicitation'*	*'Exploration'*
Features	abstraction formalization universal codification standard packages of information	embodiment association situated, localization modularized patchwork of heterogeneous knowledge
Models	mechanical + universal model of information-processing	organic + practical model of knowledge-cultivating
Methods	acquisition decision-making purchase and licensing	inquiry waging learning
Emphasis	excessive explanation + exploitation of codified knowledge	tacit circulation + integration experimental balance between the implicit and the explicit

There is a strong tendency in a knowledge-based society to raise the level of explicitation in all fields when it is confronted with the rise of material complexity, when it has to cope with a growing discontinuity in the course of innovation, and when it has to integrate an increasing diversity of actors and perspectives. Additionally, the employment of computer technologies and the progress of telecommunication strengthen the tendency to make knowledge more explicit. But neither the fundamental limit nor the financial and temporal limits of explicitation do disappear, as it was demonstrated for the scientific, the industrial and the regime innovation. On the contrary, there is coming up another strong tendency to take care of all kinds of non-explicit knowledge: the unknown, the uncodified and the uncodifiable tacit knowledge. The rising sphere of the "unknown" is acknowledged by a higher consciousness of risk, by organizational forms of sharing risk, and by methods of waging risks by scenario- and simulation techniques. More and more fields of uncodified knowledge are accepted and organized by routines and routing paths of collective learning. The tacit knowledge that cannot be codified is mobilized in hybrid work situations, in informal networks of practice and in heterogeneous networks of innovation and learning. All these forms of non-explicit knowledge gain a high relevance under a fragmented knowledge regime. The explorative knowledge style that is characterized by an experimental balance between the tacit and the explicit knowledge becomes a necessary condition

- for the creation and diffusion of scientific facts and technological artifacts in a growing multi-disciplinary landscape,
- or pushing the technological innovation in times of high uncertainties,
- for a distributed governance of innovation processes when the central authority of the state is fading and when the certainty, disposability and transferability of knowledge across organizational and institutional boundaries is restricted.

4. Fragmental diversity and explorative learning in heterogeneous networks of innovation

We know a lot about the rough features of the society we are living in by the debates about the coming of post-industrial, post-modern, reflexive modern and knowledge-based society. But we should develop more precise concepts of the organizing principles and epistemic styles that produce different types of social differentiation and various patterns of institutionalization. Two types of social differentiation were distinguished, and two styles of knowledge regimes were identified. They exist one besides the other. The knowledge regime of fragmental distribution does not substitute or follow the regime of functional specialization. One first research task is to analyze the particular distribution of these patterns over the basic institutions of a society, the national systems of innovation, the industrial branches, the technological domains and the scientific disciplines. The aim of this kind of research is to receive a fine-grained picture of the whole landscape of innovation under the aspect of dominant regimes and styles. For politicians and practioners of innovation it may be important to know whether this kind of innovation grows better under the spatial conditions of 'concentration on central places' or of 'dispersion in flows and hyperspaces', under the temporal conditions of 'sequential and standardized synchronization' or of 'simultaneous and instantaneous jazz-like concertation'.

It was assumed that there is also a close relationship between the institutional and the epistemic dimension of the two knowledge regimes. The contribution develops the concept of knowledge styles beyond the traditional distinction between tacit and explicit knowl-

edge. It is argued that one can distinguish three kinds of knowing and that knowledge styles are characterized by the emphasis on a certain kind of knowledge and by the kind of relation that they install between the types of knowing. Two knowledge styles were developed and loosely related to the knowledge regimes: The knowledge style of explicitation that favors an excessive strategy of explanation and codification and the knowledge style of exploration that trusts more on the experimental balance between the explicit and the implicit. It is a second research task to analyze the advantages and disadvantages of these both knowledge styles under different conditions, like high diversity of actors and perspectives versus standard scope of plurality or high uncertainties versus routines of risk management, and in particular situations, like research and radical innovation versus production and improvement. The aim of this kind of research is to develop an analytical concept with the help of which one can identify different knowledge styles and their critical implications on the innovativeness of organizations and systems of innovation. It shall be of great importance for future designs and decisions of innovative organizations to know more about the right balance between different kinds of knowledge, e.g. about the limits and cost of excessive explicitation, about the methods to cultivate the different kinds of non-explicit knowledge, and about the organizational forms that allow the crossing of different kinds of knowledge and that establish a productive balance between explicit knowledge and tacit knowing.

Economical analyses of knowledge and innovation follow usually a too narrow approach to grasp the interrelations and the dynamics of the distributed innovation processes. Quantitative analyses present leading factors and develop rough indicators of the systems of innovation. But they, too, miss the qualitative differences of local situations and institutional constellations. There are two ways to overcome the qualitative blindness. A first line of research elaborates the approaches on the dynamics and journeys of innovation towards a finer grained approach of comparative innovation biographies. Its aim is to dig deeper into the variety of courses of innovations than studies which search for typical phases of technological development. The focus of interest concerns critical events, typical sequences, and hybrid constellations that include actors, agencies and artifacts. The creation and the co-production of particular paths of scientific and technological innovation (see Garud/Carnoe 2001) are more important than the path dependencies.

A second line of research is closely interrelated with this line. It complements the longitudinal view of the biographical analysis with a cross-sectional view of constellations. It aims at a comparative analysis of innovation regimes under different aspects, e.g. “technological regimes” (Stankiewics 2000), “organizational regimes”, innovation regimes” (Hage 2003), “appropriabilty regimes” (Teece/Pisano 1998), and “knowledge regimes”. It elaborates the new institutional approaches towards a multi-level analysis (see Hollingsworth 1999) that includes the analysis of communities and constellations on the levels of interaction, organization and society.

The main interest of both kinds of research is to discover and to discriminate typical patterns of change in the distributed processes of knowledge production. When we are able to spell out the set of rules that constitute particular regimes, then we can answer the question which kind of organization, which style of knowing and which form of intermediary association can be rated as a more adequate institutional arrangement than others. This kind of research goes beyond economical approaches of maximization or management approaches of searching for the champion or following the actual best by bench-marking evaluations. It supposes that there are many ‘good practices’ and that the quality and effectiveness depends on particular situations and constellations which e.g. allow collective learning for a longer period than to concentrate on exploitation of knowledge in an actual situation. This

kind of approach has highly important implications for innovation management and innovation policy. It preserves managers and politicians from following a general pattern and opens spaces for diversity. Scientific disciplines and trans-disciplinary research fields require different strategies. Conventional technologies and complex technological configurations follow not the same logic of development. Traditional industrial branches and heterogeneous networks of collaboration need different policies and legal frames. Therefore we have to distinguish between the styles of knowledge regimes and to develop the adequate policies for each one. Even if the conditions of fragmental distribution are expanding, politics and management has to aim at both, the maintenance of the creative diversity of actors, opinions, and perspectives as well as the institutionalization of codes, cultural models and procedures that enable processes of collective learning. Even if the imperative on the explicitation, codification and computerization of knowledge will continue to have strong effects, politicians and managers are well-advised to take care of the explorative style of knowing that brings the different kinds of knowledge in balance with one another.

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