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Opening up Science: Towards an Agenda of Open Science in Industry and Academia

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Opening up Science: Towards an Agenda of Open Science in Industry and Academia

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Abstract: *The shift towards open innovation has substantially changed the scientific and practical perception of corporate innovation. While scientific studies on open innovation are burgeoning, present research underlies a business-centric view that has focused on the back-end of the innovation process. The impact and implications of open innovation on academic and industrial science at the very front-end of the innovation process have so far been neglected. Our paper presents a conceptualization of open science and research as a peculiarity under the roof of open innovation. We propose four perspectives, outline current trends, and present directions for future developments.*

Augmentation of Open Innovation Towards Science

For centuries, science is based on an open process of knowledge creating and sharing. However, the quantity, quality, and speed of science have changed, as has the openness of science, in recent years. In the days of Galileo, scientists had to use anagrams to hide from inquisition. Later, scientists used letters to distribute their knowledge to their colleagues. When in 1665 the first scientific journal 'Philosophical Transactions' was founded, scientists started sending their insights to scientific journals. In the last century, the number of journals exploded, but the knowledge diffusion slowed down: In some fields the peer review process takes several years from first submission to final publication. Today, more and more academic institutions open up science employing open access journals. But also large firms like Siemens, IBM and Nestlé are part of the open science phenomenon. Instead of only patenting their knowledge, they publish for free in order to participate in the science community and to indicate that a field is already state-of-the-art and thus not patentable.

Despite the historic origins and the recent trends, management scholars have neglected the burgeoning phenomenon of open science. Current literature on open innovation is predominantly underlying a business-centric view. This view assumes the profit motivation of the firm. Numerous studies investigated on how external ideas and knowledge are utilized inside the company to develop and diffuse new product offerings within the market. Additionally, scholars analyzed the possibilities of commercializing internal generated knowledge in form of intellectual property (IP) for profit generation outside the company boundaries (Chesbrough 2003a, b). Thus in the sense of existing literature, open innovation is used to reveal need-based and application-centric information along the entire product development process — from ideation to product roll-out — with a strong emphasis on commercialization. Thereby, the internal solution based information — technological know-how and competences — serves as a catalyst to translate the need information into new product offerings. Research is understood more as an enabler to achieve new offerings to customers. Thus, the very early stages of research and science have hardly been analyzed by the current open innovation literature.

Despite the fact that the historic roots of the open innovation paradigm lie in a disconnection of industrial research and its commercialization, a science centric perspective of open innovation has so far been neglected. Given potential differences in the motivational, structural, and process-related backgrounds between the existing commercial-centric perception of open innovation on the one side and open science and research on the other side, open science is an under-researched phenomenon. This article provides a conventionalization of open science and research based on literature review and semi-structured interviews with CTOs, research managers, open innovation directors, open access leaders, industrial researchers, and scientists.

The paper is structured as follows: in the next section (*section 2*), we review the literature on open innovation and open science to derive similarities and difference between both concepts. In *section 3*, we describe our methodological approach before we present four perspectives of open science in *section 4*. In the subsequent sections, we analyze and discuss current trends. The paper concludes with implications for current research and suggestions for future research.

Literature Review

Research Streams in Open Innovation

The failure of large industrial research labs to drive scientific advancements towards value generation in the early 1980s manifested an anomaly that revolutionarily changed the rules of innovation. Shortly after its foundation in

1984, also Cisco started with its open R&D strategy which ended up in outcompeting the famous, world's largest R&D center, the AT&T's Bell labs. In the Kuhnian sense (1962), this marked a paradigm shift in innovation management. Since then, the practical and scientific community called for more open models of innovation (e.g., Chesbrough 2003a,b; Christensen et al. 2005). Defined as "… the use of purpose inflows and outflows of knowledge to accelerate internal innovation, and expend the markets for external use of innovation respectively" (Chesbrough et al. 2006), open innovation heralds a new era in innovation research.

Within the last decade of scientific research, several special issues on open innovation underpinned a fundamental change in the perception of innovation (see e.g. *R&D Management* 2006, 2009, 2010, and the *International Journal of Technology Management* 2010). This has being complemented by some special issues on open source software development as a subfield of open innovation (see e.g. *Research Policy* 2003, *Management Science* 2006) This sustainable attention of practitioners and researchers shows that open innovation has gone far beyond being a short-term fashion or hype. Within the field of open innovation the following seven research streams can be summarized:

(1) Integration of external cooperation partners along the value chain*.* Downstream the value chain, von Hippel's (1986, 1988) seminar works on lead user integration highlight the virtue of user collaboration for radical innovation. Numerous studies investigated user characteristics and their impact on the degree of innovativeness, the modality of user integration, and user's motivation to collaborate (Bilgram, et al. 2008; Franke et al. 2006; Luethje 2004). The phenomenon of free revealing and the fact that the user is the only external collaboration partner with use-experience makes the user a very valuable partner (Nambisan and Baron 2010; von Hippel and von Krogh 2006). Nevertheless, studies also investigated downsides and dangers of user integration (Gassmann et al. 2010a). Upstream the value chain, research emphasized the importance of supplier integration. The integration of suppliers into the development process at a very early stage can significantly increase innovation performance in most industries (Hagedoorn 1993).

(2) Partnering and alliances. In recent years, there was a trend towards R&D outsourcing and alliances (Hagedoorn 2002). Strong specialization necessitated the need for many companies to collaborate with partner companies from the same or other industries (Schildhauer 2011). Especially, the phenomena of cross industry innovation and innovating with non-suppliers was investigated by current research including its methodological premises (Gassmann and Zeschky 2008; Gassmann et al. 2010b; Howells 2008; Herstatt and Kalogerakis 2005). Also established engineering firms take the role of innovation intermediaries moderating open innovation activities between collaborators (Gassmann et al. 2011). This indirect opening up of the innovation process is leveraging the cross-industry innovation process, not only in traditional R&D outsourcing modes but also in strategic innovation partnering.

(3) Open innovation processes. Open innovation is based on three core processes: outside-in, inside-out, and coupled. This classification provides guidance on how to complement and extend the internal innovation process by an external periphery Gassmann and Enkel (2004). Most large companies such as Siemens and BASF started to developed detailed firm specific open innovation processes. In addition some companies such as Procter & Gamble and Siemens assigned process owners with special positions and titles for open innovation within their corporations. In both corporations these directors have huge attention within the company. Leverage the scarce R&D budget naturally attracts attention of the top management, especially in large firms.

(4) Open innovation tools. As a means to implement open innovation numerous tools emerged; most of them support how to integrate external innovation sources (West and Lakhani 2008). Crowdsouring platforms like InnoCentive, 99design, Nine Sigma or Atizo bring together solution seekers and problem solvers (Bullinger et al. 2010; Sieg et al. 2010; Dahlander et al. 2008). Thereby, they generate a virtual market place for innovative ideas and problem solutions. Toolkits for mass-customization allow an adaptation of design and product features according to customer preferences based on an iterative creation process (Piller and Walcher 2006). Community based innovation enables companies to use blogs and discussion forums to exchange with a mass of stakeholders outside the company. The transfer of ethnographic studies to the cyber space (Netnography) led to new forms of debunking innovative ideas that are freely accessible over the Internet (Kozinets 2002).

(5) Open trade of intellectual property. The times where IP was solely used as a means to secure the firm's freedom to operate are over. The more open approach towards IP changed its role and importance within the firm's value creation processes (Pisano 2006). The active use of IP for in- and out-licensing unfolded new business models, which are widely discussed in scientific literature. New phenomena like patent funds, patent trolls and patent donations emerged in recent years and increasingly attracted scientific research (Reitzig et al. 2007). At the moment, there is an ongoing debate among policy makers in the European Union whether a financial market for intellectual property should be created. Policy makers in favour of new modes of technology transfer as well as financial institutions interested in new product categories are mainly driving that process.

(6) Open business models. The paradigm of open innovation impacted business models in a sense where open innovation becomes an integral part of value creation. The integration of business model thinking in the virtue of open innovation seems to be crucial (Chesbrough 2006; Kim and Mauborgne 2004). Since the appearance of thousands of open source software initiatives under idealistic perspectives (e.g. Linus Thorvald's famous 'Basar against the Catheatral'), open innovation seemed to be often non-commercial. But the business model judges whether not only value can be created but also captured. In the case of Linux many commercial successful service businesses have been developed around the open source model.

(7) Open innovation culture. Overcoming the not-invented-here syndrome (Katz and Allen 1982) presents one of the core challenges in open innovation. Studies like Herzog (2011) revealed determinants of an open innovation culture and its impact on corporate culture, communication, and incentive systems. Companies like 3M or Procter & Gamble started to integrate open innovation as a fundamental part of their corporate culture. In the case of 3M, the degree of how much outside-in thinking is encouraged became a central pillar in leadership evaluation.

The overview on the existing research streams in the field of open innovation shows the strong application and commercialization focus of the present literature. But, detailed insights on collaboration and openness in the field of knowledge creation and science are missing.

Open Science in Academia and Industry

In the context of academic and industrial science and research, the sharing and combination of information is regarded the core process of knowledge creation for the sake of advancing the state of the science and technology (Thursby et al. 2009). As scientific problems are getting more specialized and complex at the same time, it is not surprising that collaboration in science and research expanded in various disciplines within the last decades. For example in sociology science, the percentage of coauthored articles almost quintupled in the last 70 years (Hunter and Leahey 2008). Comparable trends were observed in political science (Fischer et al. 1998), physics (Braun et al. 1992), and economics (Maske et al. 2003). Studies even show that authors with a high impact factor are those who collaborate widely with others, form strong alliances, and are less likely to be bonded to a certain in-group (Pike 2010, Tacke 2010).

Despite this general trend across academic and industry science, for many years both fields seemed to constitute two worlds with different goals, norms, and needs for secrecy (Dasgupta and David 1994, Rosenberg 1990). According to Merton (1973), the principle of openness has always been an integral part within the academic community. This openness roots in a reward system that the first person to contribute new findings to the scientific community receives in return various forms of recognition (Stephan 1996; McCain 1991; Hagström 1965). Contradictory, industrial scientists were perceived as being much more concerned about confidentiality as a means to secure future returns on R&D investments (Cohen et al. 2000). Recent studies however indicate that this disparity seems to diminish as increasingly cross-institutional bonds emerged (Murray 2006; Powell et al. 2005). For example, Haeussler (2011) found that for both academic and industrial scientists the likelihood of collaboration and exchange depends on the competitive value of the requested information and on the degree to which the researcher's community conforms to the 'norm of open science' (Rhoten and Powell 2007). Some studies even propose a concurrence between academia and industry (Vallas and Kleinman 2008). Thus, academic and industrial science moved from a "binary system of public vs. proprietary science to […] arrangements which combine elements of both" (Rhoten and Powell 2007, p. 346).

The convergence of academic and industrial science and the increasing importance for collaboration and openness drive the need to gain more insight in how open science is characterized. Present studies in the field of open innovation seem to fall short in providing this insight. To derive a research agenda for open science a more detailed look on the central motives and trends seems necessary.

Methodology

Given the young nature of the phenomenon, our empirical research mainly relies on a qualitative exploratory research approach based on interviews, Internet research, and document analysis. This triangulated qualitative approach is an appropriate means to navigate unclear boundaries between phenomenon and context in the early stages of research. Our data generally relies on the primary source of semi-structured expert interviews and secondary source of company press releases and Internet research. Between 2008 and 2011, we conducted 38 interviews with different actors in technology intensive industry and academic research, namely CTOs, R&D managers, open innovation directors, senior industry and academic researchers, directors of research institutes, editors and referees of academic journals, and university presidents. This kind of triangulation allows us to minimize the bias of personal perspective and enhance the validity of the information. To combine the advantages of unstructured and semi-structured interview methods, we started with open-ended questions, followed by a structured questionnaire protocol. Besides asking formal questions regarding the institutions' motivations and barriers of opening up science, the interviewees were also strongly encouraged to provide related examples from their daily business, including current research projects. The intention of the interviews was to identify drivers, inhibitors and current trends in open science and research.

Academic research representatives of the following institutes were interviewed: Berkeley University, European Organization for Nuclear Research (CERN), ETH Zurich, Research Center Jülich, RWTH Aachen University, Stanford University, Swiss Commission for Technology and Innovation (CTI), Swiss Federal Laboratories for Materials Science and Technology (EMPA), Technical University Dortmund, Technical University Munich, University of Manchester, University of Cologne, University of St.Gallen. From industry, the following companies are included: ABB, Bayer, Daimler, Henkel, IBM, Microsoft, Nestlé, Novartis, Procter & Gamble, SAP, Schindler, and Siemens.

Perspectives of Open Science

Open science and research is characterized by the use of inflows and outflows of knowledge to advance the state of the science and technology. Taken a value chain perspective, it includes the very front-end activities of basic science, applied science, and applied research. Despite the contextual backgrounds of academia and industry, research is rather driven by curiosity, reputation, and acknowledgement than by profit and applied oriented thinking. Four perspectives of open science and research can be differentiated.

(1) Philanthropic perspective. Doing research requires infrastructural and content-related elements whose access has been predominantly restricted. Current trends foster a democratization of science and research in the sense of distributing scientific content, tools, and infrastructures freely. Many universities started to offer public lectures or courses with the goal in mind to bring science and research closer to society and to market scientific findings. Most of the public lectures are streamed online and thus are globally available (Tacke 2010).

Additionally, this trend includes the rise of open access journals that provide users with the non-restricted right to read, download, copy, distribute, print, search, or link to the full texts of articles.[1] As most traditional journals generate revenues based on subscriptions, the majority of open access journals are funded by the authors through publication fees. Within the last years, the visibility and prominence of open access journals significantly increased due to the growing numbers and the establishment of the Directory of Open Access Journals.

At the world's largest high energy physics lab CERN 3000 scientists from 174 institutes from 38 countries experiment on a budget of CHF 1 billion with the 27 km long accelerator (LHC, status 2011). The project Atlas publishes the results to the estimated 15'000 high energy physics scientists around the globe on the open access platform Atlas Twiki Portal. In doing so, the high energy physics community prepares the way for new forms of scientific exchange and communication that enable fast peer reviewed publication (Heuer et al. 2008).

In many publicly funded research projects the results have to be distributed feely. At the Swiss Commission for Technology and Innovation (CTI) the establishment of a knowledge distribution platform in form of published results is very helpful in order to receive grants. In some EU funded projects the open distribution of knowledge is a prerequisite to get the funding.

With the goal to provide open source scientific software, a group of mathematicians and engineers at the University of Notre Dame, Indiana USA, initiated the OpenScience Project. Its vision is to provide a collaborative environment in which science can be pursued by anyone who is inspired to discover something new about the natural world.[2] The platform provides software to analyze experimental data and allows an interaction with theoretical

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[1] Budapest Open Access Initiative; http://www.earlham.edu/~peters/fos/boaifaq.htm#openaccess; accessed on 06/23/2011

[2] OpenScience Project; http://www.openscience.org/blog/; accessed on 06/23/2011

models. The entire project is non-profit, driven by voluntary effort, and funded by donations.

(2) Reflationary perspective. Currently, we witness a trend towards making scientific results freely available in a pre-publication status. Knowledge is shared in a very early stage within the research process. Motives to do so are manifold. Researchers are able to reflect first thoughts, to promulgate preliminary scientific results, and to push new ideas within the scientific community. Thereby, they signal tacit knowledge and reputation that might attract other researchers and institutions (Hicks 1995). Furthermore, they are capable of actively influencing future research directions and starting new scientific discussions. Colleagues and amateurs are invited to give feedback and to join in for collaborative knowledge creation. External involvement diminishes problems with respect to local search bias and groupthink many closed scientific research teams suffer of. At the same time the journals and publishers have an own interest in pre-publications: Papers, which have been published before print will get cited higher and therefore increase the citation impact and thus attractiveness of the journal.

Due to slow and rigid publication procedures of many peer reviewed journals, the Internet offers the possibility to timely make first research results available and claim leadership of thought. According to the CERN experience in high energy physics, the open access initiative accelerated science by more than a year. When in 2008 the blueprint of the LHC accelerator was published on the Internet, thousands of downloads were registered within days. Not only colleagues but media and interested groups accessed the blueprints, too. An analysis of citation data showed that free and immediate online dissemination of preprints created an immense citation advantage (Gentil-Beccot and Mele 2009).

Moreover, the memory and transparency of the World Wide Web allows tracing thoughts and knowledge creation. This minimizes the risk of lost authorship. Comments and evaluations of peer research might give guidance in research phases of high uncertainty.

(3) Constructivistic perspective. The opening of science and research enables new collaborative forms of knowledge creation. In recent years, new interactional approaches were used to generate scientific findings. Completed in 2003, the Human Genome Project was a 13-year run undertaking with the primary goal to identify all of the approximately 20,000–25,000 genes in the human DNA. Led by the U.S. Department of Energy and the National Institutes of Health, major research contributors came from the U.K., Japan, France, Germany, China, and others. The whole research progress dramatically speeded up when the research had been opened up.[3] Another form of new collaboration is the notion of crowdsourcing scientific challenges. A well-known example is the crowdsourcing platform InnoCentive (Piller and Walcher 2006). Problem seekers pull for new scientific solutions by broadcasting problems to an unknown mass of potential problem solvers. Virtual rooms are used as an exchange platform where problem seekers and solvers can interact. Small groups formed virtual exchange platforms for loose or moderated exchange with the goal of knowledge creation.

Open platforms typically address several fields in a more interdisciplinary manner than the typical disciplinary mainstream journals. The integration of more than one scientific discipline under one roof fosters cross-fertilization of researchers and scientists. This interdisciplinary approach enhances technology fusions and the generation of innovative solutions (Kodama 1992).

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[3] The Human Genome Project; http://genomics.energy.gov/; accessed 06/23/2011

(4) Exploitative perspective. Most researchers are oriented towards the generation of novel scientific findings neglecting real life application. The active sharing and promoting of scientific knowledge enables researcher to faster close this gap towards application-oriented knowledge exploitation. In cooperation with practitioners a common shared construction of new artifacts based on the latest scientific findings is possible. By the time the research was finished, the Human Genome Project was committed towards a long-standing dedication to transfer technology to the private sector. By making technologies available to private companies, the project fostered the development of new medical applications and was receiving grants for its innovative research. At the end is a two way benefit: Research finds its way towards implementation in practice and in addition funding opportunities; industry has faster access to latest research results. Several public funded cluster initiatives in Europe have these knowledge sharing platforms which bring together universities, industry and investors (e.g. Eco World Styra, Finnish Cleantech Cluster, New England Clean Energy Council, CleanTechNRW).

Table 1 provides a summary of the some open science initiatives with respect to their applied perspective.

Table 1: Overview on open science initiatives

Initiative	Description	Perspective of open science			
		Philanthropic	*Reflationary*	*Constructivistic*	*Exploitative*
Academia	Online platform for academics to share and follow research in over 100,000 research areas; news feeds allow to follow new papers and research updates from selected academics	x	x	x	
Alexandria (UniSG)	Publishing platform and directory for publications of USG; free access	x			
Atlas Twiki Portal	Open access platform that publishes the results of the CERN lab	x	x		
CERN	Lab of high energy physicians that makes scientific results available early in the knowledge creation process		x	x	
CleanTechNRW	Cluster to promote clean technologies and foster exchange between academia and business application			x	x
CoLab Open Source Science	Open access platform for research projects which enables global and interdisciplinary collaborations; sharing ideas with the public such as the formation of scientific papers; idea of an 'online scientific conference'		x		
Directory of Open Access Journals	Internet platform that provides a comprehensive overview on all open access scientific and scholarly journals	x			
Eco World Styra	Open cluster of over 200 green tech companies and research centers			x	x
European Case Clearing House	Non-profit organization that publishes and distributes case studies from many business schools; holds workshops on case teaching and writing	x			x
Finnish Cleantech Cluster	Formation of four Finnish science and business centers to one clean technology cluster			x	x
Human Genome Project	Global research project to decode human DNA		x	x	x
Mendeley	Partially free reference management software; groups and newsfeeds enable collaboration and exchange	x	x		
Method Space	Online Platform of SAGE Publishing on research methodology; groups, blogs, Q&A, and free access to selected journals allow efficient exchange	x	x		
myExperiment	Internet platform for finding, using and executing scientific workflows	x	x	x	
Nature Network	Virtual workplace that provides researchers with apps and facilitates collaboration and information sharing through forums and blogs; focus on natural sciences		x		
New England Green Energy Council	Initiative is to accelerate New England's clean energy economy to global leadership; Council represents over 400 members			x	x
Ologeez	Social research network for academics that provides social-based recommendation service for academic search; wiki groups support		x		

	research collaboration			
OpenScience Project	Initiative that provides free open source scientific software	x		
OpenWetWare	Wiki platform for biology and biological engineering; open exchange	x	x	
PLoS - Public Library of Science	Nonprofit publishing venture (mainly focused on natural sciences and medicine) that provides scientists with high-profile journals in which to publish their work; applies Creative Commons Attribution License	x		x
ResearchGate	An online publishing and networking platform that is dedicated to science and research; usage is free of charge	x	x	
RxPG	Professional network of medical doctors and students; forums enable discussions and peer-guidance	x		x
Science 3.0	Community for sharing ideas, tools and building connections; purpose is to 'combine the hypothesis based inquiry of laboratory science with methods of social science research to improve the use of new human networks'		x	
Sci-mate	Platforms allows fast publication of ideas and knowledge	x	x	
Siemens - Technical Papers	Online website that makes Siemens publications (e.g. conference papers) freely available	x	x	
Social Science Research Network (SSRN)	Scientific network devoted to the rapid worldwide dissemination of social science research; it hosts several working paper series from numerous research institutions (e.g., INSEAD, MIT, University of California)	x	x	
Ways - World Association of Young Scientists	Initiated by the UNESCO; global social network designed for researchers to promote their work, seek help, share information, look for job opportunities and develop knowledge and relationships.		x	
Zotero	Open source management software; groups allow exchange of literature	x		

Trends and Streams of Open Science and Research

The open paradigm of science has just paved the way towards a new division of tasks and a new role understanding within scientific research. New links and forms of collaboration emerged within the science community itself but also between academic research and more application-oriented institutions. The times when research institutes demonstrated intellectual fortresses following the goal of Humboldt's knowledge creation as an end in itself seem to be over in most areas. The complexity of scientific problems and the required investments (time, expertise, and materials) to solve them dramatically increased within the last decades and necessitated the breaking of new grounds in external collaboration (Bozeman and Corley 2004). The last ten years of open innovation showed how profit-oriented entities used external recourses to increase their capacity for innovation as a measure to secure the long-term competitiveness of the company. Open innovation fundamentally influenced business strategy, general management, and organizational behavior. Based on the literature review and our own empirical analysis several trends within science and research can be identified:

(1) Role of research institutes: form ivory towers to knowledge brokers. Traditionally, there was a gap between research driven universities and application driven private companies. This gap is about to diminish, as the distribution of tasks between academia and industry changed. The tremendous rise of technology transfer fostered by many universities and private companies closer linked science and practice. For instance, the ETH Zürich and IBM jointly operate the Binnig and Rohrer Nanotechnology Center in Zurich. The center provides a common collaboration platform allowing researchers of both institutions to exchange. As equal collaboration partners, both institutions have the right to publish and to commercialize the jointly created intellectual property. This dual relationship increases the pressure on both partners to timely find applications for the scientific findings generated and to commercialize research results. The local consolidation of many highly dedicated innovation teams proofed to accelerate knowledge creation and opens up fast ways for the commercialization of current results. Additionally, mutual career paths in the ETH and IBM emerged that manifest a liaison management between both entities and create spill-over effects especially with respect to the transfer of tacit knowledge.

(2) Process: from local centers of basic research to global networks of applied research. In recent years, the self-conception of many universities and research institutes changed. Many public institutes moved from being a provider of basic research, towards a more application centric research. To enable multiplication on a global scale and to merge competences, various research institutes formed networks that targeted at providing direct solutions for business problems. The Auto-ID Labs are a prominent example. They represent a leading global network of academic research laboratories in the field of networked RFID. The labs consist of seven renowned research institutes — including the MIT Lab, the ETH Zurich Lab, the Cambridge Lab, the Fudan Lab, and the Keio Lab — located on four different continents. The goal of the Auto-ID Labs is to architect the 'Internet of things' and to provide an efficient infrastructure which facilitates new business models and applications on the basis of the RFID technology. Along the development within the Auto-ID Labs a common research platform was created that allows collaboration. The research findings are immediately translated into new product offerings and applications such as anti-counterfeiting.

(3) Outsourcing research: from make to buy. The industrial trend of reducing the value chain activities to focus on identified core competence has also affected the relationship between private, application oriented businesses and research institutes. Following this trend, expenses in corporate basic research and the value-added depth of many companies decreased. As a consequence, numerous firms started to outsource research activities: The elevator company Schindler works together with the Institute of Applied Mathematics at the University of Cologne. On the basis of precise requirements, Schindler outsourced the development of genetic algorithms for its latest elevator control systems. In this regard, the Institute of Applied Mathematics became a knowledge and technology supplier at the very front end of Schindler's innovation process. Daimler outsourced many of the telematic research to several research institutes and universities. ABB outsourced its research on inspection robotics for their installations to a joint venture with the ETH Zurich. SAP has set up several decentralized research labs on campuses of universities, e.g. TU Darmstadt, ETH and St. Gallen. Norvatis is more and more relying on start-up firms and research institutions to fill the technology pipeline in research and preclinical development.

Additionally, the outsourcing of research activities offers SME new possibilities to overcome the 'liabilities of smallness' (Gassmann and Keupp 2007). Prior, due to resource constrains, many SME were not able to conduct basic research on their own. Thus, outsourcing scientific problems to research institutions allows them to increase their competitive position.

(4) Research culture: from closed disciplinary to open interdisciplinary thinking. For decades, science was predominantly driven by disciplinary research. Within the scientific community, research streams were influenced by few dedicated and topic specific journals. A narrow and disciplinary framing of research articles increased the probability of getting accepted. Additionally, the dogma of 'publish or perish' forced researchers to keep their work a secret — at least in the early stage of competition — until submitting it to scientific journals. This development led to the formation of scientific progress but also to ivory towers.

Within the last decades, the number of academic and interdisciplinary journals grew constantly and new forms of Internet-based collaborations emerged. Offering new ways of publication and collaboration, this development caused a change of thinking towards more open and interdisciplinary research.

New scientific cross-links between various research fields offer novel platforms for publication.

(5) Financing of research: from single-source to multiple-source funding. In recent years, the increasing cost pressure on many public households, especially in the industrialized world, led to declining budgets in many public research institutions. Formerly being largely financed by public money, many universities are forced to find additional ways for financing research activities and thus progressively seek third party financing. Many universities increased their activities in technology transfer and in IP commercialization. For example, 25 Bavarian academic institutes formed a patent exploitation network, which is coordinated by a patent bureau. Under the roof of the Fraunhofer Institute, BayernPatent is responsible for the IP commercialization. Additionally, it assists inventors with the filing of patents. Thereby, it works closely together with local patent attorneys and offices. BayernPatent covers 100 % of the patent filing and maintenance costs and thus minimizes the risk for the academic institutes. Revenues are split equally between the inventor (25 %), the faculty (25 %), the university (25 %), and BayernPatent (25 %).

Whereas many universities moved from public to more private funding, numerous corporations made an opposite shift. In the 80's roughly 80 % of Siemens' Corporate Technology was financed by uncommitted corporate funds. Today, more than 70 % have to be financed by Corporate Technology on its own responsibility via third party money or business units. This trend is also reflected by several other large firms such as ABB, Daimler, and Philips, which are forced to collaborate with universities and spend seed money in basic research. This supports the universities in their research. The Stanford model (meaning Stanford

University's extensive licensing activities) still is a benchmark for the open science paradigm in terms of the closeness to industry.

(6) Focus of research: from broad to specified. Within the scientific landscape the specification of research institutes in the public but also private sector increased. The requirement to be more cost efficient forced the research activities to be closer related to the core competences — responsible for value creation and profit generation — of the executing institutes. Within the public sector, light houses of research were formed that attract new researcher as well as private companies. Numerous examples can be found in the sector of environmental technologies in Germany.

In the private sector, companies deliberately invest in basic research in strategic fields of high importance to the company. For example, Sulzer Innotec became a specialist for computational fluid dynamic. The know-how in simulation software is later used in the development of a wide variety of products.

(7) Collaboration: from lone warriors to open research clusters. Looking at the innovation landscape, the centralization of innovation within open research clusters becomes evident. Since its opening in 2006, the Philips High Tech Campus in Eindhoven, The Netherlands, has attracted several small and medium sized start-ups that use the infrastructure for open collaboration in research. Currently, over 8'000 researchers, developers, and entrepreneurs work closely together and develop new technologies and products. The spatial proximity fosters a fast exchange between the various research teams and allows Philips to monitor the latest developments in its area of interest.

Companies like SAP and Microsoft started to install decentralized research labs on university campuses to increase their absorptive capacity and benefit from spill-over effects.

(8) Patents: from stockpiling to patent donation. During the last years, the number of global patent applications of private companies has dramatically increased. Accordingly, firms are confronted with ever growing filing and maintenance costs. Recently, a trend has started: private companies donate patents to research institutions. Many companies reserve the right to licensee the patent free of charge within its field of business. Doing so, research institutes may use the patent in other fields and leverage knowledge to new areas of application enabling cross-industry innovations. A prominent case of a patent donator is DuPont. The company donated patents amounting to a value of 64 million USD to the Pennsylvania State University and VirginiaTech. The Kellogg Company gave away patents worth 49 million USD to Michigan State University. Both firms could realize important tax benefits, cost cuttings, and have benefited from positive public relations (Ziegler 2011).

On taking stock of these trends, it becomes obvious that science and research is getting increasingly open. As a phenomenon special to the framework of open innovation, open science and research moves ahead in revealing new ideas and knowledge freely. In the sense of von Hippel (1986), current developments manifest a democratization of science and research. Given the different motivational backgrounds between private and public institutions, a symbiotic relationship becomes evident, where research institutions enable research capabilities and private companies contribute commercialization know-how.

Fields Defining the Future of Open Science

Open science and research is about to change its status from a research interest of a few to a new research stream. To this end, open science and research complements an irreversible existing paradigm shift in innovation management at the very front of the innovation funnel. Nevertheless, current scientific contributions are still fragmented and are far away from presenting a holistic picture of open science and research. Many knowledge gaps within various fields are evident.

Higher acceptance. Open science is a popular topic but the general acceptance is still lacking. According to a study 89 % of all scientists favor open access journals, but only 8 % actually publish in them (Dallmeier-Tiessen et al. 2010). Despite that "open access journals unchain content and speed up science" — stated Mele (director at CERN) — the acceptances of these journals are not equally high in every scientific field. While in medicine and high energy physics the open access journals have very high impact factors, the acceptance in the management research field is rather low. However, in all fields we can observe an increasing acceptance and use of open access journals for publishing. How can a higher acceptance of open science be achieved? Respectively, it seems necessary to look at incentives and reward systems for users in open science platforms beyond pure reputational aspect.

New measurements. Today's measurement of scientific impact is mostly based on journal impact factor. This is a rather slow, closed and biased by social group effects. As the UK Parliamentary Office of Science and Technology put it 2002, peer review 'is an inherently conservative process…[that]… encourages the emergence of self-serving cliques of reviewers, who are more likely to review each others' grant proposals and publications favorably than those submitted by researchers from outside the group. New ways of complementary measuring scientific output are needed. There is a need to develop a system of 'scientific impact 2.0'. A key factor could be played by Google Scholar which publishes individual user measures. Based on that Harzing's 'Publish or Perish' database analyses openly different factors such as the so-called Hirsch index (h = number of citations = number of published paper).

The often seen splendid isolation of peer-reviewed journals from practice and society could be overcome by the diffusion of research results in social media. Research can be addressed, commented and better marketed in the new media. Post-publication will be evaluated and selected by the crowd in the net. A social media impact could include blogging, Wikipedia, comments and recommendation systems. This is a not very well researched field where more empirical evidence in selected science fields is needed.

Virtual knowledge creation. With the use of the Internet, new forms of sharing and generating knowledge came to light that led to new challenges: how can collective generated knowledge be published? What are guiding frames concerning plagiarism? How should plagiarism be handled? In the Anglo-Saxon dominated science landscape, each researcher is evaluated based on his or her individual scientific contribution, e.g. in the process of doing a PhD. This requires that a clear assignment of contribution is possible. The collaborative knowledge creation in virtual networks — often described as E-Science — challenges this dogma as a precise identification of researchers and their work is sometimes not possible. New solutions are required regarding the assignment problem in the case several authors work on one contribution. How can universities adapt current evaluation standards that foster open science and research?

Quality assurance of scientific content. The successful opening of science presupposes explicit measures for quality assurance with respect to content. Considering the rise of open science platforms, decisions about user authorizations and access rights have to be made. How do new forms of evaluation and review systems that secure rigorousness of research look like? Transparency seems to be key. The visibility of the entire research process, from the very first ideas and to the final results, is crucial for crowdsourcing quality assurance. An open question remains also regarding the platform: which is the right publication platform for which fields?

Accelerating interdisciplinary science. Based on open science platforms, unrestricted navigation across different subject areas and scientific disciplines leads to new ways on how and what kind of existing knowledge is reviewed. What is the impact of new search and language processing technologies on the creation of new interdisciplinary insights?

Outsourcing research by SME. Within an economy, SME present the largest number of companies. The effects of an open paradigm of science and research on how SME can benefit from collaborative research with academic institution have not been investigated: what are success factors? How are collaboration processes characterized? What are relevant intermediaries and platforms for the matchmaking between research and SME?

IP trade. As outlined, the tradability of knowledge in form of IP is a catalyst for opening up science and research. But, the determinants of successful trade are still under-researched. Patent valuation remains a challenge, as most patent transactions are not publicly disclosed. Efficient market places for IP might lead to more open approaches in research, as they will give more guidance in patent valuation. Furthermore, possible negative consequences of an open trade of IP — e.g., effects of patent trolls on value creation — have to be investigated in more detail. How can IP be made more tradable?

The new phenomenon of patent donation still presents a white spot in research. Closer investigations on motives and strategic premises of the donators are necessary. On the side of the patent receiver exploitation and adaptation processes might be worth looking at.

The field of open science is still at an early stage. It offers a wide field for future research. We invite researchers from different fields to contribute to that fascinating area.

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