From Open Science to Open Innovation

Prof. Henry Chesbrough

ESADE

Prof. Henry Chesbrough
Institute for Innovation and Knowledge Management, ESADE

Prof. Chesbrough is also Faculty Director of the Garwood Center for Corporate Innovation, Haas School of Business, UC Berkeley

www.sciencebusiness.net

ABSTRACT

The accelerating frontier of scientific knowledge has coincided with a renewed interest in open science by policy makers. The norms of open science promote the rapid diffusion of the latest knowledge, and invite broader partner participation in the discovery of new knowledge. This deepens the knowledge, improves its quality, and helps its diffusion (which then leads to another cycle of discovery and diffusion). As valuable as this broad engagement is, however, it does not assure the subsequent effective commercialization of scientific knowledge. Indeed, the norms of open science can, in some ways, create challenges that impede the commercialization of knowledge.

Open innovation is a concept that can help to connect the fruits of open science to more rapid translation and development of its discoveries. Like open science, open innovation assumes broad and effective engagement and participation in the innovation process. But effective commercialization of new knowledge in open innovation also requires the discovery and development of a business model.

The business model creates value within the innovation chain, but also enables the focal actor to capture at least some of that value. Relatedly, the handling of intellectual property rights questions becomes relevant to the ability and willingness of commercial actors to invest resources and undertake risky activities in hopes of developing a successful new process, product, or service. However, overly strong protection of IP, or prematurely assigning IP rights at early stages of scientific inquiry, can stifle innovation rather than advance it.

This paper explicates these concepts, and highlights the need for developing appropriate new open innovation institutions, to help bridge this gap from open science to open innovation. Several experiments are underway already, notably within the European Union as it tries to reinvigorate its own innovation economy. They seek to speed up the commercialization process of the considerable scientific knowledge amassed in such major European research institutes as CERN. Entrepreneurial risk-taking will be needed to define the most promising applications, and substantial trial-and-error will likewise be required to develop effective business models that can create and capture value, at commercial scale. Pre-competitive research in an open domain can be blended with downstream assignment of IP rights, so that the power of open science can be joined to subsequent risk-taking in the commercial realm. In this way, such institutions will show how w open science and open innovation can lead to a number of potential new business opportunities.

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OPEN SCIENCE

The pursuit of knowledge is as old as the human race, but the institutions that promoted scientific discovery really arose with the Enlightenment. Prior to that time, there were individual scientists sponsored by wealthy patrons, and there was also the founding of the early universities. But the former had strong incentives to hoard knowledge, while the latter focused most of their intellectual energy on the liberal arts (divinity being the leading degree conferred by these universities during the Middle Ages).[1]

During the Enlightenment, there was something of a Cambrian explosion in scientific institutions, as the pursuit of knowledge migrated from royal patrons to a much larger bourgeoisie. This migration caused a tremendous increase in both the volume of scientific knowledge generated, and in the speed with which new discoveries diffused within society. One landmark event was the formation of the Royal Society in 1660, which published its Philosophical Transactions of the Royal Society starting in 1665.[2] Other societies soon emerged in France (1666), Berlin (1700), Russia (1724), and Sweden (1739). By 1700, there were over 30 scientific journals being published, which would skyrocket to more than 1,000 journals a century later.

During this period of intellectual ferment, the norms of science also came to be established. One insightful analysis of these norms that proved quite influential came from Robert Merton's Sociology of Science.[3]

Merton argued that science had developed norms of behavior that cumulatively contributed significantly to the growth and quality of scientific knowledge.

These were packaged into an outline he termed CUDOS:

- **Communalism** - sharing discoveries with others, in which scientists give up intellectual property in exchange for social recognition gained through sharing

1 See Paul David's delightful history of early scientific institutions in David, Paul A. "Understanding the emergence of 'open science'institutions: functionalist economics in historical context." Industrial and Corporate Change13.4 (2004): 571-589.

2 Ibid.

3 See Merton, Robert K. The sociology of science: Theoretical and empirical investigations. University of Chicago Press, 1973.

- **Universalism** - claims to truth are evaluated in terms of universal criteria, and should be reproducible by others under the same conditions

- **Disinterestedness** - the researcher's attitude is one of objectivity; such that the researcher follows the evidence wherever it goes, regardless of its implications for profit or lack of profit

- **Originality** - research results should yield novel contributions to understanding

- **Skepticism** - all ideas are subject to rigorous, structured community scrutiny, which curates the quality of the work that results

With the advent of the Internet and the Web, these Mertonian norms have found expression in new institutions that again create even greater volumes of knowledge that diffuse even more rapidly. One concrete example is open source software.

Open source software is a method of software development in which the code base is open for inspection to all participants. This enables the software to spread rapidly to others, and also allows common routines in the software to be rapidly applied in other contexts. In tandem, this code is tested by numerous independent developers and testers, such that software "bugs" are rapidly detected and then fixed. According to Richard Stallman's famous dictum, "With enough eyes, all bugs are shallow". This has allowed open source software to produce code of high quality and reliability.

More recently, the norms of open science have been manifested in projects to expand further the access to scientific knowledge. One example of this is the Open Science Grid in the US[4]. The concept here is that wider, faster, and cheaper access to new knowledge will promote more rapid understanding and use of science. This Open Access movement has found expression in journals like the Public Library of Science, for finished scientific articles. It has also led to new initiatives like the Research Data Alliance,[5] for sharing the source data collected in the scientific process, so that research data and research methods that lead to new science can also be shared.

As the need to access data grows, as access to high quality instruments and high data volume grow, and as supporting infrastructures are developed to organize and manage access and the results from open access, the pursuit of science itself is expanding. This is leading to an era of "citizen science" or "crowdscience", where important scientific contributions can be made by ordinary people from all over the world. In astronomy, amateur astronomers are finding new stars, new exoplanets, and new phenomena. In biology, programs like FoldIt are enlisting ordinary contributors to solve complex protein folding problems. In neglected diseases, open science is finding new application. And in large, seemingly intractable problems like global climate change, open science is making inroads as well.

CERN's experience as the birthplace of the web; as contributor to grid computing initiatives such as one linking its particle accelerator to 170 labs

4 Opensciencegrid.org

5 See https://rd-alliance.org/about.html for more about the origins and structure of the Research Data Alliance.

globally (WLCG),[6] another linking several EU labs in varied disciplines (EGI)[7] and an open access repository of high-energy physics journals accessible in 40 countries (SCOAP3)[8]; and now as host lab with its Large Hadron Collider is one very large scale example of the power of open science, when it is adopted across an entire set of institutions. From its inception, CERN made provision for the widespread access to and diffusion of its research results, and invited participants from all over the world in the project.[9] The norm of openness enabled significant achievements to be contributed by very large numbers of participants, with the two foundational papers noting the discovery and verification of the so-called Higgs boson each having roughly 6,000 authors.[10] These papers led to the award of the Nobel Prize in Physics for 2013.

Open Science Does Not Directly Result in Innovation

While open science has advanced impressively in the past two decades, one cannot yet claim that it has simultaneously led to a similar increase in innovation. Indeed, there is concern within Europe that its extraordinary science base is not leading to enough industrial application of the new science.[11] In addition to the institutions that promote open science, we may also need to consider institutions that promote the application of that science in the commercial realm.

There are straightforward reasons why open science by itself may not translate into new innovations. Once a new discovery is made, it is often unclear or of less importance to the researcher(s) how best to apply it. Understanding the behavior of a new material, or a new physical property, may say little about the best uses of this knowledge. For example, it is not at all clear how knowledge of the Higgs boson could be applied commercially. To take an older example, the fundamental physics behind the principle of lasers originally developed for molecular structure studies demonstrated new properties of light.

But it would take decades to put this knowledge to practical use at any industrial scale. And it turned out that the most prevalent use of this knowledge was to be found in CD and DVD players, for audio and video recording and playback. This application was quite far from the minds of the scientists who performed the foundational science that enabled this use.

Different Incentives and Contexts

The application of scientific knowledge involves different incentives, contexts and mechanisms than those that are present in scientific discovery. In science, the fundamental questions

6 http://wlcg.web.cern.ch/

7 http://www.egi.eu

8 http://scoap3.org/

9 See Boisot, Nordberg, Yami and Incquevert, Collsions and Collaborations: The Organization of Learning in the Atlas Experiment at the LHC, (Oxford University Press: 2011) for one detailed description of the institutions governing the science at CERN.

10 See, for instance, Atlas Collaboration: "Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC." Physics Letters B 716,1 (2012): 1–29. doi:10.1016/j.physletb.2012.08.020. As we shall see below, it is unclear at this point how helpful it is to each of the individual contributing scientists to be among the 6,000 authors, in terms of personal recognition and prestige. Merton's CUDOS implies scarcity in academic credit yields prestige and recognition. When such credit is distributed across 6,000 people, the social rewards to any one individual may be diluted.

11 One interpretation of the Horizon2020 program, with its Flagship Initiatives, is that these are intended specifically to address the lack of industrial take-up of new scientific knowledge, by providing new resources to encourage such development.

are causal explanations of the behavior of some phenomenon. As Merton noted above, the scientist foregoes her possible claim for ownership of the fundamental discovery in exchange for complementary knowledge or social recognition and prestige. The ability to replicate and verify this knowledge is an important part of the scientific process. And open science norms facilitate this ability to replicate and verify knowledge, and diffuse it, in return for this social recognition or to gain additional knowledge.

The best ways to apply new knowledge are ambiguous, and involve making judgments and taking risks in what domains to explore. This kind of applied science may not be perceived as prestigious as “real science”. There are no Nobel Prizes for inspired applications of knowledge. Indeed, it can be harder to publish the results of such inquiries, unless the scope of the application is well explained. And it is less clear whether those seeking to apply this knowledge even want others to rapidly reproduce and verify their results, at least when the seekers are hoping to obtain an economic reward for this work.

Scientific researchers are often ignorant of the practical context, constraints, and priorities that must be addressed in the application of new knowledge. This contextual knowledge is not universal, and is often tacit, making it less able to be shared widely unless others have direct experience with the process that produced the initial knowledge. The conditions of a laboratory, where the experiment can be carefully described and controlled, give way to a messy reality, where many factors are in play in an uncontrolled fashion at the same time.

For these reasons, the investment of time necessary to create innovations from new scientific knowledge run contrary to the “pure” academic incentives for promotion and tenure in leading universities.

Different Funding

There are other barriers as well. Funding is an important one. Basic scientific research is usually funded by public agencies, usually employing a peer-reviewed process. This funding typically ends when a new discovery is made and then published. There is seldom any public funding for further development and application of the knowledge. The implicit assumption is that the private sector is better positioned to allocate resources to the application of this knowledge.

Yet the private sector funding is looking for a financial return on its investment. This requires a careful evaluation of risk and reward in the application of any new knowledge. While new discoveries may offer exciting possibilities, they are reported at an early stage in their development, with actual data being provided at laboratory scale, as initial proof of a concept. Translating this initial proof into a new innovation at commercial scale involves substantial risks and large investments. This can create a Valley of Death between the published results of open science, and the profitable application of that knowledge.

Intellectual Property

Another consideration is the treatment of intellectual property (IP). In open science, ownership of a discovery is explicitly eschewed, in order to promote the rapid verification and more rapid diffusion of new knowledge. Assigning

IP rights during the scientific discovery process throws sand in the gears of open science, inhibiting the free exchange of ideas and knowledge that lead to faster, better science.

When applying new knowledge to create new innovations, however, IP rights have a role to play. Social recognition is no longer enough motivation for the private sector to undertake the risky investments needed to commercialize new knowledge.[12] Some degree of protection for some limited period of time is often necessary to induce private capital into making the investments of time, money and people to attempt to introduce a new innovation.

The role of IP should not, however, be overstated. One must balance incentives for the initial innovation against the incentives to enhance and improve upon that innovation. A moderate amount of protection is a better resolution of this balance than either a regime of no protection whatsoever (which inhibits the initial risk taking and investment in an innovation), or a regime of extremely strong protection (which inhibits or slows down follow-on innovation). Having a clear idea of where a technology might be profitably applied helps in unclogging the patent landscape, since only the foreground knowledge of the specific application would be protected, while the larger background knowledge that supports the application would remain open to the wider scientific community.

12 One example of such a successful commercial activity came out of the pioneering work done at CERN by Berners-Lee and colleagues around the underpinnings of the Web (such as the http and html protocols). The University of Illinois Champagne-Urbana's supercomputing center developed a browser that allowed people to employ a "point and click" user interface for these protocols. One of the students at UI, Marc Andreeson, met up with Jim Clark of Silicon Graphics in California, and formed Netscape. It was Netscape that really developed the first business model for the point and click user interface, by giving away the client browser for free, and charging content owners for the tools needed to publish their content on the web that was "best viewed with Netscape".

The Institutions of Open Innovation

What is needed, then, in developing innovations from open science, are a set of corresponding institutions of Open Innovation. Unlike Open Science institutions, these Open Innovation institutions depend on the way and the context in which innovation is being pursued. The translation of new scientific knowledge in the US, for example, will likely differ in important ways from that translation in, say, China, Finland or Israel.

To explicate these institutions, some quick history of industrial R&D will help. In particular, an earlier set of institutions that promoted larger internal, vertically-integrated R&D can be contrasted with a later set of institutions that promote more distributed, more open R&D.

Closed Innovation

The state of external scientific knowledge expanded enormously during the 19th century. By the early 1900s, we had learned about microbes, X-rays, the basic structure of the atom, electricity, and relativity. We had also learned about a more systematic way to conduct scientific research. As Alfred North Whitehead had remarked, "the greatest invention of the 19th century was the method of invention itself."[13]

Notwithstanding the scientific breakthroughs realized in the 19th century, for most industries circa 1900, much of the new science was just beginning to be understood, and its eventual commercial uses were far from apparent. Moreover, the norms

13 Whitehead, Alfred North. "Science and the Modern World." (London: Macmillan,1925).

of science at that time suggested that any practical use from this science would come without much help from the scientists themselves. Emulating the norms of "pure" science held in leading German universities, American scientists regarded the pursuit of practical knowledge as "prostituted science".[14] There was a large void between the science embodied in university classroom lectures, and the beneficial use of those insights in commercial practice. Moreover, universities lacked the financial resources to underwrite and conduct significant experiments themselves.

The government was in no position to fill in this gap. The overall size of government in the economy was much smaller during this period in history than it is today. And the government did not play much of a role in the research system at this time. It did pursue a few initiatives, such as the creation of a patent system, and it provided limited funding for particular inquiries in weights and measures, military materials such as improved gunpowders, and in the US, some creative funding of land grant universities for agricultural studies. But overall the government played a very limited role in organizing or funding science.

It was large scale Industry that served the role of being the primary source of research funding for the commercial use of science, and industry R&D laboratories were the primary locus of this industrial research. German chemicals firms were systematically expanding their product offerings through increasingly advanced investigations of the properties of the materials they were using to create new dyestuffs. Petroleum companies were rapidly improving their yields in refining crude oil through understanding the properties of that oil. In the process, they were innovating additional new products out of this raw material as well.

Only companies of large size could afford the investments needed to support significant R&D investments. Only these companies could access the knowledge being generated through the application of new scientific knowledge. This created a strong barrier to entry that entrenched large firms, and disadvantaged everyone else.

The institutions of Closed Innovation were built around this reality. One policy grew out of economist Kenneth Arrow's insight[15] that the benefits of R&D often spillover into the rest of society. For this reason, the social return from R&D is greater than its private return to the firm performing the R&D. The implication is that society gets less R&D than it ideally wants. This led to the adoption of the R&D tax credit, to subsidize R&D spending in order to induce firms to undertake more R&D than they otherwise would perform privately.

A second institution was the primacy of government funding for basic scientific research. As a result of the mobilization of science for the world wars of the 20th century, countries chose to assign resources and coordination

14 Consider the bitter protest of Professor Henry Rowland, who lamented the fame of "tinkerers" like Edison relative to men of science such as himself. Addressing the American Academy for the Advancement of Science in 1883, he proclaimed:

> "The proper course of one in my position is to consider what must be done to create a science of physics in this country, rather than to call telegraphs, electric lights, and such conveniences, by the name of science…. When the average tone of the [scientific] society is low, when the highest honors are given to the mediocre, when third-class men are held up as examples, and when trifling inventions are magnified into scientific discoveries, then the influence of such societies is prejudicial."

15 Arrow, Kenneth. "Economic Welfare and the Allocation of Resources for Invention." In The Rate and Direction of Inventive Activity, edited by Richard R. Nelson, 609-625. Princeton, NJ: Princeton University Press, 1962.

to government research agencies. In the postwar era, government funding for scientific research expanded tremendously, creating an Endless Frontier, in the words of Vannevar Bush's famous memo to President Roosevelt.[16]

Another institution was the expansion of intellectual property protection. Large firms could negotiate with each other for freedom to operate (such as through cross-licensing arrangements), and strong IP allowed them to erect further barriers to entry against new entrants. The creation of the 10th Federal Circuit Court for IP litigation standardized and strengthened IP protection in the US, and this set a pattern that was followed in Europe as well.[17]

A final institution in many countries was the conscious creation of Industrial Champions, companies of sufficient size and scale that they could overcome these barriers. These champions provided reservoirs of technology and know-how within the society, and also significant employment opportunities as well. They often worked closely with government agencies to coordinate investment into new, promising areas of technology.

These arrangements gave rise to knowledge monopolies and oligopolies. The logic of the Closed Innovation institutions was that, in order to be good in R&D, you had to be big. In order to innovate effectively in this model, one must do everything; from tools and materials, to product design and manufacturing, to sales, service and support. The translation of new scientific knowledge would be led by the industrial champions who stood at the commanding heights of the economy.

16 "Science The Endless Frontier." A Report to the President by Vannevar Bush, Director of the Office of Scientific Research and Development, July 1945.

17 Kortum, Samuel, and Josh Lerner. "What is behind the recent surge in patenting?." Research policy 28.1 (1999): 1-22.

The Shift to Open Innovation

As noted above, the rise of open science has led to an abundance of knowledge in many, if not most, scientific fields. The proliferation of public scientific databases, online journals and articles, combined with low cost internet access and high transmission rates gives society access to a wealth of knowledge that was far more expensive and time consuming to reach in the Closed Innovation era.

The norms of science have also evolved toward more interest in not only understanding the physical world, but, in parallel, applying that knowledge. While the science being done in universities continues to be excellent, it is clear that many professors (and their graduate students) are eager to apply that science to business problems. The norms of science and engineering have changed as well: there aren't many Henry Rowlands in university science and engineering departments anymore.[18]

The rise of excellence in university scientific research, the extension of that excellence to applying that knowledge, and the increasingly diffuse distribution of that research, means that the knowledge monopolies built by the centralized R&D organizations of the Closed Innovation era are over. Knowledge is far more widely distributed

18 Indeed, one perhaps extreme contrast to Henry Rowlands comes from the current President of Stanford University. John Hennessey is an acclaimed computer scientist, and the former Dean of the Engineering School at Stanford. But he has also taken three leaves of absence during his academic career to start up new companies, and sits on the board of Google and Cisco as of this writing. While Rowlands would be appalled, Hennessey is likely a new model for a university leader, who combines deep research knowledge with deep practical experience in applying that knowledge.

today, when compared to, say, forty years ago.

One piece of evidence that supports the greater distribution of knowledge in the knowledge landscape, for example, is the changing level of concentration in patent awards. Patents are one outcome of a knowledge generation process, and thanks to the US Patent and Trademark Office, there are good data available on who receives US patents. Of the more than 400,000 patents issued by the USPTO over the decade of the 1990s, for example, the top 20 companies received only 11% of the awarded patents. Relatedly, the number of patents held by individuals and small firms had risen from about 5% in 1970, to over 20% in 1992.[19]

A second indicator of increased knowledge diffusion is reflected in US government statistics of R&D by size of enterprise. Industrial research and development is one key process that generates ideas, and makes use of them. The share of industrial R&D has increased greatly for companies with fewer than 1,000 employees from 1981 through 2008. While large company R&D remains an important source of R&D spending, its share of R&D spending has fallen in half, from over 70% of all R&D spending in 1981 to less than 35% of R&D spending in 2008. Correspondingly, the share of R&D conducted in organizations of fewer than 1,000 employees has risen from 4.4% to 25% over the same period. There seem to be fewer economies of scale in R&D these days.

The logic underlying the innovation process now is completely reversed. In an abundant landscape of useful knowledge, one can now do a great deal by focusing in a particular area, without having to do everything.

The Open Innovation Model

Open innovation is based on a logic of abundant knowledge. It has been defined as "…the use of purposive inflows and outflows of knowledge to accelerate internal innovation and expand the markets for external use of innovation, respectively."[20] The open innovation model assumes that firms or innovating institutions in general can and should use external ideas as well as internal ideas, and internal and external paths to market, as they look to advance their innovations. Open innovation processes combine internal and external ideas together into platforms, architectures and systems. Open innovation processes utilize business models to define the requirements for these architectures and systems. The business model makes use of both external and internal ideas to create value, while defining internal mechanisms to claim some portion of that value.

There are two important kinds of open innovation: outside-in and inside-out. The outside-in part of open innovation involves opening up a company's innovation processes to many kinds of external inputs and contributions. It is this aspect of open innovation that has received the greatest attention, both in academic research and in industry practice. Large Research Infrastructures such as CERN embody as a hub of a large network many of these practices

19 Chesbrough, Henry. "Open Innovation: The New Imperative for Creating and Profiting from Technology." (Harvard Business School Press, 2003; Table 3-1.)

20 Chesbrough, Henry. "Open Innovation: A New Paradigm for Understanding Industrial Innovation", in Chesbrough, Vanhaverbeke and West, Open Innovation: Researching a New Paradigm, (Oxford University Press, 2006: p. 1).

most effectively. For example, this has been demonstrated in the successful construction and operation of the Large Hadron Collider and in the enormous scientific output delivered from this initiative.

Inside-out open innovation requires organizations to allow unused and underutilized ideas to go outside the organization for others to use in their businesses and business models. In contrast to the outside-in branch, this portion of the model is less explored and hence less well understood, both in academic research and also in industry practice. In order to further improve the scientific capabilities and commercialize the research output from projects such as the LHC, new businesses and business models must be identified, explored, and undertaken.

Open Innovation Institutions

The institutions of open innovation differ dramatically from those of the earlier Closed approach. The incentives in open innovation are for specialization, collaboration through markets, exchange of knowledge, intellectual property rights, and startup formation. Large firms also play a key role in open innovation, but that role is quite different than it was in the closed era.

Because useful knowledge is presumed to be abundant, every open innovation initiative begins by surveying what is already available. Instead of re-inventing the wheel, an open innovation project seeks to leverage available external knowledge and extend upon it. Put differently, in a world of abundant knowledge, the value in innovation migrates away from the next new piece of technology (those these can still be valuable) to new ways of integrating technologies together into new solutions and new systems. This system integration skill is of great value in a world of abundant knowledge, and is one of the most critical contributions that large firms can play in an open innovation landscape.

The knowledge monopolies and oligopolies of the earlier period give way to a more distributed division of innovation labor. The universities and research institutes may function as the locus for the initial discoveries and new knowledge. But the exploration of how best to apply new knowledge, and the subsequent exploitation of that knowledge in a new market, falls to other participants in the innovation chain, based on some adopted business model. Startup firms and SMEs are now capable of launching research projects, perhaps with an academic researcher continuing to provide advice and support as an early employee.[21] Later success, should the venture survive, often comes through being acquired by a large firm to augment its own internal innovation activities. Less often, a venture may achieve its own public listing of its stock through an initial public offering. Intellectual property is critical to the transitions that technologies must navigate on their way from the laboratory to the market. The initial formation of a new spin-out venture, for example, must include some assignment of IP for the nascent organization. Any external capital provider will demand that there be some protection for the ideas being commercialized. The later acquisition of the venture will require that the acquiring firm receive all of the IP created by the venture. And so on. However, capital

21 The ability for university researchers to take 1-2 year leaves of absence from their university positions greatly facilitates this temporary reassignment to a new spin-out organization. See note 18, supra.

markets need some sense of the intended market for applying a new scientific discovery. Absent such a signal, promising science can remain stuck between academia and industry.

Inventing New Institutions

With this in mind, several actors have in recent years begun experimenting with new types of institutions or initiatives to bridge this gap between open science and open innovation. Many are being pioneered in Europe – perhaps because of the now-common belief among European policy makers that the EU suffers generally from an "innovation gap" with the US, and a rising challenge from China, and so must invent new methods to remain economically competitive. IMEC[22] is one of the best-known in Europe. Founded in 1974 at KULeuven, the top-rated university in Belgium, IMEC has been effective over the years at combining basic academic research in microelectronics and nanoelectronics, and developing it into practical semiconductor technologies now used by many of the largest ICT and chip companies in the world.

Likewise, several European governments have supported specialized national Research and Technology Organizations (RTOs) that, with private companies as customers, use new technologies to develop specific products, or solve problems; the largest and best-known is Germany's network of Fraunhofer[23] Institutes that work directly with specialized sectors of industry, from machine tools to solar power. And in 2008 the European Commission created an entirely novel open innovation program, called the European Institute of Innovation and Technology (EIT)[24]. It gathers large consortia of multinationals, SMEs and universities into networks that, spanning the EU, simultaneously develop new commercial products from university research, and train a new generation of entrepreneurs to take these and other products to market.

Among the most interesting is a new initiative by a group of big European research labs, including CERN, the European Synchrotron Radiation Facility, and the European Molecular Biology Laboratory. Called ATTRACT[25], the initiative aims to take technologies that the labs have developed for their own infrastructure and spin them out to the market, in partnership with SMEs, multinationals and other private investors. These include world class detector and imaging technologies, of use in health physics, high performance materials, and breakthrough ICT applications.

Each of these application domains represents very large markets, with different drivers and regulatory structures. The ICT sector is the fastest-moving of the three, and new innovations can often be deployed and scaled here in short amounts of time. Materials take a longer time to scale into large markets, because the material must first be proven, and then multiple applications must be attempted, and the eventual market size will depend on the success of the various uses of the new material. The health sector is the most regulated, and market success here will require acceptance by industry and adoption by both regulators and health care system administrators.

22 www.imec.org

23 www.fraunhofer.de

24 www.eit.europa.eu

25 www.attract-eu.org

ATTRACT aims to leverage the broad scientific community engaged in research activities at CERN and other members of the EIROFORUM group of laboratories, with the assistance of Aalto University in Helsinki and ESADE Business School in Barcelona. The best applications for the discoveries made in areas like detection, imaging, and computation, though, will require entrepreneurial risk-taking. Substantial trial-and-error will likewise be required to develop effective business models that can create and capture value, at commercial scale.

Pre-competitive research in an open domain can be blended with downstream assignment of IP rights, so that the power of open science can be joined to subsequent risk-taking in the commercial realm. European Research Infrastructures, universities, large firms, and SMEs and startups all have a role to play. Through its design, ATTRACT shows how open science and open innovation can be combined in order to lead to a number of potential new business opportunities.

CONCLUSION

The norms of open science promote the rapid diffusion of the latest knowledge, and invite broader participation in the discovery of new knowledge. This deepens the knowledge, improves its quality, and helps its diffusion (which then leads to another cycle of discovery and diffusion). However, the institutions of open science do not necessarily assure the subsequent effective commercialization of scientific knowledge.

Open innovation is a concept that can help to connect the fruits of open science to more rapid translation and development of its discoveries. Like open science, open innovation assumes broad and effective engagement and participation in the innovation process.

Open innovation distributes the innovation effort across a variety of participants, from universities and research institutes to SMEs and startup firms, to large firms. But open innovation institutions are required for effective commercialization of new knowledge. A process of discovery will be needed, around the world, to find and tailor the best possible models for these institutions to meet the pressing needs of the global economy.