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- CORBEL -

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Concept paper on new business models related to Open Innovation

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Content

Executive Summary

The emergence of the world-wide web (WWW) during the last three decades has completely changed the possibilities of information exchange, regarding volume, speed and efficiency of combination of different types of information. The WWW has opened new possibilities in academic and industrial research and development that has made possible novel ways of doing business. This was particularly enabled because the WWW was open and freely available. In fact, the currently most valuable companies in the world could not have developed without a free and open accessible infrastructure, namely the WWW. In analogy, we describe here the potential of Open Innovation for the development of new business models with emphasis on the role of the ESFRI BMS Research Infrastructures and their knowledge and data networks.
In a revision requested by the Project Coordinator we included examples and applications pertinent to pharmaceutical research and industry and emphasised the role ESFRI BMS Research Infrastructures can play in Open Innovetion.

Detailed report on the deliverable

The deliverable is a paper that is a separate annex to this report:
'Concept paper on new business models related to Open Innovation'
Peter M. Abuja, Kurt Zatloukal

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Appendices

Concept paper on new business models related to Open Innovation

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Summary

The emergence of the world-wide web (WWW) during the last three decades has completely changed the possibilities of information exchange, regarding volume, speed and efficiency of combination of different types of information. The WWW has opened new possibilities in academic and industrial research and development that has made possible novel ways of doing business. This was particularly enabled because the WWW was open and freely available. In fact, the currently most valuable companies in the world could not have developed without a free and open accessible infrastructure, namely the WWW. In analogy, we describe here the potential of Open Innovation for the development of new business models with emphasis on the role of the European Strategy Forum on Research Infrastructures (ESFRI) Biomedical Sciences (BMS) Research Infrastructures and their knowledge and data networks and provide examples for the application of these knowledge networks in the pharmaceutical industry.

Introduction and scope

Current state-of-the-art communication, network and information technologies became essential for effective exploitation of knowledge networks in research as well as in business models. Furthermore the inception of WWW, which can be considered an open and free infrastructure for access to and exchange of information led to a broad spectrum of innovative business types, e.g. those of Google, Facebook or Amazon. These business models benefit from trading information (including, in a broader sense, advertising) and/or goods, and they even incorporate smaller firms – who provide complementary assets - into their big portals, like Amazon does.

The WWW made possible novel (‘crowd’ or ‘cloud’-based) cooperative activities, driven by specific tools and services. They can address both the general public and more specialized interest groups, such as users or customers/clients. One of the earliest examples, *‘Search-for-ExtraTerrestrial-Intelligence’ at home* (SETI@home; https://setiathome.berkeley.edu/), was founded 1995 and is still active. It employs a world-wide network of interacting clients that could be downloaded and run on home computers. They used idle processor time to analyse radio signal data for patterns indicating intelligent activity. There was even non-monetary reward (high-scores for the most active number-crunchers, like in many computer games), a practice that has further evolved in present day competitions, such as the Camelyon competitions in image data analysis for digital pathology. The distributed computing approach has been expanded to a huge number of computation-intensive projects that span a broad field of science (a regularly updated list can be found on https://en.wikipedia.org/wiki/List_of_distributed_computing_projects), among them solutions for problems relevant for industrial R&D, such as distributed drug discovery and design, or research on human diseases.

Linking huge amounts of information has been made possible during the last decade with unprecedented efficiency and big data processing is a concept with huge potential: novel methodologies for combining and mining large repositories may lead to novel products and services. For these efforts it is crucial that data quality is reliable and that relevant data are openly available, following the FAIR [Wilkinson et al., 2015] or FAIRhealth principles (https://www.fairhealth.org/). The ESFRI BMS Research Infrastructures are well positioned to provide high volumes of data for these purposes, and as long as their value is secured by validity, i.e. data quality, they constitute an important resource not only for science but also for business R&D.

Since both terms in the title, Open Innovation and (Open) business models have become buzzwords, we will give a definition and discuss how they are linked in light of selected very recent literature. Finally, we want to give a few selected examples that highlight possibilities for business models that employ Open Innovation.

Open Innovation

A widely accepted definition of Open Innovation was coined by [Chesbrough, 2006]: it combines 'purposeful inflows and outflows of knowledge to accelerate innovation internally while also expanding the markets for the external use of innovation'. At the core of Open Innovation is the understanding that innovation should not be restricted to one or a few sources of knowledge and competence that are traditionally tightly linked with a company's internal R&D process. Neither should it rely only on the simple (re-)use of publicly available knowledge as an external source of information. Ideally, Open Innovation is the flexible management of knowledge and competence networks, integrating various disciplines. The Open Innovation process should also feed back knowledge/products/services to the network in a controlled but open way. Importantly, whatever holds for innovation in general, is likewise necessary for Open Innovation: complementary elements of knowledge are combined, but need to be sufficiently different to lead to a truly novel result [Kogut & Zander, 1992, as cited in Hallberg & Brattström, 2018]. Networks of diverse types of knowledge increase the chances that such elements are available whenever needed.

Clearly, Open Innovation does not imply handing over development advantages and Intellectual Property to the nameless public domain [Zacherl & Zatloukal, 2017]. Rather, it means the controlled release of information with the expectation to receive some kind of feedback, revenue, and joint R&D or marketing opportunities, while retaining control especially over information indispensable for securing the value of innovation. As remarked by a manager of a company engaged in Open Innovation: 'We are doing Open Innovation, not Public Innovation. Our goal is to come up with results that we share with some partners and keep secret vis-à-vis others' ([Hegedoorn & Ridder, 2012], as quoted in [Brandt & Lohse, 2014]). It is important to understand that every business model that engages in Open Innovation needs to determine how competitive advantage and Intellectual Property (IP) are managed and secured [Zacherl & Zatloukal, 2017].

Unlike Open Innovation, Closed Innovation aims at performing the whole process of design, development and commercialization 'in-house', which makes it easier to secure competitive advantage. However, there are risks and downsides associated with this strategy, in particular missing opportunities for innovation, or lack of external feedback that could lead to further improvements, both of which may eventually put the value of a product/service at risk. Insufficient feedback by customers/clients and ignoring ‘what is going on in the world outside’ increase the risk of losing the investment in R&D if the product/service does not perform, is outperformed by competition or is not accepted by the market. Other risk factors may be external (e.g. rapidly changed demands, competition, or loss of vital supplies) or internal (changed priorities, lack of innovation capacity).

Open Innovation strategies

Independent of the extent of engaging in Open Innovation (see below), Brant and Lohse [Brant & Lohse, 2014] identify three different strategies of information exchange.

Inbound

This strategy means that R&D in a company draws on external sources of knowledge and integrates it into its own activities. Although this is reminiscent of traditional ways of sourcing information, the difference is that external resources are integrated and replace (completely or in part) corresponding internal activities (e.g. because these would be beyond the capacity or outside the focus of internal R&D). A typical example would be external contract research or in-licensing that either replaces or complements a part of internal R&D that is beyond the scope, resources and expertise of the company (e.g. clinical studies performed for a pharmaceutical company).

Outbound

An outbound innovation strategy transfers (out-licenses) innovation to an external partner who either further develops the product or complementary assets, or brings the product/service to the market [Chesbrough & Growther, 2006].

Coupled innovation

It combines both strategies, ideally creating a seamless network of joint development, where knowledge and resources are exchanged to generate a joint product/service [Gassmann & Enkel, 2004]. Such collaborations can be in the form of joint ventures or other, looser, forms (e.g. in an innovation competition).

Open Innovation is not new

The Open Innovation concept is not new and did not require world-wide networks, although the WWW certainly boosted the acceptance, impact and possibilities of this innovation model. As an example, already in 1876, Edison’s Menlo Park laboratories relied on multidisciplinary teams to drive innovation [Pénin et al., 2011]. Indeed, the traditional ways of cooperating and exchanging knowledge between industry partners and academia are all found to a variable extent in Open Innovation. Even linking data domains via a network dates back already several decades: the first search engines for world-wide data networks started 1990 (*Archie*, searching the contents of FTP-servers) and the first web-based search engine was a web robot called *Wanderer*, in 1993, four years after the inception of the WWW by Tim Berners-Lee, in 1989. *Google Search* was launched 1998, well after other at that time popular search services, such as *Yahoo!*, *Lycos*, *Look Smart* and several others.

However, it has been increasingly recognized that traditional models of cooperation do not realize the full potential of present-day large networks of knowledge, user communities, academic and industrial cooperation.

Open Innovation has become increasingly important and pervasive

Appropriately handled, Open Innovation processes improve utilization of the vast networks that dominate our information age, providing fast and extensive access to information of all kinds and provenance. Not all of this information is contained in what may be called a knowledge network, since much of the commonly available information is of uncertain reliability and quality. Knowledge networks, comprising trustworthy information of assured quality, allow and stimulate developing novel products and services that address better customers' (real and perceived) needs, creating and filling market niches, reducing development and update cycles, etc.. While initial protection (by appropriate IP management) secures the value of the innovation, an outbound strategy can, e.g., improve the long-term prospects of a product/service through development of complementary products and services (often by other firms). Typical examples are open concepts that form the basis for a wide range of appliances, such as the Open Handset Alliance based on the Android operating system which presently drives a large part of mobile communication [Hallberg & Brattström, 2018]. Google owes the dominant position as a data search engine provider, which even has become a household word ('to google'), to a variety of acquisitions and mergers as well as to the strategy of offering specialized services (e.g. *Gmail*, *Google Maps*, *Google Translate*, *Google Drive*) and applications (*Google Play* – which allows other firms and individuals to develop complementary assets on the open Android operating system) with social-network, media- and communication-related services. They do not only span a broad range of networking issues of human interest, they allow also collecting user behaviour data to customers, to be combined with advertising which creates enormous market value.

Advantages and risks of Open Innovation

In reality, innovation is based on a mixed open and closed approach, since neither has only advantages or disadvantages. Often, closed innovation dominates at the beginning of a development process and evolves into Open Innovation at a later stage.

Advantages

One expectation from Open Innovation is that it generates an openness culture that will lead to a wider horizon regarding innovation possibilities and market needs, to facilitated development through knowledge and cooperation networks, and eventually to improved market potential.

Open Innovation advantages can be found in a variety of situations, e.g. through interaction with a network of experts, cooperation partners, complementary asset developers and clients or customers. In the last aspect it may benefit from *direct network effects* (where the perceived value of an innovation depends directly on the number of clients/customers using the innovation), e.g. telephone networks. Here, increasing customers' understanding of how a product/service works can increase its acceptance. Moreover, reducing the insecurity about whether other consumers will adopt it - which is important whenever the size of the network determines the perceived value of the product or service – is an additional incentive for acceptance. Other prominent examples for the power of direct network effects are professional or social networks (e.g. LinkedIn, Facebook, WhatsApp).

Indirect network effects (where openness spawns complementary assets - products or services) may also lead to benefit, such as standardization that allows compatibility between a main product with a number of accessories that can be developed by third parties. A well-known example is the acceptance of video-recording standards, where one system, VCR, dominated the market for a long time since customers (and developers) wanted to invest only in devices and media that promised long-term availability, even though other formats were technologically more advanced. This example shows that openness often increases the number of other developments adhering to a certain standard. Any disadvantages created by opening an invention to competition may be balanced by an appropriate licensing policy.

Open Innovation can also benefit from double-sided network effects where investing in one market improves the investment value in a complimentary market, and vice versa (e.g. mutual benefits of the electric car market and a network of charging stations) [Eisenmann et al., 2006, cited in Hallberg & Brattström, 2018].

Therefore, Hallberg and Brattström [Hallberg & Brattström, 2018] conclude that Open Innovation predominantly benefits from indirect network effects, through complementary products and services.

Moreover, since rarely all IP generated within a firm can be exploited within a certain time-window of opportunity, active management of such 'orphaned' IP can conversely boost innovation and salvage the investment, e.g. by sharing it. This is particularly important in areas where development cycles are long compared to the time during which an innovation can be exclusively exploited, such as in the pharmaceutical industry [Hunter & Stephens, 2010].

Initially, strong protection of central IP (which is not opposed to Open Innovation [Zacherl & Zatloukal, 2017]) may grant a grace period during which a product can be developed and the market secured. Subsequent controlled revealing of details (either as published patents, scientific publications, publicly available technical specification, standard, etc., or to selected licensees/development partners) can foster the generation of complementary assets as well as competing primary products. This competition may not be a threat to securing the value of the innovation – by appropriate management of IP and licenses, but may generate direct and indirect network effects. Both can increase the market presence of the primary product and facilitate further improvement. By these means Open Innovation may also lead to a higher perceived value by the customer [Hallberg & Brattström, 2018].

Risks

The most obvious disadvantage results from insufficient management of IP which may lead to severe loss of investment. Hence, Open Innovation management must carefully select when and to whom information is revealed under which conditions, and the expected risks and benefits need to be taken into account. Details regarding IP management can be found in a previous concept paper developed within the EU-funded project CORBEL [Zacherl & Zatloukal, 2017].

One particular risk of an Open Innovation strategy is that information of insufficient reliability or quality may be included in a development process, sometimes with devastating consequences. An example is the well-known problem of financial losses caused by not-reproducible clinical studies (which are usually performed outside a firm's own R&D department) during drug development [The Economist, 2013/10/19 – 'How Science Goes Wrong'][Freedman, Cockburn & Simcoe, 2015]. Since externally obtained information cannot be controlled and evaluated in the same way as data generated internally, mechanisms must be set up to identify this kind of problem early in the development process.

Knowledge networks advance Open Innovation and may reduce risks by providing reliable high-quality information

The present digital network culture is believed to have begun 1989 with the initial stage of the WWW created by Tim Burners-Lee at CERN. It has led to an enormous rise in the volume and efficiency of knowledge transfer over the last 30 years. While we are presently struggling with the downsides of an uncontrolled 'too-open' network policy, that particularly compromises data reliability, the benefits of network infrastructures still need to be fully reaped.

New models of academic collaboration (which was CERN's original intention), user communities, interest groups, social networks, and nowadays increasingly commerce and marketing have been established that allow highly efficient, high-volume exchange and combination of information at very low cost per data unit. Lessons learned were that increasing use of the WWW also required the development of new governance models that prevent negative developments (e.g. loss of privacy and cyber-crime) and at the same time preserve openness. Self-governing processes have led to rules of conduct; in addition, institutional, national and international regulations aim at increasing safety and security of information exchange without reducing the advantages of open networks. It is this implicit trust that made possible a dramatic explosion of exchange of data, information, ideas, services, money and goods. Besides general mechanisms regulating access rights, confidentiality and protection of IP, in academic knowledge networks (such as those provided by ESFRI BMS Research Infrastructures) there are specific self-governing processes in place to increase or ensure reliability, like peer-review, curation, and citations.

A judicious approach regarding the source of information in an Open Innovation process is mandatory to minimize the risk of failure during development. Trusted sources of information are therefore a key issue. This has been recognized in the scientific and biomedical communities, where issues of non-trustworthy data can become particularly devastating, both regarding trust in scientific results and researchers, as well as loss of investment (e.g. in the health and pharma sectors).

Academic knowledge networks increasingly emphasize the necessity to maintain highest possible standards of quality. Their classical direct and exclusive exploitation for profit by industry may be limited since most of the resources and content have been generated through public funding and their exclusive use by a single company is not possible even on a cost-recovery basis. Therefore, Open Innovation provides an environment that enhances use of infrastructure, data and knowledge generated through public funding by industry. Furthermore, special models for Open Innovation have been developed by European Research Infrastructures. Examples include Expert Centres [van Ommen, et al., 2015], deployed for biomarker discovery and development, and Innovation Hubs [https://eatris.eu/insights/unique-hub-collaboration-imaging-method-development-inflammatory-diseases/] for the development of next-generation tools for drug development. These initiatives are public-private-partnerships for generating reliable data in a quality-controlled environment, compliant with ethical and legal requirements to maximize future open use of data generated by public and private sectors.

After a grace period, data generated by and with Expert Centres must be made publicly available and integrated into a resource for the community as a whole (e.g. the European Open Science Cloud). This procedure maintains the principle that public resources and publicly financed assets (e.g. bio-samples donated by patients from which data are generated or services provided by publicly funded research infrastructures) can be made available to industry in an open manner without undermining stakeholder's interests or principles of open competition. This model creates several benefits for public Research Infrastructures since resources and services are better used by industry and additional private funds for research become available for the targeted generation and use of services and data.

Adapting business models to Open Innovation strategies

The term 'Business Model' denotes the great variety of ways how a firm conducts its business, depending on context and purpose, which makes this term rather vague. For the purpose of this paper, we choose a definition by Chesbrough and Rosenbloom [Chesbrough & Rosenbloom, 2002] that may best accommodate the link to innovation: 'The business model provides a coherent framework that takes technological characteristics and potentials as inputs, and converts them through customers and markets into economic inputs. The business model is thus conceived as a focusing device that mediates between technology development and economic value creation'.

Open innovation strategies affect business models in very diverse aspects, as described by Saebi & Foss [Saebi & Foss, 2015]: (i) the main drivers of knowledge and value creation - *content*, (ii) the restructuring of internal and external activities and links – *structure*, (iii) *governance mechanisms* that allow accessing external knowledge and integrating it into the value generating processes of a firm.

Due to the complexity and the differences in these three aspects it is impossible to arrive at a recipe for adapting & shaping them to fit with Open Innovation necessitating their individual evaluation. Saebi and Foss [Saebi & Foss, 2015] propose a continuum of Open Business models in which a particular firm can position itself. They range from 'efficiency-centric' Open Business models, where the degree of interconnection with external partners is low, over 'user-centric' and 'collaborative' to 'open platform' models which show the highest degree of connectivity. Three factors determining the type of Open Business model are distinguished:

Co-creation of knowledge – the extent of co-creation can range from the adoption and integration of readily available knowledge into the firm's knowledge base (low level of co-creation) to an open development platform that seamlessly integrates internal and external knowledge generation (high level of co-creation). On the one hand this may involve joint development between industrial and academic partners of previously unused IP, which constitutes often a substantial proportion of a firm's IP [Hunter & Stephens, 2010]. On the other hand, European Research Infrastructures can provide the whole range of co-creation, from using Common Services (low level of co-creation) to extensive collaboration with Expert Centres (medium-high level) in the framework of contractual research or a joint project. A complete integration of external and internal knowledge might mean that the firm itself becomes an Expert Centre. As an example, the Biomarker Research Competence Centre *CBmed GmbH* is an Expert Centre acknowledged by BBMRI-ERIC.

Knowledge transfer – Saebi and Foss [Saebi & Foss, 2018] distinguish three types, unilateral (inflow of knowledge) which they term an 'efficiency centric' Open Business model, dyadic (or bidirectional), which corresponds to 'user centric' and collaborative Open Business model types, and multilateral, attributed to an open platform business model. European Research Infrastructures can cover the whole spectrum of support for these models, providing existing knowledge and data unilaterally, but can also provide contractual research and bilateral collaboration with Expert Centres or other members of the Research Infrastructure. A network-based multilateral open platform is maybe somewhat more difficult to establish, but there are no insurmountable difficulties. An important factor in the knowledge transfer aspect of Open Innovation and Open Business models is the European Open Science Cloud which can provide an infrastructure and repository for all these types of knowledge exchange.

Collaborative capabilities – to reap the benefits of the above items, an Open Business model needs to develop (additional) capacities that enable it to collaborate appropriately with external knowledge providers: their extent in turn depends on the varying degree of collaboration between 'efficiency centric' (requires only low collaborative capacity) and open platform business models (require a high degree). In principle, as already mentioned above, the resources of the European Research Infrastructures may fit with any of the collaborative capabilities a firm might choose to develop – however, since Research Infrastructures operate on a European level, achieving the highest degree of integration might be a particular challenge: in such a case the firm itself would need to become part of the Infrastructure, which however is not possible for Research Infrastructures established as ERIC legal entity [COUNCIL REGULATION (EC), No 723/2009].

From the above it becomes clearer that depending on the strategic approach, the 'philosophy' and the intended goal, the variables mentioned above can be fine-tuned to match the purpose of the innovation process.

How European Research Infrastructures can support Open Innovation and Open Business models

The European Research Infrastructures can be considered to some extent as a network of diverse but highly specialized knowledge hubs that are well suited to support Open Innovation: they provide trustworthy, high-quality information that may be integrated in an Open Innovation process by varying degrees.

Different types of Open Business models can be distinguished [Saebi & Foss, 2015]:

Efficiency-centric Open Business models can benefit from Common Services and/or data for various specialized fields that fit this type of business model with (predominantly) unilateral flow of information (e.g. mining pre-existent data) and low-medium need for (additionally generated) collaborative capacity. This type of Open Business model probably requires the least degree of adaptation and restructuring of processes, since external knowledge merely complements the internal innovation. One might regard this type as an 'entry level' to Open Innovation, which may evolve to more integrated forms.

User-centred Open Business models – here the flow of information is still mostly unidirectional. However, data generation does not rely on mining of already existing data. An example for this type of Open Business model could be when Research Infrastructures generate data for the innovation process on a contractual research basis. Here, too, the aspect of complementation of the internal innovation process dominates. Bidirectionality of information flow is here implicitly given, since the data generated are exclusive to the industrial partner only for a predefined grace period, and are then released into the public domain.

Collaborative Open Business models – in addition to using services and data provided by Research Infrastructures, this business model type cooperates with the Infrastructure – e.g. through an Expert Centre – to jointly generate the knowledge required for the innovation process. The collaboration involves a bilateral flow of information and skills that integrate the Research Infrastructure in a – more or less large – part of the firm's innovation process.

This model already requires advanced collaborative capacity and skills, and while both external and internal processes act in a complementary way, they also benefit each other.

Open Platform business models – they integrate themselves into the Research Infrastructure, e.g. as an R&D company that contributes state-of-the-art knowledge and technology. Information flow is bidirectional, and internal and external innovation processes join to mutually advance their impact for both Research Infrastructure and the firm. Typically, such firms are forerunners as technology providers, specialized commercial research institutions or knowledge providers.

Truly novel outcomes by Open Innovation

Open Innovation typically is not an approach that is specific for a certain product or service which lead to huge margins of profit, simply by following through a clear-cut series of steps. Rather, it is an attitude towards obtaining, generating and integrating information that supports a series of novel products and services over the whole development process. Utilization of the possibilities of modern information technologies, for fast searching, retrieval and combination of knowledge from diverse areas, and the rapidly expanding knowledgebase in all fields, together support Open Innovation. Nevertheless, it still relies on the ability of individuals and groups to provide knowledge, and to guide and drive it.

Each and every innovation process provides its own very individual story, and the naïve notion of a 'Standard Operation Procedure for Generating Novelty by Open Innovation' is a contradiction in terms. Rather, we will present below selected examples of Open Innovation in industry, and further how Open Innovation through knowledge networks provided by the ESFRI BMS Research Infrastructures can benefit industrial and academic research.

Open Innovation is increasingly recognized by industry as an opportunity

Several industry sectors have opened up their internal research and development to harness the potential for cross-fertilization of their innovation processes. Traditionally, pharmaceutical industry employs research and development partnerships and has extended and broadened these processes embracing Open Innovation, or Open Access to data and even drug candidates: we give here a few selected examples.

Eli Lilly – Open Innovation Drug Discovery

Ely Lilly has established a platform for drug discovery that allows networked participation in their early drug discovery program. Participants and their ideas become integrated in a flexible way into the activities of the company, while maintaining their own respective IP, using the firm's tools and resources to pursue their research ideas. The programme benefits both the company and researchers, since Ely Lilly gets access to novel concepts that may lead to in-depth cooperation, and eventually novel products. Partners are given access to proprietary compounds tools and data and extensive opportunities for collaboration and joint publication [Lee et al., 2015; Lee at al., 2010].

Medicines for Malaria Venture (https://www.mmv.org/)

Research on rare and neglected diseases, such as malaria, have benefited from a variety of initiatives, among the first the Medicines for Malaria Venture, founded in 1999 to counteract the then virtually empty pipeline for new antimalarials. This extremely successful public-private-partnership has evolved into one of the most successful drug development programmes supporting numerous projects at all stages of the drug development pipeline. An example for Open Source drug discovery is presented in [Van Voorhis, W. C. et al., 2016].

Nestlé (https://www.nestlehealthscience.com)

Nestlé which is rooted in the food industry responded to the increasing interest in health-promoting properties of food by extending its research and development into the pharmaceutical sector. Today, Nestlé Health Sciences not only offers Food for Special Medical Purposes and Nutritional Therapies but performs research in its Institute of Health Sciences under a Policy on Public–Private Science & Research Partnerships. It hosts an Open Innovation Platform (HENRi@Nestlé; https://henri.nestle.com) that posts regular challenges regarding a broad variety of nutrition and health-related projects.

How ESFRI BMS Research Infrastructures can support Open Innovation

The networks of knowledge and data provided through the ESFRI BMS Research Infrastructures have specific advantages over the more general resources mentioned above, such as the WWW. In particular, knowledge and data provided can be expected to meet standards of quality, specificity, and veracity that are difficult to establish in smaller scale environments of private companies, particularly small and medium enterprises. Academic and industrial pharmaceutical research and development are particularly well positioned to make use of these networks, since they cover major areas of biomedical research. Moreover, the requirements for high-quality data combined with a broad range of expertise makes ESFRI BMS Research Infrastructures ideal sources of information for Open Innovation processes and related business models. The primary goal of pharmaceutical R&D is the marketing of new drugs or diagnostic procedures which necessitates validation in a clinical context. Therefore the traditional cooperation of industry with public academic and medical partners is indispensable and benefits all involved parties. Although concepts of Open Innovation have been in place for a long time in this business area ESFRI BMS Research Infrastructures can be regarded as new hubs of scientific excellence and facilitators for sourcing specific and comprehensive high-quality information and collaboration in Open Innovation.

One aspect where Research Infrastructures are best positioned to support Open Innovation is the increasing importance of large sets of high-quality biological samples, and associated molecular, imaging and medical/clinical data that are required for development of diagnostics and drugs. This approach towards utilization of 'big data' in biomedical research and development [Auffray, et al., 2016] with a distinct focus on the FAIR data principles [Wilkinson et al., 2015; Holub et al 2018] is their particular strength. Indeed, the ESFRI BMS Research Infrastructures provide Open Access to most of the relevant infrastructure, resources and knowledge needed in biomedical research and development [European Commission, 2016].

Conclusion

Open Innovation as enabled by ESFRI BMS Research Infrastructures could lead to novel business models as it has happened by the development of the WWW that provided the infrastructural basis for the currently most valuable companies in the world. Business models of Google, Amazon, Facebook, Twitter and several other internet social platforms and services were not possible without the WWW and did not exist before. Similarly, a series of novel business models might emerge from Open Innovation and increasing availability of open data and knowledge. Therefore, ESFRI BMS Research Infrastructures could play a central role in catalysing disruptive innovation that may shape future societies by providing critical capacities, resources and services related to Open Innovation. As a further consequence, the possible impact of ESFRI BMS Research Infrastructures on economy and society should not only be evaluated by classical indicators but should consider future yet unknown business models and effects on society.

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