ARTICLE IN PRESS

Technovation xxx (xxxx) xxx

Contents lists available at ScienceDirect

Technovation

journal homepage: www.elsevier.com/locate/technovation

Managing innovation ecosystems around Big Science Organizations

Jason Li-Ying [a,*], Wolfgang Sofka [b,c], Philipp Tuertscher [d]

[a] DTU Centre for Technology Entrepreneurship, Technical University of Denmark, Denmark
[b] Department of Strategy and Innovation, Copenhagen Business School, Denmark
[c] University of Liverpool Management School, UK
[d] School of Business and Economics, Vrije Universiteit Amsterdam, the Netherlands

ARTICLE INFO

Keywords:
Big Science
Innovation ecosystem
Entrepreneurship

ABSTRACT

BSOs are large research organizations established purposefully to address fundamental and complex scientific research challenges that cannot be addressed in isolation by individual universities, research institutes, or even government agencies. Unlike universities and other national research institutes, BSOs are unique scientific organizations by virtue of their sheer size, level of complexity, and uncertainty with respect to the outcomes of research and development. BSOs involve large networks of suppliers and collaborators in science, government, and business, constituting a complex system with permeable boundaries that offer opportunities for technology transfer, knowledge accumulation, and business creation. Hence, BSOs are influential players within complex systems of innovation, learning, and business creation. Despite their important role for national and international economies as well as society at large, our current understanding of their management and impact is underdeveloped in both theory and practice. We know less about the challenges and opportunities for innovation and entrepreneurship in a context of changing economic, technological, and societal environments that arise in the broader ecosystem surrounding BSOs.

To address this void of research, we made this special issue to focus on innovation and entrepreneurship around BSOs to create a richer foundation for future conceptual and empirical research on science management and innovation. The work included in this special issue offers some new insights regarding innovation and entrepreneurship in the context of BSOs. To embed these individual findings into existing research, we provide a comprehensive overview regarding innovation involving BSOs capturing the full picture of the fundamental issues in this regard. Thus, this introduction of the special issue offers an overview on the innovation ecosystem around BSOs as a common reference point for the fundamental mechanisms of innovation in relation to BSOs and relevant stakeholders.

1. Introduction

The impact of public research on the economy and society has long been a central concern for scholars, managers, and policy makers (Cohen et al., 2002; Kokko et al., 2015; Maroto et al., 2016; Mazzucato, 2013), and the research about the distinct effects of Big Science Organizations (BSOs) has prevailed since the early 2000s. BSOs are large research organizations established purposefully to address fundamental and complex scientific research challenges that cannot be addressed in isolation by individual universities, research institutes, or even government agencies. Unlike universities and other national research institutes, BSOs are unique scientific organizations by virtue of their sheer size, level of complexity, and uncertainty with respect to the outcomes of research and development. Several examples of BSOs, such as the Stanford Linear Accelerator (SLAC), the European Organization for Nuclear Research (CERN), European Spallation Source (ESS), European XFEL, MAX IV, the Francis Crick Institute, NASA Jet Propulsion Laboratory, Culman Centre for Fusion Energy, etc., have shown their importance in technological breakthroughs and advancement of knowledge. What is more, BSOs involve large networks of suppliers and collaborators in science, government, and business, constituting a complex system with permeable boundaries that offer opportunities for technology transfer, knowledge accumulation, and business creation (Kollmer and Dowling, 2004; Link et al., 2007). Hence, BSOs are influential players within complex systems of innovation, learning, and business creation. Despite their important role for national and

* Corresponding author.
E-mail addresses: yinli@dtu.dk (J. Li-Ying), ws.si@cbs.dk (W. Sofka), philipp.tuertscher@vu.nl (P. Tuertscher).

https://doi.org/10.1016/j.technovation.2022.102523
Received 10 January 2022; Received in revised form 21 March 2022; Accepted 24 March 2022

international economies as well as society at large, our current understanding of their management and impact is underdeveloped in both theory and practice.

Over the past two decades, there has been increasing interest in the impact of BSOs on technological innovation, organizational learning, the organization of complex large-scale projects, collaborative innovation processes with suppliers, and other spillover effects (Autio et al., 2003, 2004; Vuola and Hameri, 2006; Tuertscher et al., 2014). Most recently, research has paid particular attention to the challenges and opportunities of BSOs with regard to project management (Schimel and Keller, 2015), governance (Smart et al., 2012), and data management (Bicarregui et al., 2015) within BSOs. However, we know less about the challenges and opportunities for innovation and entrepreneurship in a context of changing economic, technological, and societal environments that arise in the broader ecosystem surrounding BSOs. To address this void of research, we called for submissions to this special issue in *Technovation* focusing on innovation and entrepreneurship around BSOs to create a richer foundation for future conceptual and empirical research on science management and innovation. We use the individual articles included in this special issue as a starting point for outlining the research landscape about BSOs as part of a broader innovation ecosystem and conclude by identifying promising research opportunities that remain unexplored.

The work included in this special issue offers some new insights regarding innovation and entrepreneurship in the context of BSOs. In the first article, Scarrà and Piccaluga (2020) conduct a systematic literature review on technology transfer and knowledge spillover from Big Science. The authors identify and synthesize several main themes emerging from the literature, including means and mechanisms for technology transfer, procurement relationships with suppliers, collaboration with public and private sectors, IP strategy and policy, impact of large facilities and infrastructures, and entrepreneurship. Notably, their research highlights the potential of open innovation tools to reuse the knowledge and technology developed at BSOs in various unrelated fields of application. In the second article, Yu et al. (2021) pay specific attention to the impact that costly cyberinfrastructure developed around BSOs has on scientific progress. The authors conduct a longitudinal case study of cyberinfrastructure development and scientific progress based on the Long Term Ecological Research (LTER) program in the United States. The results show evidence of cyberinfrastructure's impact on the discipline of biodiversity. They also show the feedback effect from the discipline to cyberinfrastructure development. The findings have strong policy implications with regard to how to fund cyberinfrastructure development for BSOs. The third article, authored by Cavallo et al. (2021) applies an open innovation lens to investigate the governance of a digital platform developed in collaboration with a BSO. The article offers theoretical implications for governing open innovation in the context of cross-sectoral collaborations between BSOs and their commercial partners. Specifically, their article highlights that governance of such collaborations needs to dynamically co-evolve with the outcomes they produce. Finally, Warenham and his coauthors (2022) show how BSOs can be used to systematically cultivate serendipity to generate spill-overs from BSOs into various industries. Based on a comprehensive case study of the ATTRACT initiative at CERN, using both qualitative and quantitative data, they conclude BSOs can cultivate serendipity by brokering relationships with industrial partners and facilitating applications in unrelated domains.

Each one of these four articles focusses on a specific aspect of innovation around BSOs. To embed these individual findings into existing research, we provide a comprehensive overview regarding innovation involving BSOs capturing the full picture of the fundamental issues in this regard. Thus, this introduction of the special issue offers an overview on the innovation ecosystem around BSOs as a common reference point for the fundamental mechanisms of innovation in relation to BSOs and relevant stakeholders.

2. Innovation ecosystems around BSOs

The innovation ecosystems perspective has recently gained traction among researchers, practitioners, and policy makers for explaining the complex set of interactions surrounding innovation activities. Innovation ecosystems refer to "… the alignment structure of the multilateral set of partners that need to interact for a focal value proposition to materialize" (Adner, 2017: 40), or "… clusters (physical or virtual) of innovation activities around specific themes (e.g., biotechnology, electronics, pharmaceutical and software)" (Ritala et al., 2013: 248). Although defined in various ways by different scholars, an innovation ecosystem is the evolving set of actors, activities, and artifacts, and the institutions and relations, including complementary and substitute relations, that are important for the innovative performance of an actor or a population of actors (Granstrand and Holgersson, 2020). Following this definition, we highlight the important factors for an innovation ecosystem. First, an ecosystem emerges within the boundaries of institutions, including policy, rules of law, norms, which govern the interactions of the actors within an ecosystem and across different ecosystems. At the same time, institutions are shaped by the evolution of ecosystems and adapt when new types of actors, activities and artifacts emerge. Second, ecosystems entail a variety of actors that each have a distinct role to play, while being interdependent with each other (Ritala and Almpanopoulou, 2017). These actors often include government, firms, risk capital (e.g., venture capital), universities and other public research institutions, and last but not least, individual innovators and entrepreneurs. Third, scholars from the MIT Lab for Innovation Science and Policy suggest that the intertwined innovation and entrepreneurship capacities are a crucial element of an innovation ecosystem (Budden and Murray, 2019). Capacities and activities are two sides of the same coin: capacity is needed to perform activities, while the performance of activities demonstrate, reinforce, and likely enhance capacities. Finally, artifacts refer to tangible or intangible technologies, products, services, and resources, based on which value can be created by some actors and captured by others so that collaborative interactions will find incentives to take place.

The innovation ecosystem of a BSO can shape a cluster of innovation activities around, for example, material science within the technology fields of neutron, synchrotron, fusion, bioinformatics, etc., by linking relevant industries which supply technologies to, adopt technologies from, and co-develops technologies with the BSO, partner universities, and other relevant BSOs. It requires a structure, a network, and a process to create value among stakeholders within such an ecosystem. The governing institutions for the innovation ecosystem around most European BSOs include, but are not limited to, a complex set of rules. Using the EU context as an example, the relevant institutions include the European Commission's Research and Innovation policy, the founding statutes of the BSO, guidelines from the European Strategy Forum on Research Infrastructures (ESFI), EU public procurement rules, and other regional and national regulations and rules.

Various types of actors co-exist and interact within the innovation ecosystem of BSO. Among others, they include users, suppliers, cocreators (incl. universities, other relevant BSOs, and Research & Technology Organizations), intermediary organizations, individual entrepreneurs, and funding organizations.

Users: The long-term sustainability of BSOs is dependent above all on sustaining and further developing the community of academic and industrial users. For its scientific success, a BSO must be directed by the scientific and innovation needs of its future users. Take the European Spallation Source (ESS) for example, the need for the ESS long-pulse neutron source and corresponding instrument suite is the result of a bottom-up neutron user driven approach (European Spallation Source ERIC Statues, 2016). Typical for ESS and similar facilities, the users include academic users (e.g., university researchers) and industry users (large established companies or small-medium-size enterprises) (BrightESS Report, 2018).

Suppliers: Suppliers are crucial stakeholders for innovation (Florio et al., 2016). CERN, for example, generates knowledge spillovers to industrial suppliers who, in turn, make further technological innovations (Autio et al., 2004). Li-Ying and co-authors (2021) outlined three different modes, in which suppliers innovate in collaboration with BSOs. In the first mode, suppliers respond to the technological push embodied in BSOs' demands by developing new solutions. In the second mode, suppliers learn from the procurement experience with one BSO, then develop other BSO customers by implementing similar solutions in a new context. The third mode suggests that suppliers learn from the procurement experience with one or more BSOs, then develop new technologies for new products, services, or processes that find customers in markets outside of Big Science.

Co-creators: This group includes universities, other research institutes and research & technology organizations (RTOs) as collaborators. Universities are typical scientific collaborators of BSOs. This type of collaboration can be achieved by various means, e.g., dual affiliation of scientific staff, joint research grants, exchange of researchers and PhD students, and other formal and informal knowledge exchanges. Similarly, other national and international research institutes are also often collaborators rather than competitors. Finally, another type of co-creator are RTOs (e.g., Fraunhofer Institue in Germany and Danish Technology Institute in Denmark), which provide research and development, technology and innovation services to enterprises, governments, and other clients. Some RTOs have private ownership and are for-profit. However, RTOs differ from private companies and universities because they are supposed to have significant government funding, supply services to firms individually or collectively in support of scientific and technological innovation and devote much of their capacity to remaining integrated with the science base. RTOs have played a crucial role to bridge the gaps of innovation systems (Albors-Garrigos, Zabaleta, and Ganzarain, 2010).

Intermediary organizations: This group of actors consists of specialized innovation hubs/platforms and industrial liaison officer (ILO) networks. Innovation intermediaries facilitate inter-organizational collaboration bringing together firms, governments, and universities to address innovation-related challenges and promoting entrepreneurship, bringing about economic development (Dalziel, 2010). Intermediary organizations' value to their network participants extends beyond knowledge brokering activities into broader systemic innovation management (Howells, 2006). The increasingly uncertain situations that intermediaries face when supporting the innovation process of their network participants give rise to high complexity in their roles and activities (Agogué et al., 2017). Some BSOs, such as CERN and ESS, have a large and effective ILO network that translates the BSOs' demand for technology and instruments into a supply base, a crucial role to enhance the BSOs' and its ecosystem's innovation capacity. In addition, in some countries, specialized innovation platforms have also been established to foster science and industry collaboration in neutron and x-ray, e.g., the LINX Association in Denmark and the LINXS in Sweden, which complement the role to those of the ILOs.

Individual innovators and entrepreneurs: Creative individuals as innovators and entrepreneurs are the fuel of an innovation ecosystem. Delmar and Davidsson (2000) identify key characteristics of nascent entrepreneurs. In the context of BSOs, individual entrepreneurs may come from within (as an employee inventor) or outside of a BSO or from university partners, industry, or the start-up community. They take technological and/or commercial risks to create value for customer needs by offering improved or new solutions.

Funding *organizations* (including risk capital): A BSO's innovation ecosystem needs substantial funding as its backbone. This includes international government funding for example from the EU (e.g., Horizon Europe, European Institute of Innovation and Technology, EU Regional Development Fund), national public funding, industry funding, private foundations, and venture capital (VC). VC finance plays an important role for innovation and entrepreneurship by investing in start-ups with high growth potential (Popov and Roosenboom, 2013). VC investment also facilitates the growth of start-ups (e.g., Audretsch and Lehmann, 2004; Colombo and Grilli, 2010). However, the role of VC financing for innovation and entrepreneurship based on technologies generated from and in collaboration with BSOs is not directly studied in extant research.

There are at least three major mechanisms by which innovation and entrepreneurship in a broad sense emerge at, for, and with BSOs:

1) Scientists and technicians employed at BSOs often have opportunities to discover technological breakthroughs or new ways of using existing technologies in a novel context. These opportunities can lead to intrapreneurial and corporate entrepreneurial opportunities through startups or spin-offs. The BSO research space is thereby broad enough to incorporate theories in opportunity recognition (Baron, 2006), mechanisms of innovation incentives (Black and Lynch, 2004), intellectual property (IP) management with multiple knowledge holders (Alexy et al., 2009), multi-party collaborative innovation (Wang and Li-Ying, 2015), and supplier innovation (Li and Vanhaverbeke, 2009).
2) Researchers at universities that collaborate with a BSO make scientific discoveries by conducting experiments that make use of the BSO's facilities and equipment. Some of the technical inventions that result from such types of experiments might have commercial value, and thus warrant being patented. New ventures can be created by university researchers based on the IP. Making the best use of scientific research results from experiments at a BSO and developing technologies that have commercial potential require specific competencies that researchers at universities often lack. Therefore, innovation capability development for universities that collaborate with BSOs deserves research attention as well. Moreover, in this context, it is also necessary to have specialized intermediaries in place. The literature on types and functions of intermediary organizations in innovation ecosystems (Howells, 2006) has not yet clearly addressed the relationship between BSOs and universities. Thus, defining the functions of these necessary intermediaries in the BSO-university-industry triangle relationship is of interest.
3) Established firms with specialized technologies and technological competencies see BSOs as market opportunities. However, there are substantial barriers to entry. These firms usually need to develop products and solutions with technology specifications developed specifically for the BSO, which is a single large customer. On the one hand, this dedicated relationship with the BSO, pushes the firm to develop new technologies to the maximum of their technological capacities. On the other hand, it creates a potential risk of becoming "locked in," since specific technologies developed for a single customer may be difficult to apply to other markets. Turning such a challenge into success may create new business opportunities for the firm (Aschhoff and Sofka, 2009). In this context, innovation intermediary organizations may play a crucial role to reduce transaction cost and collaboration obstacles (Li-Ying et al., 2021).

3. BSO research potentials

We conclude by synthesizing promising research trajectories about innovation and BSOs along four central dimensions.

3.1. BSO as keystone actor

Innovation ecosystems often rely on a keystone actor (or ecosystem leader) providing a common platform, orchestrating resources, goals, and monitoring the development of other actors in the ecosystem. A typical example is the innovation ecosystem that Apple has built around its products and services, in which Apple is the keystone actor while numerous other companies develop hardware peripherals, complementary software and services that are available within and outside the App Store. In the context of Big Science, we have also witnessed the influence of keystone actors, such as CERN, which are shaping the evolution of ecosystems around BSOs. Since its establishment in 1954, CERN has received billions of Euros of public R&D investment that have resulted in a large number of scientific advances and technological inventions. Maybe the most prominent technology emerging from CERN is the World Wide Web, which was originally conceived as an information-sharing tool between scientists at affiliated universities and institutes around the world (Berners-Lee, Cailliau, Groff & Pollermann, 1992). The invention quickly diffused beyond CERN's innovation ecosystem and undoubtedly contributed to innovation, economic development, and benefited the society at large. CERN has also been active in technology transfer and commercialization since 1993 and many of CERN's technologies are now applied in industrial solutions (e.g., GRID computing, Proton therapy for cancer, and touch screen technology). In 2018, CERN launched the ATTRACT project that invites start-ups and technology firms to use their technologies to leverage CERN's expertise in the field of imaging and detection. Such an outside-in approach complements the traditional inside-out approach through technology transfer (Li-Ying, 2018). In one of the articles included in this special issue, Warenham and his co-authors (2022) showcase the important leadership of CERN in the innovation ecosystem and uncover some fundamental mechanisms of serendipity for collaborative innovation between BSOs and industrial suppliers.

BSOs are heterogeneous along many dimensions and there is no reason to assume that BSOs are keystone actors, even though in some cases it is desirable and possible. Not all BSOs are as advanced and developed as CERN in terms of technology development, value appropriation, and collaboration. Nor do all BSOs have as strong public funding support as CERN. In fact, some BSOs may not have leeway in their publicly funded budget to pursue technology commercialization and collaborative innovation with external stakeholders. In this case, BSOs may not be able to take the keystone actor role. Future research should pay attention to finding out what the advantages and disadvantages are for a BSO to take a keystone actor role, under which conditions? Promising research questions in this regard include for example:

- Given the *BSO-university-industry* triangle relationship, it is important to have a close look of the relationships among different types of stakeholders (Wang and Li-Ying, 2015; Li-Ying, 2018).
- The signaling effects of collaborations with BSO for new ventures, suppliers, or collaborators. For example, can employees of a BSO acquire and signal their unique skill sets in a way that will propel their future careers? Is it possible for small firms to receive reputational benefit by signaling their status of being suppliers to BSOs so that they earn credits, which enable them to secure new customers or enter new markets?
- BSOs concentrate scientific personnel and equipment in particular geographical locations. How does the establishment and development of a BSO generate a wide range of socio-economic impact for regional development?

3.2. BSO platforms

A platform is often an integrated part of an innovation ecosystem, where a set of tools, services and technologies are connected to serve a common purpose of the ecosystem and allow value creation and capture by the stakeholders. In the context of Big Science, the core circle of an innovation ecosystem is most likely the scientific network of research institutions in the same science field and then extend to other interrelated networks. While often a professional network exists and functions around each BSO, an overall platform for innovation purpose that connects the related yet different networks has not been commonly witnessed. For example, in neutron science, there are European networks of research infrastructures, such as LENS and LEAPS, and national networks such as LINX (Denmark) and LINXS (Sweden), as well as the international liaison officer (ILO) networks of various research infrastructures. However, these networks are not necessarily sharing the same platform to achieve common purposes and create value. A common platform is lacking to connect the core scientific networks with relevant industrial firms, start-ups, SMEs, RTOs, universities, and other collaborators.

Articles in this special issue reveal different dimensions of platforms and infrastructures provided by BSOs. Yu and her co-authors (2022) highlight the technical dimension of infrastructures by offering insights on the importance of cyberinfrastructure to the evolution of Big Science networks. Conversely, Warenham et al. (2021) point out the value of the social infrastructure for brokering between different actors in the ecosystem. Specifically. They showcase the effectiveness of the ATTRACT platform, which was built on the scientific and industrial networks of CERN and extended to a wide range of external collaborators. Cavallo and his co-authors (2022) reveal that both social and technical infrastructures are interrelated, highlighting the dynamic nature of open innovation governance. Through an in-depth, longitudinal case study of a commercial software firm and a BSO co-developing a digital platform, they identify five processes through which the open innovation governance and its outcome influenced each other on the platform.

Future research in this direction may look further into research questions such as:

- How can a common platform lower or remove transaction costs among stakeholders for value creation and value capture in the context of Big Science. It will also be interesting to investigate how a platform unleashes the power of complementarity among stakeholders and create more opportunities for serendipity in scientific discovery and technological advance, building on the work of Wareham et al. (2021) in this special issue.
- The tension between the *scope* and *resources* of the BSO, where the former is highly related to scientific leadership and the latter is dependent on project management, stakeholders, and government funding.

3.3. Competition and cooperation

Actors in an innovation ecosystem may have both competitive and cooperative relationships (Bengtsson and Kock, 2000). They cooperate because of mutual interests in leveraging complementary resources to create value and diffuse innovation faster to a wide range; they compete as well because alternative solutions offered by different stakeholders might address the same market needs. In the context of Big Science, the coopetition relationships may take place among industrial firms, as well as among similar BSOs in different regions. For instance, there are several neutron and synchrotron research facilities in Europe, making various levels of outreach to academic and industrial partners in their own regions (BrightnESS Report, 2018). These facilities need to cooperate because it is the proper way to advance science and technology, but they might also compete by providing differentiated service to attract industry users based on easy access, supporting services, match making, IP support, etc. To date, we do little knowledge about the *coopetitive* relationship among similar BSOs in different regions and how the innovativeness of industrial users and the economic growth in different regions are influenced by such relationships.

In this special issue, Cavallo et al. (2021) found evidence that reflects on the coopetitive relationships between a commercial software firm and a BSO as to that the governance of the collaboration played a major role in resolving tensions, which had a profound impact on the design of the digital platform. Future research can build on these insights and explore for example:

- Optimal IP strategies for the BSO and its partners, given concerns about appropriation of intellectual property (IP) within an open innovation system for knowledge partners (Laursen and Salter, 2014).

- There is a rich body of literature on technology transfer from *university* to industry and how collaborations between the two sides can be managed. As BSOs are viewed as different from universities with regard to their financing structure, the purpose of science and technology development, and mechanisms for contracting with external partners, it could be interesting to investigate the extent to which collaborative relationships and learning with BSOs are different from collaboration and learning with universities, from a firm's perspective.

3.4. Coevolution within a BSO's lifecycle

Ecosystems have their lifecycles, and at different stages of the lifecycle, the ecosystem might have different purpose and play different roles to orchestrate the interaction among stakeholders (Rong et al., 2013; Dedehayir et al., 2018). A BSO also has a typical lifecycle, from theoretical specification (usually a scientific and political debate and prioritization process) to resource allocation and construction (where procurement and supply is the main focus), to operation (where scientific experiments are conducted and upgrading may occur), to finally the demolishing phase (where sustainable implementation is the focus) (Autio, 2014). One of the specific topics in this regard relates to financing and taxation of BSOs, about which, unfortunately, we did not receive any submissions for this speical issue. Future research is encouraged to explore the innovative financing model along a BSO's lifecycle.

In this special issue, Scarrà and Piccaluga (2020) present the relevance of several mechanisms related to innovation and entrepreneurship around BSOs and Yu et al. (2021) take a longitudinal perspective to examine the coevolution of the cyberinfrastructure of BSO projects. This work surely provides us with valuable insight, but to date, our knowledge is rather limited regarding the coevolution of stakeholders and the ecosystem itself along the lifecycle stages of the ecosystem. Promising research questions along this dimension include:

- The learning mechanisms between BSOs, collaborating universities, suppliers, and project management. The learning perspective can be investigated both at the organizational level—by studying the transfer of codified technologies within a certain governance framework—and at an individual/group level—by observing technicians employed at BSO, scientists from collaboration universities (who do experiments at the BSO), managers and engineering staff of supplier firms, and project management teams. Thus, theories and research approaches from a technology transfer perspective and knowledge management perspective can both be employed.
- Public procurement has impacts on the success of innovations in general (Aschhoff and Sofka, 2009). Can public procurement through BSOs drive market success of innovations? Under which conditions?

4. Conclusions

Investments into BSOs are major, long-term commitments of government funds and political attention to particular technologies with substantial promise but also uncertainties. Given the scale of the investments and the complex coordination tasks across countries, institutions and supply chains, BSOs are more than just technology producers. Instead, they have substantial effects on their partners by providing new technological infrastructures, on their regions by agglomerating skilled individuals and on their supply chains by creating demand for advanced inputs. That is why research on BSOs must have an ecosystem view and explore interactions with all types of stakeholders to share knowledge, to create mutual stimuli, to leverage complementary assets, to define common goals and diversified means to create value, and in turn, to make positive societal impact. BSOs not only advance science and develop technologies, but also provide an organizational context for processing innovations, a risk-taking culture, market orientation, and innovation capacity for the BSO and with stakeholders in its ecosystem.

Extant organizational theories or technology/innovation strategies are only beginning to incorporate the distinct nature of BSO innovation ecosystems. The size of BSOs and the multidimensional nature of their impact provide a fertile research field for scholars, practitioners, and policy maker to develop new knowledge on issues such as science and technology policy, open innovation, innovation procurement, serendipity, deep-tech entrepreneurship, and public organizations' innovation, effectiveness of public and private R&D, etc. We hope that this special issue accelerates this process.

References

Articles with this mark are included in this special issue.

Adner, R., 2017. Ecosystem as structure: an actionable construct for strategy. J. Manag. 43 (1), 39–58.

Agogué, M., Berthet, E., Fredberg, T., Le Masson, P., Segrestin, B., Stoetzel, M., Wiener, M., Yström, A., 2017. Explicating the role of innovation intermediaries in the "unknown": a contingency approach. J. Strat. Manag. 10 (1), 19–39.

Albors-Garrigos, J., Zabaleta, N., Ganzarain, J., 2010. New R&D management paradigms: rethinking research and technology organizations strategies in regions. R D Manag. 40 (5), 435–454.

Alexy, O., Criscuolo, P., Salter, A., 2009. Does IP strategy have to cripple open innovation? MIT Sloan Manag. Rev. 51 (1), 71.

Aschhoff, B., Sofka, W., 2009. Innovation on demand – can public procurement drive market success of innovations? Res. Pol. 38, 1235–1247.

Audretsch, D., Lehmann, E., 2004. Financing high-tech growth: the role of banks and venture capitalists. Schmalenbach Business Review 56, 340–357.

Autio, E., 2014. Innovation from Big Science: Enhancing Big Science Impact Agenda. Report for UK Department of Business Innovation and Skills. https://core.ac.uk/download/pdf/19888222.pdf.

Autio, E., Bianchi-Streit, M., Hameri, A.-P., 2003. Technology Transfer and Technological Learning through CERN's Procurement Activity. CERN Scientific Information Service, Geneva.

Autio, E., Hameri, A.-P., Vuola, O., 2004. A framework of industrial knowledge spillovers in big-science centers. Res. Pol. 33, 107–126.

Baron, R.A., 2006. Opportunity recognition as pattern recognition: how entrepreneurs "connect the dots" to identify new business opportunities. Acad. Manag. Perspect. 20 (1), 104–119.

Bengtsson, M., Kock, S., 2000. Coopetition" in business Networks—to cooperate and compete simultaneously. Ind. Market. Manag. 29 (5), 411–426.

Berners-Lee, T., Cailliau, R., Groff, J.F., Pollermann, B., 1992. World-Wide Web: the Information Universe. Internet Research.

Bicarregui, J., Matthews, B., Schluenzen, F., 2015. PaNdata: open data infrastructure for photon and neutron sources. Synchrotron Radiat. News 28 (2), 30–35.

Black, S.E., Lynch, L.M., 2004. What's driving the new economy? the benefits of workplace innovation. Econ. J. 114 (493).

Budden, P., Murray, F., 2019. MIT's Stakeholder Framework for Building & Accelerating Innovation Ecosystems. Retrieved from *MIT Lab for Innovation Science and Policy*. Website: https://innovation.mit.edu/assets/MIT-Stakeholder-Framework_Innovation-Ecosystems.pdf.

* Cavallo, A., Burgers, H., Ghezzi, A., Van de Vrande, V., 2021. The Evolving Nature of Open Innovation Governance: A Study of a Digital Platform Development in Collaboration with a Big Science Centre. Technovation, 102370 https://doi.org/10.1016/j.technovation.2021.102370.

Cohen, W.M., Nelson, R.R., Walsh, J.P., 2002. Links and impacts: the influence of public research on industrial R&D. Manag. Sci. 48 (1), 1–23.

Colombo, M.G., Grilli, L., 2010. On growth drivers of high-tech start-ups: exploring the role of founders' human capital and venture capital. J. Bus. Ventur. 25 (6), 610–626.

Dalziel, M., 2010. Why Do Innovation Intermediaries Exist? Paper Presented at the 2010 *Druid Summer Conference*.

Dedehayir, O., Mäkinen, S.J., Ortt, J.R., 2018. Roles during innovation ecosystem genesis: a literature review. Technol. Forecast. Soc. Change 136, 18–29.

Delmar, F., Davidsson, P., 2000. Where do they come from? Prevalence and characteristics of nascent entrepreneurs. Enterpren. Reg. Dev. 12 (1), 1–23.

European Spallation Source ERIC Statues, 2016. European Commission. https://europeanspallationsource.se/sites/default/files/downloads/2017/09/ERIC%20Statutes.pdf.

Florio, M., Castelnovo, P., Sirtori, E., Rossi, L., Forte, S., 2016. The Economic Impact of CERN Procurement: Evidence from the Large Hadron Collider. https://doi.org/10.2139/ssrn.3202209. Available at SSRN: https://ssrn.com/abstract=3202209. or.

Granstrand, O., Holgersson, M., 2020. Innovation ecosystems: a conceptual review and a new definition. Technovation 90, 102098.

Howells, J., 2006. Intermediation and the role of intermediaries in innovation. Res. Pol. 35 (5), 715–728.

Kokko, A., Tingvall, P.G., Videnord, J., 2015. The growth effects of R & D spending in the EU: a meta-analysis. Economics 9 (29), 1–20.

Kollmer, H., Dowling, M., 2004. Licensing as a commercialization strategy for new technology-based firms. Res. Pol. 33, 1141–1151.

Laursen, K., Salter, A.J., 2014. The paradox of openness: appropriability, external search and collaboration. Res. Pol. 43 (5), 867–878.

Li, Y., Vanhaverbeke, W., 2009. The effects of inter-industry and country difference in supplier relationships on pioneering innovations. Technovation 29, 843–858.

Li-Ying, J., Forneris, J., Korsholm, S.B., Jensen, A., Zangenberg, N., 2021. How do big science organizations and suppliers in Europe innovate through public procurement? – challenges and best practice. Res. Technol. Manag. 64 (2), 46–56.

Link, A.N., Siegel, D.S., Bozeman, B., 2007. An empirical analysis of the propensity of academics to engage in informal university technology transfer. Ind. Corp. Change 16 (4), 641–655.

Li-Ying, J., 2018. Dual boundary spanning: toward a typology of outside-in open innovation in the Canadian context. Can. J. Adm. Sci. Rev. Canad. Sci. Adm. 35 (3), 429–443.

Maroto, A., Gallego, J., Rubalcaba, L., 2016. Publicly funded R&D for public sector performance and efficiency: evidence from Europe. R D Manag. 46 (S2), 564–578.

Mazzucato, M., 2013. The Entrepreneurial State. Debunking Public vs. Private Sector Myths. Anthem Press, London.

Popov, A., Roosenboom, P., 2013. Venture capital and new business creation. J. Bank. Finance 37 (12), 4695–4710.

BrightnESS Report, 2018. NEUTRON USERS IN EUROPE: Facility-Based Insights and Scientific Trends. https://europeanspallationsource.se/sites/default/files/files/document/2018-06/NEUTRON%20USERS%20IN%20EUROPE%20-%20Facility-Based%20Insights%20and%20Scientific%20Trends.pdf.

Ritala, P., Almpanopoulou, A., 2017. In defense of 'eco'in innovation ecosystem. Technovation 60, 39–42.

Ritala, P., Agouridas, V., Assimakopoulos, D., Gies, O., 2013. Value creation and capture mechanisms in innovation ecosystems: a comparative case study. Int. J. Technol. Manag. 63 (3–4), 244–267.

Rong, K., Lin, Y., Shi, Y., Yu, J., 2013. Linking business ecosystem lifecycle with platform strategy: a triple view of technology, application and organisation. Int. J. Technol. Manag. 62 (1), 75–94.

* Scarrà, D., Piccaluga, A., 2020. The Impact of Technology Transfer and Knowledge Spillover from Big Science: A Literature Review. Technovation, 102165 https://doi.org/10.1016/j.technovation.2020.102165.

Schimel, D., Keller, M., 2015. Big questions, big science: meeting the challenges of global ecology. Oecologia 177, 925–934.

Smart, J., Scott, M., McCarthy, J.B., Tan, K.T., Argyrakis, P., Bishop, S., Conte, R., Havlin, S., San Miguel, M., Srauffacher, D., 2012. Big Science and Big Administration: Confronting the Governance, Financial and Legal Challenges of FutureICT. University of, Oxford. Said Business School working paper series 2012-23.

Tuertscher, P., Garud, R., Kumaraswamy, A., 2014. Justification and interlaced knowledge at ATLAS, CERN. Organ. Sci. 25 (6), 1579–1608.

Vuola, O., Hameri, A.-P., 2006. Mutually benefiting joint innovation process between industry and big-science. Technovation 26 (1), 3–12.

Wang, Y., Li-Ying, J., 2015. Licensing foreign technology and the moderating role of local R&D collaboration: extending the relational view. J. Prod. Innovat. Manag. 32 (6), 997–1013.

* Wareham, J., Priego, L.P., Romasanta, A.K., Mathiassen, T.W., Nordberg, M., Tello, P. G., 2021. Systematizing Serendipity for Big Science Infrastructures: the ATTRACT Project. Technovation, 102374 https://doi.org/10.1016/j.technovation.2021.102374.

* Yu, Y., Ibarra, J.E., Kumar, K., Chergarova, V., 2021. Coevolution of cyberinfrastructure development and scientific progress. Technovation 100, 102180 https://doi.org/10.1016/j.technovation.2020.102180.