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Well-ordered Big Science, Innovation, and Social Entrepreneurship

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12.1 Introduction

Big Science, usually means 'Big Dollars, Big Machines, Big Collaboration' and contributes to the advancement of knowledge in significant ways. Big Science is commonly associated with particle accelerators and large telescopes, but it also includes Big social, environmental, and information technology concerns such as climate change, human genome research, and artificial intelligence.

Several countries and research communities have collaborated towards achieving scientific advances that no single country or research group in one country could have produced on their own. Such collaborations have unique challenges, but left alone, the scientific community has to deal with them. Knowledge exchanges follow common academic and research practices regardless of ties to politics or geography. In the real world, however, the dynamics of knowledge exchanges are often tempered with political alignments, business interests, and legal considerations.

Volatile socially disruptive occurrences in a number of countries have recently increased, creating unrest and suspicion among and within the international scientific community. A new polarisation in global politics is resulting in even lower levels of collaborative knowledge-sharing, which will have a negative impact on how scientists conduct Big Science and transfer its beneficial outcomes to society.

The Covid-19 pandemic has exacerbated these disruptive tendencies even further. It might take even longer to close the knowledge transfer gap as physical isolation, ongoing mobility restrictions, and socioeconomic survival become more urgent issues that need to be addressed by governments and institutions (including those involved in research and outreach) during the recovery phases.

Ironically, the recovery from Covid-19 may make it the perfect opportunity to invest in Big Science discoveries that benefit humanity greatly and improve quality of life.

This chapter highlights examples of Big Science that trigger innovations that impact social wellbeing. Social, technological, and organisational innovation—together with entrepreneurship to close the gap between fundamental research

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and its application to greater benefits for society—are explained. The discussion shifts from establishing the contextual relationship between scientific research and quality of life to examples of how successes in breakthrough Big Science have led to grassroots solutions. These examples show not only earth-shattering scientific and technological solutions but also explain how social innovations can engineer grassroots responses.

12.2 Role of Entrepreneurship in Shaping People and Nations

The progress and prosperity of human civilisation have always been linked to wealth and industry. The evolution of society, from tribes to communities to nation-states, is a chronicle of individual initiatives and self-interest in the pursuit of wealth.

Such self-interest propels the nation's wealth, ensuring peace, stability, and social welfare. In essence, society's history has always been the tale of entrepreneurship, with particular emphasis on the creation and preservation of wealth.

The economic prosperity of countries is inseparable from their social development. The inclusion and involvement that have come to define wealthy societies are those in which all individuals share a relatively more equal distribution of the benefits of development. High levels of healthcare and education for citizens, as well as state guarantees of security and equal rights to citizenship, are some of the indicators of social well-being. Economic prosperity, on the other hand, is closely related to science and technology development. With such development, we witness a well-developed workforce, gainful employment opportunities and disposable incomes, a higher standard of living, efficient public infrastructure and public services, good health care, welfare, and education systems that can be sustainable in a viable economy.

The concept of balanced growth, also known as 'the big push', was highlighted in post-war studies by Nurkse (1953), Scitovsky (1954), and Fleming (1955). According to this concept, economies that are in between the pre-industrial and industrialised paradigms can advance into a higher gear by merely absorbing technological advantages that have been developed at a high cost by others.

India's leap into the digital economy, Bangladesh's move into light manufacturing, and Thailand's evolution as the 'Detroit of Asia' are examples where entire populations have experienced quality of life changes because of this technological leap (Murphy et al., 1989: 1004). Science, technology, and innovation play a crucial role in this transformation.

Investing in Big Science has a significant influence on this kind of technology transfer with investments in fundamental knowledge and human capacity building. However, Big Science development necessitates large investments in technology, infrastructure, and expertise, which in turn bestows influence based on control and exclusivity.

Naturally, countries with relatively high Gross Domestic Product (GDP) per capita are able to participate freely in such Big Science investment projects. Those nations with large research funding and technical expertise are able to contribute to such projects. Despite these challenges, Asia, South America, and some African countries are able to participate in some of the Big Science activities on a limited scale with international collaboration programmes (Praderie, 1996), for example, international projects such as ESO's Square Kilometre Array (SKA) telescope located in South Africa with additional stations located in eight other African countries,[1] known as the African VLBI Network (AVN). These radio telescope stations are part of the African Very Long Baseline Interferometry (VLBI) to produce high-resolution images of celestial objects. Another example is Chile, in South America, where ESO's flagship ground-based Paranal observatory, the Very Large Telescope (VLT) and several other telescopes are located in the Atacama Desert in Chile (Figure 12.1). This location is regarded as the best astronomical observation site by astrophysicists.

Pakistan and India became the first non-European associate members of CERN in 2015 and 2017, respectively, after decades of scientific collaboration (CERN, 2017b). By allowing scientists to take part in prestigious scientific investigations like the LHC, such scientific collaborations helped increase capacity building in developing nations.

Figure 12.1 ESO's Very Large Telescope (VLT) at Paranal, Chile
Source: G.Hüdepohl (atacamaphoto.com)/ESO

[1] SKA project involves eight African countries Botswana, Ghana, Kenya, Madagascar, Mauritius, Mozambique, Namibia, and Zambia.

Building scientific collaborations is a key mandate of CERN and ESO and has led to increasing global scientific capabilities and cultivating science diplomacy among nations. Global research infrastructures such as the Synchrotron-light for Experimental Science and Applications in the Middle East (SESAME), the International Space Station (ISS), the Abdus Salam International Centre for Theoretical Physics (ICTP), and the European Council for Nuclear Research (CERN) are shining examples of how to bring increased collaboration among various nations irrespective of their wealth, status, and scientific capability.

Equally, men and women with high intelligence were able to comprehend the origins of the cosmos and make contributions to human understanding of the living environment. Among them are exceptional individuals like Ernest Rutherford, Albert Einstein, and more recently Stephen Hawkins, a brilliant physicist and cosmologist who contributed to work on black holes and the origins of the Universe, including Hawking radiation (Figure 12.2).

Historically, it has been shown that public investment and policies are necessary to promote Big Science infrastructure for socioeconomic development. Such investment drives technological innovations that benefit nations and improve the quality of life. A notable example, already covered in several chapters, is the development of the World Wide Web (WWW), a component of the ubiquitous internet that was imagined and created at CERN (Berners-Lee and Cailliau, 1990). The WWW or Web provided open access to information-sharing among researchers around the world.

Figure 12.2 Professor Stephen Hawking's visit to the Large Hadron Collider (LHC) tunnel in 2006
Source: © CERN

Such information sharing has facilitated the continuous development of magnetic resonance imaging (MRI) and computerised tomography (CT) scans benefiting millions of people (Rinck, 2008; Cirilli, 2021).

Research knowledge, when effectively commercialised, generates enormous private wealth. It may be possible such wealth generated, as Yunus claimed, can be confined to a privileged few (Yunus and Weber, 2017). Apffel-Marglin and Marglin (2015) illustrate the unintended consequences of Big Science investments that span developmental failures, environmental degradation, and social fragmentation.

The dramatic transformation of China's economy and society over the past three decades serves as a compelling example of how significant investments in Big Science and knowledge infrastructure, when made within a highly centralised policy framework and state-controlled economy, can create human capital that is globally competitive in tandem with accelerated economic growth.

China is closing the gap with the USA and Europe on research investments. China holds significant stakes in important international initiatives like the Square Kilometre Array (SKA)[2] and China's 185-million-dollar single-dish Five-hundred-metre Aperture Spherical Telescope (FAST) telescope technology transfer from invention to innovation.

When taken into perspective, the example of centralised national growth may not be unique to China, but the size and scope of its achievement are interesting. Emerging evidence suggests that a society that is opposed to widely held views on popular representation can build citizen participation without mass electoral processes and share the fruits of economic development without a free market.

In a way, China's socioeconomic trajectory stands in contrast to another well-studied national development approach exemplified by Bangladesh. Here, small-scale private enterprise-driven growth in the national income is matched by a simultaneous rise in self-help strategies including microcredit, social services, delivery enterprises, and the developing idea of Social Business[3] championed by Bangladeshi Nobel winner Muhammad Yunus. These two cases from China and Bangladesh illustrate what the Yunus global network refers to as 'Enterprise-led Development', a strategy that shapes public participation and resource allocation to promote socioeconomic development while being supported by socially responsible entrepreneurship within the confines of legal safeguards and a clear focus on eradicating poverty.

As a result, human development indicators for Bangladesh show promise compared to its neighbours, and the Grameen Bank has become an international model for microcredit for a poverty alleviation strategy which may be as complex as Big Science problems (Bernasek, 2003). In contrast to Myrdal's (1968) Malthusian assessment of poverty in Asia, Asian economies have had 50 years of continuous GDP

[2] The SKA project gathers top experts and policymakers to build the world's largest radio telescope whose image quality will exceed that of the Hubble Space Telescope. https://www.skatelescope.org/the-ska-project/.

[3] Muhammad Yunus and Weber (2007; 2017) describes Social Business as a market-competitive non-dividend enterprise created solely to address human problems. A specific sub-set of social enterprise it is designed to counter wealth concentration.

development, driven by technological discoveries imported from the Western world while utilising low production costs. In comparison, Latin America and Africa, where knowledge transfer has been slower, show a low rate of growth.

Bangladesh and China demonstrate two similarities in their respective development journeys. Both have controlled population growth while increasing mass education levels proportionally. Alongside investments in human capital, Bangladesh and China, each in their own way, have invested in knowledge transfer within their means and context. Despite the structural constraints in two countries, they have increased the pace of development, and made resources available for improving quality of life (Nayyar, 2019). According to Myrdal's (1968) view, development must be internally based, deliberately persuaded, and nurtured. Since then, the spontaneous growth-inducing stimulus of relatively free and expanding international trade has faded in the current socioeconomic context.

Enterprise as a driver of growth has been well-established for decades. This enterprise concept is still evolving. Enterprise-led development straddles a continuum between business and philanthropy. This notion has been fundamental to Yunus' model of Social Business. Here, resources, otherwise meant for philanthropic purposes, are used as seed capital to start social impact businesses that eventually become successful and continue to channel profits into further expanding organisational scope and impact.

Similarly, Big Science investments are funds largely generated by the public and are not necessarily motivated by profit. When such investments are profitable, they open the door to commercialisation for the general public. According to Yunus' school of thought, social business investments in Big Science make sense since they share the same dynamics of solving complicated issues and combining dispersed knowledge into technologies that improve the quality of life of the most vulnerable populations.

12.3 The Role of Big Science in Social Construction

Science in general has always played an important role in the transformation of societies. A Pakistani theoretical physicist, Professor Abdus Salam, made an important contribution to Big Science. Salam and his colleagues (Sheldon Glashow and Steven Weinberg) received the Nobel Prize in Physics in 1979 for their work on the electroweak unification theory, a theory confirmed by the discovery of the 'neutral currents' in 1973 at CERN. The discovery at the Gargamelle bubble chamber was also the first experimental indication of the existence of the Z boson observed at CERN in 1983. Professor Salam contributed to the advancement of science and its applications to society, and he played a key role in the creation of the World Academy of Sciences (TWAS) and the Abdus Salam International Centre for Theoretical Physics (ICTP). The former served as a bridge for the transfer of scientific knowledge between developed and developing nations, and the latter overcame the 'Iron Curtain' that divided Europe (Del Rosso, 2014b).

Upon reflection, the swift socioeconomic development of Asia confirms the close connection between science, enterprise, and development, even if only indirectly.

All previous examples cited above, including China, Pakistan, India, Bangladesh, and Vietnam, negate Myrdal's expressed apprehension about how a number of countries would be constantly at risk due to economic stagnation, corruption, and poor governance. Theories of breaking economic stagnation in countries like India and China address a combination of progressive measures of export-oriented growth, investment in human capital, market-oriented reforms, and an open economy that combines science and technology development.

Big Science continues to play a key role in building economic independence, even as most nations cannot afford to invest in expensive knowledge infrastructure on their own. Collaborative platforms such as CERN, ICTP, TWAS, and SKA, provide an opportunity to collaborate and derive direct and indirect dividends from frontier research. The opportunities are enormous to enrich information and data sciences, medicine, education, poverty alleviation, and agricultural development (Reynaud, 2005).

If wealth is an essential component of social well-being and human development, its equitable distribution across all social strata is the goal, and successful enterprise in its many evolving forms is the channel, then science can be argued to be the catalyst. Without business, which has self-interest as its fundamental principle and is driven by the human tendency for 'fair and deliberate exchange',[4] the phenomena of wealth creation and, in fact, its concentration would not exist. Entrepreneurs would have fewer options to disrupt markets and alter value propositions in order to generate money if an open science regime were inaccessible.

Muhammad Yunus (Yunus and Weber, 2007) is quoted on how he built upon his formal expertise in economics, 'standing it on its head' to create a brand-new micro-banking ecosystem that initially served the marginalised, but now is a mainstream product across the banking industry. The Grameen network may be comparable to the network of Big Science collaborators, and it has achieved success in healthcare, infrastructure, software and communications, and professional education, building on the established theory and practice of science and its application, to design 'pro-poor' enterprise solutions to the world's most pressing problems.

12.3.1 Enterprise as Social Equity and Social Transformation

Enterprise has inherent potential as a social equity mechanism, provided it conducts itself with social responsibility and meets the core condition of 'fair exchange'. All else being equal, a fair business transaction is itself a levelling mechanism from the social anthropology perspective (Eller, 2010), because even the richest person cannot buy what the poorest may not wish to sell unless a fair exchange is agreed upon.

[4] Excerpted from Smith's *Wealth of Nations* (2000, Modern Library): Nobody ever saw a dog make a fair and deliberate exchange of one bone for another with another dog. Nobody ever saw one animal by its gestures and natural cries signify to another, this is mine, that yours; I am willing to give this for that.

Big Science organisations such as CERN and ESO have different approaches to knowledge transfer. These organisations follow the idea that the knowledge and technology developed should be made readily available to society in order to benefit the public. Profit considerations lie at the root of inequity (Yunus, 2017). As we have seen since the rise of the corporation, the propensity to place profits above social values and the abdication of personal accountability in favour of a corporate structure create a dynamic of power and privilege where profits may impose an enormous cost on society and the natural environment. Much of the criticism levelled at corporations stems from an unbridled pursuit of profits, which is frequently aided by regulatory safeguards that, until recently, made few demands on corporate citizenship and responsible business.

CERN and ESO technology transfer does not always target industry. Licencing is also used as a tool to share knowledge and techniques with other research institutes at no cost. Training and education are often used to foster entrepreneurship and prepare future generations of physicists who are capable of utilising intellectual property and engaging in start-up ventures.

The modern entrepreneur understands that bargains are ingrained in human nature and that profits are a natural outcome of value exchange. Not much is discussed about the importance of maintaining social and environmental responsibility, which is a tangible part of the value exchange. Utting (2007) examined the equity and equality aspects of doing business from the perspective of corporate social responsibility (CSR), which is being articulated by an increasing number of companies as an effort to redress the imbalance in wealth and power resulting from the conduct of business. Indicators such as the working environment, workers' rights, community engagement, and stakeholder interest show that companies invest increasingly in social and environmental remediation. However, these efforts need reformation to improve empowerment, redistribution of resources, quality of life, and equity.

The recent Covid-19 pandemic has disrupted the progress of Big Science like in many other areas of the economy. Covid had disproportionate impacts on different nations, with poor nations having to rely on rich nation for health, economic, and social support. However, Covid also provided an opportunity to demonstrate equitable access to vaccine and help needy nations. The development of the Covid vaccines at record time in several countries by selected pharmaceutical companies. Keeping in line with Open Science initiatives, more than 25 Nobel Prize winners, including Mohammed Yunus call for the Covid-19 vaccine to be declared a public good. Initiatives such as Covax, the Global Alliance for Vaccines (GAVI), the Coalition for Epidemic Preparedness Innovations (CEPI), and the Covid-19 Tools Access Accelerator (ACT) have responded to efforts to increase vaccine availability, distribution, sharing doses, and redress intellectual property rights to ensure that all nations have access to the vaccine to combat the global pandemic.

Enterprise is thus intricately woven into notions of community development and social advancement. Shared prosperity, social security, equal opportunity, and democratic freedoms are all central to the role of enterprise as a driver of equity. Social entrepreneurship and impact investments are new terms that describe the role society demands from businesses. As governments create incentives for socially responsible businesses and consumer groups rally for more social and environmentally accountable behaviour by entrepreneurs, a visible shift may be underway towards the original role of business as an equity-based mechanism for fair exchange and redistributing wealth. When Big Science generates breakthrough research that is commercialised, enterprises can generate years of profits from it. The current debate seeks to reclaim the social role expected from business and re-introduce the concept of equity that has been lost as a result of free-market profit-seeking incentives.

Big Science discovery and commercial success are not straightforward for a number of reasons. First, fundamental research is directed towards answering scientific questions and is not usually driven by the purpose of seeking commercial success. Second, the capital-intensive nature of Big Science is often distributed across numerous collaborators, making it difficult for lenders to translate into cost recovery over the short term. Third, given the amount of public resources often deployed in the service of Big Science, it is often difficult to justify them to policymakers inclined towards tangible rewards. Fourth, Big Science research can often only be commercialised with significant public subsidies, at least in the start-up phases.

Governments and corporate funders are already encouraging researchers to find ways to reduce the seeming gap between Big Science and entrepreneurial solutions. It remains a challenge, but there is evidence that commercialisation of research outcomes is a priority for leading enablers such as the European Innovation Council Accelerator and the European Institute of Innovation and Technology (Romasanta et al., 2021). CERN, for example, provides training for young researchers who later join many companies, demonstrating immediate contributions to the economy.

12.3.2 Reliable Knowledge, Trust, and Entrepreneurship

Fundamental scientific research, as the bastion of knowledge creation and a fountainhead of reliable ideas, continues to be the best source of business ideas fuelling entrepreneurial inspiration, even though it may not be as obvious to the ordinary citizen as might be expected.

The key to entrepreneurship at CERN is building connectivity. Connectivity between world-renowned scientists, engineers, and practical staff who are able to identify scientific and technological problems not only to advance concepts but also provide solutions that benefit society. This requires building a culture of entrepreneurship across Big Science organisations.

The general public leans towards those they feel they can trust. Building trust in evidence-based research in general and cohesion and respect among social actors and institutions is integral to the perception of well-ordered science and a hallmark of the success of liberal democratic societies. The goal of well-ordered Big Science is to ensure research is conducted for the public good and carried out in a transparent, efficient, and responsible manner to realise the goals of society.

At the individual level, physicists seem to have limited interest in generating public goods and research commercialisation other than the diffusion of useful knowledge. The garnering of public trust and support is necessary to sustain Big Science enterprises. As in the case of high-energy physics and astrophysics, the average citizen may rarely connect to scientific values and even not see their relevance in daily life, until innovations such as biomedical technologies, cancer cures, and imaging technology provide the link to Big Science investments.

Big Science community responds to 'grand challenges', such as environmental threats like climate change, demographic, health, and well-being concerns, and to the difficulties of generating sustainable and inclusive growth. These challenges are associated with 'wicked problems' requiring the Big Science community's strategic action as they are complex, systemic, knowledge-intensive, interconnected, and requiring the insights of many scholars and epistemic groups. This research challenges the imagination of ordinary citizens. CERN has launched citizen science projects to inform and engage the general public. Citizen science projects directly involve the public in the scientific process, and they provide meaningful engagement between science and society.

A more recent success story is Estonia, which was until 1991 a part of the Soviet Union. Estonia has established a reputation for rapid innovation piggybacked on technology infrastructure, earning the nickname *E-stonia*. In 1996, the government-owned technology investment body, the Tiger Leap Foundation, led reform towards a digital economy with large investments in ICT infrastructure. A decade later, ten corporate entities have joined the Look@World Foundation, a public–private partnership aimed at bringing digital technologies to all citizens on the right side of the digital divide. As of 2016, 91 per cent of Estonians are connected via ICT, making Estonia a premium hosting choice for online info-tech and e-commerce. Referred to as the Silicon Valley of the Baltic, Estonia demonstrates the power of collaborative innovation, bringing together companies, universities and citizen organisations to support an e-government that is highly trusted for transparency and efficiency (Anthes, 2015) and demonstrates the linkage between knowledge and moral civic power (Björklund, 2016). These examples may or may not draw close parallels to the ATLAS or CMS experiments and their visible impact on society but they illustrate the importance of sustained engagement between key stakeholders, and the maxim that luck often favours the well-prepared.

12.3.3 Enterprise Solutions

Enterprise solutions to social problems are a demonstrated reality in an increasing number of countries. The Sustainable Development Goals (SDGs) provide an anchor for social businesses. Impact investors are more prepared than ever before to back up social investments. Regulatory regimes are changing to accept social enterprises. However, the everyday outcomes of basic or fundamental research, despite being a significant contributor to scientific advancements worldwide, are less visible to the general public. Scientists can actively promote knowledge transfer by actively creating opportunities to present their research to counterparts, which is an acknowledged driver of national self-reliance.

Scientists have an inescapable role in inspiring innovation, and Japan is often cited as a constantly evolving haven for collaboration between the government, the business sector, and the research community. In 2018, the Japanese government launched the 'sandbox framework' with regulatory reform to boost hi-tech innovation, presently aimed at financial services, the healthcare industry, and mobility (JETRO, 2018; HBR, 2020).

China demonstrates another model of success in what is referred to as 'top-down innovation' (Xu, 2017), where under a national innovation strategy focused on breakthrough technologies, the government works with private investors to finance small and medium enterprises at a large scale, spearheading R&D through innovative organisational solutions. Despite criticism, the approach to innovation appears to have invigorated the innovation landscape in several enterprise clusters across the country, particularly in semi-conductors and bio-pharmaceuticals (Zhang et al., 2022).

By engaging with counterparts in government, business, and citizen organisations to showcase well-ordered research wherever possible, scientists strengthen the necessary link between science and society to establish a well-earned stake in shaping the future of enterprise-led development towards a better world.

12.4 Use of Big Science Ideas for Societal Applications

Not all Big Science projects are candidates for taking ideas from laboratories to industry. It is useful to examine some of the early efforts by individuals to steer some fundamental research outcomes to commercial applications. One such area is the medical applications of CERN's detector technologies as far back as the 1970s. At that time, knowledge was primarily transferred through the initiative of passionate individual researchers. Georges Charpak, for example, was responsible for developing the multiwire proportional chamber (MWPC) at CERN in 1968, and he was awarded the Nobel Prize in 1992 for his innovation. Multiwire chambers gave rise to further developments in the art of detectors, some of which are highly innovative. Most high-energy physics experiments make use of these methods, but their application has extended to widely differing fields such as biology, medicine, and industrial radiology (Charpak, 1992). The MWPC's ability to record millions of particle tracks per second opened a new era for particle physics. In medical imaging, its sensitivity promised to reduce radiation doses during imaging procedures, and in 1989, Charpak founded a company that developed an imaging technology for radiography that is currently deployed as an orthopaedic application.

CERN continued to build a culture of entrepreneurship. Systematic efforts in technology transfer can be traced back to 1988, when the CERN Industry and Technology Liaison Office was founded to stimulate interaction with industry and to assist in issues related to CERN's intellectual property (Nilsen and Anelli, 2016). Most Big Science organisations, including CERN and ESO, use technology transfer and knowledge diffusion activities, including the transfer of licensing of intellectual property rights, making software and hardware available under open licences, building industry interactions, and forming international collaborations, as transfer modalities. Such technology transfer opportunities also feed curiosity and the exploration of new paths for innovation and knowledge creation.

12.5 Effective Knowledge Transfer of Big Science Knowledge

In Big Science the basic notion is that all scientific results shall be made openly available to the public. Within this conviction, knowledge transfer mechanisms are not explicit. In recent times, knowledge transfer has frequently been advocated as a strategy to solve some of the most pressing issues, such as medical (Covid-19) and climate change of our times.

How is it possible to be more cost-aware when making the necessary equipment for research purposes? In general, industries are used to develop new technologies using prototypes and pilot plants using available research knowledge. Innovation requires a combination of technical and non-technical inputs. The coordination and communication among research and development teams across industry, universities, and research-collaborating institutes are necessary for the successful transfer of knowledge and continuous technological development.

At CERN, all the changes in future experiments allow for coping with the increase in size, strategic focus, and innovation opportunities of the projects and of the participating institutions and universities, which have been absorbed with time into existing work practices. For example, LHC beams are squeezed into very small beam sizes to maximise the rate of proton collisions as required for rare processes like Higgs production. In addition, the angular divergence of the beams at the interaction points was reduced, and these special settings allowed the ALFA and TOTEM experiments to measure proton–proton scattering angles down to the microradial level.

Any further changes required by the LHC and the High Luminosity LHC (HL-LHC) have been just a natural extension. The time from conception to realisation and functioning is now so large that scientists must bargain between their wish to use the most updated possible applications and the possibility of really doing it.

It is worth remembering here that CERN's accelerator construction and its upgrades are mostly accommodated within the CERN budget. The cost of the detectors and their upgrades as needed to carry out the research are mostly covered (more than 90%) by the collaborating institutes. Furthermore, in LHC experiments, almost 50% of the participants are not from CERN Member States, implying that the spillover of technological learning extends to international borders.

Big Science knowledge and ensuing technology transfers aim at broader societal impacts. However, this has not been the best case. The interests of many practicing physicists and engineers have specific research strategies in mind. Societal development is a related issue and often something hard to conceive.

Scientific performance is measured not only in terms of research outcomes but also in terms of social deliverables such as education and knowledge transfers. CERN and ESO as astrophysics experiments, the Human Genome Project, the Human Brain Project, and the European Molecular Biology Laboratory are shining examples of what they can deliver to society at large. Since its creation in 1954, CERN has had a long tradition of technology transfer, mainly through people and purchasing (Schmied, 1975; Bianchi-Streit et al., 1984; Autio et al., 2003), and collaboration agreements (Bressan et al., 2008; Florio et al., 2016).

The most revolutionary technology that has impacted our daily lives is the World Wide Web (WWW), also called the Web (Gillies and Cailliau, 2000; Berners-Lee and Fischetti, 2000; Berners-Lee and Cailliau, 1990). WWW was invented by Tim Berners-Lee in 1989. He drafted a one-page proposal (perhaps the shortest proposal at CERN) and presented it to the CERN management, outlining the general information management protocol about the accelerators and experiments at CERN. His solution was based on a distributed hypertext system. The outcome of this proposal, leading to the invention of WWW, made it possible to connect the entire world (Figure 12.3).

The need to get such scientific developments and knowledge transfer into a more structurally effective return to society led to the creation of technology transfer offices and technological parks within university campuses and near Big Science Centres.

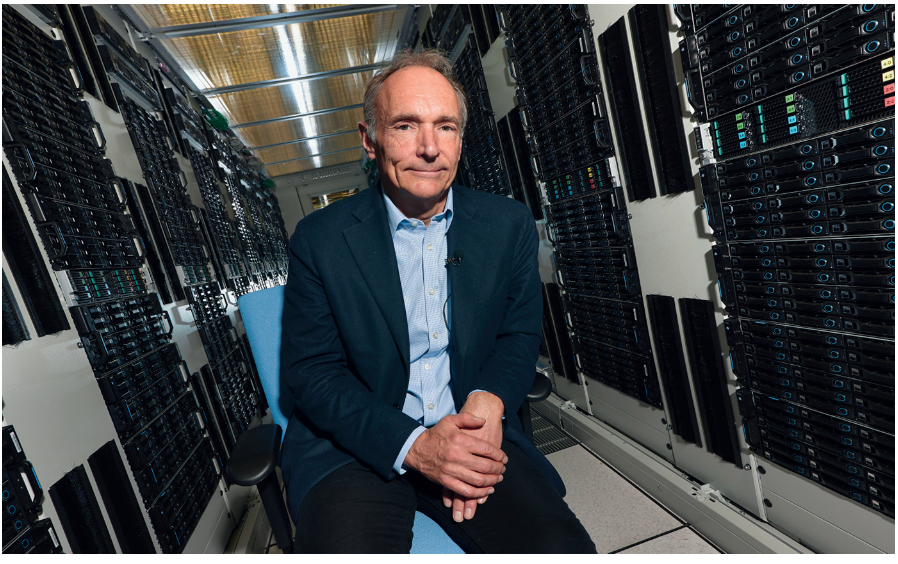

Figure 12.3 The inventor of the WWW, Tim Berners-Lee at the CERN Computer Centre
Source: © CERN

In addition, glass ceramic, laser guiding systems, ESO's RAMAN fibre amplifier technology, and software developments found commercial applications in cancer diagnostics, the telecommunications industry, and life and geophysical sciences. The scientific capability of making real-time observations, interactive data analysis, and automated processes in laboratories and institutes around the world is also having a large impact on society.

12.6 Knowledge Transfer and Knowledge Management

Several models have been created and developed to study the knowledge translation processes adopted by Big Science organisations such as CERN. These models of knowledge transfer help to understand and leverage this important process, which is at the core of innovation, entrepreneurship creation, and societal impact. CERN as an organisation, and similarly any other Big Science Centre, has its own epistemology, with its own tacit and explicit knowledge and creating entities (individuals, groups, and their organisations). The multicultural scientific and technological environment is also very important for individual and organisational knowledge creation.

Most knowledge transfer models are applied in companies that do not consider scientific knowledge acquisition and the scientific process. This is why a new knowledge management model for scientific organisations such as CERN has been created (Bressan 2004), incorporating Nonaka's four modes of knowledge conversion (socialisation, externalisation, combination, and internalisation) developed for business purposes (Nonaka and Takeuchi, 1995) with the knowledge acquisition model developed for didactic purposes (Kurki-Suonio and Kurki-Suonio, 1994) as shown in Figure 12.4.

The model of knowledge management in science is the continuous transferring, decoding, and utilising of existing knowledge to produce more knowledge. From individual perception, assessment, and analysis of the context and tools in which the five LHC experiments evolved, it has been possible to track the various aspects of knowledge acquisition. Social interaction, relationship quality, and network ties existing in the multicultural environment of LHC experiments have been shown to be associated with knowledge acquisition (Bressan et al., 2008), and contribute to innovation.

Big Science closely interacts with industry for the purpose of advancing research infrastructure and components such as magnets. Most innovative companies respond to both the push of research and development and the pull of the market. In some leading companies, attempts were made to change approaches to technological innovation. For example, using '*Lean thinking*' business methodologies delivers more benefits to society by placing people first rather than technological systems (Womack and Jones, 1996).

In a knowledge-based economy, digitisation and a circular economy go hand in hand, and they can help shape new business models. Another concept is the use of Social Return on Investment (SRoI), which was used for the first time in 2000. In

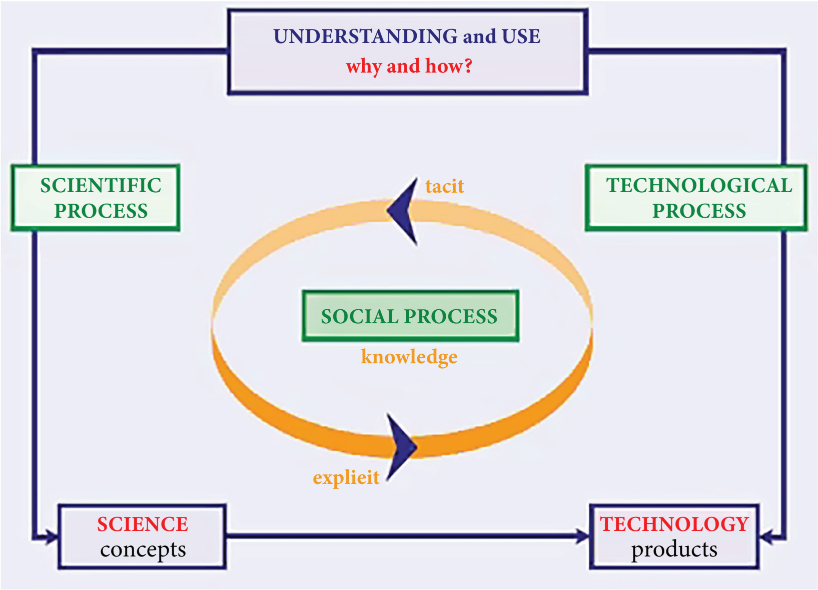

Figure 12.4 A knowledge management model

Source: © CERN

Standard Return on Investment (SROI), the social returns are based on cost versus benefit analysis to determine the value of projects using project evaluation and quantitative impact assessment. Such methods may assist the stakeholders in resource allocation, plan modification, social impact assessment, and the assessment of benefits that cannot be easily monetised. Such approaches may be used in organising Big Science projects to target social benefits.

12.7 Innovations: From Science to Society

Technology transfer, from invention to innovation and impact on society, is no longer a question resting solely on efficiency (Oliveira and Teixeira, 2010). Incidentally, technology transfer is primarily discussed from an economic perspective. However, the global context also needs to consider other important factors like ownership, culture, public policy, education, equity, and impact.

In other words, the success of a given technology transfer may rather lie in an equilibrium between the efficiency and resilience of the targeted outcome. (Abdurazzakov et al., 2020). Ciborowski and Skrodzka (2020) have shown that cooperation within economic ecosystems positively impacts innovation among countries.

Given the comparable aim of supporting social development, the same principle should be applied to technology transfer. This leads to proposing an extension of the Agency Theory (Mitnick, 2015), as a possible new sustainable economic and societal model. A Circular and Trustworthy model combines to transform new knowledge into invention and its dissemination to society as new technology products, processes, and services. In the original Agency Theory, there is one 'Principal', i.e. the donor of an invention, on the left, and one 'Agent', i.e. the user of an invention carrying out an action. The potentially unaligned relationship is handled by the setup of a contract between the Principal and the Agent (e.g. a software licence). According to this model, society is (re)introduced in the equation as a second Principal, on the right of Figure 12.5, to consider societal needs, incentives, and cost versus benefit aspects. For this virtuous circle to ignite, it is believed that both market and societal dimensions must be considered in the valuation of a given invention. Indeed, to maximise knowledge transfer to society, inventions must be forged in an accountable, transparent, and traceable manner so they can be turned into open, inclusive, virtuous, and circular technologies (Manset et al., 2017, 2023).

Motivation, and remuneration in particular, are clearly important but remain often the sole criteria of economic efficiency. The model therefore must be extended until the eventual beneficiary, i.e. society. In doing so, the model becomes virtuous and circular and thus opens the pathway to resilience in inventions and societies, which is key to progressive and long-term success in achievements. The beneficiary must therefore be an integral part of the construction process and convinced of the importance of the development.

The diffusion of innovations is largely influenced by the types of innovation, the communication channels available to diffuse new ideas, the time and degree of adoption, and the social systems. Big Science leads to clusters of innovation. Although there may be clusters adopting innovations, there are still barriers to innovation diffusion that must be overcome, such as a lack of local involvement (Rogers, 1962, 2003).

Today, with the consolidation of distributed ledger technology (DLT), emerging studies indicate mounting research interest in applying blockchain technology to knowledge-sharing frameworks (Zareravasan et al., 2020; World Bank Group, 2018) by reducing information asymmetry in collaborative networks (Schinle et al., 2020), and then projecting this catalytic potential to entrepreneurial innovation (Hashimy et al., 2021). Big Science makes it possible for multiple channels of innovation.

More particularly in the creation of peer-to-peer research and innovation networks, DLT can be seen to help in shaping the virtuous model[5] developed for this chapter and presented in Figure 12.5. This model explains the role of collaboration and economic relations in transferring knowledge. In fact, blockchains can serve the purpose of making inventions transparent, accountable, and traceable over time, while enabling their open, inclusive, and circular use in society. It can do so thanks to open information sharing not only in the ledger but also in the market and societal impact valuation.

[5] The authors of this model are David Manset, Beatrice Bressan, and Marilena Streit-Bianchi derived from Manset et. al., (2017).

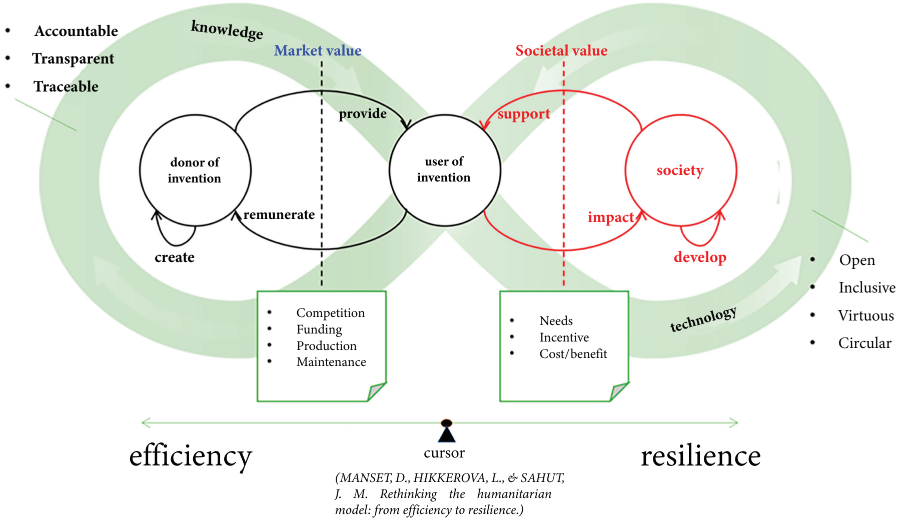

Figure 12.5 The circular and trustable model

Source: David Manset, Beatrice Bressan and Marilena Streit-Bianchi (2023). *Developed from a Model Presented in 2015 D*. Manset Master Thesis 'Humanitaire éthique, de l'efficience à la résilience'

Reflecting on the humanitarian model from efficiency to resilience, the development of a new societal and economic model to reshape humanitarian aid with the beneficiary at the centre is necessary. This is because the process of building resilience requires the involvement of the beneficiaries. Applying new standards in promoting resilience is as necessary as considering the aid recipient in terms of the means to implement an action as well as in prioritising funding. As a consequence, the beneficiary must become a participant in the construction of a more suitable model (Manset et al., 2017). While the work addressed the humanitarian field, the underlying foundations came from former research work carried out in ecology. Indeed, to further understand the necessary relationship between efficiency and resilience, let us draw an analogy between society and nature. In their work on Ecological Complexity (Ulanowicz et al., 2009), it is explained that nature does not optimise the effectiveness of the natural ecosystem alone, but rather manages to strike an unequal balance between efficiency and resilience.

Some common basic rules and principles can be applied in this interconnected world, one of which is sustainability. Big Science may not always produce rapid worldwide benefits, and some technologies like the medical technology derived as a result of Big Science take years of continuous improvements and technology transfer efforts. Even the World Wide Web (WWW), one of the most globally impactful examples of a recent technology offered free by CERN, has taken considerable time to provide social and commercial benefits.

The term 'resilience', once used to describe people who had been through traumatic experiences, is now more commonly used to describe career resilience, which is defined as effective vocational functioning under challenging circumstances (Rochat et al., 2017). In the wake of the Covid-19 pandemic, the concept of resilience has been applied to the economy and development, with emphasis placed on political instances to build more resilient post-Covid-19 societies.

Collaborative efforts are needed to diffuse tacit knowledge. Better communication and participation in the knowledge transfer process are central, and these transfer processes will benefit the knowledge transfer process in developing societies. To achieve the objective at stake, negotiations to overcome problems involving social or political borders are necessary.

Examples of several cases in Annex 1 illustrate what big science has accomplished.

12.8 Innovation Ecosystems and Systematising Serendipity: The ATTRACT Case

The pathway of Big Science technologies to breakthrough market applications is a highly serendipitous one. It is difficult or even impossible to predict the fraction of fundamental knowledge that will end up leading to new businesses and products that will transform our society. One of the numerous causes of this phenomenon is that these technologies are primarily created by research communities with the sole objective of expanding the bounds of fundamental science beyond the scope of their original mandate: to make feasible the envisioned aims or pathways for industrial and even smaller markets; to make relevant to industrial and to even fewer market-envisioned goals or pathways. Despite this intrinsic difficulty, it would be desirable to rely, at least partly, on some sort of rule of thumb or heuristic approach that ultimately allows Research, Development and Innovation practitioners and policy-makers to develop strategies for streamlining, as much as possible, the 'Lab to the Fab' odyssey.

Annex 2 outlines the serendipitous process from basic science to market and the innovation ecosystems required for beating the odds from laboratory to market.

Innovation ecosystems constitute a potentially successful construction to somehow 'systematise' this serendipitous process precisely because they integrate different actors with complementary roles and motivations towards technology and innovation. Therefore, it is important to note that successful innovation ecosystems should have a carefully crafted but flexible structure capable of satisfying the opposing interests and goals of a diverse community of stakeholders.

Numerous studies have examined how serendipity, innovation, and science interact, and it has been found that there is a trade-off between productivity and serendipity (Murayama et al., 2015). Paradoxically, a new paradigm is emerging, called 'systematising serendipity', especially within the field of digital information retrieval (Wareham et al., 2022). Besides its novelty, there are some preliminary definitions in the current literature that suggest 'systematising serendipity' could be understood as improving the chances of making connections that lead to new discoveries.

The ATTRACT (breAkThrough innovaTion pRogrAmme for deteCtor infrAStructure eCosysTem) was an initiative to support the serendipitous process of knowledge transfer (Nordberg and Nessi, 2013).

The ATTRACT is a pilot initiative that aims to provide a new breakthrough innovation ecosystem based on the 'Open Science, Open Innovation, and Open to the World' philosophy. It is steered by a consortium comprising pan-European research infrastructures, European industrial sector organisations as well as business and innovation specialists, with the help of funding from the European Commission. The overarching goal of ATTRACT is to establish a European ecosystem with a wide scope in the field of breakthrough detection and imaging technologies. These would range from sensors and detectors to computing technologies for transforming data into information and ultimately knowledge. ATTRACT's special focus on detection and imaging responds to the following factors:

i They are the backbone technologies that help European research infrastructures and their research communities push the limits of Basic Science; and
ii They are the core of future industrial developments, applications, and businesses.

ATTRACT's operational goal is to increase the chances and accelerate the translation of Basic Science technologies into marketable products. In other words, generating the boundary conditions for systematising serendipity (see Annex 2). Though still in the early stages, various qualitative and quantitative studies are beginning to be developed regarding the ATTRACT ecosystem, allowing for the initial identification of some key factors for, as was mentioned in the previous section, beating the odds. Some of them are:

1. Public funding: The ATTRACT ecosystem is leveraging public funding sources. As reported by different scholars, public funding is key for helping nascent breakthrough technologies, many of them even at the conceptual level, reach the necessary maturity for raising the interest of private capital;
2. Phase approach towards technology maturity: The ATTRACT initiative considers that 'not all Valleys of Death' look the same (Figure 12.6); and
3. This is especially the case for breakthrough technologies conceived for Basic Science purposes. Unlike more incremental technologies, which only require one stage to reach a point of interest for private capital, these technologies

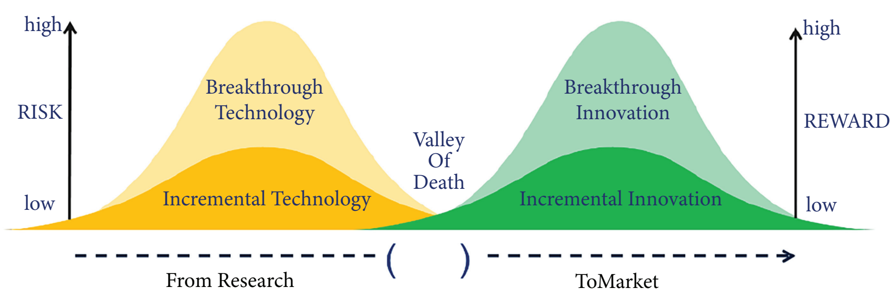

Figure 12.6 Qualitative illustration of the different 'Valleys of Death'—incremental and breakthrough innovation

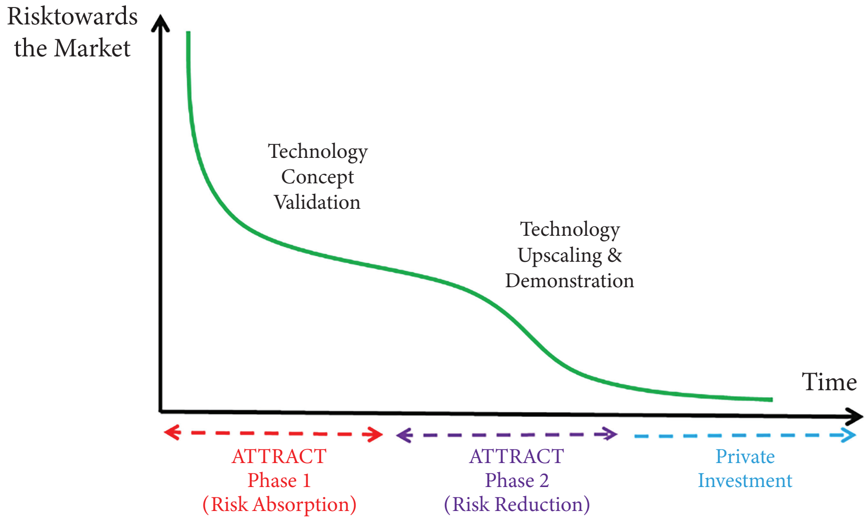

Figure 12.7 Qualitative illustration of the two phases operationally implemented within the ATTRACT initiative

Source: https://www.openaccessgovernment.org/attract-programme/121400/ Last access 22/8/23

require two stages because of the high risk associated with their initial investments before becoming a market product. First, there is the risk-absorption stage (Boisot et al., 2011), where ideas and concepts could reach a prototype level. Second, a risk-mitigation or risk reduction stage, where the most promising concepts are further helped in raising towards a pre-market product (Figure 12.7).

4. Co-innovation: Co-innovation is understood within the ATTRACT initiative as a bridge between two communities (research and industry) with, in principle, different motivations and goals for undertaking R&D&I (capital and/or resource-intensive) efforts· It entails the identification and collaborative pursuit of win–win outcomes, both by research and industrial actors, starting already at the conceptual stages of technology development and developing until the later stages of the innovation value chain (e.g. commercialisation). Co-innovation, therefore, departs from more traditional approaches in which research–industry relationships are established in a similar way to customer–supplier ones. The hypothesis, only partially confirmed by the preliminary studies, is that co-innovation would overcome three common and classic difficulties that technology transfer practitioners face:
   i 'A solution looking for a problem'. This issue often manifests when the research communities only establish relationships with the industrial ones at later stages of the innovation value chain.

ii ‘A problem looking for a solution’. This issue could be considered the other side of the coin with respect to the previous one and occurs when industrial communities try reinventing the solution for a problem that might be well known and already solved in the academic realm.

iii The common development of ‘know-how’ between industry and research communities often does not occur in a purely supply–demand context. This could lead to the development of collaborative practices that mutually build trust among collaborators.

ATTRACT is still a novel innovation ecosystem in development. Nevertheless, useful data has already been extracted during its first phase (risk-absorption) from 170 funded breakthrough technology concepts, some at an early prototype stage (CERN, 2021d). Preliminary quantitative and qualitative results indicate the validity of the hypothesis outlined above (e.g. co-innovation). Also, the confirmation of the elements mentioned and others as key ones for increasing the chances and accelerating the translation of the Basic Science discoveries into the market. The ATTRACT initiative facilitates the integration of interdisciplinary teams of MSc-level students working side by side with professional researchers from academia and industry.

The organisations steering the ATTRACT initiative are embarking on its second phase (risk mitigation), leveraging the most promising opportunities emerging out of the first phase and again relying on public funding from the European Commission (CERN, 2021d).

A manifold and interdisciplinary socio-economic study will be realised not only to achieve full confirmation of the philosophy and hypotheses behind the ATTRACT initiative but also to demonstrate that the emerging paradigm of systematising serendipity is possible in practice. These initiatives continue to diffuse knowledge generated in Big Science experiments and initiatives.

12.9 Conclusions

Social development is intrinsically linked with enterprise development and wealth creation. Private enterprises play a key role in the progress of human civilisation. Big Science contributes systematically to the advancement of knowledge and innovation to solve complex issues and contribute to society’s development. The examination of the relationship between science and complex social systems needs multiple perspectives from economic, political, and scientific considerations. The greater the complexity of Big Science projects, the harder it is to translate useful knowledge into tangible social outcomes. Complexity in the social system acts as a barrier to utilise knowledge freely. Very often, localised development propositions are necessary to address local social complexities.

A complex interconnection also exists between Big Science and enterprise development. Big Science initiatives are different from other forms of research ventures in the sense that they lead to varied opportunities through the production of enormous amounts of data, information, and knowledge that are relatively free to access and can be utilised in the public domain.

Many approaches are available to the translation of Big Science into useful products and processes. A culture of open science is needed for such translations, which involves traditional technology transfer as well as serendipitous processes. Garnering public trust in scientific research is important for the continuous progress of the scientific community in making giant leaps in socially beneficial innovations. Methods for converting Big Science into practical goods and procedures entail serendipity in both the research and its application. Such approaches also contribute to a new social order and an economic model that influence humanitarian aid with the beneficial development of the public contribution of Big Science. Together, complexity and serendipity act as catalysts to transfer Big Science knowledge by breaking down complex problems into simplified components.

The translation of Big Science knowledge into market applications might be a serendipitous process, but attempts have been made and approaches taken (e.g. ATTRACT) to systematise this process. The process should be founded on a well-ordered science that has the ability to ask the right questions and connects research with practice using multiple research processes, facilities, and collaborative inquiry. Reliable evidence and subjecting knowledge to rigorous scrutiny are required for the fundamental knowledge pursued in Big Science.

Knowledge translation processes in Big Science follow strategic and spontaneous paths, and the innovation ecosystems provide potential opportunities to establish reinforcing feedback loops between industry, universities, and government stakeholders.