



Science as a global public good: the roles of the representative bodies of science—a perspective

Geoffrey Boulton^{1,2,3}

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Abstract

Science is a special form of knowledge, a formalised approach that is rationally explicable, tested against reality, logic, and the scrutiny of peers. It has become essential to human wellbeing and is most effective as a human enterprise if treated as a global public good, free at the point of use. Science creates new possibilities, whilst complementary efforts by other stakeholders make those possibilities tangible, useable and socially and economically profitable. Realising these potentials depends on an understanding of science's interface with wider society and devising effective engagement processes between them. The international representative bodies of science, its national academies, scientific unions and associations, together with university representative bodies, play fundamental roles in articulating priorities for science, in contributing as a global public good to the resolution of contemporary global problems, in maximising the benefit and minimising the harms that might arise from scientific discoveries, and in adapted the working practices of science to contemporary challenges and opportunities. The open science movement has the potential to enhance the efficiency by which the public good of science is delivered and could evolve into a global open science commons, provided that the scientific community is energetic in adopting a practical open science vision and in removing major barriers that impede its realisation.

Keywords Public goods · Open science · Responsibilities · Publishing reform scientific geopolitics · Global science commons

The value of science¹

Knowledge has long been the most powerful of public goods: the inspiration, stimulus, and agent upon which

Because of its scope, the following article is in the form of an opinion piece, not a scientific analysis where assertions must be tightly constrained by evidence. It is based on an invited talk delivered at a meeting of the Indian National Science Academy on the occasion of the presentation of the Jawaharlal Nehru Birth Centenary Medal to Dr Marcia McNutt, President of the National Academy of Science of the United States of America.

✉ Geoffrey Boulton
G.Boulton@ed.ac.uk

¹ Regius Professor of Geology Emeritus, University of Edinburgh, Grant Institute, Kings Buildings, Edinburgh EH9 3JW, UK

² Vice Chair, International Science Council, 5 Rue Auguste Vacquerie, 75116 Paris, France

³ Regius Professor of Geology Emeritus, University of Edinburgh and International Science Council, Paris, France

most human, material, social and personal progress has been built. Science is a special form of knowledge. It is not a dispensable luxury. It helps us navigate the complex world we inhabit and has become essential to the advancement of our societies, in responding to their needs and as a basis for their progress. So widespread are the potentials of science in supporting human wellbeing that the knowledge and possibilities that it creates should be available to the widest diversity of actors in realising diverse opportunities for its productive use.

Modern science has two fundamental attributes that form the basis of its special value:

¹ The word science is used to refer to the systematic organization of knowledge that can be rationally explained and reliably applied. It is inclusive of the natural (including physical, mathematical and life) science and social (including behavioural and economic) science domains, as well as the medical, health, computer and engineering sciences and parts of the humanities. It is recognized that there is no single word or phrase in English (though there are in other languages) that adequately describes this knowledge community. It is hoped that this shorthand will be accepted in the sense intended.

that knowledge claims and the evidence on which they may be based are made openly available to be tested against reality, logic and the scrutiny of peers; and that the results of scientific inquiry are communicated promptly into the public sphere and circulated efficiently to maximise their availability to all who may wish or need to access them.

Although this approach to knowledge arose in the specific social and cultural context of Europe in the seventeenth century, it has become part of a universal human heritage as people all over the world have come to accept this approach as the best way to accumulate reliable knowledge about nature and society. Other societies had gained deep insights about the way the world functions, produced many technological innovations, and applied such knowledge to changing the world, but the specific approach outlined above has been the basis of the unprecedented explosion of knowledge in recent centuries. Science recognises the uncertainties of knowledge but has proved to be a powerful means of identifying error. It can invalidate but cannot validate. It is ethically neutral in use, for both good and evil. It cannot entirely escape the constraints of its social construction. Its outcomes are influenced by initial conditions (or assumptions), by ways of working, and by predilections of interpretation. They may be reinforced, or invalidated, by attempts at reproduction (re-working by others of the data using the same initial conditions, working methods and interpretations), or by replications (using different starting assumptions, working methods or interpretation), that reflect different perspectives of reality, leading progressively, when repeated, towards a less perspective-dominated view (Massini 2020) and from a “it is as if” (metaphorical) view towards a more realistic summation, from “it is as if the Earth were a sphere” to “the Earth is a sphere”.

Much individual and social knowledge, and so-called traditional or indigenous knowledge, is “scientific” in spirit when empirical observations of repetitive patterns of occurrence or behaviour form the basis of general rules, which may be progressively adapted as exceptions to those rules are discovered. It is not science in the strict sense as it lacks the formalised rigours involved in publishing truth claims and related evidence as a basis for testing, sceptical review and possible invalidation.

Scientific knowledge as a public good

The vision of the International Science Council is of science as a global public good (Boulton 2021). To an economist, public goods have a special meaning, that they are free at the point of use. They have two essential properties:

non-rivalrous consumption—the consumption by one individual does not detract from that by another; and non-excludability—it is difficult if not impossible to exclude an individual from enjoying the good (Stiglitz 1999). Even if one could exclude someone from enjoying the benefits of knowledge, it would be undesirable to do so because there is no marginal cost to sharing its benefits. It is important however to distinguish between “public goods” and “the public good” or the “public interest”. The former can be thought of as a commodity, a concrete noun, the latter two are abstract, referring to “what is good for”, or “what is in the interests of the public”, and are more contested concepts (Conversation 2019).

Public goods are the basis for most private goods and have proven to be amongst the most economically efficient forms of public investment (Stiglitz and Dasgupta 1971). Public goods, such as good roads, an honest police force and public education, are created at non-zero cost, but at a zero price for use. Under-supply of such public goods limits efficiency by limiting the private benefits that could derive from them: in the above examples respectively, in the efficient distribution of goods and services, in a safe environment for civil transactions, and in enabling students to derive knowledge-based benefits. As for all public goods, science is most economically efficient, and as a basis for further private goods, when its findings are made readily and rapidly available to the largest number. The rationale for predominantly government funding of basic science is that if it were largely funded by commercial bodies, they would seek to monopolise and control use of its outputs, thus denying them to others and inhibiting the wider creation of value. It is important to avoid the loss of downstream value creation by many actors through the premature capture of upstream value by private agents; an issue of increasing concern in an era of so-called “technology-giants”.

The interfaces of public good science

If the discoveries of science and the knowledge embedded in the record of science are to realise value as public goods, effective and efficient interfaces are needed for interchange with the wider community of potential users. Ideally, these need to be set within a shared epistemic frame that is understood by participants in the transaction. Science creates new possibilities, though usually in a form that is difficult to use, whilst complementary efforts, in business, government, in wider society, by individuals and by applied scientists, make those possibilities tangible, useable and socially and economically profitable. Science has the potential to reconfigure existing states of our world. The actions of others firm up these states

and make them tangible and useable. These latter actions may create new, unanticipated opportunities for beneficial application, or they may have been created in response to a well-articulated need that has stimulated a search for novel solutions. Commercial firms in particular have understood these processes, leading many to increase their investment (<https://data.oecd.org/rd/gross-domestic-spending-on-r-d.htm>) in the science capacity necessary to create physical or conceptual commodities from the possibilities revealed by scientific inquiry, which has also led to an increase in public–private partnerships that seek to make interfaces more efficient (OECD 2016).

Whilst most governments regard it as in the national interest to stimulate the creation of private goods from publicly funded scientific knowledge, private appropriation of such knowledge deprives other societal and business actors of opportunities from which they might otherwise have benefitted. The costs of such appropriation can be high, particularly so for much basic research, where benefits are often widespread and potentials to stimulate further discovery are great (Marshall and Price 2103). Large scale private capture of large areas of science and technology, protected by excessively strong intellectual property regulations, can make investments more effective and yield large returns. But it also impedes the processes of cumulative knowledge building and can slow the pace and limit the diversity of innovation.²

Patents attempt to create a balance that incentivises innovators whilst maintaining the flow of knowledge into the public domain. New knowledge cannot be patented, but processes to implement that knowledge in a commodity can be. It gives a company a fixed term monopoly on the process, or the ability to licence it to others, whilst making the knowledge available so that different exploitative processes can be developed by other market actors.

Modes of engagement

The modes of engagement across these interfaces of public good science are crucial to its influence and utility and must be well adapted to their purpose. In universities, the incentives that drive both individual and institutional

behaviours have become dominated by bibliometric indices based on publication in conventional journals (International Science Council 2021). Following the maxims that “you get what you measure”, or that “when a measure becomes a target, it ceases to be a good measure” (Goodhart 1981), the outcome has been an obsessive concentration on publication to the detriment of other forms of interaction. It is as if the purpose of science were only to serve scientists’ careers and to generate publications rather than to create a public good. Moreover, scientific publications alone, arcane as they often are, are relatively weak agents for the transmission of knowledge as a public good into the public domain. Additional means of transmission are needed.

The exigencies of the Covid-19 experience, where conventional norms were set aside to address a major challenge to society and to science, have demonstrated the efficacy of more diverse modes of working. A wide variety of scientists have creatively shared, deployed, and applied their knowledge, produced databases and websites, short circuited the cumbersome processes of conventional publication, and shared data and ideas with unprecedented openness, including across the public–private interface. They have engaged citizens directly in effective and accessible ways that have helped condition responsible public attitudes, an experience that has, except where highly politicised, embedded science more deeply in the public consciousness as a public enterprise, and not merely one contained behind closed laboratory and library doors. Scientists have acted in ways that have set aside conventional constraints and ruthlessly exposed some of the processes that inhibit the effectiveness of science in contributing to the global public good. Even scientific publishers bowed to these pressures. Although 70% of their content of is locked behind a paywall, 85% of Covid-19 related publications are open access (UNESCO 2022). The Director of the US National Institute of Health commented: “I have never seen anything like this”—“the phenomenal effort will change science—and scientists—for ever” (<https://www.theguardian.com/world/2020/dec/15/the-great-project-how-covid-changed-science-for-ever>). The challenge to the scientific community, and the universities is to learn from that experience by shifting incentives in ways that encourage a wider range of engagements and improve the effectiveness of science as a public good.

Recent years have seen a growing recognition of the importance of so-called “transdisciplinary science” that includes non-scientific stakeholders in the processes of knowledge production. It is a mode of engagement that recognises that scientific knowledge can rarely be applied and adopted successfully in a given social setting without taking into account perspectives and priorities in that setting. It requires deliberative engagement between knowledge partners that seeks to reconcile different perspectives

² Worries about the adverse effects of excessively strong intellectual property protection have been brought home in an anti-trust suit against Microsoft, which (it is alleged) has attempted to leverage the power associated with its control of the dominant operating system (itself a consequence of important network externalities which result in huge advantages associated with the establishment of an industry standard) to a broader dominance in application software. Many industry experts believe that in doing so, the overall pace of innovation in the industry may have been retarded.



in defining and addressing a problem and jointly agreeing where solutions lie. It is as important in achieving effective action for the great global issues such as climate change as it is in the provision of local ones such as the provision of a rural community water supply. The routes to solutions are very different, but the principles are the same.

The challenges for academies, international scientific unions, and universities in a changing world

The organisations of science play fundamental roles in articulating and setting ethical and professional standards, in promoting new and more efficient ways of doing science, in setting priorities for scientific inquiry, in setting and implementing policies for education and the training of young scientists and in influencing governmental bodies, both national and international, about policies that scientific inquiry suggests are important in sustaining and protecting human wellbeing. Some are well placed and efficient in these tasks, some are delinquent. Some are independent, with or without governmental financial support, some are directly accountable to their governments. However, all face a series of convergent problems that reflect a world in flux, a global political trend of increased detachment from international collaboration and a retreat into national and regional silos. A question for all the organisations of science is extent to which they wish to, or are able to, use their resources of knowledge and skill to respond to these challenges in deploying science as a global public good.

Academies at their best speak up for science as a special form of knowledge, explore and disseminate the implications of scientific discovery to wider publics, work to inform the need for and the creation of public policy, seek to ensure that the national scientific enterprise maintains high standards of ethics and efficiency, whilst collaborating internationally in working for the global public good. Most receive financial support from their national governments although striving to maintain an independent stance.

Disciplinary unions and associations at their best have been remarkably efficient in promoting new frameworks and priorities for their science, in developing and implementing standards, in creating opportunities for international collaboration amongst their national learned society members, and in supporting colleagues in poorly funded national science systems. They are almost invariably independent, and many accomplish a great deal on the slender basis of subscriptions from their members.

Universities at their best have become the great creative centres of the modern world. Although their forms, structures and avowed purposes vary greatly, from the specialised

to the comprehensive, most embody, at their core, durable common values. They research into the most intractable uncertainties of knowledge and yet also seek the practical application of discovery (Boulton and Lucas 2008). They curate, test and reinvigorate the inherited knowledge of earlier generations and seek to establish sound principles of reasoning and action. Their students learn not to be dismayed by complexity but to be capable and daring in unravelling it. They learn to distinguish between the true and the merely seemingly true; vital skills in the modern world of the internet. In the words of the poet Ben Okri, “the role of a university is to set up its students for the act of self-discovery”. The annual flood of their graduates, equipped with up-to-date knowledge into a wide variety of roles in society, is by far the most powerful agent of “technology transfer” from universities. Almost all universities uphold principles of academic freedom, but given their high levels of public funding, the need for accountability, and their importance in national political settings, it is a perennial struggle for many to maintain independence of action in teaching, research, governance and in their public statements.

Each of these groupings of institutions belong to a variety of international representative bodies: comprising the International Science Council (ISC), the Inter-Academy Partnership (IAP), The World Academy of Sciences (TWAS) and the international University Association (IUA). The question for each of these groups and their international representative bodies, as core institutions of science, is to adapt to the challenges that the twenty-first century has thrown up. There are three categories of challenge, how to respond to the major global challenges that face humanity; to the societal implications of major scientific advances; and how to adapt the practices of science to changing needs.³

Global challenges

The global environment and human sustainability

Global temperatures continue to rise at an accelerated rate and global CO₂ concentrations are at record levels even as emissions have temporarily fallen as consequence of the COVID-driven economic slowdown. It is likely that we will breach the target to limit the global temperature rise to no more than 1.5° above pre-industrial levels, agreed at the 2015 UN Climate Change Conference (COP21) in Paris. Although global targets have been agreed at a political level, the necessary coordinated action to achieve them has been

³ This analysis is largely based on an analysis in the “The interfaces of public good science” Section of the 2024–2024 Action Plan of the International Science Council, of which section the present author was principal author (International Science Council 2022).

absent. There is no agreed roadmap that will send the vital signals that private and public sector bodies and research communities need if they are to apply themselves urgently and efficiently to the massive technological, economic, and social transformations that are required if the world is to achieve net-zero carbon emissions by 2050.

The continuously increasing demand for energy, food, fibre, water and land has come at a significant cost to the biosphere, with the sheer scale of production and consumption, combined with systemic inefficiencies, misallocation of resources and waste, resulting in rapid and widespread biodiversity loss. Biodiversity underpins human life. It is responsible for a myriad of ecosystem services upon which society depends for basic life-support functions, such as the provision of food, fuel and clean water, nutrient cycling, pollination services and climate regulation. The implications for human health and well-being, societal resilience and sustainable development are potentially catastrophic.

The pandemic has thrown issues of poverty, insecurity and inequality into high relief. It has highlighted the perennial threat of zoonotic diseases where viruses jump the species barrier, with the potential to import high toxicity into human populations, thereby raising the risk of further pandemics. It has exposed critical gaps in public health systems and, more broadly, in societies' risk preparedness. It has exposed the inadequacy of international political collaboration, where "the human family seems to care so little for itself that we were unable to pool our experience, our understanding, and our knowledge to forge a common and coordinated response" (Horton 2021). It has underlined the need for a more effective interface between scientific solutions and geopolitical action on global problems, even in the context of contemporary trends towards scientific nationalism, concerns about "research security", and increased restriction of the vital freedom of scientists to exercise their responsibility to speak truthfully, freely and openly about their findings.

The internationally agreed 2030 Sustainable Development Goals (SDGs) are an implicit compact to support low and middle-income countries in tackling the immediate issues of welfare for their own citizens whilst also addresses global challenges. The world was already off-track in realising the ambitions of the SDGs before the Covid-19 pandemic, which has further magnified deeply rooted problems.

The scientific community worldwide has been energetic in researching the above problems and in identifying potential pathways for their resolution, but the collective political will for action has failed to materialise, even though political voices perennially recognise issues of "existential" urgency (Cotton-Barratt and Ord 2015). These issues pose a large question for the representative organisations of science. Is there a role that they could play in combination to advocate and precipitate coordinated global action? Are they able to

rise above their national or disciplinary concerns and go beyond the statements that many have made indicating the urgency of these issues? Could they collaborate as a global scientific community to express a unified scientific voice able to stimulate citizens, and the young in particular, to demand globally coordinated political action? Or would such an attempt merely illustrate the impotence of the voice of science in the geopolitical domain?

Science and geopolitics

Addressing the global crises of the modern era, of the environment, of widening inequalities and poverty, would be best served within a geopolitical frame where there is broad consensus and the ability to take coordinated action. Instead, we have social, political and ideological polarisation, characterised by diverging certainties that are inimical to the sceptical spirit of science, recently compounded by the re-emergence of an ancient evil, the unprovoked attack by one state on another, and where the potential for effective cooperation across the spectrum of ideologies appears to be diminishing.

The scepticism of science towards expressions of certainty, and its uncomfortable capacity to identify error are the sources of its creativity, and vital tools for humanity in a problematic present and future. In the words of Berthold Brecht "the aim of science is not to open the door to infinite wisdom, but to set a limit to infinite error" (Brecht 1939). Science flourishes most and is of greatest practical benefit to society when it has untrammelled freedom to speculate, a freedom that is only granted in open societies. It rejects the idea of absolute knowledge: to quote Richard Feynmann, one of the great physicists of the twentieth century: "I would rather have questions that can't be answered, than answers that can't be questioned" (https://www.reddit.com/r/QuoteSporn/comments/797mek/i_would_rather_have_questions_that_cant_be/).

As globalisation wanes and geopolitical stand-offs reassert themselves, some national security services have increasingly sought to regulate and restrict international scientific cooperation on the grounds of national security. This trend towards "securitisation" (https://www.timeshighereducation.com/news/marginson-push-back-securitisation-save-global-science?utm_source=newsletter&utm_medium=email&utm_campaign=editorial-daily&mc_cid=9f626f877e&mc_eid=120be536f9; Nature 2021) could seriously damage or reverse the increasingly open and collaborative international science system that has developed in recent decades. As this securitisation trend intensifies, it is all the more important that scientific and scholarly links are maintained, and if possible strengthened, for we must maintain a hope that inter-state rapprochement is re-established, if only to address the massive global challenges that collective humanity faces. Maintaining strong international links in



science and scholarship, particularly in a period of geopolitical detachment, is vital in confronting these challenges. National academies and universities, together with the international representative bodies of science should make determined efforts to preserve and develop such links. There has always been dual use of science but regulating science rather than regulating use is a counter-productive response. It is not possible, nor desirable, to attempt to control geopolitics by regulating scientific interaction.

One of the responsibilities of the representative bodies of science, and not only those that are global in their reach and membership, should be to re-double their efforts to maintain open, mutually supportive interactions between scientists, and the freedom to speculate and disagree, independently of the politics in which they are located and of their different ideological stances. The scientific community and its institutions should strive to maintain mutual links even during stand-offs between geo-political blocs such as that intensified by the current Ukraine war. Maintaining those links should be recognised as a vital commitment to the future.

Societal implications of scientific and technological advances

Major scientific discoveries and technological innovations invariably have implications for society, often through unanticipated uses to which society puts them. The acts of discovery and development carry with them the responsibility to explore, monitor, warn and seek to mitigate potential harms by those most likely to understand what these might be.

The digital revolution of recent decades is such an event. At the turn of the millennium, Stephen Hawking, the cosmologist, commented that “the next century (that is this one) will be the century of complexity” (Gorban and Yablonsky 2013). The insight is exemplified by Deep Minds gigantic leap in solving one of biology’s greatest challenges, determining a protein’s 3-dimensional shape from its amino acid sequence (Mind 2020). The digital revolution has been globally pervasive disrupting pre-existing norms and unleashing an unprecedented new era of innovation that has profound implications for science, for industry and economies, for society and for policy at all levels of governance. Massive digital data resources have provided fuel for the same artificial intelligence techniques that forty years ago were only able to produce trivial results, but now enable machine learning algorithms to unlock value across every sector. However, these technologies can also exacerbate existing inequalities, deepen exclusion and discrimination, undermine privacy, and eliminate agency and empowerment on a vast scale, potentially undermining the benefits they offer. There is a risk of potential displacement of humans from

roles hitherto regarded as uniquely human, the creation of artificial videos, biases in algorithms that can negatively impact marginalized groups, cyber-warfare, new forms of criminality and the obfuscation of reality that undermines social cohesion. It is crucial that governance and transparency mechanisms are adopted that protect the public interest. The ethics of AI use, data use and ownership, of legal constraints and regulation issues are important priorities for society and for science and its institutions.

After the early euphoria that greeted digital devices that gave unprecedented access to knowledge, enabled novel means of social interaction and circumvented the traditional gatekeepers of knowledge and information, public and political attitudes towards digital media and the companies that control them have shifted in recent years. There is a dawning realisation that technology giants and the platforms they have created do not always serve the public interest. Although they are used in practice as public infrastructures, ultimately, they serve the economic agenda of the companies, which have accumulated massive databases of personal information, excessive power to determine what is acceptable, and editorial policies that are almost law because of the companies’ overwhelming size and financial power. They have contributed to rising polarization in unconnected “echo chambers”, and extremism, with a massive role in conditioning public discourse in ways that are detrimental to scientific understanding, and the disinformation and misinformation that are described in another article in this issue.

Four groups of science-based technologies have interacted and often converged in recent years: bio-tech, info-tech, nano-tech and cognitive-tech, increasingly driven by AI, and enabled by automated decision-making, large data sets, and high-speed computing. These technologies are often problematic because the rate of their diversification in novel, high-impact use in different settings has frequently out-paced environmental, ethical, regulatory and legal considerations. At the same time, they have great promise because of their reach, scale, and optimized delivery, with a transformative potential in sectors that contribute directly to human capital such as agriculture, water, sanitation, energy, transport, education, health, nutrition, and social protection, and through greater effectiveness (targeting and localization, customization, personalization) and efficiency. They have the potential to transform scientific advances in areas such as drought resistant crops and in solution of hitherto intractable medical problems (e.g., protein folding). It is essential that enabling infrastructures and capacities required for these technologies are adopted and are globally accessible, particularly as yet another economically punishing knowledge gap is even now developing between global north and global south.

Adapting the practices of science

It is an imperative for science that it adapts to changing circumstances, including changing priorities as new horizons of discovery open up, with new technology-enabled ways of working and changes in the social setting within which science operates.

A balanced portfolio?

The urgency of the global challenges referred to above draws attention to a vital priority for mission-driven science that is delivered as a global public good, and for advocacy and assessment by scientists and their institutions. It must also be globally inclusive, not merely reflecting the priorities of the global north, for there are no global solutions without global involvement, a lesson that the “unprecedented and unfinished” (https://council.science/wp-content/uploads/2020/06/18.2_Resolution-Two_-Scientific-Publishing.pdf) pandemic has underlined.

Such efforts are however a response to immediate priorities and will not necessarily be relevant to new unanticipated issues that may arise in an unpredictable future. There is a tendency to see “useful research” only as research directed towards contemporary problems and mobilised by “mission-driven” funding. Whilst mission-driven research is vital for immediate and foreseeable priorities, enlarging the breadth of human understanding through maintenance of curiosity-driven research is a fundamental contribution to humanity’s store of knowledge and understanding for the future. It broadens the tapestry of knowledge in a way that increases the probability that as unpredictable events arise, as they will, that we will have at least some knowledge available that helps us to tackle them.

The Covid-19 pandemic provides a case in point. The scientific community reacted spontaneously and with remarkable agility to this global threat. The pandemic has produced four important lessons for science policy. The first is the remarkable capacity of science to respond to the unexpected. The second is that most of the successful biomedical innovations had their roots in curiosity-driven science that was a product of decades of public investment, even though many of the developed products were provided by private companies (a reflection of the processes described in the “[The interfaces of public good science](#)” Section). The third is that although the biomedical sciences were on the front line, a wide variety of disciplines from across the whole spectrum of science contributed their knowledge and expertise to work on a problem that has not only been a medical crisis but also a global social and economic crisis, with secondary impacts that will last for many years. The fourth is that by far the greatest part of this diverse range of innovative science was

created from public investments in research in universities. Universities generally uphold a convention of academic freedom, giving academic researchers unconstrained freedom to choose what to study, how to study, how best to communicate their findings, and the freedom to express them, including those that are inconvenient to authority. It is a process that creates a broad spectrum of scientific knowledge, which has proved to be an invaluable investment in the future. It is one of many fundamental roles that universities play, and a profound justification for the principle of academic freedom. It is important that other institutional partners in the scientific enterprise, particularly national academies, advocate the maintenance of this principle to their governments at a time when it is under great pressure in many countries.

Scientific publishing and the public good of science

Publishing has lain at the core of the scientific enterprise for more than three centuries. By enabling ideas to circulate rapidly between distant readers it catalysed a creative chain reaction that triggered an explosion of knowledge. Its efficiency and effectiveness are not peripheral issues; they are critical to the present and future of science.

Unfortunately, the current commercial business model of scientific publishing is the part of the chain of scientific production where the largest component of its public good is lost. Typical prices per published article are many times the necessary cost of publication, leading to extravagant profits of over 30–40%. Publishers appropriate the results of publicly-funded science and place the record of science behind a high paywall. Robert Maxwell, the creator of the business model, referred to it as “a perpetual financing machine”. Its effect is to diminish access to scientific knowledge, particularly in low- and middle-income countries and poorly funded institutions, either for readers or authors or both (International Science Council 2021). It is associated with several other retrograde features. Authors are typically required to relinquish copyright as a condition of publication, but they are not required to make evidence, the data, on which a knowledge claim may be based, concurrently available for scrutiny, a fundamental requirement of scientific rigour. The concept of the journal is retained as a marketing tool even though the digital era has made it redundant; and in effect, the governance of a crucial part of the scientific effort lies in the hands of private investors rather than being accountable to the scientific community.

The scientific community and its institutions are complicit in these dysfunctional processes. Individuals through their publication choices and institutions through their use of inappropriate, proxy bibliometrics sustain a flawed system of assessing the scientific contributions of researchers (Goodhart 1981, and the “[Modes of engagement](#)” Section). They are acts that sustain a business model that too frequently



works against the interests of science. However, the clamour of scientific voices seeking reform is growing, and it is vital that national academies, scientific unions and universities and their representative bodies add their voices (https://council.science/wp-content/uploads/2020/06/18.2_Resolution-Two_-Scientific-Publishing.pdf).

Open science

The social organisation of the scientific effort, as it adapts to social, political and economic changes and needs, has evolved greatly over the last 75 years. In its contemporary state it increasingly recognises that knowledge production, if it is to be effective in dealing with complex challenges, must be socially distributed, responsive to societal needs, trans-disciplinary and subject to multiple accountabilities. The implied social contract for science is shifting to one in which science is open to society: transparent and participative. Many believe that a new era of science is dawning, changing the way science is done and its capacity for discovery, whilst deepening its relationship with societies as a global public good. This new mode of open science is increasingly being advocated by national science academies and governments' science funding bodies as a priority for their national systems, focussing particularly on open data, open access publishing and openness to society. In 2021, UNESCO's 193 members states endorsed a "*recommendation on open science*" (UNESCO 2021) that encourages a deeper focus on embedding open science practices within national science systems. The UNESCO recommendations did not define open science, nor even set out its potential benefits, but did set out recommendations for the operational attributes of open science, without indicating how barriers to implementation of these attributes might be overcome.

However, a persuasive case for open science needs a clear sense of purpose, not merely a definition of process. It is proposed that open science could be the most efficient way to deliver science as a global public good, with the following benefits:

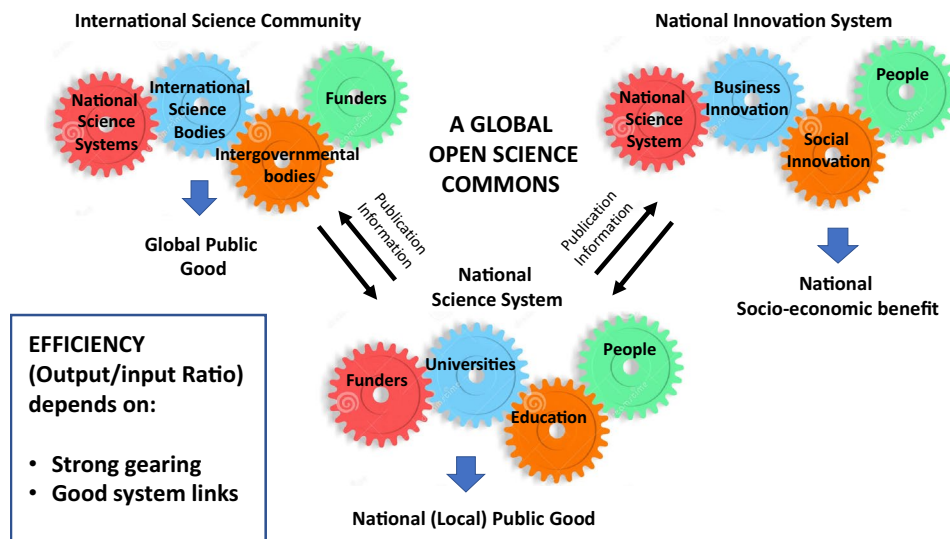
- a. Improving the rigour of science by subjecting its processes and products to open scrutiny, which could also quicken the rate of scientific interaction and enhance effectiveness by stimulating collaboration.
- b. Ensuring that the formal communication of scientific results is more efficient through global affordability and accessibility and speedier distribution.
- c. Incentivising more diverse modes of dissemination and application of scientific knowledge, which would depend upon changing the exclusive obsession with publication by reforming the processes of assessment of scientists and universities.
- d. Working towards the emergence of a more effective global scientific community and science commons.

Although the benefits of open science have largely been matters of conjecture, the global scientific response to the COVID-19 pandemic has been a powerful example of open science in action, as described in the "*Modes of engagement*" Section. There are however significant barriers to capturing such activity in a new normal. Scientists are reluctant to fully expose the evidential data concurrently with their publications. Publishers are equally reluctant to require it. The most recalcitrant issues however are closely coupled, those of global affordability, where a publishing apartheid between rich and poor fundamentally subverts any prospect of an open science worthy of the name, and the processes of assessment create incentives that work against open science. Nonetheless, it is critical that we should work to remove these barriers to open science, for which the efforts of science funding bodies and the representative bodies of science will be critical in working for and implementing effective change.

In relation item d. above, a loosely knit global science community does exist, through the medium of international research collaborations, of policy-facing bodies such as the UN's Intergovernmental Panel on Climate Change, inter-university collaborations, through the activities of high-level representative bodies of global science such as ISC, IAP, TWAS and the GYA and of national academies and scientific unions and associations. Could the developing open science movement stimulate greater international interaction and greater coherence of effort to the benefit of the global public good? Fig. 1 conceptualises idealised relationships within overlapping national and international spheres of activity of science. It is not a template for organisation, although could be realised through a variety of modes of organisation.

The figure differentiates between three idealised interactive systems: a national science system that delivers local public goods; a national innovation system, part of the role of which is to draw down and exploit scientific understanding for national socio-economic benefit through effective interfaces with the science system (see Sects. 3–4); and an international scientific community operating to maximise the role of science as a global public good. Crucial parts of this idealisation are the efficiency and penetration of ideas, information and knowledge (a. and b. above) throughout a global science commons. A major barrier to the realisation of such a commons is inequality of access to the mainstream of scientific communication. The current mainstream is adapted to the ability to pay of wealthy regions of the "global north", which to a large extent excludes out authors from the "global south", with the consequence that the flow and ideas between them is far weaker than it could be. The so-called transformative deals of major publishers based on payment by the author of article processing charges (APCs) (which, unlike most other global commodities, do not vary in price between New York and Dar es Salaam) particularly discriminate against scientists from the global south.

Fig. 1 Idealised view of relationships within a global science commons



Such processes create the perspective that most scientific advances have been made in the global north, that northern priorities are global priorities, and can lead to the exclusion of and contempt for knowledge and priorities in other regions. Such a view implies that southern science needs to develop so that it looks more and more like that of the north. It is argued that ‘these [northern] partners inevitably guide the problems and the methodological and epistemological choices of African researchers towards the only model they know and value, the one born at the centre of the world-system of science—without questioning whether this model is relevant to Africa and its challenges’ (Piron et al. 2017). Such biases affect our understanding of the human and natural world and make it more difficult for researchers from parts of Asia, Africa and Latin America to contribute effectively to what should be a global enterprise. A global science community has become a greater reality in recent years, but it will not have come of age until it replaces a unipolar perspective with an inclusive universalism capable of building an authentic global knowledge commons.

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