Global science for global challenges: the landscape of international scientific collaboration

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Introduction

We face global scale challenges, from the COVID-19 pandemic and climate, to security and justice, and they are becoming increasingly complex and dynamic. In the pandemic we witnessed what can be achieved when scientists are able to collaborate. The challenges we face today are similar in their scale and complexity, and we need a similar coordinated, interdisciplinary, international response. Yet the economic, social and political barriers to effective international scientific collaboration remain significant, and in many cases are growing even greater. Without deliberate strategies to tackle these barriers, we risk a knowledge and innovation deficit where the evidence needed to inform strategic decision-making and the technologies required to address the most urgent problems are unavailable.

What would those strategies look like? The answer is not obvious, nor will there be only one. International scientific collaboration is multi-faceted, highly interconnected and constantly evolving. It is a foundation of innovation that can truly transform our societies in meaningful ways that address inequity. Yet, it is hard to measure, especially in ways that provide meaningful feedback to decision-makers and leaders on the effectiveness of policies or processes designed to support scientific collaboration. But gaining insight is critical to informing collaborative approaches to tackle the barriers. Whilst identifying the factors and dimensions that can help or hinder international scientific collaboration risks becoming a fool's errand, the stakes are too high not to try.

We need to have a conversation about how best to support and secure international scientific collaboration moving forward. To kick-start that discussion, we undertook an initial exploration of the dimensions, tensions and knowledge gaps around international scientific collaboration. Our work is informed by multi-stakeholder dialogues combined with original quantitative analysis using publicly accessible data from over 130 countries.

What we found were tensions ranging from the familiar, like a lack of funding and prolonged visa processing times, to the more pernicious, like perceived national security threats and the broader geopolitical retreat from multilateralism. Our quantitative analysis underscores the complexity of this landscape; trends that define features of international scientific collaboration among countries with high levels of domestic investment in research and development do not carry over simply to the

rest of the world. Put another way, there is much we still cannot explain and do not understand about the *global* landscape of scientific collaboration. However, the presence of unknowns must not be used as an excuse for inaction.

Efforts to reduce and mitigate the impact of barriers to international scientific collaboration will need to face this complexity head on rather than ignoring it. The bulk of what counts, and we mean count literally in the sense of what we can measure, as international scientific collaboration generally happens as a by-product of domestic investment in research. Therefore, if we are serious about meeting global challenges we will need to make a renewed commitment to scientific collaboration with purposeful, focused attention and investment by both public and private stakeholders.

What is needed for successful collaboration?

Individual scientists are often highly motivated to collaborate internationally. Collaboration allows access to study sites, tools, or expertise that are unavailable domestically. Additionally, collaborations often result in increased impact and prestige, as papers with more international co-authorships tend to receive higher citation rates compared to those produced by scientists from the same country.

Motivation is one thing; doing is another. International scientific collaboration is multi-faceted, highly complex and dynamic. Understanding the landscape of factors that help or hinder it is a necessary first step to developing durable, resilient and genuinely transformational collaborations. Our stakeholder discussions identified five core pillars underpinning successful international scientific collaboration (Figure 1).

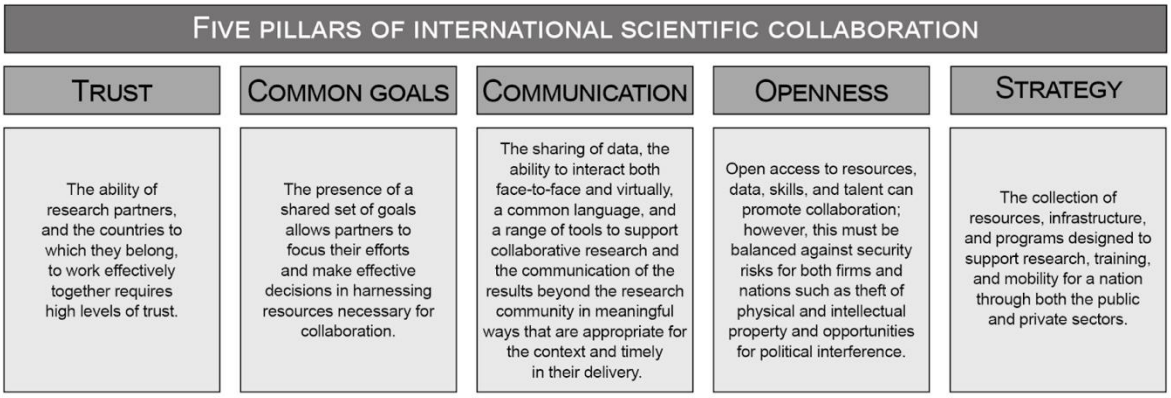

Figure 1 Five pillars of international scientific collaboration

Of course, none of these pillars exist in a vacuum, and the extent to which any pillar impacts collaboration depends on a spectrum of choices made by individuals, governments, and businesses, as well as the broader technological, cultural, regional, and political context in which collaboration happens. Nevertheless, it was possible to establish broad consensus that successful, resilient collaborations require alignment among these five pillars.

Which countries are collaborating?

Capturing a global snapshot of collaboration and the forces that shape it is not a straightforward task, as there is no single widely accepted metric to describe collaboration. In part, this is due to the

diverse ways in which collaborations happen: across geographic regions, over different time scales (short, medium and long term projects), at different levels of formality, and broad ranging funding models (public and private funders, awarding bodies that are institutional, national or international), not to mention different disciplines, institutions, and sectors.

To consider international science collaboration, we considered the data available on international co-authorships on academic publications, which is arguably the most widely accepted metric in the literature (Khor & Yu 2016; Nature Index).

The first thing to note from the analysis is that some countries collaborate far more than others. Predictably, variation in collaborative output tracks both the overall population size and economic size of the country, at least when measured as gross domestic product (GDP). The US, for example, produced over 1.4 million internationally co-authored publications in 2020 (data downloaded from SciVal) and China over 800,000, whereas low- and middle income countries produce orders of magnitude fewer. For example, South Africa generated 75,691 papers while Namibia produced 2,029.

The fraction of publications that are from international co-authorships is interesting, since this gives an impression of the extent to which a country's scientific output relies on international collaboration. Figure 2 shows how the proportion of publications involving international co-authorships changes as a function of total domestic investment in research and development data (measured as government expenditures on R&D (GERD)).

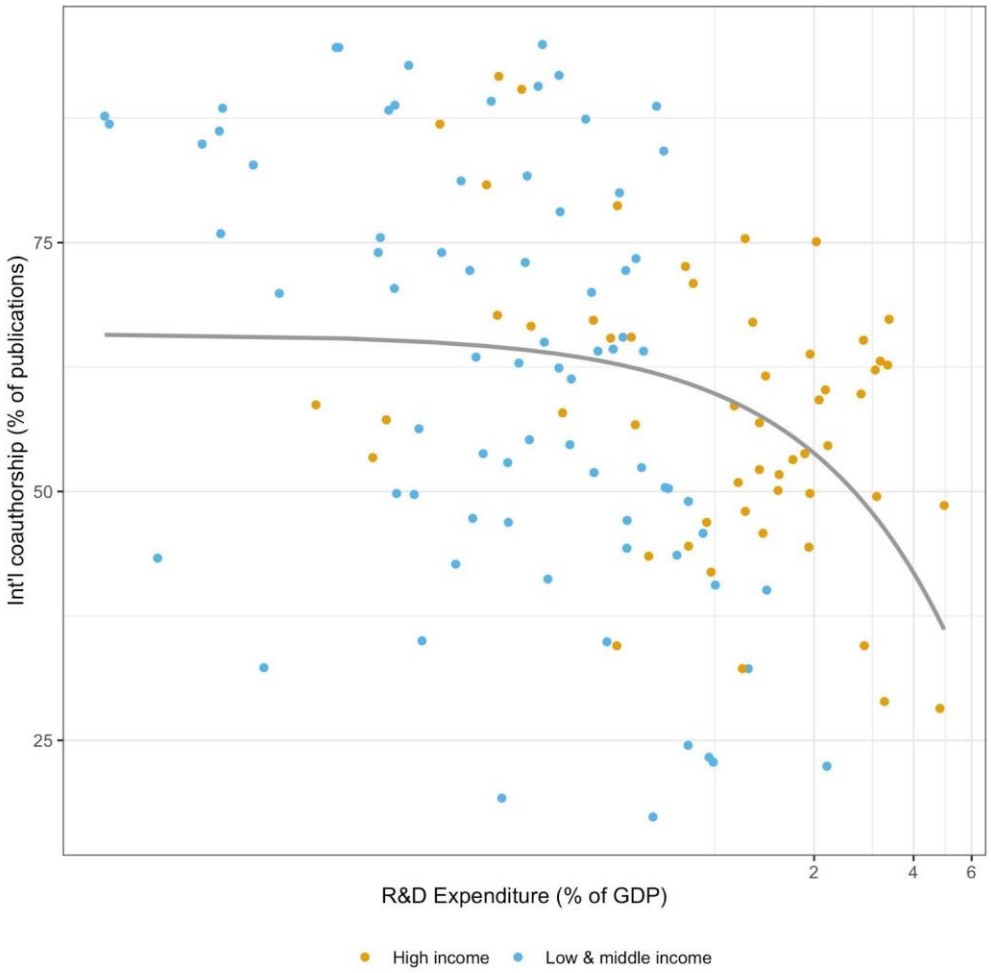

Figure 2: The proportion of publications involving international co-authorships and total domestic investment in research and development data (measured as government expenditures on R&D, (GERD))

Two things are worth noting. One is the downward curving line which suggests that, on average, countries investing least in domestic R&D tend to collaborate internationally relatively more than countries with higher R&D investments. Low investment in domestic R&D means that doing any science at all requires intellectual and monetary subsidies from other countries. If this situation comes at the cost of de-emphasizing domestic research priorities, there is a real risk that evidence gaps become reinforced, rather than repaired, by international collaboration.

The other is the level of variability of the data. Countries vary in the extent to which they collaborate internationally across all levels of the R&D investment spectrum. Clearly, there can be many other factors influencing either collaboration itself, the total output of the country, or both. Identifying precisely which factor, or more likely, combination of factors, play the most influential roles in advancing or hindering international collaboration in specific contexts is a pressing issue.

The importance of trust

In all our discussions around how to best support international collaboration, the one theme that every participant emphasized was trust. Trust forms the bedrock on which effective collaborations are built and without it, collaborations are unlikely to be initiated or sustained in the long run.

The importance of trust for international scientific collaboration is highlighted by the World Values Survey (WVS), a global network of social scientists who have been surveying people's attitudes and values in nearly 100 countries since 1981. The WVS includes a question on the extent to which people of other nationalities can be trusted. Figure 3 shows how the fraction of international co-authorships on publications, our measure of international collaboration, changes as a function of the answers to this survey question.

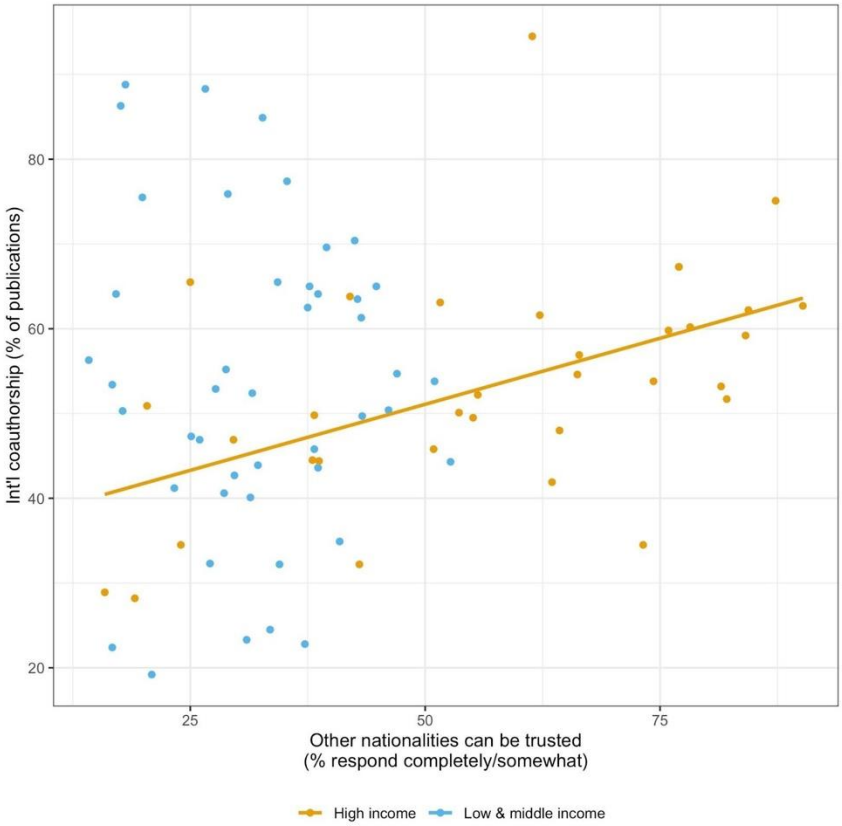

Figure 3 The fraction of international co-authorships on publications by level of trust in other nationalities (WVS).

What is most notable is how the fraction of co-authorships increases as levels of trust increase in high income countries (gold dots and line). This likely reflects strong trade and diplomatic relationships among high income countries, together with their more substantive investments in R&D. Again, the variability is high, and especially so for low and middle income countries where there is no relationship between collaboration and trust, perhaps reflecting a heterogeneous range of factors such as regional disparities, geography, and more modest investments in research capacity.

There are many gaps in the data around international scientific collaboration

Our analyses of how GERD and trust relate to international co-authorships reveals some intriguing trends but has limitations. We have examined just two correlates of one metric, after all and we have clearly missed some other important factors that play a role in facilitating collaboration internationally such as those related to mobility including visa processing times or how open a country is to others, or the extent to which countries commit to open science and data sharing amongst many others. The scatter around the regression lines suggests these other factors could be important. While we did our best to collate as many additional factors as we could, on the advice of our stakeholders, the data were only reported sporadically and often in an uncoordinated way. In short, there were too many gaps to provide a clear picture of the landscape of international scientific collaboration.

Another limitation is our use of international co-authorships to measure collaboration across borders. This metric is just one dimension of collaboration, and many would argue it is among the least interesting or important. By definition this metric does not count collaborations through training programs or projects in the private sector that do not result in academic publications. While it is possible in principle to gather other metrics to reflect these dimensions of collaboration, for example by tracking international students in a given country or the nationality of joint patent-holders, again there are often more gaps than records at the national level, at least in the public sphere. No single metric will capture the complexity of how collaboration happens globally. If we are serious about getting a handle on how well countries collaborate internationally, we will need to initiate and commit to producing fuller datasets for a wider set of metrics.

Barriers

Many researchers looking to collaborate internationally have encountered obstacles to doing so. The impact of these obstacles on collaboration is hard to measure, in part because they can be region, discipline, or career-stage specific. Through our stakeholder discussions we sought to identify the most important cross-cutting barriers. Any actions taken to enable international scientific collaborations now and in the future will need to address these obstacles:

1. *Funding retrenchment* - It is generally acknowledged that addressing levels of health, well-being and prosperity requires collaboration between countries, and between business, industry and researchers. International scientific collaboration is no different. Efforts to address international collaboration in science will need to gain visibility and be championed, especially given the costs sustained in 2020 and 2021 during the pandemic and the food and energy security challenges being precipitated by conflict and economic downturns across the world. While there have been pledges to ensure funding for research and development in some nations, there have also been many casualties. When difficult decisions are being made about limited resources, there are a growing number of instances where investing in making funding available that encourages international scientific collaboration is not making the cut, signalling real challenges for achieving broad global goals such as Net Zero and the UNSDGs.

2. *Balancing openness and security* - Open access to data benefits both publicly- and privately-funded research. This has been especially true during the pandemic, where online viral genome repositories support both vaccine development and viral surveillance. Open data resources similarly underpin discovery and long-term monitoring in other disciplines central to achieving the SDGs like climate forecasting and biodiversity. At the same time, and against the backdrop of a retreat from multilateralism that began before the pandemic, fears around foreign influence over scientific research and access to data are growing in many nations. Balancing the benefits of open access to data against potential national security risks, not to mention the cost of supporting robust data infrastructures and stable financial support into the future, are needed to ensure effective collaboration in a world where many of the threats we will face do not respect political borders. If we can reach a point where science is considered to be a 'commons', there is significant potential of increasing opportunities for international scientific collaboration and realising its benefits.

3. *Accessible infrastructure and resources* - Building capacity for collaborative research and innovation remains a foundational challenge, especially when it comes to ensuring we have systems and infrastructures that nurture and enable accessible knowledge networks. It is important to consider how lessons learnt during the pandemic, such as increasingly flexible patterns of working and the development of blended approaches to collaboration activities

through the use of online platforms, can create opportunities to increase the representation and diversity of collaborations. Funders have a role to play in ensuring structural inclusion is woven into grant calls, and research institutions in the public and private sector will be key to shaping ecosystems that enable collaborative working across regional borders.

Opportunities

Realizing the full benefits of international collaboration demands we take full advantage of opportunities to make international collaboration effective and resilient. Our stakeholder discussions identified three key opportunities:

1. *International collaboration can support and strengthen domestic research ecosystems* - No country possesses the full complement of talent and infrastructure needed to support a high functioning research and innovation ecosystem. International collaboration can be an effective mechanism to address these gaps because it allows a country to make use of sources of knowledge, innovation and human capacity that are not available domestically. At the same time there are risks: collaboration can make a country reliant on external subsidies for research, infrastructure and talent, and place the sovereignty of a country over its intellectual property and research outputs in a precarious position. Based on our analysis of international collaboration in relation to GERD, those countries at greatest risk are the ones that invest least in domestic R&D.

2. *The changing nature of knowledge dissemination* – The pandemic accelerated changes in the way peer review and scientific publishing processes happen. Preprint servers, social media, and text messaging apps all contributed to a dramatically shortened peer review process, motivated by the urgency of the pandemic. This shift in how scientists communicate with each other has not only changed the locus of debate from print to online, it is changing the peer review process itself and the role academic journals play in that process. Peer review via social media, while rapidly accelerating the process of vetting knowledge, relies on personal networks or those created by social media algorithms to feed knowledge exchange and risks reinforcing existing inequities and bias stemming from information filtered through algorithm-driven echo chambers. Journals, for their part, are beginning to shift from being gatekeepers of knowledge to the final repository for it. Effective collaboration demands evidence get a fair hearing and this means ensuring the technologies we use to vet evidence are, and remain, as democratic as possible.

3. *New tools for communication must be harnessed to promote dialogue* - The relationship between science and its stakeholders is dynamic and operating in evolving systems. Considering what effective communication and engagement beyond the academy looks like is an ongoing dialogue that will be critical as we look forward. Ultimately, if we can create pathways that bring together diverse perspectives and understandings of the world, along with contrasting methods and tools for collaboration and dialogue, there is a real opportunity to bring collaborative science into the real world to solve problems in ways that have currency in a range of economic, political and cultural contexts in which challenges manifest.

Recommended pathways to safeguard international scientific collaboration

We set out to paint a portrait of the landscape of international scientific collaboration from a combination of stakeholder dialogues and data. Complexity and data gaps notwithstanding, the

results shine light on specific pathways in that landscape that can help maximize the benefits of collaboration.

- *Better measures of scientific collaboration* - We measure what we value and value what we measure. It is telling, then, just how poorly we measure international scientific collaboration. Metrics capturing the full scope of scientific collaboration through training, innovation and funding, in addition to co-authorships on academic publications, are needed, and this data needs to be regularly reported.

- *Improve the capacity for collaborative and equitable innovation* - Most collaboration is the by-product of domestic investment in R&D. Governments, public and private funders, as well as research institutions must come together with deliberate, targeted support for collaborations beyond national borders. Investments could include long-term, collaborative research programs, as well as agile, rapid and responsive funding calls like those seen in the pandemic. Capacity could also include strong legal frameworks around intellectual property that support equitable benefit sharing and 'brain-circulation' programs that allow talent to gain international experience while also having opportunities to return home.

- *Build trust by supporting networks* - Strong collaborations rest on trust, and trust can only be built on relationships and dialogue.The Global Young Academy offers one example of how a network can nurture ongoing open ended dialogue that builds community, trust and opportunity. Fellowships enabling policy makers to work within science environments, and vice versa, and newly emerging media fellowships offer similar opportunities to build networks beyond the academy. Efforts to support indigenous knowledge in research are desperately needed, as are dialogues between scientists and global leaders, policy makers and those entrusted with governing national and international agendas. Central to this mission is rethinking how we recognise and reward excellence in our research institutions, and how we foster a diverse research ecosystem that accommodates different forms of excellence (such as research, teaching, engagement) to ensure a pipeline of scientists able and supported to work collaboratively.

- *Work to provide secure and sustainable data sharing* - Open data is a global public good that can spur innovation. New models for long-term support of open data repositories that do not rely on contributions from a few countries or funders are needed. In addition, a set of standards around data security, privacy rights and intellectual property protection are necessary to support the open sharing of data to the extent that it is feasible and acceptable to all parties involved.

Conclusion

Realizing effective scientific collaboration, and especially international collaboration, is not an easy task. There is no 'one size fits all' pathway, each path needs to navigate complexity that is shaped by a wide range of factors including issues of trust, income status, historical antecedents and the changing geo-political landscape.

To achieve productive, transformational and equitable collaborations that thrive and that foster new innovation and breakthroughs, international scientific collaboration needs deliberate attention and investment by a range of actors including researchers, funders, and the public and private sectors. Some collaboration will happen as a natural by-product of domestic investment in science and

innovation, but these are not likely to be the kind of transformative partnerships required to meet the global challenges we are facing. Instead, more focused support for collaboration across the public and private sector, especially those made possible by technological innovations in data sharing, analysis and communications, is needed.

Scientific collaboration is an essential tool for addressing global challenges like the environment or emerging infectious disease. These challenges have broad impacts that do not respect political boundaries. There is a clear need to enable international scientific collaboration that can bring the best of human capacity together within infrastructures that reflect the global scale of the challenges we seek to address, and to produce the insights from science that are sufficiently holistic and diverse that can deliver the solutions that we need.