Findings and Directions on National Industrial Policies[1]

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The end of the Cold War, and the geopolitical and economic reshuffling that followed during the 1990s, permanently broadened, accelerated, and changed the character of economic globalization. Of particular importance, economic globalization has distributed deep competence in science and engineering (S&E) and innovation around the world; public and private R&D now closely approaches or exceeds two percent of GDP in 20 nations.

The impacts of increasing innovation and R&D intensity are pervasive and the degree of global economic integration (speed, frequency, and geographic insensitivity in transactions, investment, and trade) are unlike anything in human history. Schumpeterian creative destruction has become global and accelerated. It shares the stage with geopolitical shifts as a major force in reshaping relations among nations, affecting economic growth and human welfare around the world.

There is no going back. Whether it is the rise of China's economy and S&E enterprise, the rapidly changing landscape of S&E and innovation capability globally, or the nature of cross-border challenges (climate change, data privacy, communicable diseases, or requirements of national security alliances) the world is not returning to 1990.

Most nations are still using the old-world playbook for national innovation-driven industrial policy:

- Increase public and private R&D expenditures;
- Increase investments in education at all levels up to and including education of research-capable personnel;
- Target public support for research and education toward emerging (or promising) technologies and industry sectors;
- Strengthen existing domestic institutions of research and education through additional funding linked to missions likely to advance emerging technologies and industry sectors;
- Create pull on innovation through public-private research collaborations and government procurement; and
- Support and nurture domestic companies (start-ups to mature companies) in emerging technologies and sectors.

[1] This document draws on an ongoing project at the BRG Institute based in Emeryville, California. Project context and purposes can be found at https://www.brginstitute.org/project-description. Several background working papers prepared for the project are available at: https://www.brginstitute.org/working-papers while others will be finalized and posted in the next several months.

[2] This project is supported by a grant from David Sainsbury. Lord Sainsbury was the chair of J. Sainsbury plc between 1992 and 1998 and served as the United Kingdom's minister of science and innovation from July 1998 until November 2006. He is the founder of the Gatsby Charitable Foundation and the chancellor of the University of Cambridge.

These are necessary activities but not a sufficient strategy in world where R&D and innovation capabilities are widely distributed. In 2020, strategic and innovation-driven national industrial policy requires abandoning blind adherence to logic of "free trade" in favor of game strategic approaches focused on value capture and national security. Newly critical elements of a game strategic industrial policy include:

1. Adjusting traditional industrial economic policy goals of productivity growth and economic development to align with defense against national security threats in areas such as health, food, energy, security of elections/governance, privacy, and cyber security.
2. Creating and managing alliances (strategic groups) of collaboration and competition with other nations, thereby tapping the R&D and innovation enterprise outside the country (which, for every country, exceeds R&D and innovation enterprise within the country).
3. Pursuing broad sovereign-to-sovereign multilateral agreements in S&E and innovation as well as in trade and investment.
4. Shaping the activities of domestic and foreign multinational corporations (MNCs) — large and small — to capture value important to citizens (not solely for producers or shareholders).
5. Cultivating the domestic and cross-border activities of research universities and public research enterprises to deliver outcomes in the national interest.

Project Findings and Directions to Date

Seven findings and directions of the project to date are summarized below.

1. **The emergence of dense, global, public and private science and engineering (S&E) knowledge networks means that, in 2020, no country goes it alone in S&E or innovation.**

In 1960, the US government and US companies were responsible for 70 percent of global research and development (R&D). Today, the US government and companies are responsible for less than 30 percent of the $2 trillion of annual global R&D spending. While the data are far from perfect, there are more than 20 countries that — because of R&D investment per capita, R&D as a percentage of GDP, or recent large-scale R&D investment activities — can be characterized as R&D-intensive[3].

The 20 most R&D-intensive countries are responsible for the vast majority of research universities, government and private research labs and are the source of most global innovation. They are also home to the vast majority of degreed scientists and engineers at the bachelors, masters and PhD level. While there are gaps, of course, the combination of global supply chains for goods and services, increasingly international education and international collaboration in

[3] The 20 "obvious" R&D-intensive countries include Australia, Austria, Belgium, Canada, China, Denmark, Finland, France, Germany, Israel, Japan, the Netherlands, Norway, Singapore, South Korea, Sweden, Switzerland, Taiwan, United Kingdom, and the United States. The next tier (based on good performance on a couple of metrics in research or research-based education) includes Brazil, Czechia, Iceland, Italy, India, New Zealand, Russia, Saudi Arabia, South Africa, Spain and Turkey.

university-based research, and the global spread of innovation and R&D activity by MNCs means that there is a single global S&E knowledge network, less constrained by distance or borders than at any time in the human history.

> *Next Steps: There is a fairly robust body of knowledge of global collaboration in science but very little work/analysis about globalization (exchange and collaboration) in applied S&E knowledge networks, industrial R&D, or talent (labor markets, emigration, and immigration). This needs to be remedied as soon as possible to establish a basis for better understanding international economics and paths forward for policy.*

2. **Dramatic growth and dispersion of S&E knowledge networks and R&D intensity is forcing changes in the way nations promote and develop key strategic sectors (national industrial policies)**

While the world is accustomed to some cross-border activity it is now the case that many aspects of large, R&D-intensive nations are becoming similar to the smaller R&D-intensive economies of Israel, Denmark, New Zealand, and Singapore. These nations have long relied heavily on complementing domestic investments R&D, human capital, and physical capital by drawing on the same outside the nation through cross-border collaboration and exchange in innovation. This new reality raises challenges for any nation long accustomed to thinking of national industrial policy as a domestic policy matter.

In particular, it is worth noting four important impacts of globalization on historically important domestic economic policy approaches to growth and competitiveness:

a. Widespread global dispersion of S&E applications capability means dramatically **increased difficulty for a nation to capture economic value from its own national government investments in research.**
b. The growth of global labor markets for science and engineering talent (even with restrictions on immigration and emigration) means **increased difficulty for nations in capturing value from its own investments in education.**
c. Global supply chains are increasingly the critical innovation ecosystem for a company or industry. This means that **all nations depend on innovative activities in other nations for product, process, and service innovations**; blanket domestic content legislation or domestic content requirements in government procurement can cripple innovation in an economy.
d. **Many taxpayer-financed and "national" S&E assets are functionally controlled by footloose multinational companies (MNCs) and leveraged for profitability with slim or no national value capture** or contribution to national welfare. There is often a disconnect between the taxpayer financed S&E advances and the uses of new taxpayer financed S&E knowledge by companies operating globally.

Most important, perhaps, is the perspective shift required of governments from a focus on national S&E dominance – whether that is in government or university labs or in corporations based in a country – to a model that blends international S&E collaboration and exchange with market competition.

Next Steps: The comparative analysis performed by this project an initial analysis of the impact of accelerating S&E globalization on national government industrial policy requirements and approaches. It is far from comprehensive. The next steps should be a) to compile and compare the sectors or technologies that R&D intensive countries have identified as strategic; and b) perform more in-depth policy and political analysis, on a country-by-country basis, of the impact of dense, rapidly functioning global networks of S&E knowledge exchange and collaboration.

3. **The economics and geopolitics of the 21st century require that nations form and participate in multilateral strategic innovation and R&D groups; industrial policy will increasingly align with, and carry elements of, national security policy.**

Nations have always practiced game strategy (alliances; state sponsored attempts to lead in emerging technologies; selective use of tax, regulatory and economic policies such as antitrust; and sabre rattling and actual hot wars) to secure economic benefits for citizens or domestic companies, or to secure geopolitical clout.

The shift to an S&E-intensive globalized economy, however, changes the requirements for successful government action. The overarching theme for national industrial policy today is that innovation-dependent approaches, like effective national security, require the engagement of other nations (and companies headquartered in other nations) in a dance of genuine collaboration with genuine market competition.

Nowhere is this more apparent than in national reliance – for most advanced manufactured goods and services – on complex cross-border supply chains and extra-national sources of innovation and R&D. The reality is that it is impossible (and certainly cost prohibitive) for nations to avoid dependence on intermediate goods, services, innovation from outside the nation. There are exceptions, when a country is willing to pay the price to develop and maintain true independence, in advanced and specific national security capability. In 2020, however, nations overwhelmingly depend on goods, services, and innovation from outside their borders.

Therefore, to succeed in the current global economy, countries will need to balance political domestic pressures to "win" in every global technological or market competition against the reality of globally distributed innovation capability and the constraints imposed by sovereign-to-sovereign agreements necessary to integrate effectively in, and benefit from, the global economy.

To this end, governments will need more dexterity – and flexibility over time – in establishing commercial and innovation alliances (multilateral strategic groups) than they are accustomed to exercising.

Next Steps: The comparative analysis performed by this project is and early systematic look at the impact of accelerating S&E globalization on alignment of process between national security policy and national industrial policy. The next step might be more in-depth policy and political analysis, on a country-by-country basis, of the impact of the

accelerating development of dense global S&E networks on increasingly conjoined national security and innovation-dependent industrial policies.

4. **The alignment of the R&D and innovation activities of multinational corporations with national interests is poorly understood, but increasingly important to, national innovation-dependent industrial policy.**

Since the end of the Cold War, free trade and the removal of antitrust/competition law scrutiny from licensing have opened up more truly international structures (and temptations) for MNCs. These have been limited by specific export controls and other similar limitations on international activity, but what is unprecedented is the ability and desire of MNCs legally to locate significant activities in countries that are strategic competitors of the home country or its allies.

Therefore, what is new – or at least newly apparent – is the degree to which the S&E and innovation activities of both small and large multinational companies may vary in their alignment with the interests of citizens of the country of their incorporation or headquarters.

There is, so far, no theory or sufficient body of work which can guide national industrial policies in areas of importance to MNC behavior as diverse as standards, regulation, corporate governance, trade, taxation, antitrust, and public R&D investment.

Next Steps: In this field of applied analysis, the path may be the accumulation of examples – a set of industry- or sector-specific analyses that can mined for general insights about the role of industry-government relationships in national economic outcomes. In particular, a sector-by-sector analysis of whether and how MNCs should take into account, by choice or government regulation, the national interests of the home country and its allies when entering into what are currently legal technology transactions or investments in or with countries that do not play by the same international trade, investment, or S&T investment rules.

Also, the emergence and growth of small and medium sized MNCs is important but not well understood. This trend overlaps substantially with – and may undermine the national interests in – local, regional and national innovation ecosystem initiatives intended to promote tech-based start-ups and SMEs. This dynamic and under-appreciated aspect of MNC management, and its relationship to national policies and multinational agreements, should be the focus of significant management science analysis and policy development going forward.

5. **International collaborations by universities in research and education are critical to global stability and welfare but approaches and governance need to be updated in light of the evolving roles of cross-border innovation in national economic outcomes.**

Like MNCs and global supply chains, research universities and public-private research partnerships are at the leading edge of globalization of R&D and S&E knowledge networks. This is the case even though the organization and operation of universities is heterogeneous, both within many countries but especially when typical models of universities in one nation are compared to typical models in another.

Despite differences in organizational aspects as fundamental as sources of funding (different proportions of tuition and state support, and varying research funders and funding approach) and governance (ranging from state owned and operated to private, autonomous, and not-for profit) most universities embrace global norms and a global culture of openness and freedom of inquiry. Long before corporate R&D was globalized, the global research university "system" had created the scaffolding for, and begun to fill out, a civic S&E knowledge network driven by cross-border individual investigator collaboration and mobility, and by intellectual curiosity.

In general, the growth and globalization of this civic system of collaborative investigation, education, and knowledge exchange has provided tremendous benefits to humankind and been constrained only by direct national security concerns. Even during the Cold War there was collaboration and sharing across the Iron Curtain but within guardrails established by national governments concerned about weapons development by adversaries or other threats to security.

With this as context, two long-term trends are forcing a reassessment of the relationship between universities and their home countries. First, tertiary educational activities are increasingly economically important to R&D-intensive nations. In the US, for example, tertiary educational activities account for more than three percent of GDP. Further, foreign students studying in the US generated (in 2018-2019 academic year) over $44 billion as an exported US service, representing approximately 20 percent of total US service exports. And, of course, the vast majority of rapidly growing, new technology companies in any nation are founded by, and employ, university graduates and often by individuals with advanced degrees in science or engineering.

Second, as R&D-intensive nations have embraced industrial policies, research universities have come to play an explicit and significant role in those national strategies. Both historically and recently, the charters of universities frequently include, or lead with, missions of contribution to human welfare through research and teaching which contribute to economic growth as well as public health, food security, or other civic goals. National industrial policy is refreshing the long-standing pressure on universities to demonstrate the contribution of their activities, both domestic and cross-border, to the national welfare.

In most R&D-intensive countries, research universities have considerable experience justifying their receipt of taxpayer funding (including special tax treatment) by demonstrating local, regional, or national economic or civic contributions. In an era of competing national industrial policies — when national industrial strategies depend on university-based research and education — universities face the expanded challenge of also justifying their cross-border engagements.

To a large extent, research universities, or coalitions of universities, have not dedicated much attention to the role of their cross-border activities in home-nation economic outcomes.[4] The assumption has been that if they live within the national security constraints established by their home-nation government, their cross-border activities are in the national interest. This may be

[4] An exception is "Responsible Internationalization: guidelines for reflection on international academic collaboration" by the Swedish Foundation for International Cooperation in Research and Higher Education.

entirely true but it may not be sufficient to maintain political, policy and taxpayer confidence that international engagements are truly in the national interest.

This is complicated by the fact that governments and universities operate with two, sometimes orthogonal, sets of values. Universities put a premium on open access and academic freedom. At the same time, the international economic activities of most nations rest on principles of "fair" relations among nations, the bedrock of which are national treatment (treating foreign nationals or companies in the same way you treat citizens and domestic companies) and reciprocity.

The national industrial policy related challenges for universities, therefore, are to engage aggressively in justifying cross-border engagement, living strictly within the constraints created by domestic national security concerns, and working internationally to reconcile the norms of openness with the principles of national treatment and reciprocity.

The benefits for universities from engaging in this way could be profound, including a) bilateral and multilateral sovereign-to-sovereign agreements on international research collaboration by universities, and b) opening the door for multilateral agreements that pool university-based research funding and/or reciprocally open funding programs (in all countries covered by the agreement) to university and university-private entities from outside the nation doing the funding. This desirable future make take many years to emerge but, in the meantime, university engagement in these issues is important simply to protect current levels of productive international university engagement in S&E from the centrifugal forces of trade and investment protectionism and nationalism.

> *Next steps: Current and future multilateral negotiations (and agreements) on innovation-dependent industrial policy could be substantially improved though both national and global discussion forums, for university and national leaders, challenged with a series of concrete topics where principles of international economic relations need to be reconciled with academic values of openness and academic freedom. In its initial stages, the purpose of a multinational forum would be to reconcile the language and practices of sovereign-to-sovereign commercial relations (e.g., trade and investment agreements) with academic norms. In later stages a global forum could be a source of concrete proposals for multilateral collaboration, and even pooled funding, for elements of university-based research and higher education.*

6. **Innovation-driven industrial policy needs to include the human capital-focused economic adjustment activities of post-secondary institutions, from workforce education and re-training to attracting skilled and entrepreneurial immigrants.**

By 2030, automation — a form of Schumpeterian disruption — could displace up to 400 million workers globally. At the same time, many R&D-intensive countries are experiencing local talent shortages in a variety of specialized technical areas critical for innovation ecosystems to function. It is critical that education, re-training, and immigration, as well as other economic human capital-focused social adjustment activities, are not treated as afterthoughts in development and execution of innovation-dependent industrial policies. While not the only

important actor, tertiary educational institutions have a unique and essential role in outcomes at the intersection of human capital and innovation.

Post-secondary educational institutions — in providing pre-employment education — can focus on transformational knowledge development, yielding graduates who are flexible in responding to changes in work patterns. They also have irreplaceable functions in training and re-training for specific and evolving work-related skills (as well as in developing best practices for curriculum and pedagogy, and monitoring and evaluation for these fields). In ways that vary dramatically by country, private sector employers, government agencies, labor unions, charities, and for-profit entities such as trade schools (and evolving equivalents such as programming boot camps) also provide training and retraining for workers.

Investment in education and educational institutions are critical to any R&D-intensive nation, but no country can rely solely on local human capital to advance next generation technologies to commercial and societal advancements. Many S&E-intensive nations also depend on fixed-term and permanent migration to fill roles in tech-heavy fields in academic settings, established companies, and start-ups, and to create new innovation-rich enterprises. Immigrants with high levels of education, or immigrants educated in their destination R&D-intensive country, account for outsize percentages of both entrepreneurs and scientific and engineering talent in many nations.

Immigration and emigration are, of course, key features of an increasingly globalized S&E talent pool. Worldwide, numbers of internationally mobile tertiary students and high-skilled immigrants have grown substantially in the last 20 to 30 years. Student visa processing has somewhat caught up in varying degrees, ranging from harmonization in EU countries to lengthy and unpredictable wait times in other nations. Work and start-up immigration rules, by and large, have not. In many countries, world-class students can learn and train at top universities, but are then unable to remain in the host nations after graduating. This can deprive host countries of technical and entrepreneurial talent, harming the local economy and job market, and putting host universities at a disadvantage in the global competition for human capital.

There is wide variation in national levels of public investment in education and re-training, as well as policies designed to attract and retain talented human capital from elsewhere in the world. Variation in policies and practices includes, but is not limited to, agile workforce training and retraining programs, and new and revised work visa categories, and worker-centered coordination between higher education institutions, employers, non-profits, and governments. There is a large body of evidence to review here for approaches that have worked well and those that have not in different countries. The examples of Denmark, Germany, and Singapore are among those to consider.

While the global economy has done quite well overall in recent decades, and certain regions have thrived, many former manufacturing hubs (and now regions dependent on natural resource or fossil fuel industries) have become hollowed out, with levels of misery in entire communities not thought possible in economically advanced nations. A nation's tech-driven industrial policy is unlikely to succeed, in metrics or optics, if large segments of a nation's populace are left behind. Educational and workforce adjustment policies are both valuable in their own right, and as

elements of managing the risk that politics of adjustment and resentment will come to dominate and undermine strategic industrial policy intent.

> *Next Steps: There is a clear national interest in the ability of universities, companies, governments, and charities to collaborate on large-scale workforce education and re-training, and on global high-skilled talent attraction and retention. It would be useful, therefore, to develop and support a standing forum for discussion among post-secondary education institutions, educational policy makers, companies, and labor organizations in liberal democracies. Discussions should cover issues of technological change, workforce development, talent recruitment, and innovation-based business creation needs. The benefits of an international dialogue would be to take-up cross-border issues (such as education-driven migration and national brain drain concerns), as well as to provide direct value in sharing experiences with regard to the role of public and private national institutions in addressing linked human capital and innovation challenges.*

7. **Win-win interactions among national industrial policies requires new "big tent" and "small tent" agreements among nations.**

Every nation has a national industrial policy, either by active plan and activities or by default. Turning a blind eye to these competing national industrial policies is unwise and unproductive. Further, trying to shoehorn the interplay of national industrial policies into trade agreements will fail. To be successful, the emerging world economic order will need to reconcile, almost certainly through multilateral agreements, tech-dependent national industrial policies.

It is a simplistic but useful analogy to think of multilateral agreements as establishing competitive sports league rules. The very purpose of the league is to foster competition and the rules exist to promote competition and prevent (as in antitrust laws) a single team finding a source of advantage (steroids? deflating the ball?) that dampens genuine competition or, in Schumpeterian market terms, innovation.

It is important that new, broad multilateral agreements for commercially oriented S&E (the big tent) allow bilateral or multilateral side deals (the small tent) in support of strategic groupings and alliances (see item 3 above and in the appendix). This is consistent with existing broad multilateral agreements such as the WTO which allow bilateral or multilateral side deals as long as a) they are declared; and b) the structure of the side deal is consistent with the underlying multilateral agreement (in this example, WTO).

Second, as articulated above in item 3 and illustrated in examples in the appendix, there are compelling reasons to consider and engage in targeted international S&E agreements separate from broad multilateral agreements. Even if every nation in the world signed a commercially oriented S&E collaboration agreement, a pair of nations, or coalition of several nations, may want to pursue, for example, a separate data privacy and data management strategic R&D group (small tent).

While this description implies a sequential path (big tent first, then smaller tents as necessary), the process of obtaining multilateral agreements will certainly be messy and overlapping. In the

coming decade, nations will need to work through a global S&E system (big tent) that is fair by agreement and accommodates both significant political/economic structural differences among nations and strategic groups (small tent) focused on particular sectors or problems.

> *Next Steps: There is critical groundwork to be done in two tracks. First, at a national level, to follow the path created by international trade and investment negotiations, most countries will need to establish of a forum of S&E stakeholders (government officials, businesses, national labs, universities, think tanks etc.) to discuss and debate the status of national S&E-related multilateral needs as the path to formalize a national action agenda. In some countries there will be existing (and overlapping) groups that might play this role so it will be important to resolve those conflicts and settle on terms of reference for the task/group which focus on the domestic groundwork to engage in broad S&E-related multinational negotiations.*
>
> *Second, there is the groundwork necessary to engage a core group of nations in discussions about launching multilateral negotiations. This could start with, for example, the formation (and initial agenda setting for) a standing G7 S&E working group (similar to the standing B7 ("business 7").*

Findings Translated into Directions for Government Policy

At a minimum there are six functional directions for governments to consider as they revise their strategic, innovation-driven, national industrial policies. While some of these functional elements have a domestic focus, all are either directly related to bilateral and multilateral sovereign-to-sovereign agreements or very heavily contextualized (boxed in?) by the actions of other nations including allies, malign actors, and strategic competitors.

Alliances and Alignment

1. Improve governmental international S&E strategy and increase dexterity in selecting and pursuing allies for R&D and innovation-driven economic growth and competitiveness; pursue bilateral and multilateral sovereign-to-sovereign R&D and innovation agreements as necessary or expedient.

2. Pursue national legal, regulatory, tax, antitrust and other policies with the goal of aligning the actions of MNCs with national goals in cross-border S&E knowledge and innovation.

Investment and Management of R&D

3. Revise approaches to targeting and executing government (taxpayer) supported research, development, and demonstration (RD&D) investments. For many nations, the primary challenge is in shifting to engage cross-border public and private S&E networks while maintaining a focus on national interests.

4. Devise policies to assure research universities and public-private research partnerships are effective contributors to national interests in a global collaborate/compete global environment.

Talent and Adjustment

5. Provide mechanisms, institutions, and policies in education and immigration to maintain human capital parity with other nations, avoiding underdevelopment of domestic talent while competing worldwide to attract human capital.

6. Create policies and best practices for economic and human capital adjustment to technical and societal change and integrate that activity with strategic, innovation-driven industrial policy.

   Next steps: The six strategic directions above arise from a comparative analysis of national industrial policies and national S&E enterprises, but there is considerable additional work to be done to deepen the analysis and inform implementation. In particular, the project made no attempt to assess (or benchmark relative to other R&D-intensive nations) national performance. Assessing/comparing the structural characteristics of all 20 to 25 R&D-intensive nations is a daunting task, so the most constructive next step may be a deep comparative analysis covering a much smaller set of R&D-intensive nations – 3 to 5 – with the idea that the methodology could be extended both to other R&D-intensive nations and to nations that are considerably less R&D intensive.

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[5] The project Working Group is listed at https://www.brginstitute.org/working-group. Members of the Working Group have been actively involved in developing this paper but this is not a consensus document. Bruce Guile and Eion Lys are responsible for the content, errors, omissions and any opinions expressed in this document.

Appendix

The Pressing Need to Test New Approaches: Five "Small Tent" Opportunities

As companies have globalized their R&D activities, so should nations as long as they have the necessary dexterity and multilateral agreements to assure returns to national taxpayers. The "small tent" proposals below are developed (or in development) to illustrate, and demonstrate the viability of, multinational public-private international R&D and innovation collaborations. The examples below are focused on pre-competitive R&D collaborations or on civic missions (such as public health).

The distinguishing feature of these proposed collaborations is that they align with a game strategic approach to national industrial policy. Most will be alliances among several, not all, nations and MNCs to pursue clearly articulated goals such as development of shared competitive capacity, or a public purpose such as building privacy and national security guardrails for international data-dependent AI or health-related research.

a. Next generation **mobile wireless** network international, public-private R&D consortium (*6G International R&D and Innovation Consortium: Case Statement and Proposal* released October 12, 2020).

b. Standing multinational research collaboration in **digital epidemiology.**

> *Digital epidemiology is a rapidly advancing basic and applied research field that is of importance to a wide range of operational enterprises such as medical providers, national and local public health enterprises, insurance providers, pharmaceutical and medical device manufacturers, and of course, national security enterprises worldwide. The logic for international public-private research collaboration is tightly linked to the advantages of a coordinated and directed global scale effort in data collection (or access) and digital tools for both basic and applied epidemiological research. The benefits of scale and scope for an internationally collaborative research enterprise depend on navigating privacy, national security, and intellectual property concerns of both national and company participants as well as agreeing how and what data are to be collected and/or accessed.*

c. Multinational research, design, and trial deployment (beta testing) aimed at **remaking electric power grids for weather-dependent renewables.**

> *The world's electric power grids are huge legacy systems and among the most expensive and extensive infrastructures ever built by humankind. This globally distributed (and sometimes cross-border) infrastructure is facing a host of transitions driven by market trends and modernization for efficiency and risk reduction even while the grids are extended to serve a growing global population. These shifts — such as from centralized production to distributed*

production and from centralized control to adaptive AI and electromechanical (smart grid) controls — are expensive and technically challenging. They are also context for the globally distributed and environmentally critical challenge of remaking power grids to accommodate, renewables, especially weather-dependent renewable energy sources.

The context for the proposed R&D consortium includes both a) the substantial need for decentralized global investment to modernize and extend electric grids and b) the very rapid growth in weather-dependent renewables as a source of electric power in many countries. The proposed international consortium has a narrow focus on R&D to solve common (and sometimes shared) technical challenges in growing/integrating weather-dependent renewables into electric power grids in member countries. These challenges include, but are not limited to, grid-scale (or distributed) energy storage; the technical and economic integration of dispatchable sources with weather dependent sources; frequency regulation without heavy spinning metal; efficient long-distance transmission (renewable resources are rarely where the demand is); and sensing and analysis of the grid state from generation through transmission to distribution to demand.

The logic for international public-private collaboration in research, design, and trial deployment of solutions to remake power grids is tightly linked to the pressing need for rapid development and deployment of new approaches. The a) large market scale (many potential applications), and, b) diversity (different sources of energy by location and grid) that could be addressed by a global collaboration, together have the potential to substantially speed up the development and deployment of solutions, with benefits in direct economic impacts for many countries as well as for the critical global goal of reducing greenhouse gas emissions. The benefits of scale and scope for an international, public-private collaborative development and trial deployment enterprise depend on navigating the national security and intellectual property concerns of both national and company participants.

d. Standing multinational program on technology-governance intersections in **privacy and security in global (distributed, cross-border, big data-dependent) research enterprises in AI and digital twins.**

Research and applications in AI/machine learning and digital twinning depends on access to data, both historical and current data streams. Usable, if not immediately useful, data are generated by increasingly data-intensive scientific enterprises and by an explosion of sensors in industry, commerce, and the household internet of things, as well as by very rapid growth in user-generated click data. There is an important, already large, and rapidly growing aspect of research and application in AI and digital twins that mines existing databases and real-time data streams. This work is increasingly, if not inherently, cross-border.

In addition, there is a continuing need for cross-border data sharing in fields such as medical research where poorly understood or inconsistent national and international privacy regulations currently deter data sharing. The "move the program to the data" approach (as opposed to creating large data pools) has

obvious privacy and security benefits but there are both technical challenges, and, as data resides in different countries and is controlled by different public and private actors, issues with regard to governance, compliance and contracts. An international collaboration could become a trusted source of solutions to link data users (researchers, developers) to data sources while maintaining privacy and security. The benefits here are not just those of scale and scope but, with adequate participation from multiple governments and companies, this may be the only path to a trusted international system/infrastructure to support rapid global innovation.

e. Global research collaboration and center on problems in **coastal zone infrastructure** and built environment adaptation to sea level rise.

Sea level rise due to global warming is a truly global problem. A substantial portion of the world's population lives within 100 miles of an ocean or sea that will be affected by inches or feet of sea level rise over the next few decades. A critical aspect of humanity's adaptation to the now-inevitable impacts of climate warming is R&D to increase the speed and lower the cost of adaptation in coastal infrastructures and the built environment. The logic for international public-private collaboration in research, design, and trial deployment of coastal infrastructure solutions is tightly linked to the pressing need for rapid development and deployment of new approaches.

There is a large market scale (many potential applications) and diversity (different local, regional, and jurisdictional conditions) of the challenges that can be addressed by a global collaboration. This combination has the potential to measurably speed up the development and deployment of solutions, with extensive benefits in direct economic impacts for many countries, and is aligned with the critical global goal of adaptation to climate change. These benefits of scale and scope for an international, public-private collaborative development and trial deployment enterprise depend on navigating the security and intellectual property concerns of both national, regional and local governments as well as company participants.

Such consortia can both create immediately beneficial knowledge for participating universities, companies, and governments – and act as experiments for best practices in multinational R&D sharing and exchange.