A strategy for Australia's international engagement in science and research based on positioning in key transnational research value chains

Australian Council of Learned Academies (ACOLA) Project on: *Asia Literacy: Language and Beyond*

FINAL REPORT

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Executive Summary

Key policy points

1. Australia's current emphasis on prioritising selected bilateral research cooperation relationships at the national level could be strengthened and augmented by considering how we can leverage broader multilateral research networks. These broader multilateral networks generate useful knowledge spillovers and synergies between complementary capabilities. In a globally inter-connected research effort based on multilateral collaboration, these broader networks are themselves *intangible assets* that may be under-exploited at present.
2. In recognition of this opportunity to strengthen the return-on-investment in international research collaboration, the report proposes engagement with the concept of transnational research value chains (networks of multilateral science and research collaboration). In business, transnational value chains (often managed by multinational corporations) loop through different national economies. Transnational research value chains function in a similar manner: looping through different countries – each of which contributes to the performance of the value chain as a whole. Participation in cutting-edge research at a global level requires distinctive capabilities of value to these multilateral research networks – the value of which stems from the *combination* of the distinctive capabilities provided by research teams in participating countries (resulting in a value of the whole that is greater than the sum of the discrete inputs). It is this combinational source of public value that justifies shifting to a focus on engagement with transnational research value chains as a key unit of analysis. This important functional attribute can be overlooked if a bilaterally-based perspective is relied upon.
3. A strategy based on positioning Australia in the key transnational research value chains that drive progress of the global knowledge frontier provides a practical approach to exploiting the intangible asset values created by these multilateral research networks. In this strategy, the attractiveness of a particular country as a research partner is based on both what it has to offer us, and what we can offer them, directly and on the potential utility of the broader ('second order') web of international collaborative relationships in which that country is embedded. These indirect relationships generate potentially important knowledge spillovers that can be tapped into via international engagement.
4. This strategy needs to be coupled with a nuanced understanding of the science and research strengths, and the policy challenges, of Australia and current and potential research partners. It is this understanding that will allow us to align the strategy with national policy priorities, given that Australia and other countries have unique challenges which will naturally prioritise certain science and research areas over others. It will also allow us to identify key shared challenges that will drive long-term future investment within national science and research systems. This report focuses on Asia, given Australia's place within this rapidly developing region which will be a key driving force of science and research during this century. With significant societal challenges emerging (or becoming more critical) across many Asian countries, the humanities and social sciences (HASS) are also becoming increasingly important. Multidisciplinary teams are needed to properly address these complex policy challenges and to generate 'global public goods'.
5. At present, our ability to utilise the concept of transnational research value chains is limited by a combination of poor data availability and weak analytical methods. Readily available data on patterns of international research co-authorship (such as Thomson-Reuters *InCites* ™ used in this report) currently represent this aspect of international collaboration as sets of bilateral links that masks the true underlying multilateral nature of much collaboration. When data on this underlying multilateral collaboration is analysed by researchers and policy analysts there is a tendency to produce highly complex relationship maps that lack a sense of functional structure (unpacking the structure and performance of the collaboration network). The result can be confusing network diagrams exhibiting a poor signal to noise ratio that can, as a result, be confusing to policymakers, resulting in a continuation of the prevailing bilaterally-based strategy – simply because data that treats multilateral collaboration as if it were sets of bilateral

collaboration are more readily accessed and interpreted. As a result, it is not possible at present to provide robust data on the structure and performance of transnational research value chains. This important work still needs to be carried out. **This gap between strategic possibilities and currently available data should not prevent the policy community from exploring the options highlighted in this report.**

6. Given that new types of metadata on international co-authorships specifically designed to address the current limitation of a bilateral representation of more complex multilateral networks are expected to be released later this year, the opportunity to transition to the new recommended approach is opening up. The analytical challenge will be to develop better ways of handling these complex data that moves beyond the current tendency to produce complex and potentially confusing maps of apparent collaboration networks. This report suggests that an analytical emphasis on the comparative structure and performance of transnational research value chains may provide one solution to this challenge. Future analysis in this area should ideally identify evidence of inter-connections between science and research value chains and the business value chains that also loop through different national economies (a system in which a country's competitiveness is expressed in the ability of companies to win and retain positions in these transnational value chains).
7. Given the greater complexity, and higher likelihood, of cross-cultural factors affecting success in an engagement strategy based on transnational research value chains, the higher rewards are associated with greater risks. Consequently, the cross-cultural understanding provided by the humanities and social sciences becomes one of the most important key success factors in navigating the risk-reward relationship associated with engagement with transnational research value chains.

Summary of the argument

The strategy for Australia's international engagement in science and research proposed in this report is framed around the concept of 'science diplomacy', which is defined as how a country: informs foreign policy objectives with scientific advice; facilitates international science cooperation; and uses science cooperation to improve international relations between countries (The Royal Society 2010).

The strategy reflects the important shifts that are taking place in the global research effort. These shifts involve a broadening and a deepening of activities.

Science and research is broadening because more countries are involved, often at higher levels of intensity in an expanding range of research fields. The increasing prominence of Asian countries in this broadening is especially evident.

Science and research are deepening because the:

- intensity of collaboration between countries is increasing, and;
- more channels for disseminating findings are made possible as traditional printed academic modes of dissemination are augmented by various online mechanisms – many with open access.

The resulting increase in the complexity of science and research poses challenges for policymakers seeking to prioritise the allocation of scarce resources.

From Australia's perspective key questions are:

- How do we achieve cost-effective international engagement in science and research?
- How do we map, and understand the implications of, our strengths and capacities in science and research?
- How can we maximise Australia's contribution to shared societal challenges at an international level?
- Which new capabilities should we seek to develop?
- What sort of role in leading and facilitating international collaboration should Australia seek to achieve given our physical location and capabilities?

The solution put forward here is to re-frame how we think about international engagement by transitioning from a perspective-based mainly on bilateral international relationships towards a perspective that recognises the complex inter-connected nature of global science and research.

As with most effective strategies, this vision is informed by available empirical evidence but it is not induced from that evidence. Rather, the proposed strategy is a creative response to emerging patterns – a response that seeks to position Australia in an as effective manner as possible given likely future trends in global science and research in general, and Asia's role in this global system in particular. As things currently stand the data and supporting analytical methods are not able to map transnational research value chains in a functionally coherent manner – that task remains to be done once the necessary data is released later this year.

If the global frontier of research in a field is dominated by groups of many countries structured as a core of a small number of countries that drive progress, and a periphery of a larger number of countries that keep-up with this progress via participation in the cluster, then the most efficient and effective strategy is to consider how well we engage with these multinational clusters of research collaboration.

This 'systemic' stance adds greater pragmatism and realism to our approach to international engagement by placing how we approach relationships with particular countries within the broader context of the *other* research relationships in which those countries are involved. If these webs of collaboration between countries with complementary research capabilities are approached as 'intangible assets' (the clusters of collaboration are themselves a source of value) then the return-on-investment for Australia stems from our ability to leverage these clusters via the ways in which we approach collaboration with specific countries. In effect, Australia's strategy makes explicit what is currently implicit: if we collaborate with country X then who else is country X collaborating with that enhances their attractiveness to us? The innovation in the proposed strategy is to shift away from treating these third-party relationships as 'nice to have' second order effects, and towards treating this systemic dimension as the primary value proposition for international engagement.

This shift in strategy places the value of cross-cultural understanding and capability at the centre of enabling factors (an aspect of particular importance given the growing prominence of Asia in the global research effort). Cross-cultural factors can be hard to handle in bilateral contexts. When the more complex issue of several interacting cross-cultural dimensions is faced, as in the case when researchers in several countries are collaborating, then the challenge is more complex and therefore more challenging. Asia literacy – defined in its broadest sense as the ability to manage cross-cultural considerations in the Asian region, and more specifically as cultural awareness and understanding of Asia, and having Asian linguistic capabilities and a cosmopolitan mind-set – is not a nice to have capability. Asia literacy is a need to have capability simply because in an increasingly inter-connected global research effort in which Asia is of growing importance, Asia literacy becomes a critically important success factor for effective and efficient international engagement. Without effective Asia literacy Australia risks becoming marginalised as the region plays an increasingly powerful role in global science and research.

This systemic strategy also highlights what other nations have to gain from collaboration with Australia. Our position on the periphery of Asia, and our relatively well-developed research links with Asia and associated cross-cultural capabilities makes Australia an attractive research partner to the United States and European countries that currently tend to dominate cutting-edge research (sitting in the core of collaborative international clusters). By leveraging our valuable networked research links with Asia, we can amplify our attractiveness as a research partner beyond the level set by our relatively small proportion of global R&D investment. In short, a systemic approach to international engagement in science and research plays to Australia's existing strengths and our future potential. Asia literacy delivers this systemic approach by increasing the efficiency and the effectiveness with which we engage with Asia and, in so doing, increasing the value of our 'network positioning' in the global research endeavour.

The proposed strategy based on adopting a systemic approach enabled by Asia literacy can be given additional weight by paying greater attention to the balance between competition and cooperation in international engagement. This perspective recognises that academic research (and its uses) can combine competitive aspects with the collective shared benefits associated with generating global public goods (outcomes with collective international benefits for which exploitation in one country does not exclude exploitation in other countries – e.g. developing a vaccination for malaria on a non-profit basis). It is therefore misleading to approach international engagement primarily as a competitive dynamic.

This more rounded approach to intended benefits has the major advantage of prioritising both innovation and global public good outcomes. Arguably, Australia has exhibited mixed performance to date in achieving an adequate return-on-investment in innovation outcomes – but strong performance in achieving a return-on-investment in achieving global public good outcomes. The proposed strategy therefore plays to our strengths not our weaknesses. As such, it enhances Australia's ability to pursue soft power and related diplomatic objectives associated with playing a high profile role in generating global public goods.

In the holistic approach recommended, Australia should still seek to foster a system of bilateral collaborative relationships – but designed to exploit the opportunities and risk mitigation advantages created by *systemic collaboration*. This involves approaching international engagement as a transnational 'value chain' that loops through a number of countries rather than as a set of more limited exclusive bilateral relationships.

Rather than representing the world's research effort as a combination of discrete countries conducting activities around various separate and distinct fields of research, we should treat the global research endeavour as a system of transnational research value chains that loop through many countries – linking collaborating researchers in these countries. In a similar manner to industry, these value chains comprise much of the global economy – they therefore should be, but rarely are, the primary unit of analysis. A country's long-term standing is strongly influenced by its ability to win and retain positions in these transnational research value chains (and in some cases drive the formation of new value chains at the cutting-edge of research). Indeed, business funded R&D tends to align with industrial transnational value chains so there is a tangible link between research and industrial value chains that can be particularly important for business-academic cooperation.

The implications of this assessment for an international engagement strategy are that we should ensure that we collaborate with the leading countries in a given research value chain (usually the United States, major European countries and Japan at present) whilst *also* collaborating with less capable countries in our region with converging and overlapping policy priorities and challenges – assisting them in their science and research catch-up efforts.

This strategy would represent a sea-change in Australia's approach towards international research collaboration by creating a more rounded 'realist' policy stance better able to exploit the opportunities opened up by the highly networked nature of modern research (especially at the cutting-edge). As such, the new value chain oriented stance would close the gap that has opened up between bilaterally dominated international engagement strategies for research and the complex network-based reality of much of the global research effort.

This realist stance is aligned with the Chief Scientist's vision. In April 2013, the Chief Scientist noted three critical pathways to increase Australian engagement on the global science and technology stage: maintaining and strengthening research relationships with high-performing nations that enhance our performance; nurturing long-term research relations with emerging science nations, particularly in our region; and collaborating with nations that have complementary research priorities and challenges (Office of the Chief Scientist 2013).

The proposed value chain-based approach positions Australia as a key regional node in the system of transnational research collaboration, while building upon our established bilateral relationships. It therefore allows us to use 'science for diplomacy' (e.g. support trade policy), but also allows us to pursue diplomacy for science (facilitating international scientific and research cooperation for its own ends). The strategy still allows us to pursue bilateral regional capacity building objectives (important for stability and economic development), but not at the expense of losing out from opportunities to benefit from collaboration with the major science powers.

Indeed, the emphasis on generating global public goods in addition to the currently prevalent competitive stance focused on innovation outcomes assists us to articulate the required balance by informing how we design our web of bilateral collaborative activities in such a way that they generate the systemic outcomes we seek.

A transnational research value chain approach also has the advantage of maximising the benefits from both competitive and cooperative research. Some researchers may collaborate to make advances that seek to generate global public goods, while other researchers may compete to generate knowledge that is privately appropriable (e.g. a patented technical innovation to be taken up by business). Most research value chains incorporate both public good and private good objectives. We therefore require a perspective that encompasses competition and cooperation, public good and private good objectives, and that recognises the inherently transnational basis of much of the global research endeavour. The use of transnational research value chains addresses all these requirements.

The approach also recognises that the existence of knowledge spillovers between discrete research projects means that a transnational research value chain can comprise both direct research collaborations and also indirect knowledge sharing by virtue of these spillovers. The existence of these spillovers adds further weight to the utility of focusing on the nature and extent of transnational research networks. Recognising the role of these knowledge spillovers also has the advantage of opening up a channel for considering the opportunities and risks posed by cross-cultural considerations, which in turn stresses the role of Asia literacy. As tacit knowledge is best communicated face-to-face, these spillovers are only effective when cross-cultural factors are handled effectively. Conversely, poor cross-cultural capability does not just limit the effectiveness of these knowledge spillovers, it can also increase the risk of negative impacts by misreading subtle culturally embedded signals and when making decisions.

Finally, a focus on transnational research value chains is compatible with synergies between different research fields. It is often the case that an advance in one field stimulates or enables advances in other fields. The concept of a transnational research value chain is well suited to capturing these synergies (much in the same way that these synergies take place in industrial supply chains as each stage in the sequence adds value using distinctive competencies).

Enhanced Asia literacy is a critical success factor in delivering an effective strategy focused on transnational research value chains. It closes the gap between potential benefits and actually achieved benefits. Asia literacy is *the* major risk-reduction capability in such a context. A transnational research value chain may weave together different strands of disciplinary expertise in order to be effective. Cross-cultural understanding is one such strand because without it, the research value chain may unravel when circumstances become difficult.

The resulting strategic prioritisation framework is evolutionary but not revolutionary. It does not require multilateral initiatives per se (which can be costly, impractical and risky), but instead asks that our various bilateral relationships are considered from a broader ‘architectural’ and network based perspective.

The next step in delivering this value chain based approach would be to map the system of complex science and research value chains that loop through Australia, or do not loop through Australia but which we would like Australia to participate in. Australia could then set ‘design’ objectives for what a preferred role as a key node in this global system should look like.

For too long, Australia has neglected the opportunity to exploit our regional role by paying insufficient attention to this systemic perspective relative to an overly simplified bilateral stance that has overlooked these major opportunities. It is now incumbent on those who analyse and interpret bibliometric data to provide more realistic maps of the closely inter-connected nature of the global research endeavour. A number of universities and other research entities in Australia already generate maps of their complex evolving collaborative profiles. Consequently, momentum in shifting to a transnational research value chain-based perspective is now increasing – it now requires the government policy framework to align with this emerging strategy.

It is understood that Thomson-Reuters may be implementing a major functional enhancement to their readily accessed *InCites*™ online data access facility that will allow transnational research value chains to be mapped. It will therefore soon be possible to develop the evidence-base to support the proposed strategy.

Introduction

The purpose of this paper is to contribute to policy formulation in regard to Australia's international engagement in science and research. Specific attention is paid to the role and importance of Asia literacy – defined broadly as the ability to manage cross-cultural considerations in the region. That is say, linguistic, socio-political and other aspects of how the humanities and social sciences can contribute to both the national interest and the provision of global public goods.

Part One examines how the global science and research landscape is changing. A particular emphasis is placed on tracing how Asian countries are increasing their prominence. This section of the paper draws attention to Australia's performance relative to other nations and highlights salient issues for international collaboration. It also provides a brief overview of Australia's current policies for international science and technology engagement and collaboration, both in the Asian region and also on the global stage. It reviews Australia's existing research internationalisation strategies and infrastructure for engagement, and provides an overview of Asian science and research systems (and identified priorities and challenges). This section highlights the impediments to, and limitations of, Australia's current engagement strategy, and makes the argument for an ambitious and forward-looking science and research diplomacy strategy.

Part Two considers the distinctions between competition and cooperation, global public goods and private goods as they relate to science and research policy. It argues for a more equitable balance in policy thinking between objectives associated with private appropriation and excludability in the uses of research and objectives association with generating global public goods. Given the inherently international, and often strong public good aims of public science, this part of the paper stresses the importance of *not* subsuming public science within innovation policy because to do so conflates private and public good oriented outcomes. It argues that it is preferable to treat innovation and public good outcomes as distinctly different (though often inter-connected) returns on investment.

Part Three considers ways of thinking about national differences in science and research capability. It stresses the importance of thinking very carefully about the opportunities and the risks that arise from asymmetric capabilities (in which one country may get pulled-up by collaborating with a more capable nation whilst the more capable country risks being pulled down via that collaboration, mainly via opportunity costs of who else is *not* being collaborated with). It also highlights the ways in which governments will legitimately seek to pursue broader policy objectives through science and research collaboration.

Part Four explores the utility of adapting the concept of transnational value chains to inform strategic priorities for international engagement in science and research. It stresses the importance of being able to capture the strong inter-connectedness of the global research effort (most especially at the high end of the capability spectrum). It also highlights the importance of 'braiding' together understanding from the humanities, social sciences and the natural sciences and engineering in order to exploit emerging opportunities and mitigate risks when operating in transnational research value chains – a multilateral context that requires sophisticated approaches to managing complex cross-cultural challenges (hence the central importance of Asia Literacy in a strategy based on engagement with transnational research value chains).

Finally, Part Five draws the arguments to a conclusion and highlights a set of practical actions required to refine and execute the recommended approach. It considers how a strategic approach based on transnational research value chains can be implemented, and what this would mean for how bibliometric data are analysed and interpreted.

Appendix A provides a broad overarching overview of the policy priorities of, and challenges facing, a number of representative countries in the Asian region, including: China, India, Indonesia, Japan, South Korea, other representative ASEAN countries, and the Pacific islands. It shows that certain shared challenges and areas of policy alignment and overlap provide the basis for effective collaboration between Australia and its Asian neighbours in particular research and science sectors. This detailed material is presented in an Appendix in order to provide an evidence-base upon which the main body of the report can draw, but with the advantage of avoiding side-tracking the main arguments.

The main take-home message from this paper is that an opportunity now exists for Australia to start to articulate an ambitious yet realistic strategy for our international engagement in science and research. This strategy focuses on engagement with the transnational value chains that tend to characterise cutting edge research (i.e. groups of several collaborating countries) - as distinct from an approach based solely on sets of bilateral collaboration with particular countries without consideration of the broader network positioning of those countries.

It is timely to propose such a strategy because more easily accessible metadata on academic publications may be released in the next few months that makes it feasible to start to map and analyse changes in these transnational research value chains on a more cost-effective basis. At present, it requires highly specialised and costly technical expertise to extract and analyse metadata on multilateral national authorship patterns. This is because the more user-friendly data access portals (such as Thomson-Reuters *InCites*™) are designed to facilitate tracking bilateral but not multilateral national authorship patterns (in so doing representing more complex configurations of multi-national authorships as overlapping/duplicated bilateral national authorship counts).

The recommended approach has the major advantage that it aligns with similar analytical work on the global value chains that loop through different national economies that is now made possible by the release of OECD-WTO data that integrates trade and production data in different national economies. Indeed, science and research are integral to these broader global value chains. The result of adopting this more integrated approach would therefore be a closer coupling of science and research policy with industry/innovation and trade policy, alongside a crisper articulation of how science and research also generate global public goods that create useful shared outcomes that are not captured in industry/innovation and trade performance. The value generated by transnational research value chains encompasses both private (appropriable) and public (shared & non-exclusive) value.

Part One: The changing global landscape for science and research

The global research landscape is changing rapidly. The rise in the volume of outputs has accelerated as a larger number of countries become more far more active in science and research as they seek to catch-up with the leading 'science powers'. China, India and other countries in Asia are becoming far more prominent in the global science and research effort (and especially that portion associated with English language publications).

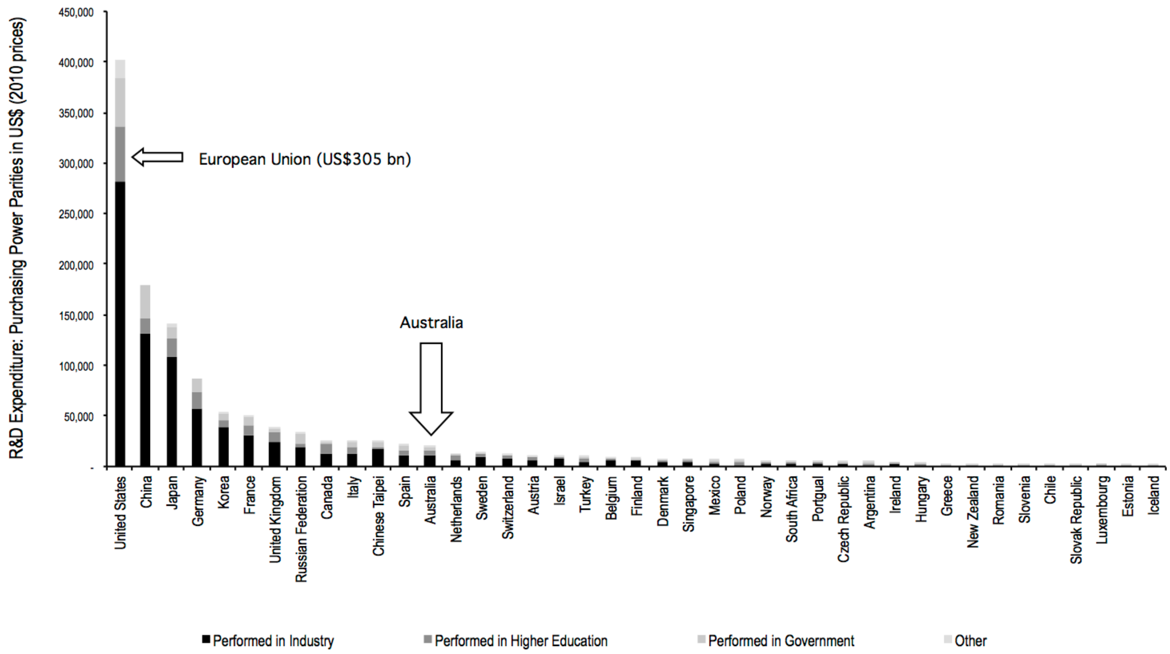
The changing balance of global R&D

Figure 1 contains a profile of the global R&D picture. Australia is a small-scale player in terms of global spending on research and experimental development (R&D). Whilst this relatively low spending makes it difficult to 'compete' internationally (especially in cutting-edge research fields that require large-scale efforts) it also makes international collaboration an especially compelling strategy because this allows the vastly greater spending of the leading science powers to be leveraged.

Australia's attractiveness to other higher-spending nations lies in our geographical position (the leading science power in the southern hemisphere, southern skies for astronomy, proximate to Asia, the southern oceans and Antarctica), unique flora and fauna etc. – as well as in our internationally distinct fields of research such as health and medicine.

This mix of natural asset endowments and created assets is best exploited by adopting a broad perspective towards the diverse types of property rights involved in research: from appropriable innovation objectives to the global public goods generated by public science. Part Two discusses the advantages of broadening how we frame these diverse outcomes from science and research.

Figure 1: Asymetries in identified global R&D spending

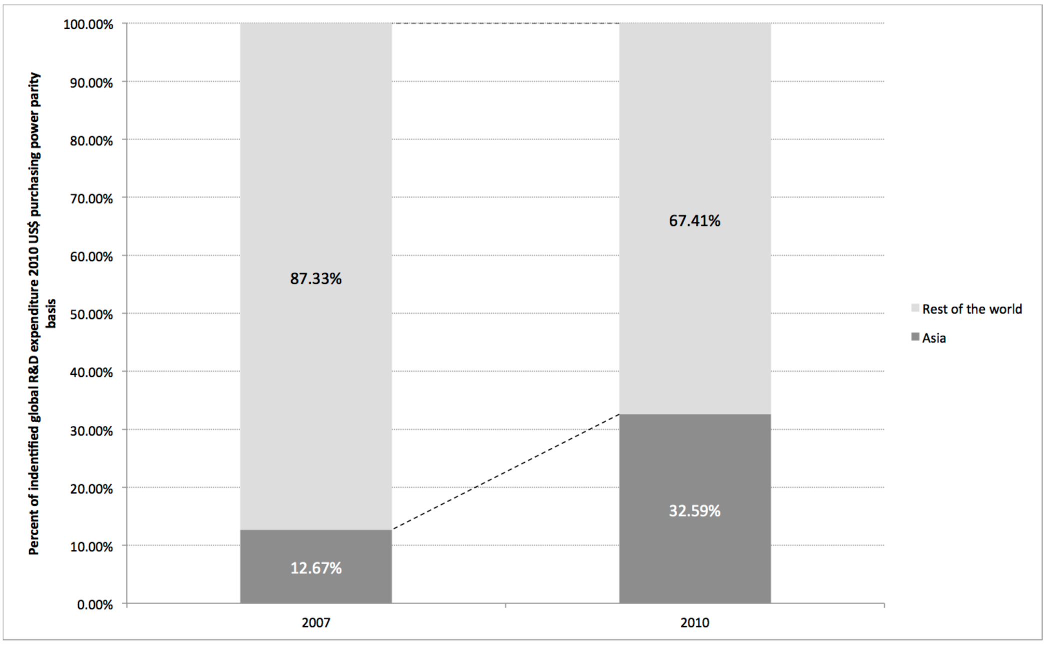


Note: The European Union has been added into the graph above to show where Europe as a whole stands compared to the United States and Australia.

Source: (OECD StatExtracts 2014) (graph produced by the authors)

Figure 2 demonstrates how, in addition to the global economic centre of gravity shifting to the east (as highlighted in the Australian Government's Asian Century White Paper), so too is the centre of gravity in the global R&D effort – and at a dramatic pace. In 2007, Asian countries accounted for just under 13 per cent of identified global R&D. Just three years later this proportion had risen to 32.6 per cent. China's rapidly increasing R&D expenditure is a major driver of this significant shift in global R&D. In 2007, measured on a purchasing power parity basis, China's R&D expenditure amounted to 8.63 per cent of the global total. By 2010 this proportion had risen to 14.47 per cent. This resulted in China's R&D effort shifting from 23.5 per cent of that of the US in 2007 (around 60 per cent of Japan's R&D spend) up to 44.5 per cent in 2010 (1.27 times that of Japan).

Figure 2: Asia's increasing prominance in global R&D



Source: Evidence Base for Chapter Six of *Tasmania's Place in the Asian Century* White Paper (prepared by Mark Matthews as lead chapter author) See (Tasmanian Government 2013),

This is a significant shift for Australia because it places us closer to one of the emerging growth poles in the global research effort.

The growing prominence of Asia in global science and research

Exhibit 1,

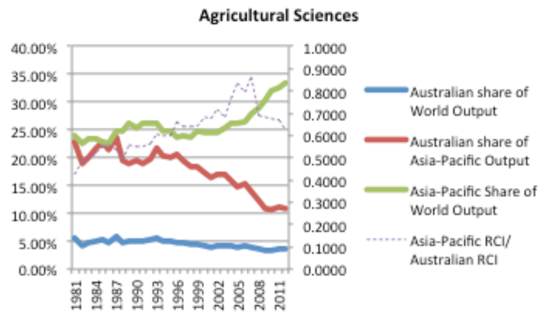
Exhibit 2 and Exhibit 3 provide a birds-eye view of the growing prominence of Asia-Pacific in the global research effort using Thomson-Reuters *InCites*™ data. The specific field of research definitions used (which are biased towards science, engineering and medicine) matter less than the overall picture provided – a picture that signals a clear increase in Asia's role. The graphs, using Relative Citation Impact (RCI), clearly show that Asia-Pacific's share of global research output has increased across all fields of research from 1980 until 2012, with the most notable growth starting in the 1990s. In this context, RCI expresses a nation's aggregate average citations per publication relative to the global average. Hence, an RCI of 1.2 indicates that a particular nation's authors are cited 20 per cent more than the world average. As such, RCI is one measure of the quality of research.

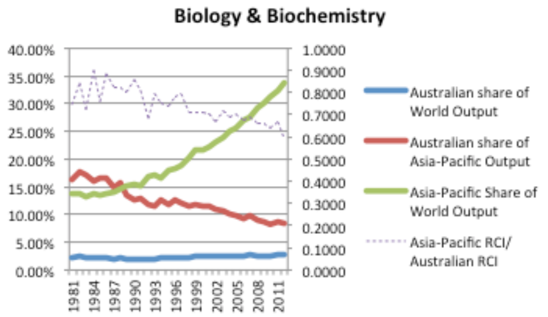
These findings very much correlated with Asia's extensive economic growth in the 1990s, fuelled by China's and India's economic liberalisation and the emergence of the 'Asian Tigers', which allowed substantial resources to be invested in research and development.

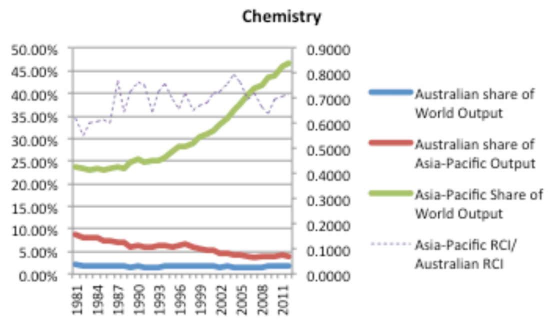
Exhibit 1: The growing prominence of Asia-Pacific in the global research effort (part 1)

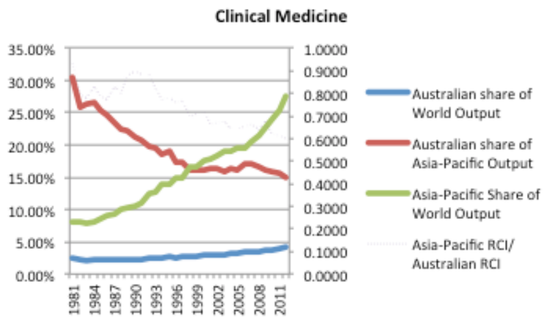
Percentage shares of global research output are plotted on the left hand axis. The ratio of Asia-Pacific's Relative Citation Impact (RCI) over Australia's RCI is plotted on the right hand axis – the lower the value, the more of an advantage Australia has in RCI (e.g. a ratio of 1.000 suggests equal RCI).

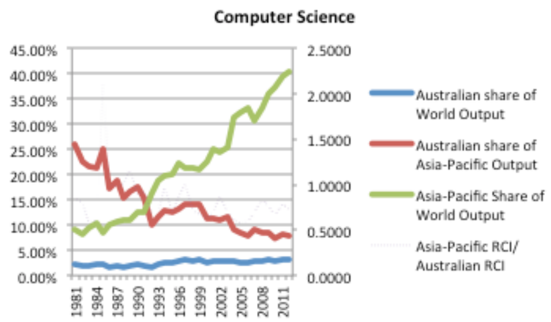
Note: InCites™ excludes the United States from their definition of Asia-Pacific, which is useful as the below therefore captures the vast increase in East and South Asia's share of global research output. Note however that Australia is also captured in the definition of Asia-Pacific, and therefore Australia's RCI performance as compared to Asia should be even better than captured in the Asia-Pacific RCI/Australian RCI ratio.

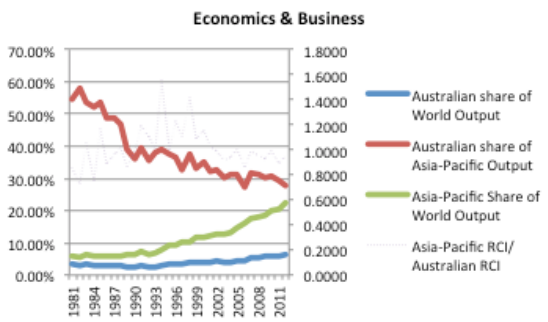


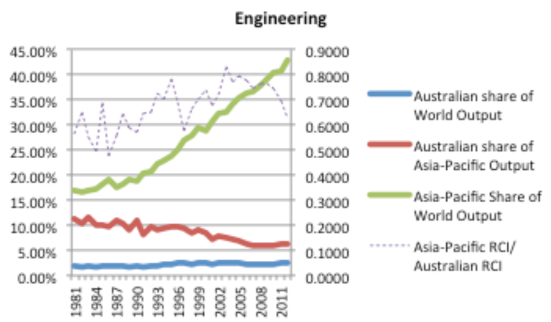


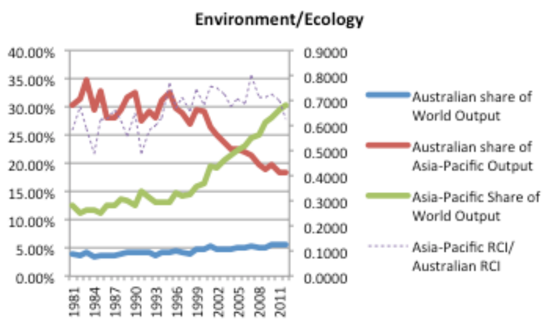






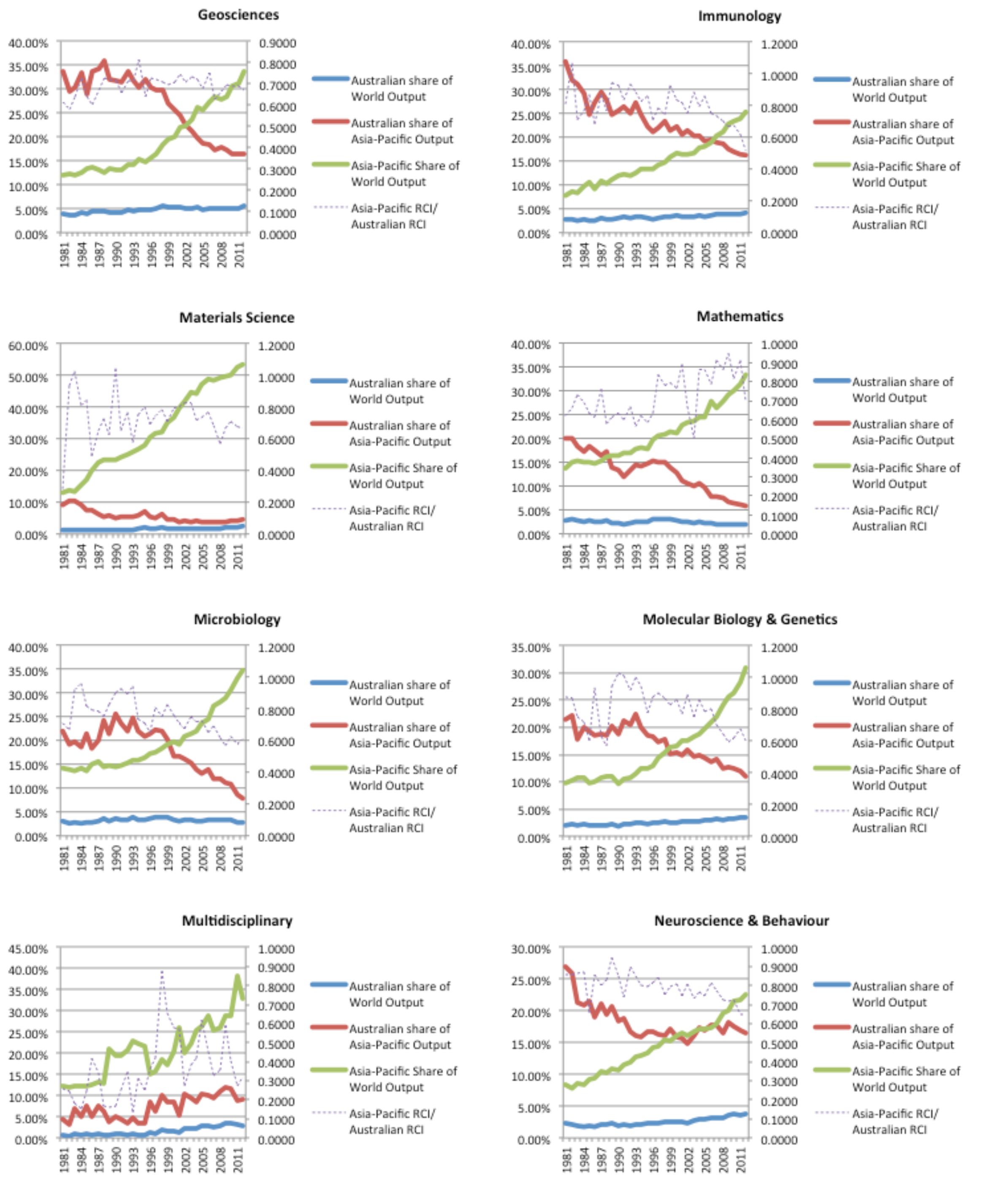






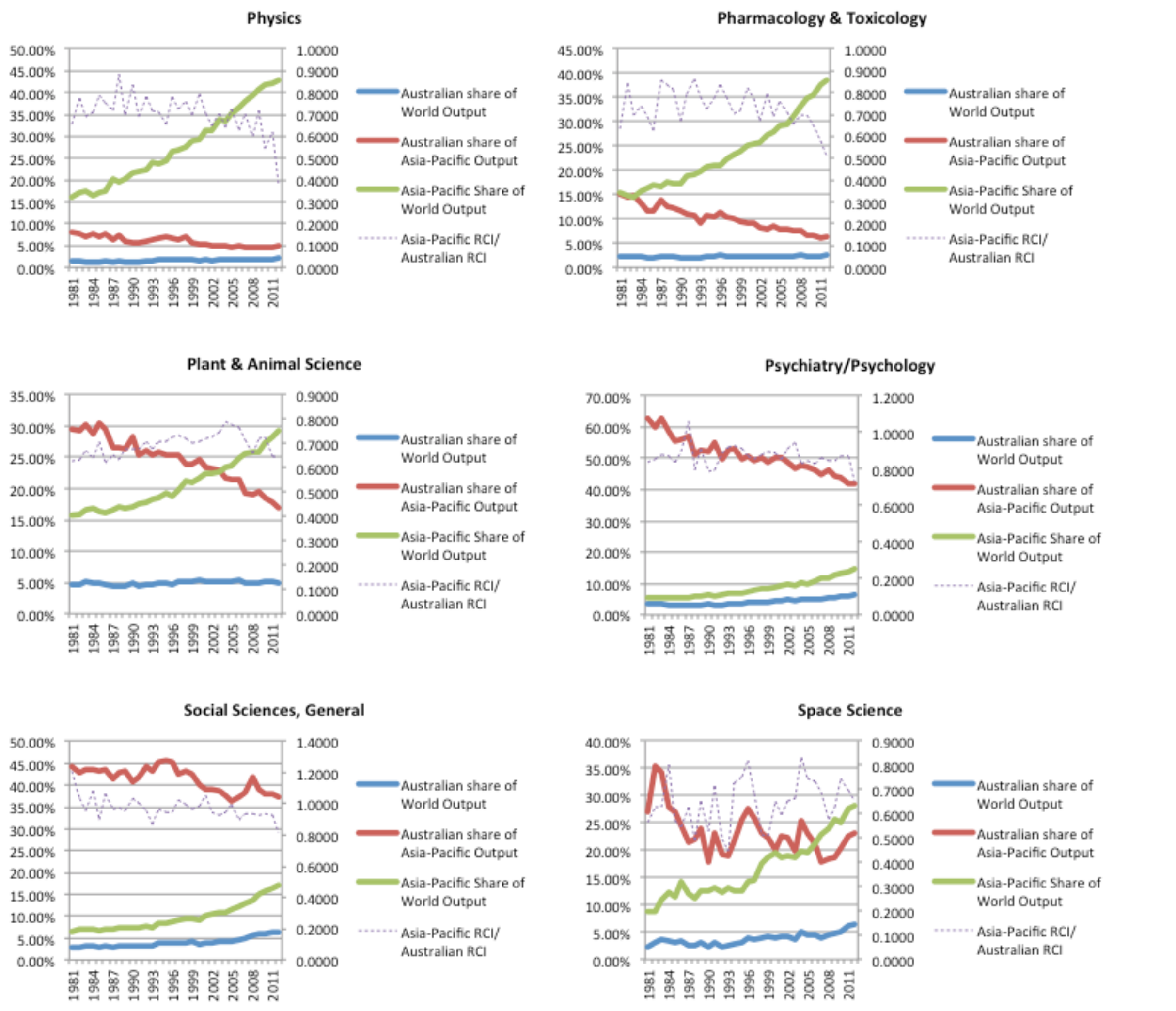
Sources: Graphs and underlying analysis generated by the authors using Thomson-Reuters *InCites*™ data downloaded in May 2014.

Exhibit 2: The growing prominence of Asia-Pacific in the global research effort (part 2)



Sources: Graphs and underlying analysis generated by the authors using Thomson-Reuters *InCites*™ data downloaded in May 2014.

Exhibit 3: The growing prominence of Asia-Pacific in the global research effort (part 3)



Sources: Graphs and underlying analysis generated by the authors using Thomson-Reuters *InCites*™ data downloaded in May 2014.

The ramifications of the broadening and deepening of global science and innovation

The importance of international collaboration in driving progress in science and research continues to strengthen. This reflects the potency of combining complementary intellectual expertise and resources.

These shifts involve a broadening and a deepening of activities.

Activities are broadening because more countries are involved, often at higher levels of intensity in an expanding range of research fields. This increasing prominence of Asian nations in this broadening is especially evident. Activities are deepening because the intensity of collaboration between countries is increasing, and more channels for disseminating findings are made possible as traditional printed academic modes of dissemination are augmented by various online mechanisms – many with open access. The resulting increase in the complexity of science and research poses challenges for policymakers seeking to prioritise the allocation of scarce resources.

From Australia's perspective critical questions now include:

- How do we achieve cost-effective international engagement in science and research?
- How do we map, and understand the implications of, our strengths and capacities in science and research?
- How can we maximise Australia's contribution to shared societal challenges at an international level?
- Which new capabilities should we seek to develop?
- What sort of role in leading and facilitating international collaboration should Australia seek to achieve given our physical location and capabilities?

Profile of Australia's current policy settings and engagement

Australia does not currently have a science and research diplomacy strategy. However, there is now growing momentum to establish a broader science and research strategy. In April 2013, Australia's Chief Scientist proposed that such a strategy could be useful, stressing the need to "provide a coherent framework for science and technology related policies and programs" (Office of the Chief Scientist 2013). That argument stemmed from previous reports recognising the need for further engagement on science matters, including the *Science Engagement and Education* Report published in 2003 and the *Inspiring Australia: A National Strategy for Engagement with the Sciences* Report published in 2010. However, these reports have focused on raising awareness of science, and of the government's strong commitment toward supporting science and research (Department of Innovation 2009), rather than on developing a science and technology strategy per se.

In 2012, the *National Research Investment Plan* set out a comprehensive national research investment planning process. Whilst this Plan recognised that some 97 per cent of global research occurs outside Australia, and that Australia "must engage with the international science community and access knowledge, research expertise and infrastructure that is not available in this country" (Department of Industry 2012a), it did not articulate an international engagement strategy. The *National Research Investment Plan* did, however, highlight Australia's research priorities and challenges. Identified societal challenges included (Australian Government 2012):

- Living in a changing environment;
- Promoting population health and wellbeing;
- Managing food and water assets;
- Securing Australia's place in a changing world; and
- Lifting productivity and economic growth.

15 research outcomes were covered broadly under the Strategic Research Priorities released by the government, which tied into the societal challenges identified above (Australian Government 2012):

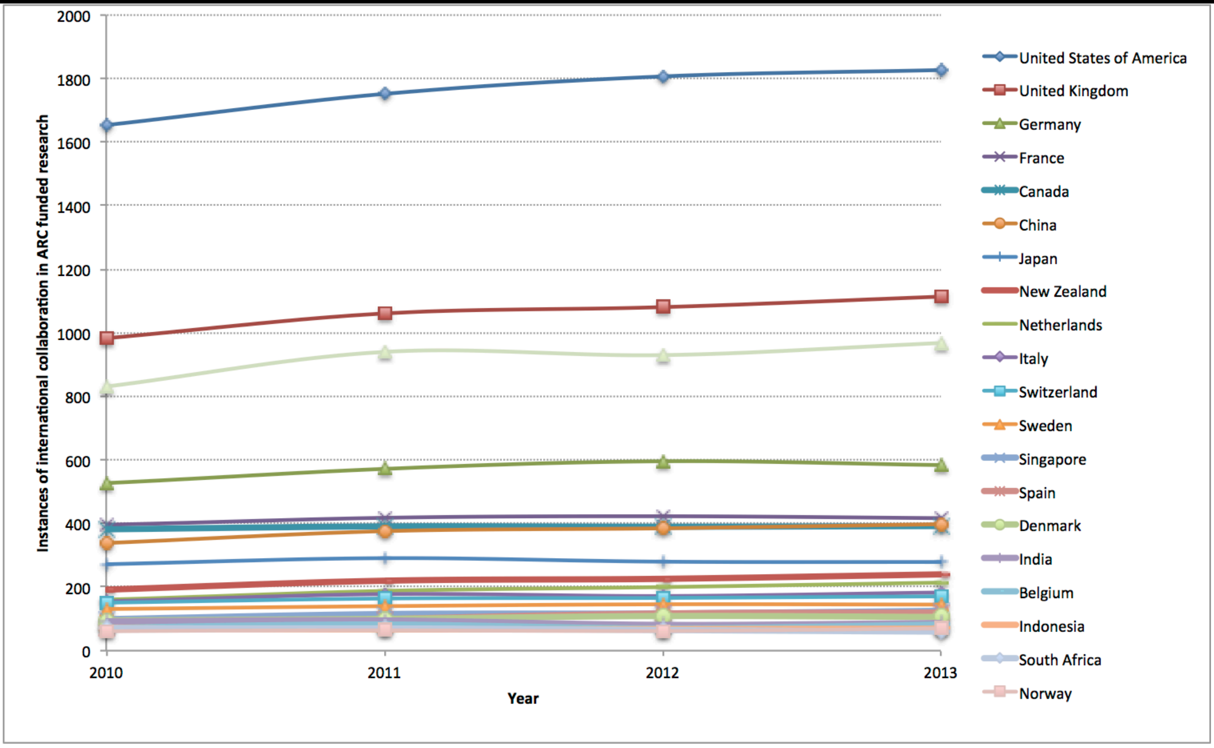
- Identify vulnerabilities and boundaries to the adaptability of changing natural and human systems;
- Manage risk and capture opportunities for sustainable natural and human systems
- Enable societal transformation to enhance sustainability and wellbeing;
- Optimise effective delivery of health care and related systems and services;
- Maximise social and economic participation in society
- Improve the health and wellbeing of Aboriginal and Torres Strait Islander people
- Optimise food and fibre production using our land and marine resources
- Develop knowledge of the changing distribution, connectivity, transformation and sustainable use of water in the Australian landscape
- Maximise the effectiveness of the production value chain from primary to processed food;
- Improve cubersecurity for all Australians;
- Manage the flow of goods, information, money and people across out national and international boundaries;
- Understand political, cultural, economic and technological change, particularly in our region;
- Identify the means by which Australia can lift productivity and economic growth;
- Maximise Australia's competitive advantage in critical sectors; and
- Deliver skills for the new economy.

These very broad outcomes were to cover cross-cutting themes such as the environment, resources, health, food, energy and competitive industries (Department of Industry 2012a).

Infrastructure for international engagement

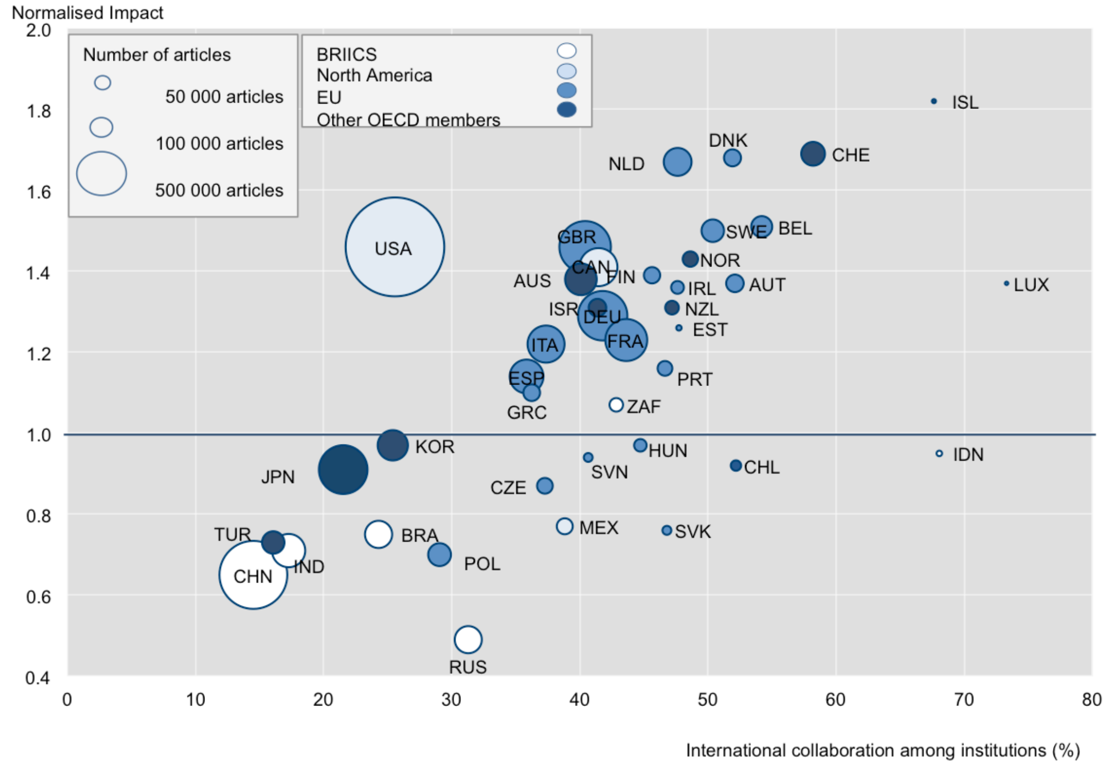
The key driver of formal support for international research collaboration at the Australian government level is the Australian Research Council (ARC) *National Competitive Grant Program* (NCGP), and to a lesser extent the National Health and Medical Research Council (NHMRC) grant schemes. Figure 3 shows that there is substantial international collaboration on ARC-funded projects, although collaboration is still dominated by partnerships with US academics, and to a lesser extent, UK academics.

Figure 3: International collaboration in ARC funded projects



Source: Graph generated by authors from Australian Research Council (ARC) data

Figure 4: Scientific production and the extent of international scientific collaboration, 2003-2011



Source: (OECD 2013b) Note: Data drawn from OECD and SCImago Research Group (CSIC), *Compendium of Bibliometric Science Indicators 2014*, based on Scopus Custom Data, Elsevier, May 2013

The Department of Industry provides funding to support research and science collaboration between Australia and two of its key partners in the region, India and China, through the *Australia-India Strategic Research Fund* (AISRF) and *Australia-China Science and Research Fund* (ACSRF). These programs are managed and co-funded in a collaborative manner with counterpart agencies in India and China.

In addition, the Department of Foreign Affairs and Trade (DFAT) provides funding under the *Government Partnerships for Development* (GPfD) program for capacity building and development activities in the Indo-Pacific region. While activities under this program are unlikely to deliver high impact research, they are also nurturing long-term research connections with developing countries in the region, and showcasing Australia's capabilities in particular sectors.

To support international research collaboration and education outreach, the Department of Education, through Australian Education International (AEI), has a network of around nine Counsellors in strategic Embassies and High Commissions throughout Asia (and also in Washington DC and Brussels). The mandate for these Counsellors is to manage the government's engagement with partner countries on education and science matters. These various grant schemes, along with AEI's international network and other reoccurring (and one-off) diplomatic engagement initiatives, are currently the key instruments of Australia's international science and technology research engagement.

State of Australia's international science collaboration

Taking into account the size of Australia's research sector, Australia's performance is average when it comes to international collaboration. Figure 4 shows that Australian research institutes collaborate internationally on around 40 per cent of publications. Contrasting levels of international collaboration and Relative Citation Impact (RCI) - what the OECD refers to as 'normalised impact' - "it appears that in small developed nations… high levels of R&D support go hand-in-hand with international collaboration and result in high impact research results" (Pettigrew 2012). A populous country such as the United States may have sufficient academic critical mass within its own research sector to generate a high RCI, but Australia is not in the same position. Therefore, whilst Australia performs well in comparison to its developed North-east Asian neighbours Japan and South Korea, it could potentially improve its RCI standing by increasing its international collaborative outputs. Table 1 reinforces this point by suggesting that Australia's growing share of the world's top 1 per cent highly cited publications can be partly attributed to international collaboration, particularly in the natural sciences and engineering. See also Figure 10.

Table 1: Quality measures of Australia's research publications and attribution to domestic and international collaboration

Indicators

	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012
Share of World Publications	*2.46*	*2.77*	*2.89*	*2.92*	*2.97*	*3.03*	*3.10*	*3.20*	*3.29*	*3.39*
Number of fields with higher than world average citation rate by field	*10*	*13*	*16*	*17*	*17*	*17*	*18*	*19*	*20*	*21*
Citations per publication	*3.08*	*3.90*	*4.94*	*5.08*	*5.29*	*5.57*	*5.75*	*6.00*	*6.22*	*6.36*
Share of world's top 1% highly cited publications in natural sciences and engineering				*3.79*	*3.99*	*4.42*	*4.87*	*5.14*	*5.43*	*5.49*
Share of world's top 1% highly cited publications attributed to international collaboration in natural sciences and engineering				*1.31*	*1.46*	*1.72*	*1.94*	*2.16*	*2.47*	*2.49*
Share of world's top 1% highly cited publications in social science and the humanities				*2.65*	*2.98*	*3.54*	*4.31*	*4.66*	*4.79*	*5.14*
Share of world's top 1% highly cited publications attributed to international collaboration in social science and the humanities				*0.86*	*1.14*	*1.21*	*1.47*	*1.48*	*1.75*	*2.07*

Source: (Department of Industry 2013) Note: Data drawn from *InCites*™ and Thomas Reuters in 2012.

It is therefore promising that there is substantial growth in research collaboration between Australia and key Asian countries – Australia is deepening its collaboration with Asia faster than the United States (and on average) the rest of the world (see Table 2). By 2010, China ranked as Australia's third ranked science publication partner, while Australia ranked as China's sixth, higher than would be expected based on Australia's global rank as 12th largest producer of scientific papers (Department of Industry 2013). By 2012, China became Australia's major collaborating partner in several fields of research including mathematics, chemistry and engineering (Office of the Chief Scientist 2012).

Australian researchers have also been actively engaging researchers from other Asian countries. As of 2010, Australia is also Japan's 9th ranked publication partner, India's 10th ranked publication partner, and South Korea's 9th ranked publication partner (Department of Industry 2013).

Impediments and Limitations

There is substantial scope for improving Australia's current science and research international engagement performance. The current infrastructure for international collaboration is relatively unfocused, given the lack of the national science and technology strategy, and also the government's broad scoping and defining of key thematic areas for science and research engagement. Australia's current identified societal challenges provide a basis for engagement, but are also still too broad to provide any substantial research focus.

Another limitation of the existing engagement infrastructure is its focus on bilateral rather than multilateral relationships. The AISRF and ACSRF focus on developing collaboration between Australia and one of two partner countries, while the GPfD preferences applications focused on one partner country (or a small grouping). The focus is often on benefits for partner countries and Australia, rather than on potential collective benefits for the wider region.

By virtue of the strength of its academic and research sector, Australia has positioned itself very well to be a node within several key clusters of collaborating countries on particular key issues and themes. There is therefore substantial room for a strategy for engagement in science and research to generate useful additional benefits. By capturing both the degree of convergence between the policy priorities and challenges of different countries (see below and Appendix A: Country Profile Snapshots), and also the relative capacities of different countries in different sectors, we can foster a system of bilateral collaborative relationships designed to exploit the opportunities and risk mitigation advantages created by broader multi-nation clusters of collaborative activity. Australia can take advantage of its situation by becoming a proactive actor in international science collaboration, at exactly the right place and time.

Table 2: Change in collaboration (as measured in multiples from 1995-2010) globally, and among Australia, the United States, and a sample of Asian countries

World	World	*Multiple*	Australia	*Multiple*	United States	*Multiple*
1995	*79,128*		*3,940*		*36,361*	
2010	*185,303*	*2*	*13,188*	*3*	*79,581*	*2*
United States						
1995	*36,361*		*1,448*		*N/A*	
2010	*79,581*	*2*	*4,223*	*3*	*N/A*	
China						
1995	*2,914*		*161*		*1,112*	
2010	*24,164*	*8*	*1,815*	*11*	*10,917*	*10*
India						
1995	*1,583*		*48*		*606*	
2010	*6,033*	*4*	*330*	*7*	*2,021*	*3*
Japan						
1995	*7,554*		*225*		*3,603*	
2010	*15,144*	*2*	*694*	*3*	*5,587*	*2*
Singapore						
1995	*359*		*36*		*106*	
2010	*3,424*	*10*	*404*	*11*	*1,062*	*10*
South Korea						
1995	*1,283*		*821*		*21*	
2010	*8,064*	*6*	*4,342*	*5*	*270*	*13*

Sources: (National Science Board 2012; Office of the Chief Scientist 2012). Note: This is looking at number of collaborative publications per year.

Summary of science and research systems, policy priorities and challenges in Asia and the Pacific

Asia and the Pacific is a vast and varied region, with countries at various stages of economic and scientific development. Some countries, such as Cambodia, are classed as underdeveloped countries and do not have a strong science and research base. Cambodia is still designing its S&T policy, where we can expect that building human and institutional capital across a range of sectors will be the priority focus (Turpin & Magpantay 2010). Timor Leste is perhaps in a more novel position, having, like Cambodia, suffered from recent political conflict and turmoil but also needing to develop new institutions since independence. On the other side of the spectrum, Singapore is emerging as a leading niche S&T power, particularly in the fields of biotechnology and medical research, while Japan retains its position as part of the core global S&T trifecta (the other two cores being the United States and the European Union). In between these two extremes on the spectrum lie a number of developing countries - such as Malaysia, Indonesia and Thailand. The (re) emergence of China and India as global powers adds further complexity to the mix, especially given that the size of their economies (and research potential) significantly dwarfs that of their neighbours in the region. It is therefore not surprising that the countries in the region exhibit huge variation in the development of their science and research systems, and also in science and research priorities and associated emphases in investment.

Below we provide a brief overview of key salient points and trends regarding Asian science and research systems, science and research collaboration, policy priorities and challenges, before moving on to some comments on cross-cultural considerations. Snapshots of particular countries of interest to Australia, and also some representative ASEAN countries, are provided in Appendix A to showcase the diverse array of science and research policies across the region.

Regional science and research systems

Overall, it is possible to highlight some key salient points regarding Asian science and research systems:

1) **Stated priorities are generally more focused in S&T than in the humanities and social sciences (HASS).** This is primarily due to the focus on economic development and growth across many of these countries, where it is perceived that S&T and innovation are intertwined, and where the commercialisation of R&D outputs is paramount. Even in the more developed countries (eg Japan, South Korea and Singapore), HASS does not seem to be a major focus. One might argue that this is slowly changing in the face of a number of growing long-term challenges (see Table 4), but national governments are still, on the whole, prioritising S&T. It is perhaps useful that the Australian Academy of the Humanities has just, as of July 2014, received a grant to 'map the humanities in the Asia region'.
2) **Very different science and research governance models exist**, ranging from the socialist model of central planning to the more liberal approach associated with particular science and research systems. The latter liberal approach is often defined as a *technoliberalism* approach, whereby there is minimal state intervention and where liberalism, privitisation and deregulation has been emphasised (Posadas 1999). Singapore, Thailand and the Philippines are often countries identified as having taken a *technoliberalism* approach, having relied heavily on technology transfer (Schuller et al. 2008). Japan, South Korea and Taiwan are often argued to have followed a strategy of *technonationalism*, where there has been a lot of emphasis into the development of national technological competence and a general aversion toward dependence on foreign technology. Malaysia and Indonesia, and later on China and India, have all taken a relatively mixed approach.
3) **Institutional challenges within science and research systems vary widely.** For example, Thailand has relatively ineffective supra-ministerial cross-cutting policy processes and a lack of co-ordinating mechanisms, making it difficult for the Ministry of Science and Technology to coordinate with economic ministries such as the Ministry of Industry (UNESCO 2010). This is unlike the systems in place in Australia, Japan and South Korea.
4) On the whole, **S&T policy has become integrated with innovation policies** as countries seek to use science to drive economic competitiveness and development. Tied to this, and as Mouton posits, funding support to HASS varies widely under the different science and research systems (Mouton 2007). A key challenge will be to ensure that science policy is not subsumed under innovation policy – to ensure that public good outcomes that do not have tangible private sector benefits are still pursued.
5) **There is growing alignment between national medium-long term challenges and identified strategic research priorities** – with the improvement of institutional and human capital across the region, there is recognition that effective S&T priorities are the key to addressing medium-long term challenges across many countries.
6) **The role of universities in knowledge production is variable**, due to a lack of sustained investment in university R&D and small cohorts of qualified researchers and scientists in many countries. Government Research Institutes (GRIs), Private Research Institutes (PRIs) and multilateral organizations are as, if not more, critical than universities within many science and research systems.
7) **Funding mechanisms for R&D are equally variable**, with different countries illustrating varied levels of direct government support for research – some countries continue to facilitate

private sector R&D investment, while others push substantial government resources into R&D around key strategic themes and issues. Some underdeveloped and developing countries are reliant on external and multilateral funding for R&D. (See Table 3)

8) There is **a growing focus on policies to promote and manage cross-sector R&D**, through programs such as collaborative funding schemes and initiatives similar to Australia's Cooperative Research Centres (CRCs) program.

International Science and Research Collaboration

With globalisation, the communications revolution and the emergence of the tiger economies and now China and India in Asia, collaboration in science and research is growing rapidly throughout the region. Overall, it is possible to highlight some key salient points regarding international science and research collaboration:

1) **Global integration is diversifying the array of international cooperation partners**. With an increasing number of countries developing strong S&T capabilities, policy makers and scientists increasingly look around to cooperate with partners with leading global positions in specific research fields.

2) **All countries are still, at some level, dependent on the science and research systems of the United States, the European Union and Japan**; given these countries' strong S&T capabilities and relatively large research and academic communities.

3) **The formula for international science and research collaboration strategies across most regional countries is pretty similar**. For example, China, Japan and South Korea are taking the same approach toward science and research cooperation and collaboration – focusing on global joint research, highlighting the characteristics of regional S&T cooperation, participating actively in international organisations and programs, expanding exchange cooperation agreements, and securing S&T globalization investment and improving domestic efficiency.

4) Differences in the form of, and the rationale for, international science and research collaboration are due to different countries' development situations. Broadly speaking, underdeveloped and developing countries (eg Cambodia, Bangladesh, Pacific island countries) are more likely to engage in exchanges facilitating technology transfer, and technical and human capital expertise. These countries would be more open to development support (in terms of ODA) and are therefore more susceptible to S&T and soft power diplomacy. Developing countries (eg China, Malaysia and India) are still seeking technology transfer, but are prioritising indigenous innovation and hoping to reduce their dependence on foreign technologies. Fully developed countries (eg Singapore and Australia) are primarily looking to link in with hubs of excellence in particular research fields.

5) **The competition for attracting the best scientists and engineers has intensified**. With various countries competing to be leaders in particular strategic fields (such as in medical research), individual science and research systems are finding it difficult to attract world-class talent. Even Singapore, a hub for medical research, has a shortfall in human capital. With global migration increasingly easier, the issue of '**brain drain'** remains paramount for underdeveloped and developing countries attempting to build up coherent S&T capabilities.

6) **China and India are having a marked impact on regional science and research capacity**, and other regional countries are increasingly looking to their science and research strategies before framing their own around them. The potential impact that both countries will have on the science and research arena once their capabilities are truly world-class is immense. Countries in the region are cognisant of this – for example, the 2005 RAND Report on Korea's 'Strategic Choices in Science and Technology', commissioned by the Korea Institute of Science and Technology Evaluation and Planning, was entirely framed around 'China's rise' (Seong et al. 2005). In Australia, mining-related R&D has been facilitated through the Chinese and Indian driven commodities boom (UNESCO 2010).

7) **National policy preferences will guide but will not determine the academic agendas and preferential collaborative partners of individual scientists and academics.** Many tend to pursue their own academic agendas irrespective of national policy preferences, and academics and scientists in less developed countries tend to rely on established contacts with

former colleagues and supervisors abroad due to a lack of information on international funding possibilities and lack of access to scientific networks (Schuller et al. 2008).

8) **Historical and colonial ties substantially influence the choice of international science and research collaborative partners**. While Schüller et al. make the case that the importance of historical (and colonial) S&T ties are starting to diminish (Schuller et al. 2008), it is clear that these former ties still heavily explain the choice of collaborative partnerships. For example, Indonesia still has strong research ties to the Netherlands, Singapore to both the United Kingdom and Japan, and Vietnam to Western Europe (from the colonial era) and Eastern Europe and Russia (as part of the former Communist bloc). Diasporas are also important, as reflected in the Chinese academic diaspora's strong tendency to collaborate with academics and scientists still based in China.
9) **Academic and science and research collaborative networks are often created through academic and student exchange programs** and students opting to study in a foreign country. Many co-authored papers between the United States and Asian countries are between former colleagues. Strong alumni networks could be effective mechanisms for delivering effective S&T collaboration down the track. The Australian Department of Innovation recognised this when it argued that 'the large number of Chinese students studying in Australia has the potential to develop networks that assist future collaborative efforts' (Department of Industry 2011).
10) **Language proficiency, and particularly proficiency in English as the primary language of academia, is a large determining factor for collaboration and in the mobility choices of scientists** – the Anglo-Saxon countries (the United Kingdom, the United States, Australia and Canada) have a large advantage due to shared language. Many international researchers have cited language as a major barrier to working in Japan and South Korea, and both of these countries, although technologically advanced, have a much lower proportion of international researchers in permanent roles in comparison to other countries, and also have lower rates of S&T collaboration compared to actual potential. (Department of Industry 2012b; Ko 2013).

Shared challenges and areas of policy alignment in the region

1) **There is growing attention being paid to climate change, sustainable development, and green and renewable energy**, partly driven by the market but also through global and public debate and expectations.
2) **Key strategic areas are seen as driving forces for R&D on the global stage, and as areas where international science and research collaboration can facilitate the delivery of global public goods**. Singapore has aptly taken the lead on identifying some of these core driving forces, which the city-state argues includes: aging, renewable energy, climate change and sustainability, urbanisation, infectious diseases, food security, and water supplies. Table 4 illustrates a rough list of identified research and science and research thematic priorities of key Asian countries – this, combined with the common and shared challenges many of these countries face, provide a basis for arguing for increased international science and research collaboration.
3) **Australia is already substantially engaged in science and research collaboration across the region**, much of it driven by individual universities and research institutes. For example, the University of Sydney has the 5th most co-authored papers of any international institution with Chinese institutions, while University of Melbourne has the 8th most with India and 12th most with Japan (Adams, King & Ma 2009; Adams, King & Singh 2009; Adams et al. 2010). Among the Pacific island countries, Australia is a, if not the, lead science and research collaborative partner country. These extensive connections could be even further leveraged with regional and European/American universities to bring in broader networks of top-tier talent.

Table 3: Gross domestic expenditure on research and development, and source of expenditure

Country	GERD		Source of R&D		
	2000 (% of GDP)	Latest (% of GDP)	Government	Business	Other (including private non-profit and private higher education)
China	*0.9*	*1.98 (2012)[&]*	*21.6% (2012)*	*74% (2012)*	*4.4% (2012)*
Japan	*3.0*	*3.35 (2012)[&]*	*16.4% (2011)*	*76.5% (2011)*	*7.1% (2011)*
South Korea	*2.3*	*4.36 (2012)[&]*	*24.9% (2011)*	*73.7% (2011)*	*1.4% (2011)*
India	*0.7*	*0.8 (2007)*	-	-	-
Indonesia	*0.1*	*0.1 (2009)*	*84.5% (2001)*	*14.7% (2001)*	*0.8% (2001)*
Singapore	*1.9*	*2.04 (2012)[&]*	*38.5% (2012)*	*53.4% (2012)*	*8.1% (2012)*
Malaysia	*0.5*	*0.6 (2006)*	*41.4% (2011)*	*55% (2011)*	*3.6% (2011)*
Vietnam	-	-	*74.1% (2002)*	*18.1% (2002)*	*7.8% (2002)*
Cambodia	-	-	*17.9% (2002)*	-	-
Philippines	-	*0.1 (2007)*	*26.1% (2007)*	*62% (2007)*	*11.9% (2007)*
Thailand	*0.3*	*0.2 (2007)*	*37.9% (2009)*	*41.4% (2009)*	*20.7% (2009)*
Australia	*1.6*	*2.19 (2010)[&]*	*34.6% (2008)*	*61.9% (2008)*	*3.5% (2008)*

Sources: (Economic and Social Commission for Asia and the Pacific 2013; Anon 2014b) [&](OECD StatExtracts 2014)

Table 4: Priorities and Challenges of selected countries

Country	Column A: Identified Research and S&T thematic priorities	Column B: Some long term challenges
China	Advanced manufacturing; agriculture; information and communication technologies; resource management; water management; renewable and low-carbon energy; social welfare issues; environmental issues	Aging population; managing mobility and urbanisation; environmental degradation; reducing dependence on technology transfer from developed countries; managing energy needs; sustainable and inclusive growth; food and water security; healthcare system
Japan	Green innovation; renewable and low-carbon energy; promotion of life innovation (focus on medical research, disease diagnosis and prevention)	Aging population; decreasing population; loss of social and economic vitality, downward trend of industrial competitiveness; managing energy needs; healthcare system; attracting and maintaining human capital
South Korea	Green innovation; renewable and low-carbon energy; information and communication technologies, nano technology and biotechnology	Aging population; managing energy needs; attracting and maintaining human capital; healthcare system
India	Space, nuclear and defence; information and communication technologies; biotechnology; agriculture; energy; health and drug discovery; materials; environmental issues; climate variability and change	Harnessing a demographic dividend; managing mobility and urbanisation; environmental degradation; reducing dependence on technology transfer from developed countries; managing energy needs; sustainable and inclusive growth; food and water security; human capital; transport infrastructure
Indonesia	Climate change; global warming; deforestation; environmental issues; natural disaster mitigation	Managing mobility and urbanisation; infrastructure; environmental degradation; reducing dependence on technology transfer from developed countries; sustainable and inclusive growth; food and water security; human capital; managing energy needs; transport infrastructure

Country	Column A: Identified Research and S&T thematic priorities	Column B: Some long term challenges
China	Advanced manufacturing; agriculture; information and communication technologies; resource management; water management; renewable and low-carbon energy; social welfare issues; environmental issues	Aging population; managing mobility and urbanisation; environmental degradation; reducing dependence on technology transfer from developed countries; managing energy needs; sustainable and inclusive growth; food and water security; healthcare system
Japan	Green innovation; renewable and low-carbon energy; promotion of life innovation (focus on medical research, disease diagnosis and prevention)	Aging population; decreasing population; loss of social and economic vitality, downward trend of industrial competitiveness; managing energy needs; healthcare system; attracting and maintaining human capital
South Korea	Green innovation; renewable and low-carbon energy; information and communication technologies, nano technology and biotechnology	Aging population; managing energy needs; attracting and maintaining human capital; healthcare system
India	Space, nuclear and defence; information and communication technologies; biotechnology; agriculture; energy; health and drug discovery; materials; environmental issues; climate variability and change	Harnessing a demographic dividend; managing mobility and urbanisation; environmental degradation; reducing dependence on technology transfer from developed countries; managing energy needs; sustainable and inclusive growth; food and water security; human capital; transport infrastructure
Indonesia	Climate change; global warming; deforestation; environmental issues; natural disaster mitigation	Managing mobility and urbanisation; infrastructure; environmental degradation; reducing dependence on technology transfer from developed countries; sustainable and inclusive growth; food and water security; human capital; managing energy needs; transport infrastructure
Singapore	Biomedical sciences; information and communication technologies; engineering; and chemicals and energy	Managing mobility and urbanisation; attracting and maintaining human capital
Malaysia	Advanced manufacturing; advanced materials; microelectronics; biotechnology; information and communication technologies; energy, aerospace; nanotechnology; photonics; and pharmaceuticals	Harnessing a demographic dividend; environmental degradation; reducing dependence on technology transfer from developed countries; healthcare system; transport infrastructure
Vietnam	Information and communication technologies; manufacturing; materials; automation and electronic-mechanic technologies; and environmental technologies	Harnessing a demographic dividend; managing mobility and urbanisation; infrastructure; environmental degradation; reducing dependence on technology transfer from developed countries; sustainable and inclusive growth; human capital; managing energy needs; development concerns
Cambodia	No S&T strategy document	Institutional and human capital; development concerns; environmental degradation; social welfare system; education system
Philippines	Biotechnology; information and communication technologies; agriculture and forestry; health and medicine; micro-electronics; materials; the environment; natural disaster mitigation; energy; and manufacturing and process engineering	Population growth; institutional and human capital; sustainable and inclusive growth; development concerns; environmental degradation; social welfare system; education system; loss of social and economic vitality, downward trend of industrial competitiveness; transport infrastructure
Thailand	Information and communication technologies; biotechnology; materials; and nanotechnology	Institutional and human capital; social welfare system; environmental degradation; transport infrastructure; sustainable and inclusive growth
Australia	Very broad priorities (see 'Profile of Australia's current policy settings and engagement')	Lifting productivity and economic growth; managing food and water assets; environmental change; attracting and maintaining human capital

Notes on Table 4: The information in Column A ("Identified Research and S&T thematic priorities") is drawn from the priorities identified in national S&T strategy documents. Refer to the individual country breakdowns in Appendix A (for Australia, refer to the 'Profile of Australia's current policy setting and engagement in Part I). This column focused on thematic priorities identified in these documents.

The information in Column B ("Some long term challenges") is a relatively brief overview of challenges identified by the authors through the process of putting together this Report – it illustrates that while individual countries face unique sets of challenges, there are a large number of common challenges that could benefit from regional research collaboration. Column B is not expected to be an exhaustive list of challenges facing each country. Some terms in Column B require further explanation: 'Harnessing a demographic dividend' refers to a country entering a time of 'demographic dividend', where a growing concentration of population in the working age bracket provides the opportunity for strong economic growth and development; and human capital refers to the stock of human knowledge and competency within a particular country, which is developed through education and capacity building (and often through skilled migration)

Part Two: Grasping the range of research outcomes from innovation to global public goods

Competition and collaboration

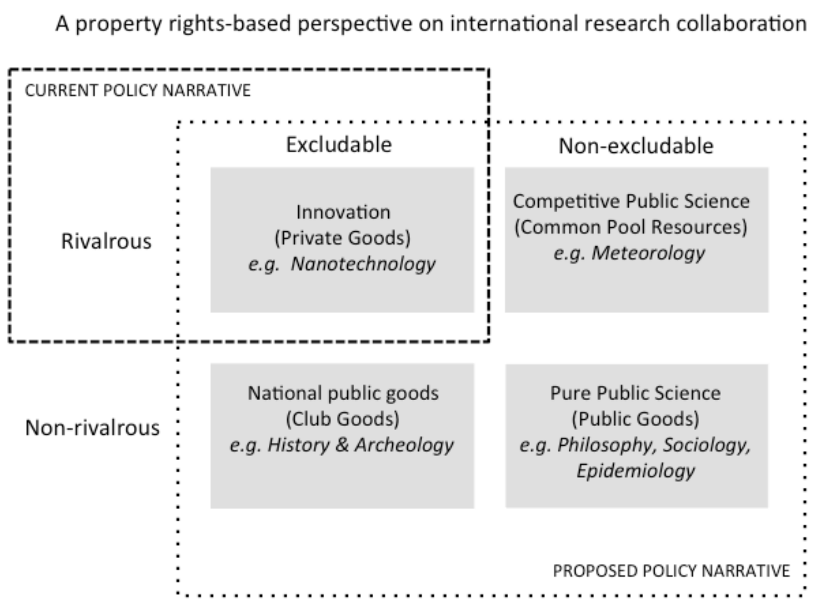
Contemporary discussions of science and innovation policy frequently refer to the need for different countries to 'compete', for instance in allocating adequate funding for research and experimental development (R&D) relative to other countries. These contemporary discussions also highlight the importance of international collaboration in research. It is also common for funding for public science to be subsumed under a broader emphasis on achieving 'innovation' objectives: resulting in a policy narrative that frequently overlooks how different public science is from innovation per se. The result can be confusing and can send mixed signals to the general community (are we trying to cooperate or compete with different countries?).

Towards a more comprehensive approach based on differing property rights

Given these circumstances, it may be useful to use an inclusive taxonomy that distinguishes between different types of research on the basis of property rights, in so doing encompassing innovation and public science. Figure 5 illustrates this point by distinguishing between academic research that is excludable and non-excludable and rivalrous and non-rivalrous. It draws on the sort of thinking used in political economy to arrive at a more nuanced understanding of how shared resources can be managed under particular conditions and thus avoid the 'tragedy of the commons' (Ostrom 1990).[2]

The diagram highlights: (a) the way in which the current policy narrative focuses tightly on innovation objectives (that are in essence excludable and rivalrous), and (b) the broader range of intended outcomes and associated property rights that would be covered by a more comprehensive (and accurate) policy narrative. This more comprehensive perspective is also relevant to cross-cultural capability in the sense that it provides a richer context for understanding diverse attitudes to intellectual property and associated socio-economic/cultural norms.

Figure 5: A framework for conceptualising research outcomes on the basis of property rights



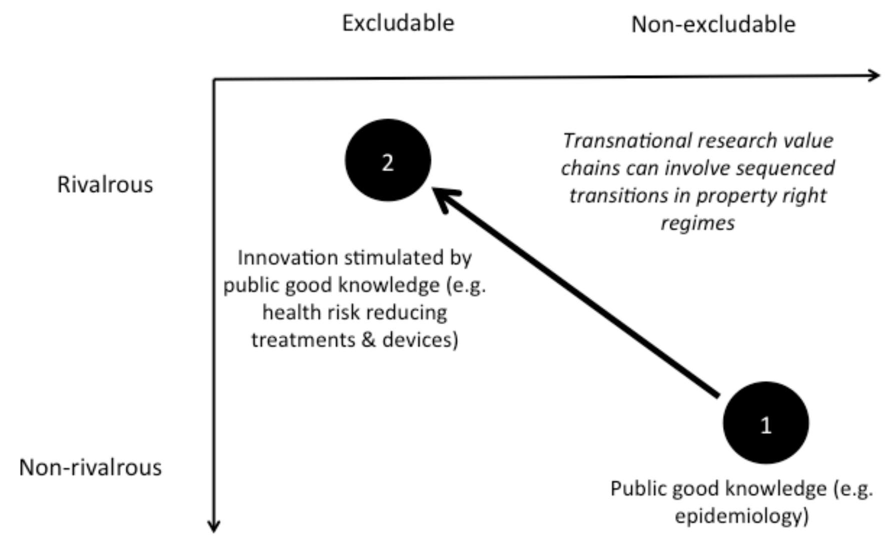
Sources: the authors (drawing on political economy research on Common Pool Resources).

[2] The 'Tragedy of the Commons' refers to the risk that in the absence of property rights, rational people pursuing individual self-interest will deplete shared natural (and other) resources, see (Hardin 1968). Elinor Ostrom's work demonstrated that the tragedy of the commons is not inevitable if those involved at the local level organise themselves to reduce this risk via developing exploitation rules that have certain well-specified characteristics.

Figure 6 illustrates how a transnational research cluster can involve transitions between different property rights regimes. In this case, public good knowledge in epidemiology relating to health risks drives (appropriable) innovation objectives.

The implications are that a strategy for international collaboration in research will be most robust (i.e. less likely to fail) if it adopts a more comprehensive approach to the different types of research that exist. Such an approach does not subsume science policy within innovation policy – rather it encompasses innovation and public science objectives.

Figure 6: How shifts in property-rights based outcomes take place



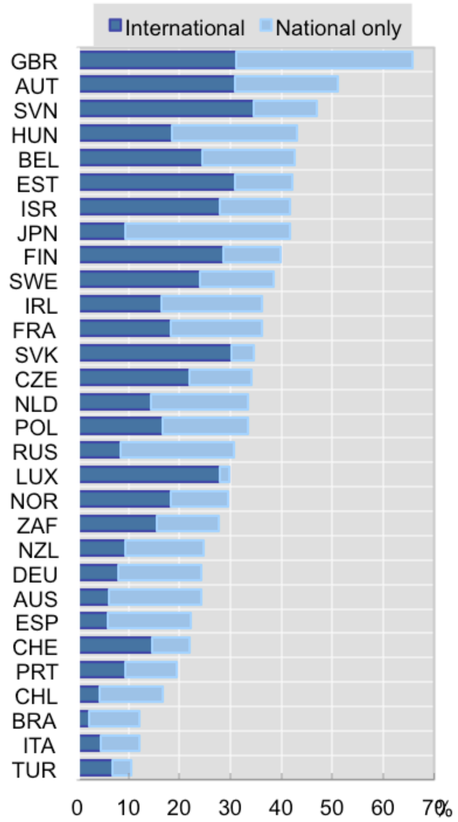
Sources: the authors (drawing on political economy research on Common Pool Resources).

This perspective recognises that international engagement in research involves a mix of competition and cooperation: a mix that can change over time and can also vary within transnational research clusters. This means that a medium sized country like Australia is able to play a globally significant role by making significant contributions to global public goods (via public science), that in turn can drive innovation achieved overseas – the benefits of which will accrue to Australians through new and improved products and services. In such an internationally inter-dependent system it makes little sense to frame science and innovation policy in national silos.

The challenge is to maximise the return on investment (framed in terms of public value rather than narrow commercial returns) by prioritising the most compelling transnational research clusters in this global context. The 'soft power' attained by playing a leading global role in public science can be of greater value to the national interest than the yield on seeking to be a low level contributor to the global innovation effort.

This strategy is especially important given that Australia also lags significantly behind many other countries in private-sector R&D collaboration – by nearly all accounts, Australia fares far worse in private-sector R&D collaboration than in science and research collaboration. Figure 7 shows that Australian firms do not collaborate very often with foreign partners (6.1 per cent) (they also do not collaborate very much within Australia (18.1 per cent) (OECD 2013b). Australia has a relatively low level of integration into the innovation value chain, with the Department of Industry suggesting only 1.6 per cent of all Australian firms engage in international collaboration on innovation (25th out of 26 OECD countries) (Department of Industry 2013). Given this, an international engagement strategy should continue to emphasise how collaborative research outcomes can make significant contributions to both global public goods and innovation. This can encourage both private-sector R&D collaboration and (more importantly) more private-public partnerships in R&D.

Figure 7: The mix of national and international collaboration in business innovation



Source: (OECD 2013b)

Knowledge spillovers, international collaboration networks and cross-cultural factors

A transnational research value chain can comprise both direct research collaborations and also indirect knowledge sharing by virtue of the knowledge spillovers that usually take place between discrete research projects. This is because it is common for advances in understanding achieved by particular research projects or scholarly activities (if not directly funded) to inform both future research (that may be conducted with different collaborators), or, inform concurrent research in which some of the collaborating researchers are involved – but potentially also with different research partners.

Knowledge spillovers in research and innovation are an acknowledged source of competitive advantage that has been highlighted in a range of economic analyses over recent decades. Recognising the role of these knowledge spillovers in international collaboration also has the advantage of opening up a channel for considering the opportunities and risks posed by cross-cultural considerations, which in turn stresses the role of Asia literacy. As tacit knowledge is best communicated face-to-face, these spillovers are only effective when cross-cultural factors are handled effectively. Conversely, poor cross-cultural capability does not just limit the effectiveness of these knowledge spillovers, it can also increase the risk of negative impacts (what economists call negative externalities) by misreading subtle culturally embedded signals and when making decisions. In short, a focus on transnational research value chains that recognises the importance of knowledge spillovers (as positive and, potentially, negative externalities) provides a means of placing Asia literacy centrally in the strategy and policy framework.

Although it is often difficult to obtain evidence on the scale/severity of problems associated with cross-cultural factors it is prudent to recognise the importance of this issue – and to try to ensure that policies and strategies pay due attention to this challenge. From the literature and also specific country strategies on international science and research collaboration, it is clear that cross-cultural understanding is a key element in successful science and research collaboration. The framework and modalities by which collaborative programs are designed is essential – failing to take into account cultural misunderstandings, preference and perceptions can be a recipe for failure.

It has been argued, for example, that ASEAN scientists find face-to-face monitoring more helpful than bureaucratic reporting procedures, the latter indicating a lack of trust; and that ASEAN scientists aim to work in long-term programs where as non-ASEAN scientists tend to look at short-term projects, case studies, and collection of samples and data (Schuller et al. 2008). For another example: In a survey of a number of Japanese multinationals, China was considered to be the most problematic of Japan's Asian neighbours to work with due to substantial cultural differences - the concepts of reciprocal obligations such as 'giri' and 'gimu' (obligations in terms of debt and duty) were argued to be accepted by Vietnamese and Filipino counterparts, but not so much by Chinese counterparts (Hirt 2012).

Bezanson, who laid the foundations for Vietnam's thinking on a national S&T strategy, kindly reminds us that Western (and Australian) concepts around science are often at odds with the Asian understanding of the role of S&T – he illustrated this by positing how many in Asia would argue that 'science played virtually no role in the technological and industrial advance in East Asia' and 'imitation [is seen as] the entry point to innovation'. These contrast with the Western preoccupation with invention and the centrality of R&D to technology learning (Bezanson 2000).

For an Australian example, Australia had an S&T cooperation partnership with ASEAN called the ASEAN Australia Development Cooperation Program (AADCP) from 2002-08, which funded a large number of S&T projects across many sectors aimed at promoting economic and social development and integration within the ASEAN region. While focused on capacity-building, the completion report nonetheless identified some key lessons useful for Australia, including 'the importance of greater engagement and participation with the private sector in project identification, preparation and implementation' and 'the need to ensure opportunities for leverage and synergies between research studies and project implementation are maximised' (Barber & Collett 2009).

Part Three: The complex pay-offs and risks associated with research collaboration

One way of thinking about international collaboration in science and research is to frame the costs, risks and benefits in terms of a 'pay-off' matrix (Matthews, Biglia & Murphy 2009). The basic form of such a matrix is presented in Figure 8.

This framework distinguishes between three types of collaboration scenario:

- forge ahead opportunities – a situation in which both parties are currently strong performers (RCIs above 1.0);
- pull-up opportunity and pull-down risk – two situations in which one party is a strong performer and one party is a weak performer; and
- catch-up opportunities – a situation in which both parties are weak performers.

It is important to stress that there is a strong rationale for bilateral collaboration in each of these four quadrants. The framework is therefore able to inform the bilateral element of international collaboration strategies. When forge-ahead opportunities exist both parties stand to gain by exploiting economies of scale and scope in these research fields together with other synergies between distinctive capabilities (such as research infrastructure assets). In such circumstances the potential benefits will tend to be fairly symmetrical, and as a result relatively unproblematic compared to the other scenarios. When a mix of pull-up opportunities & pull-down risks exist the situation is more asymmetric and potentially problematic. One party may stand to gain more than the other party. In this case it is important to be clear as to why the cooperation is prioritised, particularly in relation to other 'collateral benefits' in the diplomatic and trade domains. The long-term benefits of capacity-building associated with collaboration in the 'pull-up opportunity and pull-down risk' quadrants can often outweigh the short term opportunity costs faced.

Figure 8: Framing international collaboration in science and research as a payoff matrix

	Country Y Capability Index > 1.0	Country Y Capability Index < 1.0
Country X Capability Index > 1.0	X: Forge-ahead opportunity Y: Forge-ahead opportunity	X: Pull-down risk Y: Pull-up opportunity
Country X Capability Index < 1.0	X: Pull-up opportunity Y: Pull-down risk	X: Catch-up opportunity Y: Catch-up opportunity

Source: (Matthews, Biglia & Murphy 2009)

Figure 9 shows how this approach was implemented in relation to research cooperation between Australia and the European Union countries (treated as a whole) using Relative Citation Index as measure of relative capability (see (Matthews, Biglia, Henadeera, et al. 2009) for details). Note that this application of the method focuses on the EU-Australian research collaboration dimension because the work was supported by an EU-Australian science cooperation project (the Forum for European-Australian Science and Technology cooperation). These high-level estimates are provided simply in order to demonstrate that this sort of framework can be implemented empirically. It would ideally be used with more detailed data than reported here (at the 4 digit rather than 2 digit level).

Figure 9: Application of the collaboration payoff matrix to Australia – EU-27 collaboration

	EU-27 Strengths Relative Citation Impact > 1.1	EU-27 Borderline Relative Citation Impact 0.9-1.10	EU-27 Weaknesses Relative Citation Impact < 0.9
Australian Strengths **Relative Citation Impact > 1.1**	Geosciences Physics Plant & Animal Science	Clinical Medicine Ecology/Environment Education Mathematics Space Science	
Australian Borderline **Relative Citation Impact 0.9-1.1**	Agricultural Sciences	Biology & Biochemistry Chemistry Computer Science Engineering Immunology Materials Science Microbiology Molecular Biology & Genetics Multidisciplinary Science Neurosciences & Behaviour Pharmacology Psychology/Psychiatry Social Sciences, general	
Australian Weaknesses **Relative Citation Impact < 0.9**			Economics & Business Law

Source: (Matthews, Biglia & Murphy 2009)

This sort of capability gradient-based approach can also be used to infer international patterns in collaboration pay-offs using data on Relative Citation Performance. This is illustrated in Table 5, which uses traffic light-type colour coding to indicate whether Australia (and Canada, China, India and the United States) is likely to be achieve a 'pull-up' gain for a 'pull-down' opportunity cost from bilateral international collaboration (see (Matthews, Biglia & Murphy 2009)).[3]

[3] The data presented are for ecology/environment research alone. Due to restrictions on the data set by Thomson-Reuters more comprehensive data covering other research fields must be requested in writing from Mark Matthews.

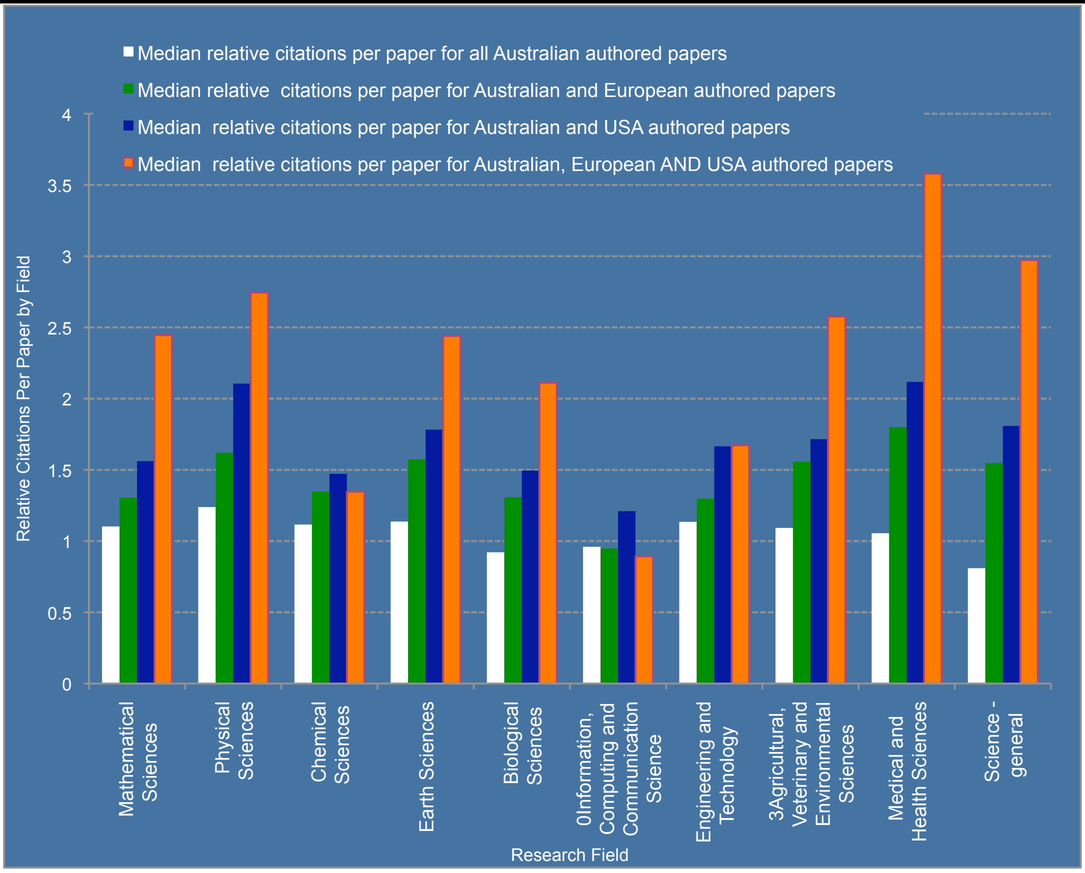
Table 5: Mapping of pull-up opportunities and pull-down risks between selected countries for ecology/environment research

	AUSTRALIA	CANADA	CHINA	INDIA	USA
SWEDEN	1.22	1.21	2.18	2.75	1.15
NETHERLANDS	1.18	1.16	2.10	2.65	1.11
DENMARK	1.16	1.14	2.06	2.61	1.09
UK	1.16	1.14	2.06	2.60	1.09
FINLAND	1.12	1.11	2.00	2.53	1.05
BELGIUM	1.12	1.11	2.00	2.52	1.05
NEW ZEALAND	1.11	1.10	1.99	2.51	1.05
USA	1.06	1.05	1.90	2.39	1.00
CANADA	1.01	1.00	1.80	2.28	0.95
LUXEMBOURG	1.01	1.00	1.80	2.27	0.95
AUSTRALIA	1.00	0.99	1.78	2.25	0.94
GERMANY	1.00	0.99	1.78	2.24	0.94
FRANCE	0.99	0.98	1.76	2.23	0.93
ESTONIA	0.96	0.95	1.71	2.15	0.90
AUSTRIA	0.95	0.94	1.70	2.15	0.90
EU-27	0.92	0.91	1.63	2.06	0.86
SOUTH AFRICA	0.90	0.89	1.60	2.02	0.84
MALTA	0.84	0.82	1.49	1.88	0.78
SPAIN	0.83	0.82	1.48	1.87	0.78
CZECH REPUBLIC	0.79	0.78	1.40	1.77	0.74
ITALY	0.78	0.78	1.40	1.77	0.74
PORTUGAL	0.78	0.78	1.40	1.77	0.74
LATVIA	0.73	0.72	1.30	1.65	0.69
ROMANIA	0.72	0.71	1.29	1.62	0.68
HUNGARY	0.70	0.69	1.24	1.56	0.65
GREECE	0.67	0.67	1.20	1.52	0.63
IRELAND	0.67	0.66	1.19	1.51	0.63
SLOVENIA	0.61	0.60	1.08	1.37	0.57
CHINA	0.56	0.55	1.00	1.26	0.53
BULGARIA	0.55	0.55	0.99	1.24	0.52
POLAND	0.49	0.48	0.87	1.10	0.46
CYPRUS	0.48	0.47	0.85	1.08	0.45
INDIA	0.44	0.44	0.79	1.00	0.42
SLOVAKIA	0.43	0.42	0.76	0.96	0.40
LITHUANIA	0.33	0.32	0.58	0.73	0.31

Source: Matthews et al unpublished analysis of national capability differentials by field of research

Figure 10 highlights one of the key aspects of transnational research value chains, the tendency for collaboration between researchers in several countries to yield superior citation performance to bilateral collaboration (see (Matthews, Biglia & Murphy 2009)). Note that these benefits from international collaboration stem from co-authorship with colleagues in scientifically advanced countries. A less positive impact takes place when collaboration with less advanced countries is involved. However, this sort of analysis is still incomplete because it does not satisfactorily decompose the pure 'scale' effect (a larger number of authors from different countries associated in particular with 'big science' projects, and access to unique research facilities such as CERN) from a national diversity effect (the impact of international collaboration per se). This sort of analysis is also sensitive to the way in which US-based researchers tend to have an RCI advantage, hence collaborating with US researchers lifts citation performance – as distinct from a pure 'international' collaboration effect.

Figure 10: Relative citation performance for bilateral and multilateral collaboration



Source: (Matthews, Biglia, Henadeera, et al. 2009)

These types of analysis of bilateral research collaboration are, however, an incomplete representation of reality because so much of global research is now of a multilateral nature. Once on shifts to a consideration of more complex transnational value chains these differences in research capability become less of an issue. This advantage is considered in the following section of the paper.

Part Four: Transnational value chains and the global research effort

The broader significance of global value chains for science and research

Public policy tends to be formulated around distinct themes: trade policy, industry policy, science and innovation policy, employment policy, business regulation etc. Whilst policymakers are fully aware of the important inter-connections between these different policy domains, these links tend not to be reflected in a more comprehensive policy stance.

Official statistics also tend to align with these policy domains. One consequence of the way in which official statistics are presented at the international comparative level is to reinforce a silo-based perspective, notably in relation to trade policy. The input-output tables that map each countries inter-industry sales, and the resulting pathways to final demand, are the closest that we get to an integrated approach, but these input-output tables are traditionally country-centric and do not link production via trade in all nations that have significant economic inter-dependecies (which most do).

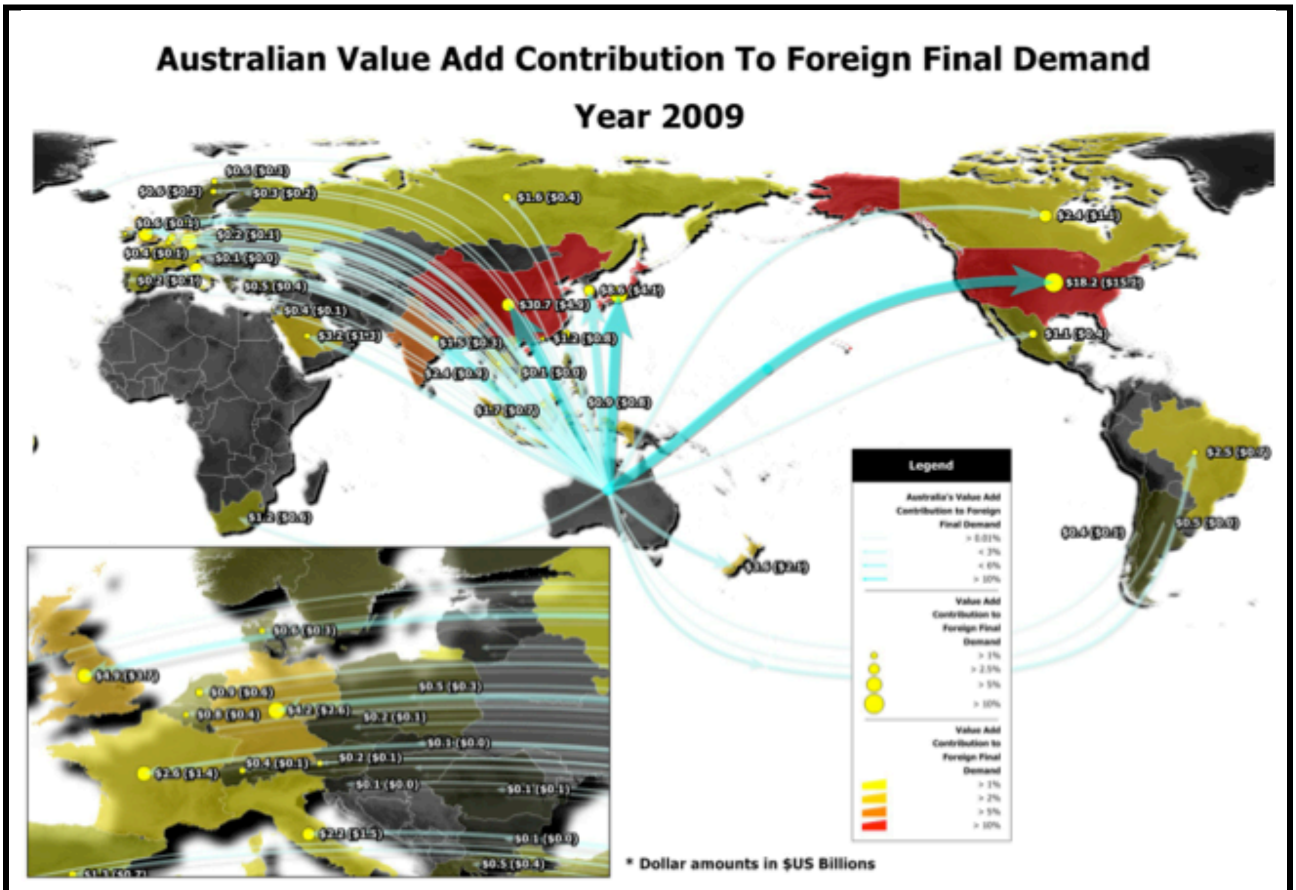
The real structure of the global economy consists of transnational supply/value chains that loop through different national economies. These transnational value chains are mainly controlled by multinational corporations (MNCs). The decisions made by these MNCs determine the countries in which production activities will be located (and re-located), and hence trade, jobs and business-funded R&D investment. These decisions taken at a global level, and that weigh-up different countries' relative merits, have profound impacts upon each country's trade and industrial performance (and especially employment levels). It is therefore a mistake for policymakers in a particular country to assume that their national policy settings will have a *direct* impact upon national industrial and trade performance. Rather, their national policy settings will (or will not) yield results primarily on the *indirect* basis of how MNCs react when weighing up a wide range of factors that determine which countries they select for participation in the transnational value chains which they are the architects of. In short, national competitiveness is judged by MNCs and on the basis of broader considerations that relative prices (e.g. geopolitical and social risks and other long-term factors). This means that national competitiveness is in essence a matter of winning and retaining positions in the transnational value chains that make up the bulk of the global economy.

In recognition of this reality, efforts have been made over recent years to integrate the national input-output data that decsribes the structure of each national economy with the data on international trade that describes how these national economies inter-relate. The result is, for the first time, a global dataset better able to capture the full interdependencies between different national economies. This systemic picture of the global economy allows transnational value chains to be mapped because it makes it possible to trace how flows of value added loop through different national economies – often in complex ways with repeated loops through the same country at different stages of value added. In fact, Australian researchers played a leading and catalytic role in driving this move to produce an integrated global input-output dataset (as part of efforts to trace embodied carbon emissions in the global economy). That initial work is now reflected in joint OECD-World Trade Organisation data that makes it possible to understand the evolving structure of the global economy in ways that were not possible before.

The following data visualisation using OECD-WTO data shows Australia's contribution to foreign final demand achieved both via direct and indirect pathways (i.e. pathways that can loop through several countries in ways that are hard to capture without this globally integrated input-output dataset.[4]

[4] The advantages of this new integrated global dataset are discussed in (OECD 2013a).

Figure 11: Mapping industrial transnational value chains



Source: experimental data visualisation work carried out by the HC Coombs Policy Forum (2012)

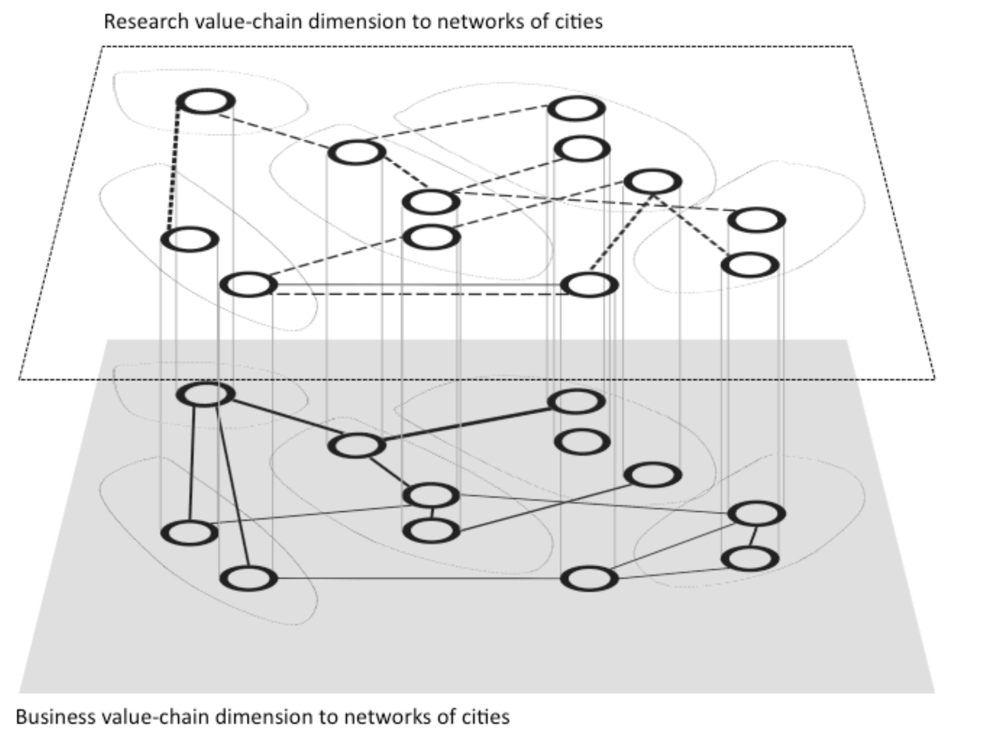
This technical potential, which is only now just coming on stream, is of significance to science and research policy for several reasons. Firstly, levels of business R&D investment in an individual country are not, as some commentators assume, driven solely by national policy settings and prevailing business conditions. Companies will invest in R&D in attempts to win a position in particular transnational value chains (e.g. supplying components sub-assembies or services to Boeing) and will sustain those investments in R&D in efforts to retain their position in transnational value chains. Secondly, innovation outcomes (the return in investment in R&D) are determined by success in winning and retaining these positions in transnational value chains. Thirdly, scientific breakthroughs of industrial relevance play an important role in establishing new transnational value chains and in making other existing transnational value chains obsolete. Fourthy, and of greatest relevance to a strategy for international engagement in science and research, those aspects of science and research that relate to these *industrial* transnational value chains are not independent variables, they are dependent variables driven by decisions made by MNCs at a global level. To the MNC making decisions over which countries and the particular activities in those countries that will participate in the transnational value chain(s) that they manage, the synergies between science and research and all other aspects of a value chain will be considered. This can be thought of as the way in which a thick cable is made up of different strands of rope woven together in such a way as to be mutually reinforcing. Science and research are one of those strands of mutually reinforcing activities/assets. Cross-cultural capability is another such strand. It is also worth noting that business investment in R&D in any one country can be strongly influenced by corporate strategies focused on winning and retaining positions in transnational value chains, i.e. business R&D will increase as a result of these value chain focused activities – irrespective of 'national' considerations.

Finally, these (industrial) transnational value chains have a major lesson for how we approach all science and research. Recognising the significance of the transnational value chains that loop through different national economies in trade and industry policy (and all related areas) has a similar implication for how we approach international engagement in science and research. To the (major) extent that work at the cutting-edge in science and research involves collaboration between researchers in multiple countries, then these collaborative networks may usefuly be treated as transnational value chains. To do so would usefully counter-balance a tendency to approach all international engagement in science and research simply as a matter of bilateral collaboration (an approach that can gloss over the strong multinational nature of that collaborative activity).

This connection between business and science and research value chains is illustrated in Figure 12. In recognition of the importance of cities as the key locational nodes in both business value chains and science & research value chains, the diagram expresses both types of network as links between cities (much of global GDP is generated in cities and much global R&D is spent in cities). From this perspective, imports and exports that cross national borders, as well as cross-border collaborations and flows of know-how and intellectual property associated with research collaboration, are both driven to a major extent by the comparative advantages possessed by *cities.* The comparative advantages of cities combines natural endowments in the cities' hinterlands, the intangible benefits of business links between cities (such as easier availability of risk capital), and other intangible asset values such as cultural factors that make cities so productive.

The important point to grasp is that the concentration of both business and research activities in cities, and the key role played by transactions/links *between* cities, means that the inter-connections between business value chains and science and research value chains tend to take place in cities. As the diagram illustrates, in some cases business and research value chain structures are correlated by virtue of the cities they loop through, whilst in other cases the two value chains are de-coupled. This urban dimension to both types of value chain points to useful ways in which research in the humanities and social sciences (in particular) can contribute to our understanding of the structure of the global economy and the global research effort.

Figure 12: Diagrammatic representation of how both business and research value chains link cities together



Source: the authors

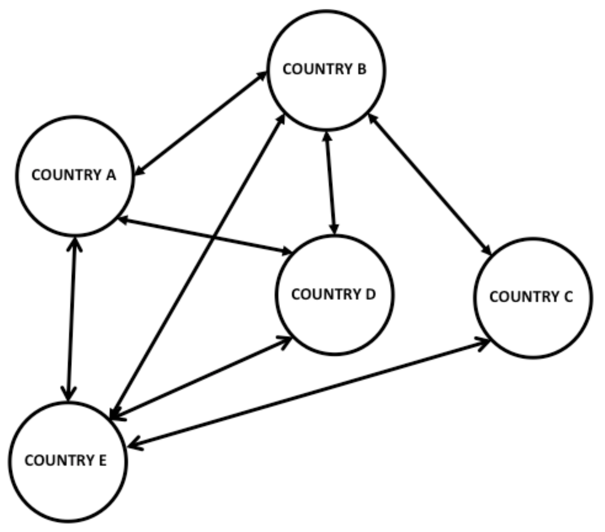
The concept of a transnational *research* value chain

We are familiar with thinking about international research collaboration as links between researchers in two (with data reflecting that perspective). As a result, we can overlook the more complex nature of collaborative activities. For example, researchers who received Australian Government support for bilateral research cooperation with colleagues in China were pleasantly surprised to discover that some of their Chinese colleagues had joint appointments in leading US universities. As a result, what was anticipated to be bilateral research collaboration ended up being trilateral – and more effective as a result because complementary assets in three rather than two nationally prominent research teams were combined.

The other collaborative links that our bilateral partners maintain can be as valuable, even more valuable, as the direct collaboration – in effect becoming (via knowledge spillovers) intangible assets themselves (a form of 'relational' or social capital based on network characteristics). It is useful, therefore, to approach international research collaboration as *networks* that link researchers in different countries – sometimes in complex ways that are not accurately represented in simple analyses of bilateral collaboration patterns.

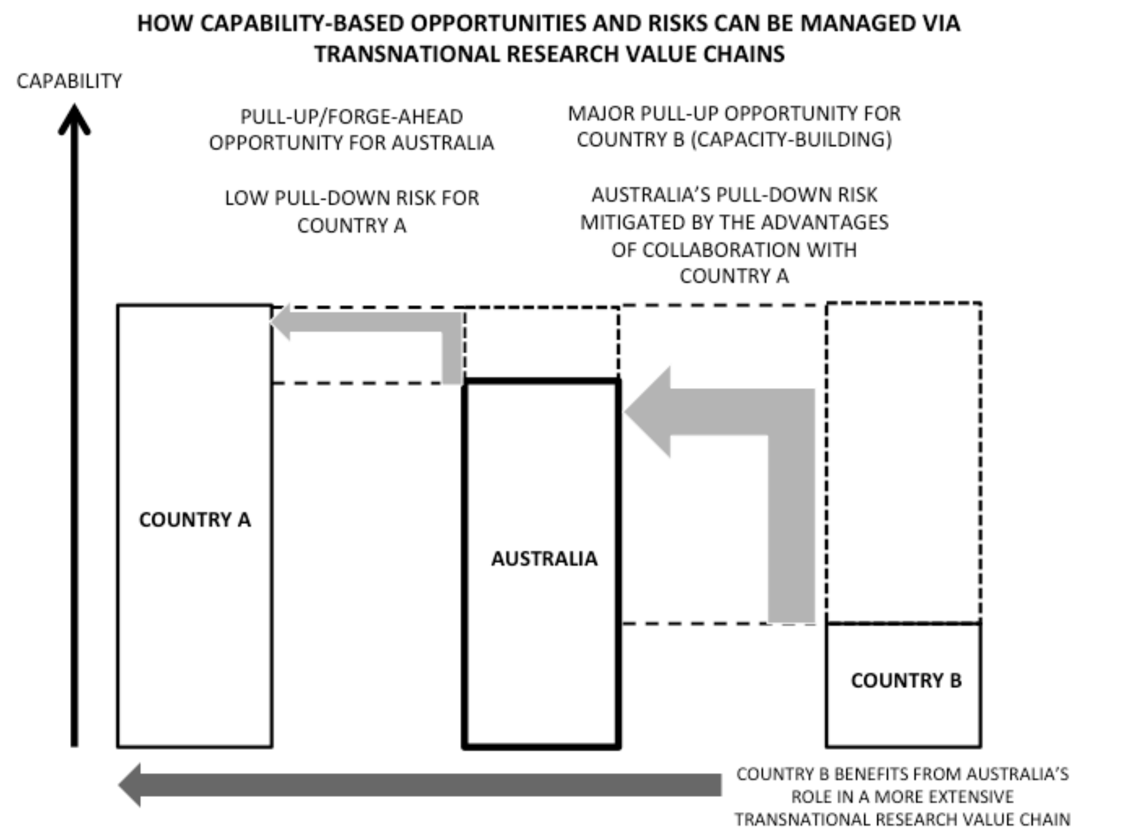
Figure 13 illustrates this sort of collaboration network – a network in which the advantages generated by direct collaboration with researchers in a different country are, in turn, impacted upon by which other countries those researchers are also collaborating with (or have collaborated with in the past). Figure 14 illustrates one consequence of this network structure: the way in which the pay-offs to collaboration are affected by the broader web of collaborations that researchers in a given country participate in. The overall message is that collaboration networks matter, and that we therefore require much better data and analysis of the impact of these complex networks of direct collaboration *and* the indirect consequences of the overall collaboration patterns.

Figure 13: Networks of collaboration and the concept of transnational research value chains



Source: the authors

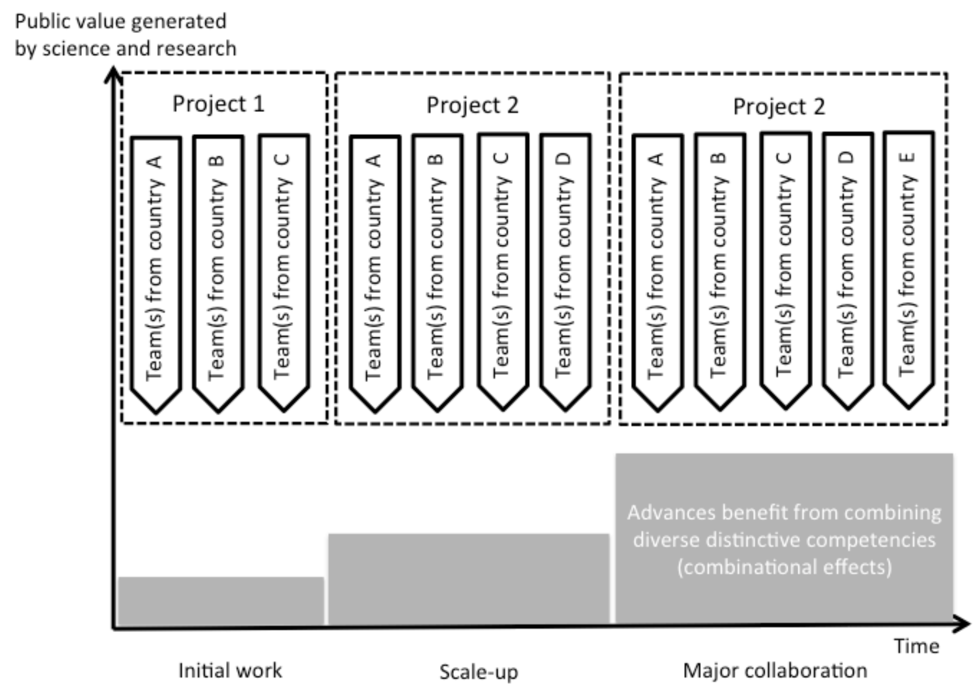
Figure 14: Exploiting capability differentials in transnational research value chains



Source: the authors

Figure 15 illustrates how transnational research value chains build public value over time, and via sequences of projects with different research collaborators. For each partner, the other additional research links they are part of, and associated knowledge spillovers, can be an important benefit. The value chain is not just one project – rather it is the ensemble of work that generates public value.

Figure 15: Illustration of how a transnational research value chain builds public value



Source: the authors

Mapping transnational research value chains

Mapping transnational value chains in science and research is a challenging task because the complex reality of inter-dependencies in research (reflected in joint authorships that span several countries) means that it is difficult to disentangle country-specific from research field-specific factors.

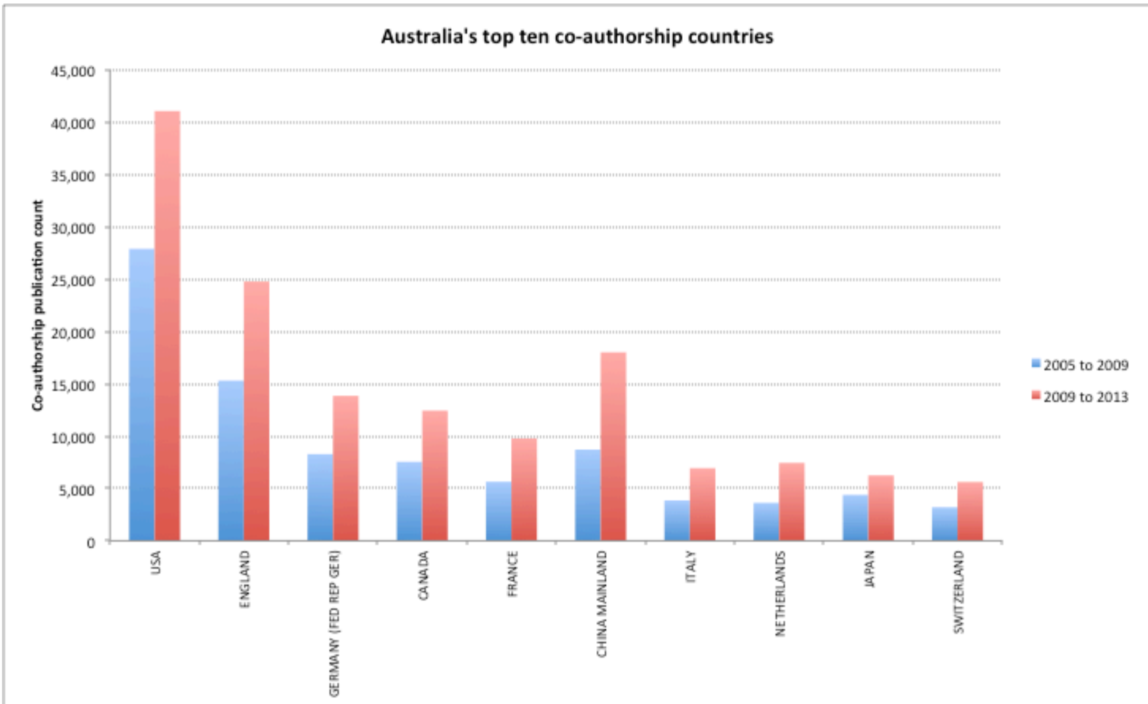
Whilst it is relatively easy to interpret metadata on publications and citation performance (an activity known as bibliometrics) *as if* simple differences between country and research field-specific performance are at work this is not an accurate interpretation of the available data. The reality is that the more highly cited papers tend to involve larger numbers of authors, in turn, likely to be located in a number of different nations. In other words, international collaboration of a bilateral, and often multilateral, nature is integral to observed academic performance in many research fields (notably in science, engineering and medicine). This means that an analysis that appears to indicate that Country A achieves an X per cent better performance in relative citation rates compared to Country B may in fact reflect collaboration between researchers in Countries A and B - and many other countries as well. Data that, on the surface, indicates major differential performance in relative citation performance (performance gradients that can drive collaboration incentives) *may actually reflect collaboration in the first place*. Cause and effect is hard to disentangle in such circumstances.

Whilst these considerations can make it very difficult to isolate pure country-specific capabilities (as distinct from the collective benefits shared by several collaborating nations) they tend to relate to high-end rather than lower end research capabilities. It is therefore easier to apply country capability assessments to countries in science and research catch-up mode. Bearing this ‘entanglement’ limitation to the data in mind, an analysis of key bilateral capability gradients for Australia vis-à-vis other countries (as reflected in relative citation performance) indicates that Australia is improving performance in a number of research fields - in some cases surpassing the United States and/or the United Kingdom. Australia is therefore positioned towards the high-capability end of the capability spectrum, and well placed to use ‘high-end’ international collaboration to maintain a leadership position whilst also using our position to build useful collaborations with Asian countries in catch-up mode.

The easily accessible sources of bibliometric data (such as *InCites*™) simplify the complexity of multi-author publications by counting each author as ‘one’. This approach contrasts with a pro-rata division of multiple authors, i.e. 4 authors each being counted as a 0.25 authorship contribution – an approach that can make it easier to grasp patterns of multilateral national authorship.

The 'multi-count' approach, when applied to counts of inter-country co-authorship, results in easily grasped descriptive statistics that are especially useful for measuring bilateral resource collaboration. For example, Figure 16 graphs Australia's top ten co-authorship countries for two five-year time periods: 2005 to 2009, and 2009 to 2013. It shows the prominence of the United States and England[5] in our co-authorship profile, even though, as per Table 2, it is clear that co-authorships with Asian countries are also increasing quickly although from a much lower base.[6] The problem is that this representation of the data masks a far more complex reality: international co-authorships are characteristically multilateral rather than bilateral (Adams 2013). Consequently, this sort of representation of international collaboration is not able to communicate the ways in which many academic publications actually involve authors in three or more countries. The picture provided by Figure 16 is misleading because it does not divide authorships up in a pro-rata manner (or adjust the authorship data in some other way that reflects multilateral collaboration).

Figure 16: The multi-count approach toward counting collaborations



Source: Graphs and underlying analysis generated by the authors using Thomson-Reuters *InCites*™ data downloaded in May 2014.

Illustrative mapping of research collaboration in the Pacific

Whilst it is possible to analyse complex networks of co-authorship, this requires highly specialised technical skills (and is costly to achieve). Thomson-Reuters have very kindly provided the following data visualisations of research collaboration in the South Pacific. These illustrate one approach to mapping multi-country research collaboration. Figure 17 maps the diverse sources of funding for research performed in Pacific countries. Figure 18 maps the web of collaborative relationships reflected in co-authorships. This demonstrates that researchers in the United States, Canada, Australia, New Zealand, United Kingdom, France and Germany are all significant collaborators with South Pacific countries. If this sort of mapping technique is applied to specific research fields then it illuminates the structure of transnational research value chains. Figure 19 shows the inter-institutional

[5] InCites treats the UK as a set of separate countries (England, ,Northern Ireland, Scotland, Wales)

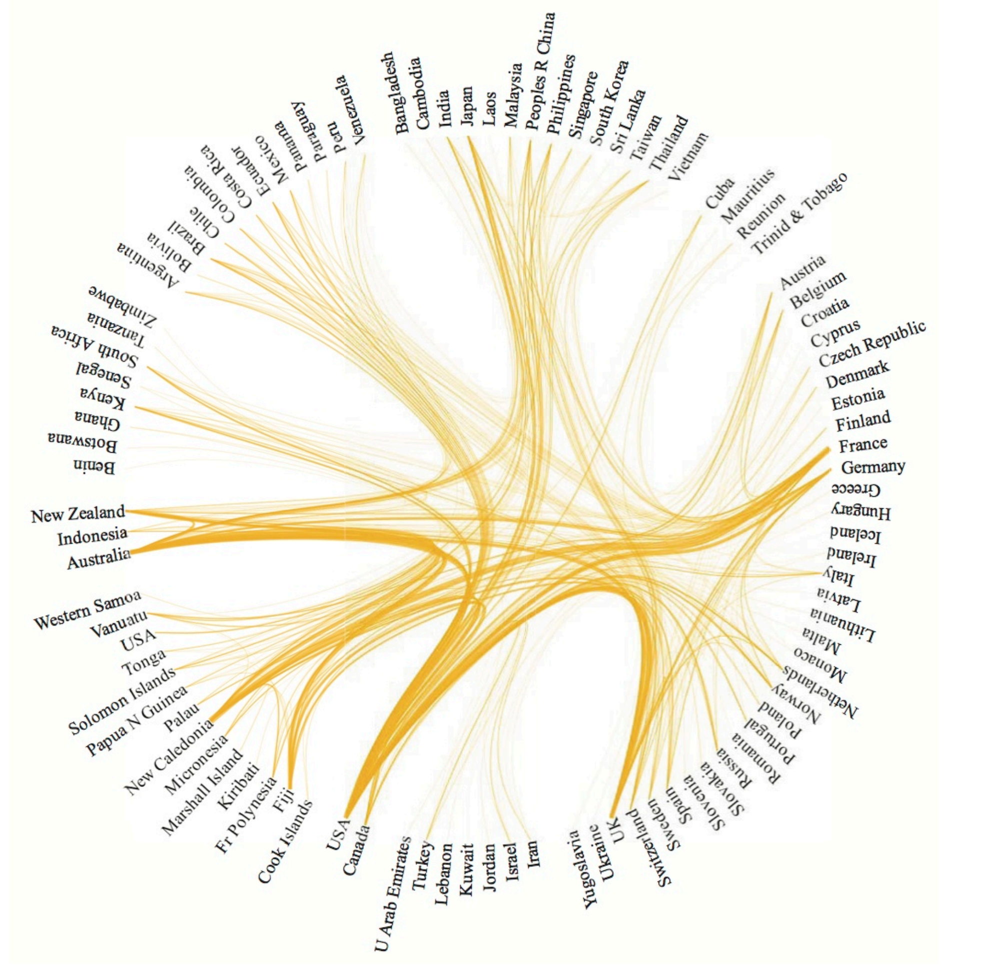
[6] Note that Figure 16 looks at 4 year periods, as compared to Table 2 which looks at yearly figures.

collaborative links in the South Pacific. Although it is not yet clear whether or not the pending enhancements to the *InCites*™ data portal will allow these sorts of collaboration maps to be generated, if this feature is introduced it will greatly assist in mapping transnational research value chains.

Figure 17: National funding sources for research performed in the South Pacific

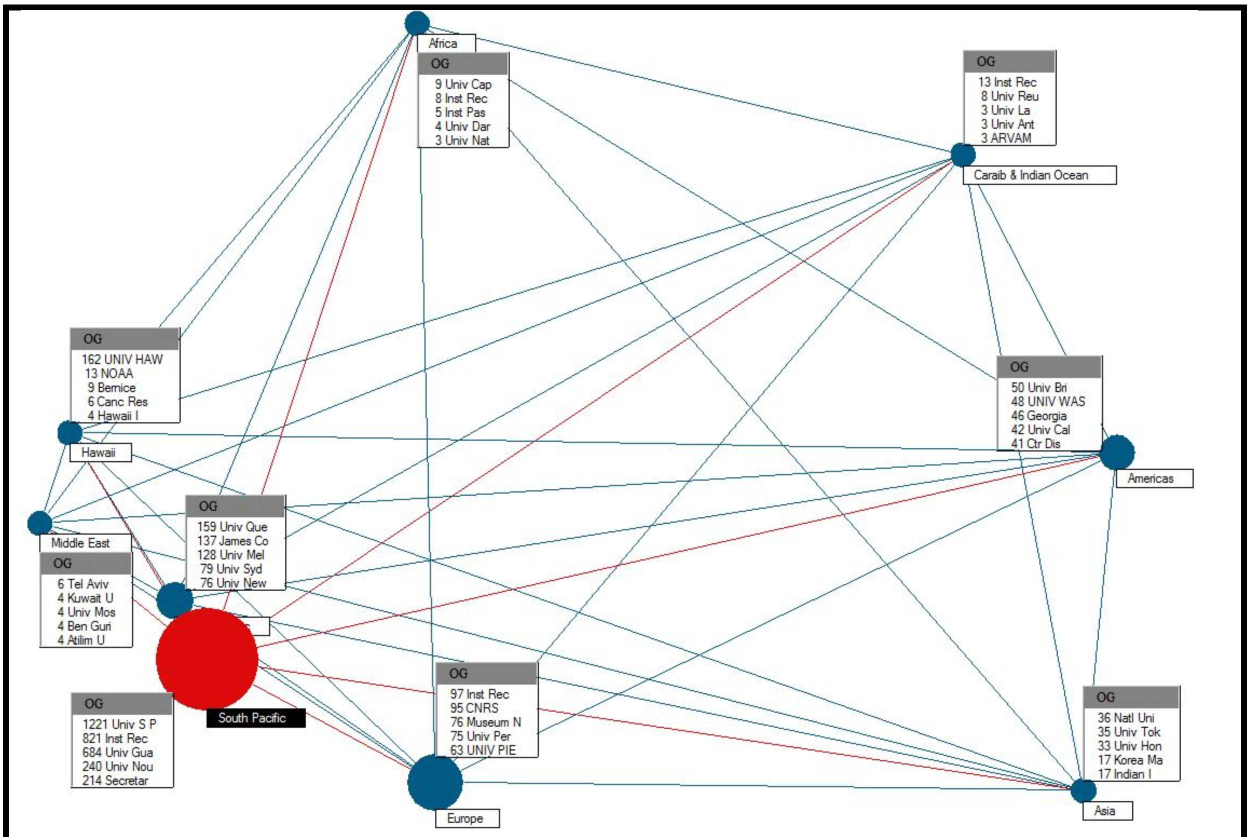
Source: Data visualisation provided specially by Thomson-Reuters as support for this paper.

Figure 18: Patterns of research collaboration in the South Pacific



Source: Data visualisation provided specially by Thomson-Reuters as support for this paper.

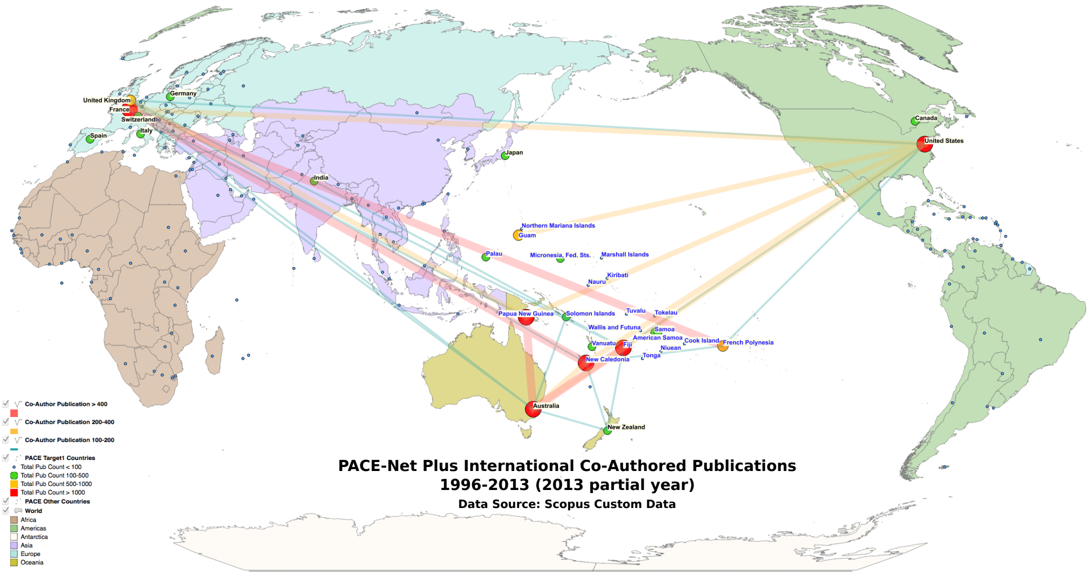
Figure 19: Institutional links in the South Pacific



Source: Data visualisation provided specially by Thomson-Reuters as support for this paper.

Additional data on the Pacific is provided by the following data visualisation (using Scopus data) that was prepared as part of an EU funded capacity-building initiative in the Pacific. It shows the international publication partners of the limited number of researchers in Pacific countries – highlighting how these researchers are collaborating with Australian, US and European colleagues.

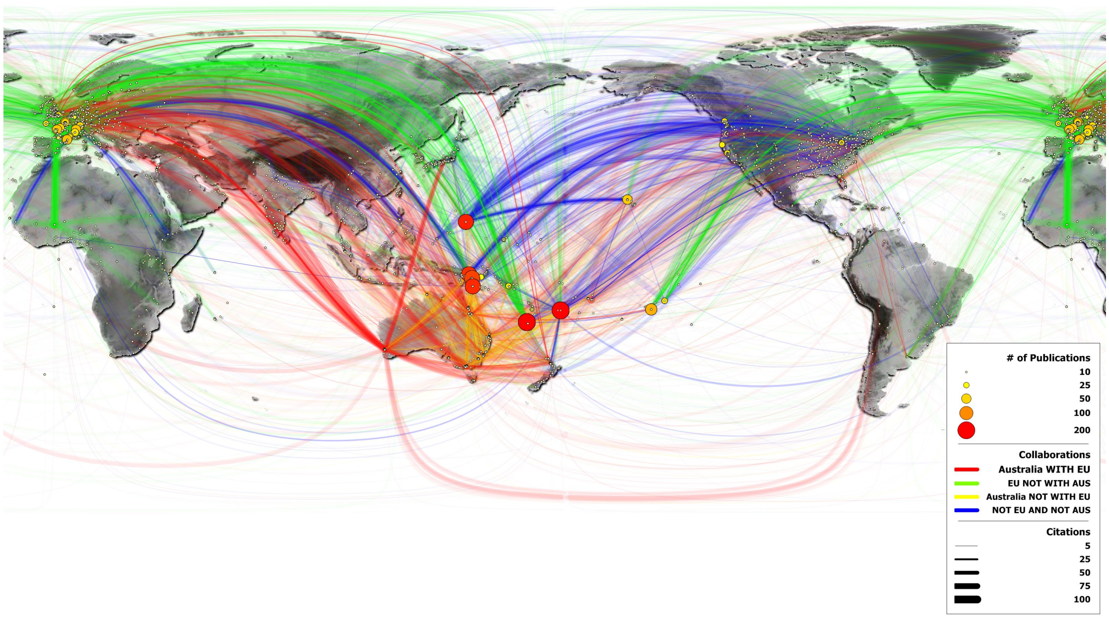
Figure 20: Illustrative mapping of international co-authorships involving researchers in Pacific countries



Source: (Daniell 2013). Analysis and data visualisation carried out by Brett Cuthbertson and Paul Wong using a customised use of Scopus data.

Patterns of international collaboration at the institutional level are, as would be expected, more complex and are visualised below.

Figure 21: International co-authorships by Pacific institution



Source: As in Figure 20

These data visualisations illustrate one of the main challenges faced in mapping transnational research value chains – the sheer complexity of the profiles that result (in almost all cases the patterns of international collaboration are far more complex than the relatively simple and small-number based example of Pacific research presented above). When data on this underlying multilateral collaboration is analysed by researchers and policy analysts there is a tendency to produce highly complex relationship maps that lack a sense of functional structure (it is difficult to unpack the structure and performance of the collaboration network). The result can be complex network diagrams that exhibit a poor signal to noise ratio that can, as a result, be confusing to policymakers – resulting in a continuation of the prevailing bilaterally-based strategy. It would be more useful to find ways of characterising these complex networks in such a way that their structure and function is highlighted – rather than simply communicating the large number of nodes and connections between those nodes.

One way of responding to this challenge would be to focus analyses (and approaches to data visualisation) on the *interactive effects* via which the combination of distinctive competencies and other assets (such as unique or rare data and research facilities) created by multilateral research collaboration generate an overall research contribution which is greater than the sum of the individual contributions (i.e. synergies are at work).[7] A more analytical approach to mapping complex international research collaboration would, in turn, allow Australia to highlight and more easily communicate our locational advantages as a key science power in the Southern Hemisphere that also has extensive collaborative research links in Asia and the Pacific.

The global research system (as reflected in the English language publications tracked by current bibliometric data sources) has been likened to a volcano sitting on a platform of lava that spreads out from its base (a metaphor in which altitude reflects research productivity, which is it turn positively influenced by the extent of collaborative links). There are a small group of countries towards the top of this volcano that collaborate closely end effectively with each other, and that benefit from strong synergies and complementarities between their respective research capabilities. Most other countries play a more peripheral role in this complex collaboration network (in effect sitting in the lava field at the base of the volcano). They are less interconnected and less productive as a result. (For this sort of network-based analysis see (Leydesdorff & Wagner 2008)).

The policy implications of these analyses of complex global research collaboration patterns is clear: *Australia should seek to increase its proximity to the core of highly inter-connected nations that define the frontier research productivity*. This, in turn, requires a strategy based not simply on prioritising bilateral research collaboration with particular countries, but that also considers (as the main priority) the identifiable networks of collaboration in particular research fields that align with our national interests.

The main implication for future bibliometric work is that it would be far more useful to present policymakers with maps of the networks of collaborating countries that define the cutting-edge of research in particular fields than to persist with overly-simplified (and inaccurate) bilateral representations of this more complex multilateral reality.

Quantity and quality in research outputs – toward the development of an effective capacity index

While Relative Citation Impact (RCI), as earlier discussed, is a useful tool in assessing the strength of research across various fields in different countries, it only provides part of the answer. For example, generally speaking a country that has a high RCI but a very small research base is often a less compelling partner for collaboration than a country with a comparable RCI but far larger research base.

One easily calculated indicator of the ‘effective capacity’ of research in a given country can be produced simply by multiplying shares of global research output by RCI. This ‘Effective Capacity’ Index, as we call it, captures, albeit crudely, the combined impact of quantity and quality of research output.

Exhibit 4 summarises the implications of the divergence between quantity and quality of research using the field of agricultural science as an illustration.

[7] There are technical parallels between such an approach and the methods adopted by economists and economic historians to analyse economic growth and productivity growth (which measure these interactive effects between independent variables: effects that often cannot be further decomposed in a causal manner).

Exhibit 4: The implications of a divergence between output quality and output quantity in research: illustration for Agricultural Sciences

Figure A shows how Relative Citation Impact (RCI) has changed over time for a small selection of nations. RCI, as described, is one easily obtained measure of research quality.

In this field of research the United Kingdom exhibits the highest RCI, followed by Australia, the United States and China. The Asia-Pacific region (which excludes the USA in the Thomson-Reuters definition) has exhibited a fairly steady increase in RCI since 1980.

Figure B shows how output volume relates to RCI for these countries (plus some others not graphed in Figure A). This highlights the fact that there is no clear relationship between quality and quantity (this is a common feature of most research fields). Figure C demonstrates the implications of this varied relationship between quantity and quality by showing how a ranking of countries by RCI averaged over the five years 2008 to 2012 (a proxy for quality) relates to a measure of 'effective capacity': assessed here as in index that multiplies shares of global research output by RCI. The rationale for using an effective capacity index of this type is that it combines quality and quantity (see Exhibit 5). In general terms, a country that has a high RCI but a very small research base is a less compelling partner for collaboration that a country with a comparable RCI but far larger research base.

In the case of Agricultural Science, Figure C shows us that whilst the UK has the highest RCI it also has a relatively low volume of research output (which brings down its combined quality and quantity capacity index). On the other hand, Australia and the United States exhibit both relatively high quality and quantity in research output – leading to a high effective capacity index. Therefore in general terms, Australia and the United States will constitute more compelling partners for research collaboration in this field.

Figure A

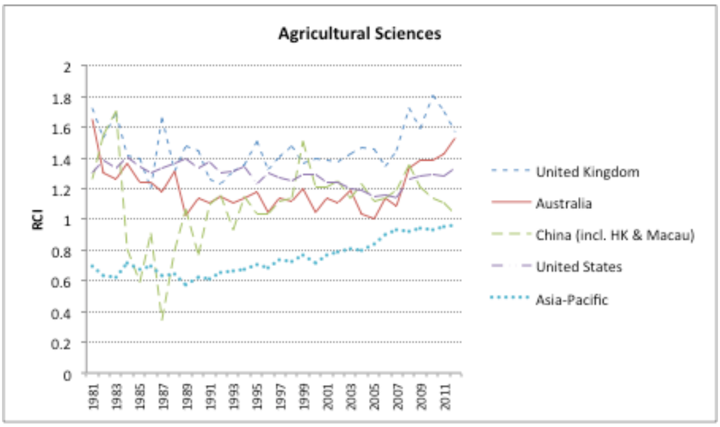


Figure B

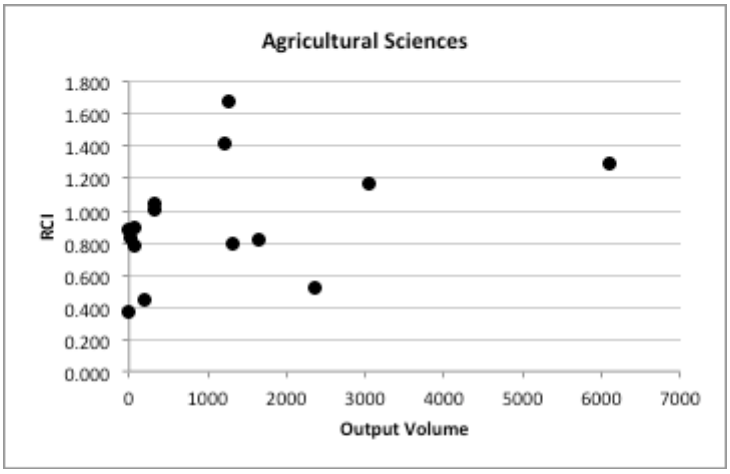
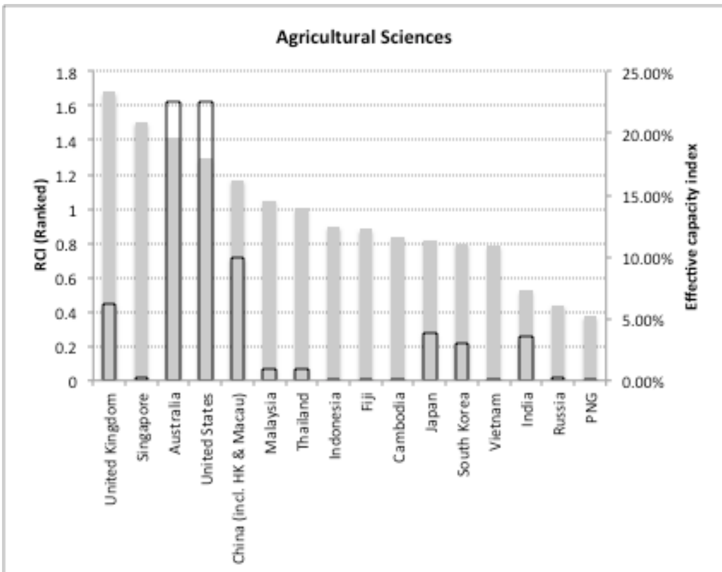


Figure C



Sources: Graphs and underlying analysis generated by the authors using Thomson-Reuters *InCites*™ data downloaded in May 2014.

We have examined the utility of the 'Effective Capacity' index in response to the prevalence of an increasing number of countries becoming active in English language research publications, but often at low output levels and variable quality (as reflected in relative citation performance). We recognise that this 'Effective Capacity' index is useful as a means of capturing the mix of quality and quantity evident in national contributions to the global research effort, especially as there is now a general trend toward a larger number of active countries contributing to global research (especially from Asia) – the dominance of the traditional 'science powers' is becoming less marked.

Exhibit 5 shows how the 'Effective Capacity' index captures changes in the field of Agricultural Sciences, with China (and other countries) catching up to the United States. Exhibit 6 illustrates how a dramatic increase in both the quantity and quality of Singapore's publications in Computer Science are driving Singapore's catch up efforts in that field.

Exhibit 5: The effective capacity index – China and the United States in Agricultural Sciences

Figure A shows the behaviour of effective capacity for agricultural sciences from 1981 to 2013. The decline in the United State's effective capacity is notable, as is the rise of China's effective capacity.

Figure B shows why the United State's effective research capacity has dropped. Whilst the volume of US output has been increasing, its share of global output has been decreasing, as has the RCI of US research. As a result, the United States no longer holds the dominating position in agricultural research that it held in the early 1980s.

Figure A

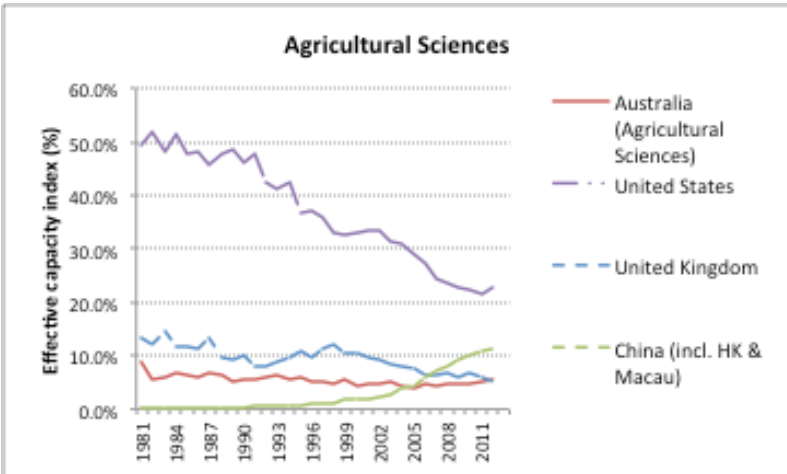
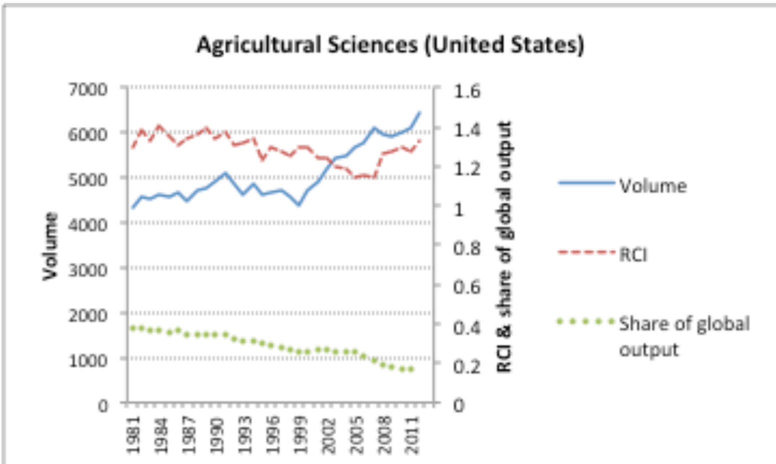


Figure B



Sources: Graphs and underlying analysis generated by the authors using Thomson-Reuters *InCites*™ data downloaded in May 2014.

Exhibit 6: Research catch up – Singapore in Computer Science

Figures A and V provide an illustration of research catch-up in action – as reflected in Singapore's performance in the computer science field.

Figure A plots the effective capacity index for Singaporean computer science (which shows a marked increase since the early 1980s).

Figure B shows how this increase in effective capacity, as is usual in this catch-up context, is based on large increases in both the quantity and quality of publications.

It is especially important to note the very low numbers of publications in the early 1980s and 1990s because this is a common feature in Asia. Australia's current potential to benefit from, and contribute to, research in the region relates to a large part to the dramatic transformations that have taken place in the quantity and quality of research in Asia (as illustrated in this example from Singapore).

Figure A

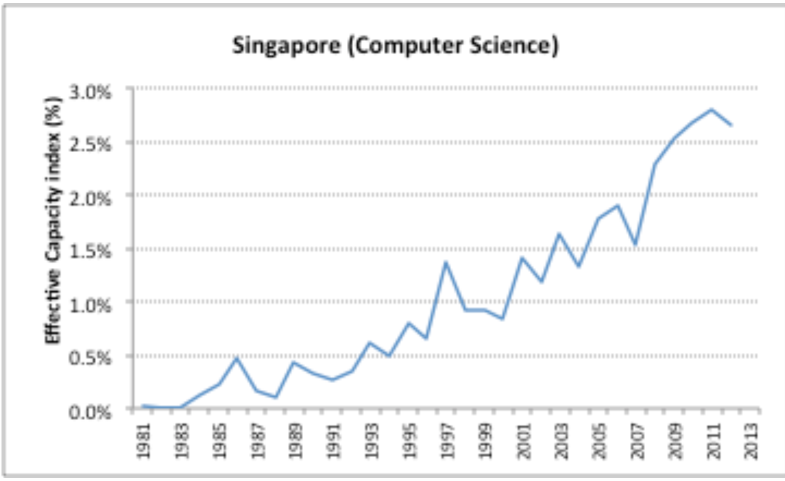
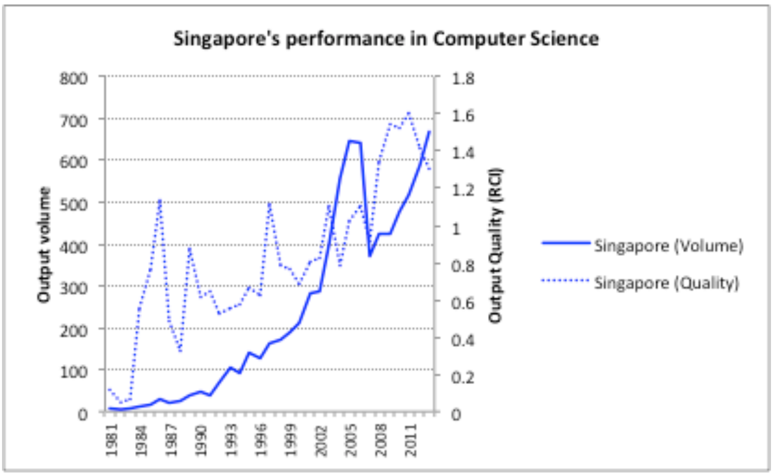


Figure B



Sources: Graphs and underlying analysis generated by the authors using Thomson-Reuters *InCites*™ data downloaded in May 2014.

Enhancing interoperability in research funding mechanisms

The concept of *interoperability* in science and research provides a practical approach to achieving enhanced international cooperation useful to engaging with transnational research value chains. *Interoperability* in this context refers to the development of the capacity to configure cooperative research activity quickly and cost-effectively in such a way that it exploits complementary capabilities (see (Matthews 2009))

The vision is to be able to move quickly to work together, be flexible in how this work evolves (changing direction, adding new partners easily) and disengage quickly and easily when objectives have been met or the need for cooperation otherwise dissipated. This more agile approach complements more rigid project-based approaches (characteristically slow to start and hard to re-direct in the light of experience and unanticipated developments). *Interoperability* based approaches exploit synergies between existing and complementary research in different countries. Enhanced interoperability can be achieved via such mechanisms as synchronised funding application cycles, standardised internationally compatible funding agreements and joint peer review processes.

This approach can be attractive to governments because it provides a means of exploiting synergies between national research funding without requiring dedicated funding for international research cooperation. The approach is also particularly well-suited to supporting participation in transnational research value chains because it provides the necessary agility and allows for a more inclusive stance than is possible by targeting limited funding for bilateral research cooperation with a restricted number of countries. This sort of approach may be especially useful as a means of supporting engagement with transnational research value chains because effective engagement with a number of countries is required.

Demonstrating the value proposition represented by Asia literacy

In a 2012 CPA Australia and Enright survey, Australian respondents generally considered that having access to bilingual skills are relatively unimportant. This Australian sentiment is a substantial cross-cultural impediment, given that in the same survey non-Australian respondents (mostly from partners in Asia) considered that this is an important factor driving competitiveness (Enright & Petty 2012). To some therefore, cross-cultural capability (the mix of linguistic and socio-cultural understanding that influences how effective individuals and teams can be in cross-cultural contexts) can appear to be rather vague and, perhaps, not especially important. However, the impact of cross-cultural capability can in fact be profound and very valuable in regard to the efficiency and effectiveness with which international collaboration in science and research is executed. This aspect is best explained by considering how cross-cultural capability acts as an investment risk management mechanism – something that is important whenever funding and significant in-kind resources are allocated to international research collaboration.

There are important lessons to be gleaned from industrial experience here. Indeed, large corporations pay particular attention to cross-cultural considerations precisely because this impacts upon productivity and return-on-investment performance. In industry there are well-developed technical methods for assessing and managing investment risk. Two of these methods lend themselves to demonstrating the economic value of cross-cultural capability: risk-adjusted assessments of Net Present Value (NPV) and experience/learning curve analyses.

Exhibit 7 contains an illustration of how the value of cross-cultural capability can be reflected in investment appraisal by using risk assessment methods. In essence, the better cross-cultural capability is, the higher the risk-adjusted Net Present Value (known as Expected Value) of an investment involving international research collaboration will be. This is because the probability and the associated cost of failure are reduced.

Exhibit 7 Using the *Expected Value* equation to demonstrate the economic value of Asia literacy

In economics and finance the impact of risk is sometimes assessed mathematically using calculations of 'expected value' that take the following basic form:

Expected Value = $[P_s \times NPV_s] - [P_f \times NPV_f]$

Where: P_s = Probability of Success

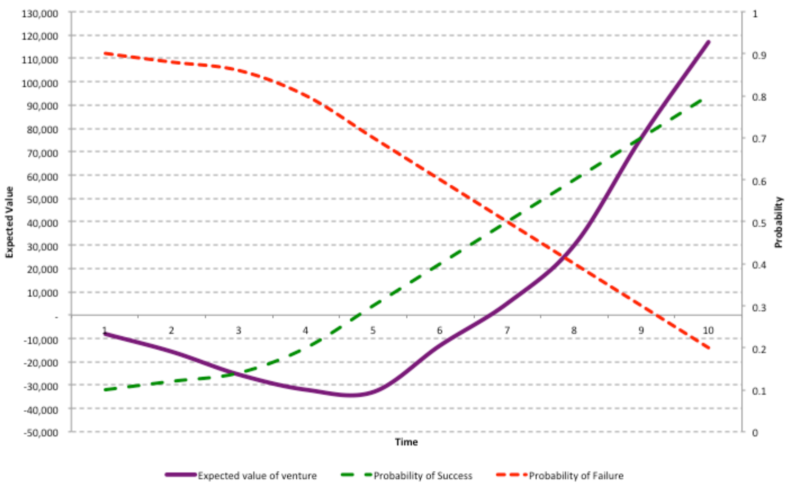
P_f = Probability of Failure (1- P_s)

NPV_s = Net Present Value of Success

NPV_f = Net Present Value of Failure (cost of failure less and cost recovery)

From this Expected Value perspective, the standard research (and innovation) process follows the sort of pattern graphed in Figure A. Because we usually have to spend increasing amounts of money to drive up the probability of success (and drive down the probability of failure) it is usual for this risk-adjusted Net Present Value to become negative and get worse before finally improving and eventually entering positive territory). In the innovation process, venture capital and other investors characteristically invest at different points in the expected value trajectory. In the process of allocating research funding, past track record is weighted heavily on the assumption that it is the most reliable way of reducing these 'investment risks'.

Figure A



Source: Authors' calculations

The same financial risk-based perspective can also be adopted when thinking about the opportunities and risks associated with international research collaboration. This is also a process of 'learning-by-doing' involving costs and risks when seeking to generate a return on investment (however framed and including generating global public goods/public value). The more one collaborates internationally the better one gets at making it work – and this includes the experience gained in anticipating and managing the risks faced in collaborating (especially when cross-cultural factors are faced).

We can demonstrate the value of different levels of Asia literacy, treated here as the ability to identify and manage the risks faced in handling cross-cultural factors by expressing Asia literacy as different probabilities of success and failure. This is illustrated in the following two Expected Value equations. Note: the financial values used here are arbitrary assumptions used simply to illustrate the impact of different levels of risk. More realistic financial values would relate to the anticipated benefits of particular collaborations (including public good values).

(A) Expected Value (High Asia Literacy) = [0.6 x $100m] – [0.4 x $40m] = $44m

(B) Expected Value (Low Asia Literacy) = [0.2 x $100m] – [0.8 $40m] = -$12m

As can be seen, the higher probability of failure associated with low Asia literacy compared with a lower probability of failure associated with high Asia literacy results in an Expected Value of -$12m compared to one of $44m. Note: it is also possible to reflect different levels of Asia literacy in variations in the Net Present Value (NPV) of success and of failure. However, these variables have been kept constant in this illustration in order to highlight the impact of different risk levels on the return on investment in international research collaboration. Similarly, the value of learning-by-doing in handling international research collaboration can be expressed in reductions over time in the probability of failure.

This use of the expected value approach provides a hard-nosed illustration of the value of cross-cultural capability in reducing the investment risks faced in international research collaboration in Asia.

Source: the authors

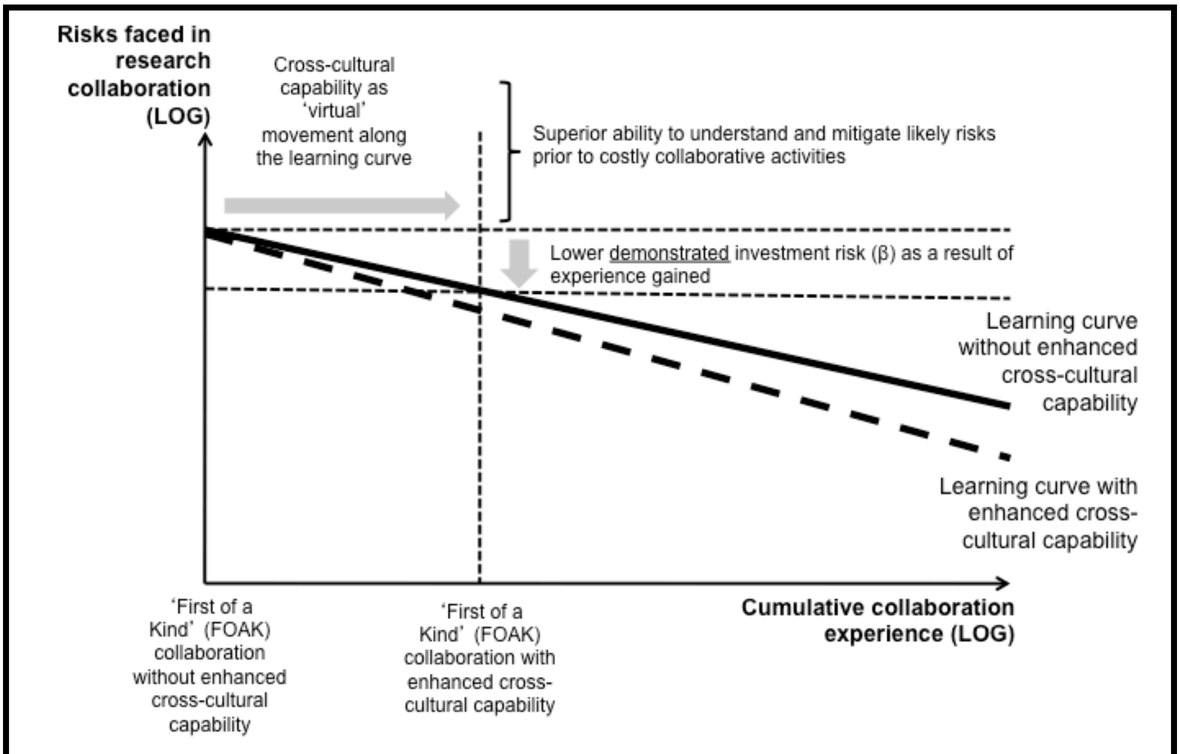
Figure 22 expresses the value of cross-cultural capability in a complementary risk-based approach by considering the impact on experience/learning curves. In industry, experience curves are a very important tool for pricing tactics and production management (especially in aerospace, shipbuilding, large power stations and other complex products). This is because unit costs decrease as cumulative production experience increases. As a result, break-even sales points for products such as aircraft (and therefore prices negotiated for orders by airlines and other customers) are estimated on the basis of forecasted learning curves. The steeper the learning curve the more dramatic the reductions in unit cost to be achieved as production volume increases.

Indeed, academic research plays an important role in this aspect of industrial performance by allowing for 'virtual' progress along a learning curve before actual production takes place. As theoretical sophistication and the ability to reflect that theoretical understanding in the simulation modelling of complex systems improves, there is, in effect, a substitution of (relatively cheap) theoretical production progress for real (far more expensive) production progress. In complex engineered systems like aircraft, design flaws and 'bugs' in general tend to be discovered once real physical components are assembled and tested. This de-bugging process is in fact one of the main drivers of learning curve based productivity gains. In the design and assembly of large-scale power stations this feature is referred to as 'First of a Kind' (FOAK) cost levels. The goal in such industries is to leverage theoretical understanding and simulation modelling capability (tools often generated by collaboration with academia) to create a situation in which the first physical product actually built exhibits the design and manufacturing experience previously associated with several units having been build and 'de-bugged', resulting in major cost savings (see (Matthews 2006) for a discussion of these issues in relation to science and technology policy).

In recognition of this, Figure 22 uses a conventional learning curve-based productivity framework (that incorporates the FOAK factors noted above) to highlight the importance of cross-cultural capability. In the context of international collaboration in science and research learning curves can be treated as risk management methods. Collaboration is a process of learning-by-doing: the more you do it the better you get at doing it. Consequently, a learning curve based framework provides a useful way of demonstrating how cross-cultural capability has tangible and important benefits in terms of the efficiency and effectiveness with which international collaboration is conducted. In this framework, cross-cultural capability generates useful benefits via a combination of FOAK-type advantages (better cross-cultural understanding allows real collaborations to start further down a given learning curve) and steeper learning curve gradients (better cross-cultural understanding allows faster learning in the face of opportunities and risks).

Given that effective participation in transnational research value chains looping though Asian countries is likely to require multi-cultural expertise, this learning curve-based framework provides a potentially useful means of demonstrating the value of Asia literacy. Put simply, Asia literacy will provide a more compelling risk-reward relationship and allow for more effective learning-by-doing in international engagement. In principle, these benefits can be quantified representative case studies and examples. This aspect of Asia literacy will be especially important in implementing a strategy based on participation in transnational research value chains simply because whilst the opportunities opened up by collaboration with researchers in several nations are higher – so too are the investment risks due to the increased complexity of the relationships involved.

Figure 22: Using an experience-curve model to highlight why cross-cultural capability is a valuable risk reduction asset



Source: The authors

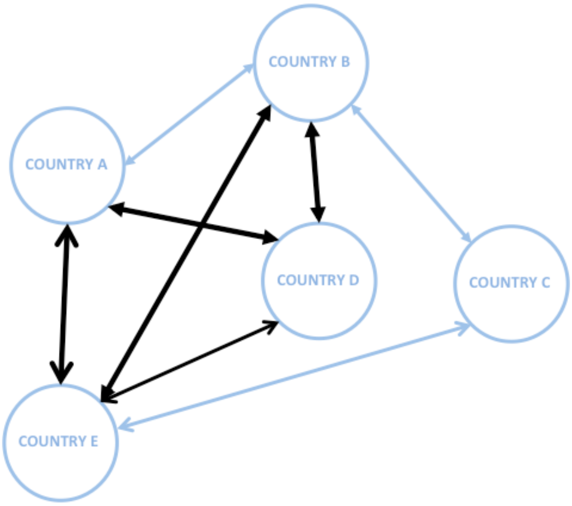
Part Five: Conclusion and next steps

This paper advocates an ambitious and potentially very useful shift in how Australia approaches international engagement in science and research. The proposed prioritisation framework is based on shifting away from a country-dominated perspective towards international research collaboration and towards a focus on the nature and extent of each country's participation in the transnational research value chains that loop through and link different countries. In this recommended policy stance, broader measures that generally support collaboration 'bottom up' are potentially more useful than targeted country-specific initiatives.

In this network based approach, the *attractiveness* of a given country as a research collaboration partner in a given research field lies in the combination of that country's role in specific transnational research value chains together with the *feasibility* of collaborating with researchers in that country (including research interoperability and cross-cultural considerations). The assessment of the potential payoffs to research collaboration with particular countries shifts away from bilateral gradients (the extent to which a particular country is more or less capable than we are and/or possess unique or rare research assets) and towards an assessment of the payoffs of participating in particular transnational research value chains that link several countries. As Exhibit 8 illustrates, the primary unit for consideration by policymakers becomes the transnational research value chain itself (which can be thought of as a network-based intangible asset) - not discrete countries in isolation from those networks of research relationships.

Exhibit 8: Network principles behind the proposed strategic prioritisation framework

The web of collaborative relationships that link different countries constitutes a key intangible asset, and focus for international engagement in science and research.



Source: the authors.

The following steps would form the basis of a suitable strategic prioritisation framework for implementing the recommended approach.

1. Develop and apply analytical methods better able to cope with the complex realities of transnational research value chains (especially in regard to characterising their structure and functional effectiveness as collaboration networks).
2. Use these improved analytical methods to map significant transnational research value chains using bibliometric analyses of international research collaboration networks (the *links between* active countries that in combination drive research progress).
3. Identify transnational research value chains of importance to Australia (as both global public good, national policy priorities and innovation outcomes).
4. Assess Australia's current role in these high priority transnational research value chains using a risk management framework:
    - how large is the gap between the current and potential contribution by Australia-based researchers?
    - what additional national benefits would stem from closing this gap?
    - which costs and risk factors should be consider in attempting to close any gaps between current and potential future performance?
    - To what extent does Australia's cross-cultural capabilities (and Asia literacy in particular) help to reduce these risks?
5. Define and put in place actions intended to improve Australia's participation in priority transnational research value chains (informed by the risk management framework).
6. Monitor progress and learn from experiences gained from seeking to improve Australia's participation in priority transnational research value chains (*to include quantified assessments of the investment risk-reducing impact of cross-cultural capability using the formal methods outlined in this paper*).
7. Monitor the evolution of the global research collaboration network and its constituent transnational research value chains in order to identify emerging value chains of potential importance to the national interest

The next step in implementing the suggested approach will be to commence work on mapping the key transnational research value chains in the global science and research effort. This will be an on-going collective process best achieved if/when Thomson-Reuters implement the planned enhancement to their readily accessible *InCites*™ data portal, which will reduce the cost and technical difficulty of carrying out such work. Just as a number of analysts currently use *InCites*™ to conduct analyses of patterns of bilateral research collaboration as and when required, the ready availability of data able to capture clusters of multinational collaboration will enrich our grasp of this, more complex, issue via a range of collective efforts and debates. It will also be useful to compare the results obtained from the alternative *Scopus* data source as each source of data has comparative strengths and weaknesses.

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Appendix A: Country Profile Snapshots

Preamble

These Country Profiles are very brief snapshots of the policy priorities of, and challenges facing, a number of representative countries in the Asia and the Pacific, compiled through desk research and the informed knowledge of the authors. The focus on S&T in these Country Profiles is reflective of the focus of these countries in their science and research priorities, and the relative lack of information on the priorities on humanities in these countries. While many of these countries do recognise the vast challenges they face in the humanities, many of them are still focused on research that can be commercialised (especially where countries are trying to incentivise private R&D investment). In general, basic and HASS research has been neglected in government planning, although this is gradually changing with the understanding that there is a growing list of shared and critical challenges facing the region across many areas (including the environment, health and energy).

China

Current International Science and Research Collaboration

Beginning around the 1990s, China's output of academic and scientific papers expanded dramatically. Its comparative growth is striking, far outstripping the rest of the world. Since then, the spread of countries China collaborates with has remained relatively steady, with strong collaboration with the United States, Northeast Asia, Europe, Australia and Singapore (Adams, King & Ma 2009). The United States comprises of around 42 per cent of China's international collaboration, while the European Union accounts for 36 per cent (Blau 2013).

Chinese immigrant scientists to other countries are playing an important role in China's international scientific collaboration, especially in English speaking countries (Wang et al. 2013). That said, a recent study comparing the academic outputs of China, South Korea and India showed that China lagged behind in terms of international collaboration papers and highly-cited papers (Gupta & Gupta 2011).

The Science and Research System

Particular government initiatives launched in the mid-late 1990s, such as Project 211 (strengthening approximately 100 key universities and colleges) and Project 985 (developing several world class universities), have been aimed at developing a high level elite group, which has proved a powerful force for knowledge development and innovation (Adams, King & Ma 2009; Department of Industry 2011). China now has a strong research base, including the Chinese Academy of Social Sciences and top universities, many of which collaborate internationally and widely. China's GERD reached 1.77 per cent of GDP in 2010, and the country now has the second largest R&D expenditure after the United States. In general, public research is strongly oriented towards applied and experimental R&D (OECD 2012a).

There has been a shift in China's approach towards international S&T collaboration. In many ways, it has become even more strategic. While initially China focused on developing general international S&T cooperation, it is now becoming more proactive and targeted on science related to particular policy priorities, and is starting to 'go abroad' and not just be reliant on technology imports. It is also, at the same time, more open to cooperation driven by multiple players (Bound et al. 2013).

Policy Priorities and Opportunities

As a Nesta report stipulates, 'after three decades of rapid economic growth, debate in China is intensifying about how to direct innovation towards social and environmental goals' (Bound et al. 2013). It is also clear that China is adopting a range of policies to facilitate 'indigenous innovation and to reduce dependence on developed countries for advanced technologies.

The *National Medium- and Long-term Program for Science and Technology Development (2007-2020)* is a comprehensive document outlining many of China's policy and research priorities, and stresses the role innovation should play in addressing many of the country's short and long term challenges (The State Council 2006). The current Five-Year-Plan for S&T Development emphases some strategic and emerging industries (including manufacturing, agriculture, ICT); challenges around resources, energy, water, and the environment; and issues around the changing demography of the country, for example urbanisation and an ageing population (OECD 2012a; The State Council 2006). Social welfare issues will continue to be important, especially due to the government's intention of expanding public-welfare provision and the continuation of chronic low-level instability across the country due to land ownership disputes and environmental degradation (Economist Intelligence Unit 2014a). Some key areas of focus were reflected in the 2012 Innovation Cooperation Dialogue between the European Union and China, which covered low-carbon energy systems, green transportation, space technologies, health aging, and information and communication technologies (Blau 2013).

China's research strengths are evident in the fields of physical sciences and technology, with materials science (such as chystallographic and metallurgy), chemistry and physics all strong fields. Notable growth areas include the agricultural sciences, and life sciences such as immunology, microbiology, and molecular biology and genetics (Adams, King & Ma 2009). China has a strong grip on innovative materials.

Considerations

China has a tradition of setting up special economic and high-technology zones. While the government is trying to strengthen linkages between its special zones through developing infrastructure (e.g. high speed rail) and legal frameworks for development, it is important to consider that some parts of China can be considered 'developed' (e.g. the Coast) while the country's western regions lack the absorptive capacity to capture knowledge flows (OECD 2012a).

The broader issue of intellectual property rights continues to be an area of dispute between China (and other emerging markets) and more developed countries, as China in particular has often been accused of copying patented products and ideas (Blau 2013). However, China's capacity for 'incremental re-innovation' is gradually seen as an important competitive asset. China has sophisticated manufacturing networks capable of adapting products and technologies very efficiently (Bound et al. 2013).

There are still areas where governance of science and research can be improved, including: improving framework conditions for innovation; fostering absorptive capacity in the Chinese business sector; and strengthening organisations and mechanisms for public support of innovation (Department of Industry 2011). While China is invested in harnessing its S&T capability, it is unclear how effective it will be in reforming some of these issues given the government's focus on rooting out corruption and judicial reform.

Japan

Current International Science and Research Collaboration

Japan's international science and research links show a very sharp association with other leading economies, indicating that international collaboration may be more driven by domestic economic activity than through particular strategies. It does not collaborate as heavily with the United States as some other developed countries (e.g. the United Kingdom or Australia), and comparative speaking does not collaborate as much as its G7 and regional partners (Adams et al. 2010). It is recognized that a key weakness of Japan's science and research system is its low level of international collaboration, in both academia and the private sector (OECD 2013c).

Japan's current international S&T collaboration activities are aimed at resolving common regional issues across Asia, and in dealing with new developments in S&T such as the need to capitalise on Japan's strengths, promotion of international activities for advanced S&T, promotion of coordination and cooperation with developing countries for global-scale issues, and reinforcement of national foundations (Anon 2011).

The Science and Research System

Major corporate groups that are among the world's largest R&D investors dominate the country's S&T system. Japan's business sector accounts for almost 77 per cent of total GERD, and is mostly focused on technology intensive manufacturing, TV and communication equipment, motor vehicles and pharmaceuticals. However, the private sector does not rely heavily on contracted public research or international collaboration (OECD 2012d). The Japanese government has been trying to encourage more public-private collaboration through supporting collaborative research centres and other technology transfer processes (National Research Council of the National Academies 2010).

Since the 1990s, Japan has also been overhauling its science establishment with the goal of restoring strong economic growth and promoting innovation, to mixed (and slow) results. Coordination of S&T strategy, while involving several ministries, is managed by the Council for Science and Technology

Policy, which reports directly to the Prime Minister and ensures executive level attention to S&T policy (National Research Council of the National Academies 2010).

Policy Priorities and Opportunities

Japan has identified the basic role of future S&T policies to be: integrating the promotion of science, technology and innovation policies; giving greater priority to the role of human resources, and implementing a STI policy created with broader society. (Anon 2011). In 2011, the Japanese government endorsed the 4th Basic Plan with a budget of around A$314 billion (around 1 per cent of GDP over the five year period) (Department of Industry 2012b).

Two key challenges which Japan have identified in *The 4th Science and Technology Basic Plan (2011-15)* are 'an aging and decreasing population as well as a declining birthrate, plus a loss of social and economic vitality; and long, downward trend of industrial competitiveness'. A number of key priority areas identified included reconstruction and revival from the Fukushima disaster, promotion of green innovation (including renewable energy and low-carbon issues), promotion of life innovation (and a focus on medical research, disease diagnosis and prevention, and improving life for the sick, elderly and disabled) (Anon 2011). Even in spite of severe budgetary pressures, the government has preserved S&T budgets and certain areas (such as energy and green technologies) have even received more funding (OECD 2012d).

The push toward renewable energy has become more prominent in the context of the Fukushima nuclear disaster. While nuclear power still retains the status of 'base-load power', in 2014 the government pledged to double the share of renewables in Japan's energy mix by 2030, from 10 per cent at present (Economist Intelligence Unit 2014e). Japan is already the most energy-efficient country in the world (National Research Council of the National Academies 2010), and there's every reason to suspect that it will continue to be a leader in the field of green and renewable energy.

Japan's research strengths are evident in the fields of physics (especially applied physics and condensed matter physics), pharmacology & toxicology, and biology and biochemistry. It has also been historically strong in the field of materials science and physical sciences, with paper & wood, ceramics, and biomaterials all ranking highly. Emerging fields of research strength include chemistry, microbiology, immunology, plant and animal sciences, and space science (Adams et al. 2010).

Considerations

As mentioned in the overview, language seems to be a strong barrier to international collaboration. Many international researchers cite language as a major barrier to working in Japan, and its clear that Japan has a much lower proportion of international researchers in permanent roles in comparison to other countries (Department of Industry 2012b).

Geopolitical competition and historical issues between Japan and its Northeast Asia neighbours (China and the Koreas) makes collaboration in particular security-oriented fields difficult, especially in the context of the current government's increasingly nationalistic tendencies and the reinterpretation of Article 9 and the constitutional principle of 'collective self-defence' (Economist Intelligence Unit 2014e).

On a longer-term note, Japan has the highest ratio of public debt to GDP in the developed world, a very unsustainable position in the long term. It is unclear how the government will continue to sustain large-scale investment in S&T if Japan's economic position worsens, especially taking into account Japan's demographic profile and shrinking workforce.

South Korea

Current International Science and Research Collaboration

South Korea is one of the most R&D intensive countries in the world, ranking 3rd in GERD as a proportion of GDP in the world in 2011 (Ko 2013). GERD as a proportion of GDP has increased from 1.87 in 1990 to 2.39 in 2000 to 3.37 in 2008 (Yim 2004; Campbell 2012) to 4.36 in 2012. South Korea maintains many connections with the United States, due to strong alumni networks and the post-WWII legacy. However, the country does not collaborate as widely as it should, and it is clear that its relatively insular economy (foreign R&D investment in South Korea is very small) is reflected in its relatively weak S&T collaboration (Ko 2013; Yim 2004). However, the country has started to facilitate more engagement and collaboration with European and regional partners with strong S&T capabilities (Ko 2013).

South Korea's current international S&T collaboration activities is focused on: the strategic expansion of global joint research; highlighting the characteristics of regional S&T cooperation, active participation in international organisations and programs, and securing S&T global investment and improving indigenous efficiency (Ko 2013).

The Science and Research System

South Korea's S&T system is dominated by private sector corporates, who account for around 74 per cent of total GERD. Private sector R&D was encouraged as a means to develop the country's economy. The IT industry and (to a lesser extent) the biotechnology industry have been the major drivers of R&D in the country (Campbell 2012), with one particular sector – radio, television and communication equipment – making up 48 per cent of all South Korean business R&D (by far the largest share in one sector among OECD countries) (OECD 2012e).

Historically, in addition to facilitating private-sector R&D investment, the government had focused on creating a state-led research capacity in the form of government research institutes (to the neglect of universities) (Campbell 2012). Only recently has there been a shift to basic rather than applied research, and the empowerment of the university research sector (OECD 2012e).

In recent years, there has been a push to streamline the S&T system with the creation of a new National Science and Technology Commission in 2011 as a permanent body under the office of the President. A Presidential Advisory Council on Science and Technology was also established in 2013, to replace an existing Council on Education, Science and Technology (Ko 2013). R&D expenditure flows have suggested that there is a weak relationship between the public and private sectors (Yim 2004), and therefore the government is pushing forward with a substantial number of schemes (including the Technology Holding Company system) to try and improve industry-academia collaboration (OECD 2012e).

Policy Priorities and Opportunities

The *2013 Third Science and Technology Basic Plan*, as a holistic guiding document, identified thirty main strategic areas for R&D investment. These fell into a number of categories mostly focusing on: IT and telecommunications, green and environmental technologies, nano technology and biotechnology (Ko 2013).

The Low-carbon Green Growth Policy is a major priority, with the government envisioning Korea as a leading green power – this prioritises green technologies and has facilitated pressure toward integrating and commercializing R&D outcomes in this area (Ko 2013). This priority is reflected in the 557 initiative, which has earmarked US$2.4 billion to invest in green technology, and the government's commitment to raise 'green' R&D to 2 per cent of GDP (OECD 2012e).

It is clear that the government clearly links its S&T policies to the success of the economy. For example, in 2010 the Ministry of Knowledge Economy outlined a major plan to restore competitiveness in the IT arena (especially in the context of Apple's ascendancy in the tech market) – this effort focused on cutting edge innovative areas such as 'the development of a 3D industry, merging of medical and IT technologies, and applying IT technologies to more traditional industries, such as automobiles, robotics, machinery and shipbuilding' (Campbell 2012). In 2003, the government had identified ten growth engine industries through the Next Generation Growth Engine program critical to South Korea's continued economic growth – six of these fell into the IT product category. This program also highlighted South Korea's emphasis on tangible products rather than intangible knowledge goods (Seong et al. 2005).

Considerations

Like Japan, Korea does not recruit overseas talent especially well - only 0.3 per cent of top quality migrant researchers live in Korea, one of the lowest among OECD members (Ko 2013). The country also has a very wide gender gap. The government has instigated some schemes to support women in S&T careers, and others to try and internationalise the Korean research system (eg Global Korea Scholarships Program) (OECD 2012e).

One security issue unique to South Korea is its complicated relationship with North Korea. In many ways, South Korea has attempted to use inter-Korean S&T cooperation to facilitate close co-economic development between North and South, focusing on resolving difficulties in the North such as food and energy shortages (Yim 2004).

South Korea is also in a very unique and challenging position. While it has become a major player in the private sector in the field of electronics and telecommunications (ie Samsung and LG are major Korean brands), it is somewhat caught between still dominant developed countries (eg Japan and the United States) and rising developing countries (eg China) who are all interested in excelling in the ICT field. It is a big question as to whether Korea can establish stronger international networks and inject more creative and innovative thinking into its science and research strategy.

India

Current International Science and Research Collaboration

The science policy literature has often compared India to a 'sleeping giant'. Compared to other countries with a major research base, it 'slumbered' through the 1980s and started to awaken in the 1990s. Since then, the number of research publications from India has 'caught up with other [countries] in a strikingly brief period' (Adams, King & Singh 2009).

India has a number of bilateral R&D agreements focusing on particular themes. For example, its agreement with the United States focuses on clean energy, with the United Kingdom on next-generation telecommunication), with the EU on energy and water technologies and with Australia on strategic research (OECD 2012b). Research collaboration is strongest with the United States, although Western Europe (the United Kingdom, Germany and France) and Northeast Asia (Japan, South Korea, and increasingly China) are also important partners (Adams, King & Singh 2009).

The Science and Research System

India's research base is dominated by universities and private research institutes. There has been, however a tremendous increase in the number of foreign R&D centres based in the country, growing from fewer than 100 in 2003 to around 750 by 2009 (UNESCO 2010). Many major multinationals are setting up R&D institutions in India to take advantage of R&D development capacity and availability of young and emerging scientists (Gupta & Gupta 2011).

At 66 per cent of funding as per 2012, Government remains the main R&D funder (OECD 2012b). The Government is hoping to drive the private sector to increase its R&D investment to at least match the public sector's R&D investment, through the creation of the National Science, Technology and Innovation Foundation, which is to be established as a Public-private partnership (Ministry of Science and Technology 2013).

Policy Priorities and Opportunities

India's science and research priorities revolve around faster, sustainable and inclusive growth. An 'inclusive' model of innovation has been quite critical due to the scale of the country and the importance placed on science and innovation to deliver improvements across all across society. As Sam Pitroda, the Chairman of India's National Innovation Council has put it, 'the big transition in India is to a place where [the best brains] are working on the problems of the poor'. Hence, the country is finding ways to provide 'frugal solutions to India's chronic problems of providing food, energy and water security to [its] people' (Bound & Thornton 2012).

The Government was hoping to strengthen GERD to reach 2 per cent of GDP by 2012 – recent figures suggest this is unlikely to have happened, but it is a promising sign that India continues to develop objectives around significant R&D investment. As mentioned above, India is keen to develop an innovation system to stimulate industry R&D, and is also intent in enhancing productivity in agriculture and the informal sector (OECD 2012b).

Strategic research priorities have been identified as 'space, nuclear and defence, ICT software, biotechnology and pharmaceuticals' (OECD 2012b) and 'agriculture, telecommunications, energy, health and drug discovery, materials, environment and climate variability and change' (Ministry of Science and Technology 2013).

Reviewing India's academic and research output from 1999 until 2008, its academic performance in microbiology and pharmacology and toxicology, along with in computer science, has grown markedly. Other specific fields of research in which India is focused on include agricultural engineering (and other agriculture-related fields), the medical sciences and the material sciences (Adams, King & Singh 2009).

India's heavy reliance on imported coal and changing demographics in the country means that energy supply security is also an issue of critical importance to the country. The country understands that its current energy portfolio is an issue and India's *2008 National Plan on Climate Change* showcases India's interest in focusing on research relating to 'solar energy, energy efficiency, water and strategic knowledge on climate change (OECD 2012b).

Considerations

India is still a challenging place to be a researcher. Dropping economic growth has been compounded by a paralysis of government due to corruption scandals, lack of infrastructure investment and the political inability to pass critical reports (Bound & Thornton 2012). There is a lack of human capital. The research population is relatively small, and the country only has one world-class university (Adams, King & Singh 2009).

While the country's democratic institutions are firmly entrenched, the emergence of regional and state-level political parties on the country's national level will likely lead to a decentralisation of power over coming years (Economist Intelligence Unit 2014c). Coupled with more protests from the expanding middle class and India's youth, it is unclear whether the country will be able to continue investing further funding into R&D.

Indonesia

Current International Science and Research Collaboration

Many Indonesian institutions have strong ties to Japan and historical links with the Netherlands. Cooperation with Japan predominates due to long-term personal relationships and ease of funding access. Many cooperation projects fall into the category of capacity building, as they concentrate on training, exchange of researchers and networking (Schuller et al. 2008).

Overall, S&T collaboration is seen as important to compensate for existing deficiencies in S&T Government institutions indicate that funding and co-patenting, and a focus on country-specific and global thematic priorities, are why international S&T is important. Individual scientists feel that access to new S&T knowledge; cooperation networks; exchange of research personnel; and an increase in reputation are the most important factors. (Schuller et al. 2008).

The Science and Research System

The Ministry of Research and Technology is responsible for driving S&T policy and has authority over seven R&D agencies (UNESCO 2010). Overall, there is very low R&D intensity in Indonesia. Although the country had a long and rich history of science and innovation during the Dutch colonial era, all efforts were geared towards Dutch interests and the vast majority of support went to Dutch scientists (Mouton 2007).

Some of the key research institutions in Indonesia today are international research institutions, such as the Centre for International Forestry Research (CIFOR) and the Economic Research Institute for ASEAN and East Asia (ERIA), the latter of which is incidentally strongly supported by Japan. Many of these research institutions focus on agriculture, and play an important role in the country's agricultural research system (Mouton 2007). However, since 2008 there has been a notable increase in scientific productivity, possibly due to favourable Government policy and financial incentives to encourage R&D collaboration and the allocation of at least 20 per cent of the budget to education. Indonesian researchers seem keen to collaborate with foreign institutions (Lakitan et al. 2012).

Policy Priorities and Opportunities

Indonesia's National Research Council identified climate change, global warming and deforestation as the key thematic issues of interest for S&T (Schuller et al. 2008). With serious energy and environmental challenges (natural resources are overexploited and domestic energy demand is rising), these are clearly key policy challenges (OECD 2012c). Some other identified thematic programs include agro-technology; marine science; and natural resource accounting (UNESCO 2010).

The latest five year refinement plan (2010-14) of the country's long-term development plan, *Vision and Mission of Indonesian S&T Statement 2005-25,* focuses on quality of human resources, development of S&T through improved R&D capabilities, and economic competitiveness (OECD 2012c).

Considerations

In 2008, the National Reform Council highlighted the following challenges toward improving Indonesia's innovation (Schuller et al. 2008): predominance of public R&D; sector-development approaches; weak linkages among S&T actors, few tech-economic cluster initiatives; and limited access to knowledge pools. Benyamin Lakitan, Deputy Minister for S&T Institutional Affairs, suggested insufficient industry and government trust toward domestic R&D institutions as another key obstacle (Lakitan 2011).

The Science base is relatively low, as Indonesia does not have a world-class university and does not publish with impact. Public investment in R&D is also low (OECD 2012c). R&D accounted for 0.5% of GDP in 1982, but fell to 0.07% by 2005 (Schuller et al. 2008).

Indonesia also has a complex and strict regulatory environment where government and SOEs continue to play a major role. Innovation is hampered by significant barriers to entry, and basic infrastructural issues (especially in the context of the archipelago's geography) and a weak education system continue to prove problematic (OECD 2012c). The focus on nationalistic policymaking is likely to continue under the new incoming Government from October 2014, stemming any prospects of liberalising market reform and an improved investment climate (Economist Intelligence Unit 2014d). Corruption will also be a key systemic governance challenge for Indonesia, although the Anti-Corruption Commission is making inroads into the political elite (Economist Intelligence Unit 2014d).

Political stalemate with Australia over asylum seeker policy will continue, with ramifications for all forms of collaboration (including science and technical) between Australia and Indonesia.

Singapore

Current International Science and Research Collaboration and the Science and Research System

Singapore is the clear leader in S&T development in SE Asia, with Malaysia coming a far second. International S&T collaboration is strongly supported by government and has been the key to Singapore's economic and technological success (Schuller et al. 2008), especially given the country's city-state status and lack of natural resource endowments. The government has continuously placed a large emphasis on knowledge transfer from multi-national corporations, which has helped to increase the international competitiveness of Singaporean companies and firms. The country has also followed a *technoliberalism* approach - while providing extensive state support for S&T development, it has also facilitated large-scale international S&T collaboration and a relatively open market. There is a concerted federal approach toward transitioning the results of R&D to the private sector, which is facilitated through Singapore's clustering of major research institutions to enhance overall efficiency and effectiveness – Fusionopolis, a clustering of a seven research institutes at the cutting edge of the infocommunications sphere, and Biopolis, a purpose built biomedical research hub bringing together researchers from the public and private sectors together to collaborate, are key leading examples (UNESCO 2007). This has allowed Singapore to maintain its position as a global hub for business investment and talent (National Research Council of the National Academies 2010).

As the most technologically advanced country in SE Asia, Singaporean institutions collaborate extensively with partners across the globe. The United Kingdom and Japan still benefit from previous colonial ties with the country, with both collaborating extensively with Singapore on biomedical sciences – many UK and Japanese universities and research institutes also have subsidiaries based in Singapore. That said, Singapore has an extensive collaboration network with the United States due to the latter's leading position in various fields, while Singapore's historical and cultural ties with China explain a large number of exchange programs between the two countries (Schuller et al. 2008).

With most Singaporeans speaking English as their 'foreign language', tertiary study in the United States and the United Kingdom is preferred compared to EU counterparts. Japan comes third (Schuller et al. 2008). This also partly explains the long-standing academic and professional networks between the United States, United Kingdom, and Singapore. Within SE Asia, there is also strong research cooperation with Thailand, Malaysia and the Philippines, and growing collaboration with China and India due to the latter's rapid technological development (Schuller et al. 2008).

Most international research collaboration has been around the medical sciences, due to Singapore's aspirations of establishing itself as the centre for medical and pharmaceutical research. This stemmed from the country's recognition in the late 1990s of the biomedical sciences as an area with tremendous growth potential, and the country's commitment toward 'public sector basic and mission-oriented R&D that is closely aligned with industry development opportunities' (A*STAR 2011). As Lim Chuan Poh, the Chairman of Singapore's Agency for Science, Technology and Research, points out; this strategy has reaped extensive dividends, with more than 100 global biomedical science companies now carrying out large-scale business operations in Singapore (Poh 2013).

Policy Priorities and Opportunities

Singapore's government has identified and developed an R&D agenda focusing on Singapore's competitiveness in four large economic clusters, which are: biomedical sciences; electronics and infocommunications; engineering; and chemicals and energy (A*STAR 2011). These strategic areas are aligned with what Singapore sees as driving forces for R&D on the global stage, including: aging, renewable energy, climate change and sustainability, urbanisation, infectious diseases, food security, and water supplies. With its highly educated and technologically developed society, Singapore aspires to becoming 'a major economic powerhouse by finding innovative solutions… and selling the knowledge it has developed' (National Research Council of the National Academies 2010).

Two Singaporean universities are of critical importance for R&D in the country: the National University of Singapore (NUS) and the Nanyang Technological University (NTU). Their fields of focus are very much aligned with the government's strategic direction, with research at NUS focused on the biological sciences, chemistry, pharmacy, mathematics, and physics, and research at NTU focused on nanotechnology and nanoscience, interactive and digital media, and the life sciences (Schuller et al. 2008).

The rationale for Singaporean interest in international S&T cooperation is varied. For government institutions, there is a great emphasis on transnational learning, innovation benchmarking and co-patenting. The shortage of skilled manpower for R&D, especially in Singapore's priority areas of research, is also a central motivation for collaboration. Individual Singaporean scientists put a strong emphasis on: access to S&T, scientific publications, reputation, increase in co-patenting, increase in research capabilities, and exchange of research personnel (Schuller et al. 2008). Most notable is the absence of access to funding and research infrastructure in these lists – Singapore's substantial government support for R&D and world class infrastructure means this is of little importance.

Immigration continues to be one key vexing policy issue for Singapore. There is a local perception that the rapid rise of people living and working in Singapore has put a significant strain on national infrastructure and has increased the cost of living. Migration and urbanisation, two intertwined issues, would therefore be two HASS areas of policy interest to Singapore.

Considerations

There is little to doubt that Singapore will continue to be successful in realising its innovation goals should the international climate remain similar. The main challenge for Singapore continues to be attracting and keeping experts in key S&T fields in the global race for the brightest minds.

Singapore has a relatively small research base. As the US National Research Council of the National Academies put it, 'Singapore has a lot of intellectual endeavour and has formed an excellent environment for innovation, but the country's size renders the total effort relatively small compared to that of much larger countries' (National Research Council of the National Academies 2010).

Key vulnerabilities for Singapore include unfavourable swings in the global economy, given the country's globalised economy and R&D sector, and rising tensions in the South China Sea, given that Singapore's trade dependent economy is reliant on safe waterways.

While Singapore's relationship with Malaysia has warmed immensely (correlating with increasing research ties between the two countries), its relationship with Indonesia continues to be cold – diplomatic spats between Singapore and Indonesia remain common (Economist Intelligence Unit 2014h). Singapore, like Australia, is keen to increase its engagement in Africa and with China.

Malaysia

Current International Science and Research Collaboration

S&T collaboration has historically been very strong with the UK due to colonial and language ties. This connection has stayed strong due to alumni networks and common research programmes, although there is no formal bilateral S&T agreement between the UK and Malaysia. In the 1990s, Japan was a preferred S&T partner given its leading technological and economic position in Asia, although the scope for collaboration broadened to include many other countries in the 1990s, including other East Asian and Western European countries (Schuller et al. 2008). Due to its unique Islamic and cultural links, Malaysia also has a substantial number of S&T relationships across the Organisation of the Islamic Conference (OIC).

The Science and Research System

The Ministry of Science, Technology and Innovation is Malaysia's leading national institution on S&T policy. The key research institutions in Malaysia are those funded and supported by the government in areas of key strategic importance, although historically most of these institutions have focused on agriculture and commodity crops due to the latters' importance to the 1990s (and current) Malaysian economy (Schuller et al. 2008).

The Government has clearly recognised the role S&T plays in the economy, and has placed a high premium on S&T policy. During its technology-based industrialisation in the 1990s, the government developed a National Innovation System (NIS) to move the economy from manufacturing to higher value-add activities (Asgari & Yuan 2007). Investment in R&D as a percentage of GDP doubled from 0.37 per cent in 1992 to 0.64 per cent in 2004. Malaysia's focus on aligning S&T priorities with economic priorities (and prioritisation of value-add activities) has incentivised the private sector to invest a substantial amount in R&D as well, with ~65-70 per cent of total R&D expenditure coming from the private sector in 2004 (Schuller et al. 2008; Mouton 2007). This has now dropped to around 55 per cent, suggesting that the Malaysian government has been providing even stronger support to the sector of late.

This relatively easy access to funding for domestic research projects from Malaysian and government sources means that funding and S&T infrastructure are not as important to Malaysia's international cooperation outlook (Schuller et al. 2008). With the Malaysian economy expected to continue its strong growth, with EIU forecasting 5.5 per cent GDP growth per annum from 2015-18 (Economist Intelligence Unit 2014f), this relatively successful R&D investment model will continue.

Policy Priorities and Opportunities

Malaysia has its *2007 National Innovation Model*, which highlights its balanced approach between *technoliberalism* and *technonationalism*. For example, two major 'thrusts' identified by the Government include (and in parallel) 'acquiring new and imported technologies', and 'promoting development of indigenous S&T capabilities in strategic and key technologies' (Mohamad 2010).

Malaysia's *Second National Science and Technology Strategy*, put out in 2002, highlights Malaysia's focus on linking S&T with economic interests. It aims to become a developed and industrialised country by 2020, and sees S&T development as a core component. The *Strategy* very importantly highlights a number of key areas for S&T focus, mostly focused on 'key technologies of the future' and sustaining support for Malaysian industry. These areas include: advanced manufacturing; advanced materials; microelectronics; biotechnology; information and communication technology; multimedia technology; energy, aerospace, nanotechnology; photonics; and pharmaceuticals (Government of Malaysia 2002). The government has focused on funding research in these areas, building on top of an already very established concentration in agriculture and commodity crops.

This S&T heavy strategy revolves around Malaysia's development challenges and the country's aspirations to graduate from middle-income to high-income status. These challenges are based on six 'stylised' facts on Malaysia (common to many middle-income countries), including: rapid economic growth, rapid structural change, consistent openness, macroeconomic management, social progress, institutional quality, and political economy and ownership structures (Hill et al. 2012). One major challenge Malaysia faces in the medium to long term is the maintenance of their universally acclaimed national healthcare system. Demographic and lifestyle shifts are making Malaysia's population older and less healthy, and healthcare spending already accounts for over 10 per cent of total government expenditure (Economist Intelligence Unit 2014f).

Considerations

Not many universities in Malaysia have a measurable S&T impact (Asgari & Yuan 2007). It seems that there is a weak university-industry linkage and a low rate of commercialisation of research findings by universities (Schuller et al. 2008), although the government provides substantial support toward public universities. Schüller et al. also argue that 'mobility funds and funding for international collaboration networks by the government are rather limited and not very encouraging' (Schuller et al. 2008). The government has instead focused on creating bilateral S&T agreements.

On the political front, the United Malays National Organisation (UMNO) faces significant challenges to its grip on power in the years ahead. However, it is unlikely that Malaysia's gradual (and always rocky) transition into a multi-party democracy will damage political stability.

Vietnam

Current International Science and Research Collaboration

Vietnam maintains and has continued to expand S&T collaborative ties with Europe, while Japan and the United States have emerged as two new key partners. While close ties with Russia and a number of Eastern European countries including Poland and the Czech Republic still exist, stemming from Cold War era ties, the European Union, the United States and Japan are the key cooperation partners today (Schuller et al. 2008).

Most collaboration takes place in the form of capacity-building projects, either financed bilaterally or multilaterally – Japan is Vietnam's largest overseas development aid (ODA) donor. Vietnam's emerging ties with the United States are usually private, with funding coming from top-tier universities or foundations. Vietnam is starting to engage with ASEAN and China and neighbouring countries on strategic fields (eg with Thailand on agriculture and health care). Geographic and cultural proximity is a prime reason for this (Schuller et al. 2008). Vietnam is also moving into the position of being an equal investor in some key collaborative projects, rather than just receiving international funds (Ly 2013).

Vietnam does not have an in-depth strategy for international S&T collaboration, although it is promising to see that 'international integration on science and technology' is classed as the fifth main viewpoint in Vietnam's S&T strategy (Anon 2012).

Government representatives put emphasis on transnational learning, country-specific priorities and funding as key reasons for international collaboration, while individual scientists and academics are motivated by access to collaborative networks, new S&T, exchange of research personnel and students, expansion of research capabilities and funding. Government research institutes also highlighted access to research infrastructure, increase in reputation and scientific publication (Schuller et al. 2008).

The Science and Research System

In many ways, S&T strategy in Vietnam is still subsumed to macro-economic planning, a legacy from the country's socialist roots. S&T was seen as a vital part of a self-sufficient economic model. Since the late 1980s, there has been a gradual shift toward greater liberalisation of higher education and science (Mouton 2007).

The Ministry of Science and Technology is responsible for the formulation of S&T policy and their implementation, although other ministries are involved. There has been a sharp increase in the number of R&D institutes in the country since the 1990s, and a shift away from government research institutes toward non-government and private institutes. That said, the two key research institutes are still the Vietnamese Academy of Science and Technology (focusing on natural and engineering sciences) and the Vietnamese Academy of Social Sciences (Schuller et al. 2008), both institutions of which have been privileged to receive funding from the central government to carry out science and research priorities (Mouton 2007).

Almost half of the funding for university research in Vietnam comes from international sources, suggesting that there is a lack of national funding for universities. Overall, heavy teaching loads, aging staff and a lack of financial resources make it difficult for universities to prioritise research (Schuller et al. 2008). The government is planning to increase GERD, to reach a level of 1 per cent by 2015 and rising to 1.5 per cent to 1.7 per cent from 2016-20 (Ly 2013).

Policy Priorities and Opportunities

The Strategy for Science and Technology Development for the 2011-2020 period forms the basis of Vietnam's S&T strategy. The strategy is relatively holistic, as it stresses that the S&T should be used to help Vietnam meet the basic requirements of a modern industrial country. Key 'prioritised technology directions' include: information and communication technology; biology technology; new material technology with a focus on manufacturing; automation and electronic-mechanic technologies; and environmental technologies (Anon 2012). This is relatively similar to the key identified areas of preferred international S&T cooperation fields identified by Schuller et al. in interviews with Vietnamese stakeholders, which included: ICT and software development; biotechnology with a focus on agriculture; health with a focus on tropical diseases; advanced materials; automation and electronic-mechanic technologies; atomic energy and new energy; cosmology technologies; and mechanic-machinery technologies (Schuller et al. 2008).

Considerations

There is a lack of financial support from Government for collaborative activities, and difficulty of publishing in international (primarily English) journals (Schuller et al. 2008).

There is substantial deficiency in Vietnam's technological infrastructure, and the national R&D system is organised in such a way that commercialisation of research is both difficult and expensive. Within Vietnam itself, S&T institutions have tended to work in isolation. Linkages between Vietnam's R&D institutions and the private sector are few, and there are serious quality issues with regard to academics and scientists (Bezanson 2000).

As a one-party developing state, the key issue for Vietnam is facilitating strong economic performance, especially in the context of a relatively disappointing economic performance from 2012-13. The way the government manages to deal with corruption, given a recent high-profile scandal over the misuse of Japanese aid funds, will also be critical given the large role ODA plays in the country (Economist Intelligence Unit 2014j).

Vietnam's regional relations can often be tense, especially due to disputed territories with China, Mekong River dam disputes with Laos, and political tension with particular Cambodian political parties (Economist Intelligence Unit 2014j). One can expect Vietnam's relationship with the United States to continue to grow, and through that, increasing US-Vietnamese S&T cooperation.

Thailand

Current International Science and Research Collaboration

In general, Thailand is a developing S&T country with modest scientific output and research intensity. The country has strong collaborative ties across Asia, in particular with Japan and neighbouring countries in ASEAN. It also has a strong S&T relationship with the United States and with several European countries, including France, Germany, Hungary, the Netherlands, Sweden and the United Kingdom. It seems that partner countries are often chosen on the basis of their S&T and academic strength in particular disciplines and sectors. While there is no stated preference for particular partners (Schuller et al. 2008), it does seem that Thailand is growing its collaboration extensively within the region, with a heavy focus toward ASEAN and other Asian countries.

Its ties with Japan are particularly strong, given Japan's leading S&T position in Asia and Japan's role as one of Thailand's most important economic partners. Thai institutions collaborate with Japan on a wide range of S&T fields, including on: food, agriculture and fisheries; biotechnology; life sciences; energy; and the environment. Collaboration with other partners tend to focus on more limited fields: biotechnologies and the life sciences for the European Union (and transport and aeronautics specifically with France); nanosciences, nanotechnologies, materials and new production technologies with the United States; health with China; and the environment with Australia and New Zealand (Schuller et al. 2008).

Government representatives put emphasis on transnational learning and country-specific priorities as key reasons for international collaboration, while individual scientists and academics are motivated by access to new S&T, collaborative networks, research capabilities and funding (Schuller et al. 2008).

The Science and Research System

Within the Ministry of Science and Technology, the National Science and Technology Development Agency (NSTDA) is the key institution focused on S&T policy. It has been responsible for the formulation of national S&T policy since 1992, and for the funding and administration of R&D projects and the four national research centres. These four centres represent the core technologies where government support is concentrated - ICT; biotechnology; materials technology and nanotechnology (Schuller et al. 2008).

The higher-education sector, which includes a substantial number of both public and private universities, is accounting for a larger share of R&D investment (Schuller et al. 2008). The Ministry of Education has also designated 9 universities as National Research Universities. These 9 leading research-intensive universities will receive the largest proportion of government funding and will be looking to collaborate internationally (Department of Industry & Australian Education International 2013).

Overall, the science and research system suffers from ineffective resource allocation and a loose structure. The country also has relatively ineffective supra-ministerial cross-cutting policy processes and a lack of co-ordinating mechanisms, making it difficult for the Ministry of Science and Technology to coordinate with economic ministries such as the Ministry of Industry (UNESCO 2010) It is also problematic that the country's primary and secondary education system remains 'archaic' (Warr 2011). Starting from a relatively low base, the government is planning to increase GERD to 1 per cent by 2016 and 2 per cent by 2021. This will be coupled with substantially increasing the number of Thai R&D personnel and facilitate the increase of private R&D expenditure through incentives such as tax incentives and matching grants (Durongkaveroj 2014).

Policy Priorities and Opportunities

The *National Science Technology and Innovation Policy 2012-2021* forms the basis of Thailand's science, technology and innovation strategy. The strategy is relatively holistic, and recognises the need to balance between economic and social development. The four key critical thematic inputs into this Policy include 'demographic and social changes', 'energy and the environment', 'green innovation' and 'regionalism' (Durongkaveroj 2014), with a strong focus on social inclusion. These inputs tie in with some of the critical challenges facing Thailand, including long-term neglect of environmental degradation and the wasteful management of the country's water resources, rising inequality and a growing rural-urban divide (Warr 2011). There has understandably been a broadening of priorities to support the development of scientific knowledge across all areas, rather than just the four core areas covered by the national research centres (Schuller et al. 2008).

These fields of focus are relatively similar to the key identified areas of preferred international S&T cooperation fields identified by Schuller et al. in interviews with Thai stakeholders, which included: health; food, including agriculture, bio- and nanotechnology; energy; environment; and ICT (Schuller et al. 2008).

Considerations

The country remains polarised between supporters and opponents of former Prime Minister Thaksin Shinawatra. Political stability remains elusive, especially as the country's political divisions – mostly between the middle class elite based in the capital and the more populist rural constituency – seem to be unbridgeable (Economist Intelligence Unit 2014i). This is likely to detract from any policies focusing on developing Thailand's science and research capacity.

There seems to a cultural preference in Thailand towards working within the region and with Asian partners. The argument is often made that it is easier to work with Asian colleagues, given common values and the increased likelihood for long-term follow through on projects. Thais also seem less inclined to support long-term research exchange – most Thai scientists and academics prefer to stay in Thailand, meaning than brain drain is not really an issue for the country (Schuller et al. 2008).

Philippines

The Science and Research System and Current International Science and Research Collaboration

The Philippines has struggled since the Asian financial crisis. In general, science and research in the country is relatively undeveloped, having in many ways gone backwards over the last decade. GERD is very low at around 0.1 per cent – this dropped from the early 1990s where GERD was around 0.22 per cent (Philippines Department of Science and Technology 2002) - funding and support for science and research is lacking. As an example, the National Research Council of the Philippines (NRCP), which is responsible for funding and supporting basic research, only had a budget of around US$450,000 in 2009/10 (Llano 2010). The country has very few scientists and academics in proportion to the overall population, and it fares badly in patent rankings.

The Department of Science and Technology (DOST) is responsible for the formulation and implementation of national R&D strategies. Former S&T strategies, including the *1991-2000 Science and Technology Master Plan*, were overly ambitious and lacked resourcing to carry out proposed investments and reforms. Another more specific plan, the *1993-1998 Science and Technology Agenda for National Development*, targeted specific industries as 'export winners' in consultation with industry without considering broader scientific and research long-term objectives. The more recent DOST Medium-Term Plan recognised the twin challenges of needing to build long term S&T capability addressing more critical poverty alleviation issues (Philippines Department of Science and Technology 2002).

The current *National Science and Technology Plan for 2002-2020* takes a broad approach, recognising that it must take a holistic approach to development. Strategies outlined include: niching and clustering; addressing pressing national problems; developing human resources; providing support to industry (in particular SMEs); accelerating technology transfer; building and upgrading S&T infrastructure; strengthening collaboration; promoting and popularising S&T and improving S&T governance (Philippines Department of Science and Technology 2002; UNESCO 2010).

The country does not have a clear international S&T collaboration strategy. While different policy documents do highlight particular potential benefits of international collaboration, including technology transfer and further funding opportunities, there is not a strong push toward internationalisation. Where there is international collaboration, it mostly focuses on in-country development cooperation programs or collaboration with ASEAN partners on certain shared challenges. The Japan-led Asian Development Bank, the main multilateral provider of development support in the region, is based in Manila.

Policy Priorities and Opportunities

The *National Science and Technology Plan for 2002-2020*, along with the Philippine Council for Advance Science and Technology Research and Development, has outlined a number of broad long-term S&T priorities for investment and development, including: agriculture, forestry and natural resources; health/medical sciences; biotechnology; information and communications technology; microelectronics; materials science and engineering; earth and marine sciences; fisheries and aquaculture; environment; natural disaster mitigation; energy; and manufacturing and process engineering (Philippines Department of Science and Technology 2002; SEA-EU-Net n.d.). The country is also trying to identify key areas for innovation-led growth, with particular mention to biotechnologies and ICTs (UNESCO 2010).

Historically speaking, agriculture has always constituted a considerable proportion of the government's R&D budget. The government recognised the public nature of agriculture R&D. In the early 2000s, only around 14 per cent of R&D was being spent on the environment and human health (Mouton 2007).

The three main short-term challenges include improving the country's public finances, enhancing investment and creating jobs (Economist Intelligence Unit 2014g). Other key pressing national problems include: poverty; poor health; rapid population growth; food shortages; water; energy; housing; low levels of income; low productivity; environmental deterioration; cyber-terrorism and poor governance (Philippines Department of Science and Technology 2002). Infrastructure constraints are also considerable, given the country's problematic power and energy sector, and reform is very much a priority in the country's public primary and secondary schooling system.

Considerations

The ambitious targets set out in the *National Science and Technology Plan for 2002-2020* are not supported by institutional and economic capacity, given the country's financial situation and its substantial host of policy challenges. While many countries in the region are forging ahead in science and research, the Philippines is falling behind (UNESCO 2010).

The Pacific Island countries

Current International Science and Research Collaboration

There is an emerging S&T presence in the Pacific region due to common concerns confronting many of the Pacific island countries, in particular climate change. A number of regional bodies, many of which are based in Fiji, and key regional organisations play an important role in providing high-quality information on research on critical issues and challenges facing Pacific island countries (UNESCO 2010). Some key regional organisations include the Asia Pacific Regional Environment Network, the Pacific Islands Forum Secretariat, and the Pacific Operations Centre of the United Nations Economic and Social Commission for Asia and the Pacific.

International science and research collaboration is relatively non-existent for most of the Pacific, except for Fiji, Papua New Guinea, New Caledonia and French Polynesia (see 'Illustrative mapping of research collaboration in the Pacific' in the Main Report for details). For scientists in these four countries, co-authorship is very important given the shortage of S&T capacity within the Pacific. France is a preferred partner of French Polynesia and New Caledonia due to cultural and historical ties, while Australia and the United States are common S&T collaborators across all of the countries (UNESCO 2010). Most international engagement is in the form of development partnerships, as overseas development assistance (ODA) is extensive. Key partners for the region include Australia and New Zealand, Japan, the European Union, and to a lesser but growing extent, China and South Korea. The World Bank and Asian Development Bank are multilaterals with a relatively large role, and numerous UN agencies and private foundations provide support and technical expertise in particular sectors.

Technology transfer and capacity building is at the crux of the Pacific island countries' collaborative engagement efforts. As the Fiji government postulates, 'the lack of funding, qualified personnel and state of the art facilities limits the extent of quality scientific research and technology development in Fiji… the opportunities lie in adopting and diffusing technology that have been successfully proven overseas and have been assessed to be suited to the local context' (Government of Fiji 2013). As an example of such efforts, in May 2012 the Fiji government signed an agreement with South Korea to expand knowledge exchange in the field of ocean science and technology (Government of Fiji 2013). In general, Pacific island countries are also trying to facilitate more tertiary institution links with international partners. This allows Pacific island institutions to 'learn from their experience and benefit from their resources' (Department of National Planning and Monitoring 2010).

Science and Research Systems

With the exception of Fiji, Papua New Guinea New Caledonia and French Polynesia, Pacific island countries generally lack any substantial form of science and research systems. As of 2010, these four countries and territories accounted for 86 per cent of articles published in the Pacific region (UNESCO 2010). As a recent review of the Pacific Plan (designed to strengthen regional cooperation) highlighted, science is a relatively low priority for Pacific island countries facing extensive development challenges (Anon 2014a).

The Secretariat of the Pacific Community (SPC), previously known as the South Pacific Commission, plays a key role in developing S&T capabilities in the region. Founded by Australia, France, New Zealand and the United States, the SPC now acts as an international body focused on providing S&T capabilities and technical expertise to its member countries (22 Pacific island countries and territories). Most of its programs are funded by the European Union and Australia (UNESCO 2010).

There has been a gradual improvement in R&D capacity in the higher education sector, with institutions such as the University of the South Pacific (USP), the Fiji School of Medicine, and more recent institutions such as the University of Fiji (UoF) and the Fiji National University taking the lead (UNESCO 2010). There is definitely interest in creating regional capacity in R&D, with UoF establishing centres such as the Centre for Energy, Environment and Sustainable Development and the USP establishing a Renewable Energy Research and Technology Transfer Centre to play a key role in renewable energy technology in the Pacific.

One can hope that Pacific island countries will follow the lead of PNG, which in 2008 established a Research, Science and Technology Council to advise the PNG government on R&D and S&T.

Policy Priorities and Opportunities

Pacific island countries, unlike their counterparts in Asia, have struggled to meet Millennium Development Goal targets, especially around the eradication of poverty and in achieving development targets. For example, Papua New Guinea's absolute poverty rate has increased since 1990. As a result, most of the Pacific island countries can still be classed as 'underdeveloped', and face some common priorities and challenges including food and energy security; regional IT infrastructure and connectivity; education; and health (UNESCO 2010). Climate change mitigation and sustainable management of the world's oceans are also two issues of critical and shared concern among all Pacific island countries (The Australian National University et al. 2013). The SPC's research focus is aligned quite well with these priorities and challenges: land resources, including forestry and agriculture; marine resources; and social resources, with a focus on women and youth.

Considerations

Most Pacific island countries suffer from substantial public debt but also substantial investment needs, particularly in infrastructure and education. Most countries want to be more economically self sufficient, but lack the critical mass necessary for a successful and productive economy. This means that all of the Pacific island countries remain difficult destinations for foreign investment, reflected for example in Fiji's outlawing ownership of media organisations by foreigners in 2010 (Economist Intelligence Unit 2014b).

The fortunes of the lucky Pacific island countries that are richly endowed with natural resources, such as Papua New Guinea and Fiji, rest quite strongly with the fortunes of international resource companies in the countries, and effective government negotiation with them over appropriate taxes on exports.