THE FUTURE OF RESEARCH: OVERVIEW TO 2040

A BACKGROUND PAPER FOR AUSTRALIAN UNIVERSITIES

THOMAS BARLOW

2019

ACKNOWLEDGEMENT

This report was commissioned by the University of New South Wales.

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PREFACE

This paper was commissioned from Dr Barlow to help inform discussions at UNSW about the future of Australian research, and to stimulate discussion among members of Management Board and UNSW Council on strategic planning beyond the scope of our existing 2025 Strategy. I sought an independent perspective to provide nuanced projections of the ways in which our sector might evolve over the decades ahead, and advice on how a university like UNSW might anticipate and respond to these changes.

The quality of the paper and the advice within it exceeded expectations and I am delighted that this document is now being made publicly available so that others may also benefit from its wisdom.

As Dr Barlow notes, research is by its very nature difficult to predict. The '20-year bets' set out in this paper are obviously speculative, yet there is great value to be found in canvassing the possibilities. He describes a future in which Australia's research intensity increases, our comparative advantages are more confidently exploited, and opportunities for international collaboration and investment rise.

The paper identifies specific frontier areas in which Australian research might place greater strategic emphasis – from areas such as applied quantum physics and artificial intelligence and automation, to energy breakthroughs, medical devices and the genome revolution.

Dr Barlow also delivers some timely cautions, warning against non-strategic adherence to popular trends, including broad research objectives that are laudable in theory but overly ambitious in scope, or placing too great an emphasis on multidisciplinary approaches.

Reassuringly he predicts that our main single source of research funding will remain government funding – if so, that will be a wise investment in the social and economic future of Australia. He also anticipates that a greater proportion of individual academics will have a specialist focus in research or teaching rather than delivering equally in both areas.

This document is a superb rendering of a difficult brief. It brings structure and rigour to thinking about how our sector may evolve and to anticipating what the future of Australian research will look like to 2040. I thoroughly recommend it.

Professor Ian Jacobs BA, MA, MBBS, MD, FRCOG
President and Vice-Chancellor, UNSW Sydney
Professor of Women's Health

BETS ABOUT THE FUTURE OF RESEARCH

Few areas of human endeavour have proved more intractable to prediction than research. Researchers don't follow a deterministic path to the future; they stumble onto it. They are constantly surprised by their own discoveries.

Despite these difficulties, there are benefits in thinking seriously about the future of research: for researchers, institutions, and policymakers. Several guesses as to what Australian university research will look like in 2040 are summarised below.

SUMMARY OF 20-YEAR BETS

UNIVERSITY RESEARCH SYSTEM

Research Expenditures: By scale of expenditures, the Australian university research system will be 60%-100% larger than it is today.

Main Sources of Research Funding: In aggregate, Australian universities will be paying for 50%-60% of their research using their own funds.

External Sources of Research Income: Governments will continue to account for a majority of Australian universities' research income, accentuating the importance of political relationships and of being active in politically fashionable fields.

Research Intensity: It's plausible to imagine that the pre-eminent Australian universities will be equally, if not more focused on research, as they are on teaching.

Research-Teaching Specialisation: Current terminologies about work function will be replaced by new ones like 'teaching-focused' and 'research-focused', and fewer than a third of university academic staff will be roles that combine both functions.

COMPETITION & COLLABORATION

Global Competition: The number of research-active universities will soon exceed 2000, but the more important change will be the number of research-active universities currently operating at low scale that shift to undertake research at high scale.

Research Assessment: The global research literature will double, producing new disciplinary fragmentation, stronger linguistic, national, and regional networks, and increasing use of non-volume-based markers of research excellence such as journal reputations, peer recommendations, and collaboration patterns.

International Collaboration: Two thirds of Australian universities' research output will involve an international co-author while Australian research policies will become more closely embedded with those of its allies.

Dominant Regions: North America will still be the leading region for high-impact research, followed by East Asia (particularly in high-tech fields). European institutions will remain influential but with reduced significance on the world stage. India and Southeast Asian nations will have a rising influence.

Industrial Engagement: Business will account for two thirds of Australian R&D, broadly in line with the situation in Europe, but well behind that in China, Japan, and the USA; consequently, industrial investment in universities will increase to match OECD norms, albeit driven by a minority of universities with industrially-relevant portfolios.

SUMMARY OF 20-YEAR BETS (CONTINUED)

TRENDS IN KNOWLEDGE PRODUCTION

High-Growth Domains: The technological domain will share an equal significance in the literature alongside physical sciences and life sciences, while medical and health sciences will entrench its dominant position, accounting for over a third of total global research.

Technological Drivers: The biggest breakthroughs in every field (perhaps even in the humanities) will be driven by research groups that are most active in seizing and leading a new paradigm based on automation and a compute-intensive approach to experimentation, observation, and analysis.

Political Fashions: Government priorities will include many that are quite different from those of today, inspiring a host of newly fashionable initiatives, and spurring new forms of advocacy from within the research community. This will produce a resurgence of investment far beyond today's popular themes of health and environment.

Intellectual Fashions: Intellectual trends will come and go with increasing rapidity, so originating or picking high-impact trends will become more important than ever, and the professional judgement and expert intuition required to discriminate in this regard will be more valuable than ever.

Knowledge Fragmentation: Some Australian universities may introduce more over-arching multidisciplinary structures, but all will have greater sub-disciplinary specialisation and the fundamental disciplinary specialties will continue to provide the core organising principles for research.

HOT TOPICS

12 frontier areas from the present that look like stepping stones to the future:

1. Statistics, data science, and visualisation
2. Applied quantum physics
3. Next-generation materials
4. Surveillance and sensor technologies
5. Artificial intelligence and automation
6. Energy breakthroughs
7. Imaging technologies
8. Genome revolution
9. Push for personalisation
10. Medical devices
11. Digital world
12. Quantification in the humanities, arts, and social sciences

THE FUTURE OF RESEARCH

Any of these guesses may ultimately be proved wrong. Over a 20-year timeframe, projections about the future of research are necessarily speculative. But there is insight to be found just in thinking through the possibilities. For Australian universities having to place bets on the future, and aspiring to excel in research in 2040, it looks as if there will be advantages in aiming to be:

Empowered – high in scale, more research-intensive, and better equipped to invest their own resources and make their own strategic choices in research;

Globally-facing – deeply networked internationally, and engaged most especially with partners in countries with strong economies on both sides of the Pacific;

Selective – about the subfields in which they specialise, and about how and where they publish, so as to maximise global perceptions about the quality of their output;

Technological – active both in developing breakthrough technologies and in adopting new technologies to transform research practice;

Persuasive – not merely relying on today's fashionable capabilities (e.g. in environment or health), but able to create compelling cases for investment in other areas too; and

Adaptable – able to adjust positively and opportunistically to technological, scientific, social, political, and geopolitical changes.

1. THE FUTURE OF KNOWLEDGE CREATION

Predicting the future is easy. We can predict the motion of the moon and the planets with exquisite precision. Most of our machinery – computers, televisions, aeroplanes, automobiles, entire factories – are designed to act in predictable ways. In an age of public schooling and standardised social structures, there are many aspects of our personal lives that follow an inherently predictable course. Certainly not all aspects of the future are unpredictable.

Yet predicting the future of research is hard. The discovery of new knowledge is inherently creative, and creativity typically has a chaotic quality. Research is a product of complex and evolving social arrangements, which do not usually follow deterministic trajectories like machinery or physical bodies in space. Most of important of all, research involves the probing of the unknown, which means that its discoveries (and their implications) are often unpredictable by definition.

There have been examples where astute individuals have made surprisingly accurate forecasts about the future of discovery. Richard Feynman foresaw the creation of the new field of nanotechnology. Vannevar Bush established a vision of the internet even before the invention of the transistor or the optical fibre cable. George Moore famously proposed a rate for semiconductor technology advancement, which has proved accurate over several decades. Yet their success has been the exception rather than the rule.

The willingness of highly intelligent and well-informed persons to make judgements about the future of knowledge, the ease with which they are able to persuade others of their vision, and the tendency of their forecasts subsequently to prove erroneous has been a source of great tragedy in human society. I don't wish to join the ranks of failed seers. I certainly don't pretend to be able to see the future more accurately than anyone else.

Nonetheless, it is clearly of value for organizations to think about the long term. In this report, I've been asked to ponder what research might look like at Australian universities in 2040. This is a useful question for the leaders of an institution to deliberate upon as they try to plan strategically for an uncertain future. Although I am sceptical of my capacity to see what lies ahead, I've tried to address the question as rationally as I can by following three simple rules:

> First, I've broken the problem into parts on the grounds that smaller puzzles are usually easier to solve than large ones.
>
> Second, I've collated historical data on past trends in order to quantify as prudently as I can what might be possible over the next 20 years.
>
> Third, I've tried to think in terms of 'speculations' and 'bets' hoping that this will help my readers to remember that I am merely putting forward hypotheses not predictions.

This approach has its limitations. Perhaps the most obvious is that historical data extending back even 25 years will fail to encompass an Australian recession. Speculation about the future based upon what's happened in the past is also likely to underestimate the odds of a significant discontinuity. Australian universities have changed enormously over the past two decades, but largely via an evolutionary process. The future may bring about much more punctuated and sudden disruption.

My speculative thinking is that, by 2040, Australian universities will be even more active in research (and more research-intensive) than they are today, that they will spend even more of their own funds on research but that they will retain a strong dependence on government. I hypothesise that global competition will continue to intensify and that new quality measures will emerge to differentiate the best institutions from their emerging challengers. I am doubtful about a renaissance in Australian industrial partnerships with Australian universities but see accelerating opportunities for collaboration and investment overseas.

On the question about which areas of research are most likely to thrive, I see no reason to anticipate any diminution in the fallibility of human beings, and therefore fully expect many researchers and funding bodies to remain captive to the influence of political and intellectual fashions. Under a business-as-usual scenario, one should expect a steady continuation of the growing political appetite for medical and environmental research. However, significant changes to Australia's economic or strategic circumstances could unwind things on this front.

More importantly, I do anticipate big changes in the kinds of questions it is possible to answer, in line with advances in the technologies and tools at our disposal, especially in computing, communications, and instrumentation. The impact of computing will surely bring increased quantification to the research paradigm across all disciplines, while automation will surely have a more specific impact in moving traditional experimental research onto an industrial scale.

My hunch is that universities will change more radically over the next 20 years than they have done in the hugely disruptive period since the Dawkins reforms undertaken 30 years ago, but I may be wrong. The world as a whole seems to be changing so quickly at the moment, perhaps we are due for a breather. I am certainly resigned to the likelihood that I may well be wrong in every bet I make. There are too many uncertainties and too many unknowns.

With this in mind, I encourage you to read, think about, and discuss the ideas I put forward, but remember always that the most important characteristic for any university that wants to plan for the distant future is *adaptability*.

2. THE UNIVERSITY RESEARCH SYSTEM

The structure of the Australian university research system has changed considerably over the past 20 years. This prompts the question whether historical trends amount to the start of a longer-term trajectory or whether we've come through a one-off step change that will evolve into a new steady state.

In a society in which few things seem permanent, it seems natural to argue that there is plenty of systemic change yet to come. The following summarises five key speculations about what the Australian university research system will look like in 20 years, along with some implications should these bets prove right.

20-YEAR BET	IMPLICATIONS
2.1 Research Expenditures: By scale of expenditures, the Australian university research system will be 60%-100% larger than it is today.	Universities should plan for significant growth in their research portfolios or they will lose market share and reputational advantage to more aggressive competitors.
2.2 Main Sources of Research Funding: In aggregate, Australian universities will be paying for 50%-60% of their research using their own funds.	Universities can expect to have greater control in setting their own directions in research. This will be liberating but will require discipline to ensure that good decisions are taken.
2.3 External Sources of Research Income: Governments will continue to account for a majority of Australian universities' research income, accentuating the importance of political relationships and of being active in politically fashionable fields.	Universities and researchers will need to engage politically, and institutions should be prepared to use their own funds to leverage political decision-making about research investment.
2.4 Research Intensity: It's plausible to imagine that the pre-eminent Australian universities will be equally, if not more focused on research, as they are on teaching.	Universities will need to embed research considerations in all major decisions, and they will need to treat research not just as an add-on to enhance their marketing endeavours, but as part of their core business.
2.5 Research-Teaching Specialisation: Current terminologies about work function will be replaced by new ones like 'teaching-focused' and 'research-focused', and fewer than a third of university academic staff will be roles that combine both functions.	Universities will have to work harder than ever to maintain harmonious relationships between teaching-focused and research-focused staff, and they will likely adopt more active monitoring and management of staff performance in research.

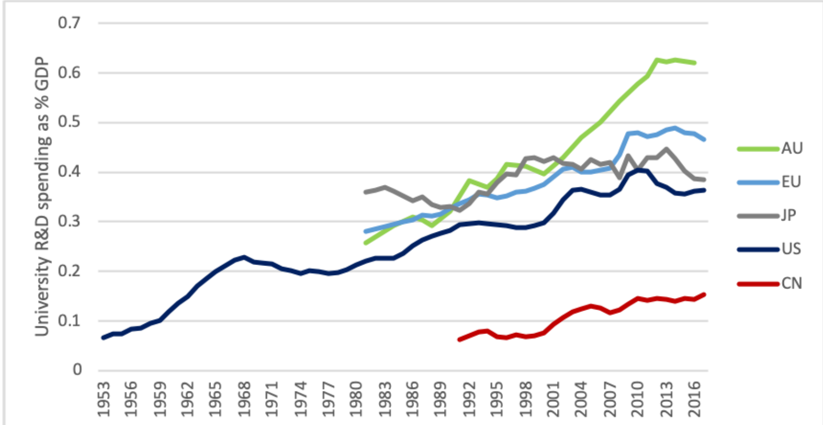
2.1 RESEARCH EXPENDITURE

QUESTION: Will aggregate investment in Australian university research continue to increase?

WHY IT MATTERS: There is a strong relationship between scale of investment and research output. Historically the world's leading universities in research have been those with the most resources; and the countries with the best research universities have typically been those with the greatest capacity and willingness to fund university research.

DATA: OECD data on university R&D expenditures enable study of long-term trends (Exhibit 2.1). As of 2017, nations with the highest spending intensity were Denmark (1.0%), Switzerland (0.90%), Sweden (0.86%), Norway (0.70%), and Austria (0.70%). Australian spending intensity was also high (0.62%) but these benchmarks suggest there is still room for growth.

EXHIBIT 2.1 – UNIVERSITY R&D SPENDING AS % OF GDP



Note: Derived from OECD 2018, NSF 2018, and BEA 2018.

ARGUMENT: Investment in university research has out-paced economic growth for half a century, albeit with periods of stagnation, usually coinciding with wider economic contractions. This indicates a very promising trend for universities. Note too that because research is such an influential determinant of university reputation, universities have strong incentives to undertake research and to raise funds to make it happen.

COUNTER-ARGUMENT: Universities have expanded dramatically over this period reflecting a surge in student numbers due to (a) demographic effects (primarily due to the Baby Boomers and Millennials), (b) a new social contract which has seen a huge increase in the proportion of each age cohort attending university, and (c) the opening of international student markets which has dramatically increased revenues for Australian universities. If (a) and (b) represent trends that have run their course and if international student markets soften then the broader financial impacts on Australian universities will likely have serious negative consequences for research.

EXTREME CASE: Societies can turn against their universities (e.g. Germany in the 1930s, China in the 1960s and 1970s) and economic collapse can have very serious implications for university research (e.g. Russia in the late 1980s and early 1990s). However, events like these tend to be rare and would seem unlikely in the Australian context.

20-YEAR BET: In the short term, Australian universities' research revenues (and hence their expenditures) are vulnerable to an economic downturn. In the long-run, however, the intensity of investment in Australian university research looks likely to sit in a band between 0.6% and 0.8% of GDP. *Assuming the Australian economy expands by 2.5% pa over the same period, the Australian university research system will be 60%-100% larger in 20 years than it is today.*

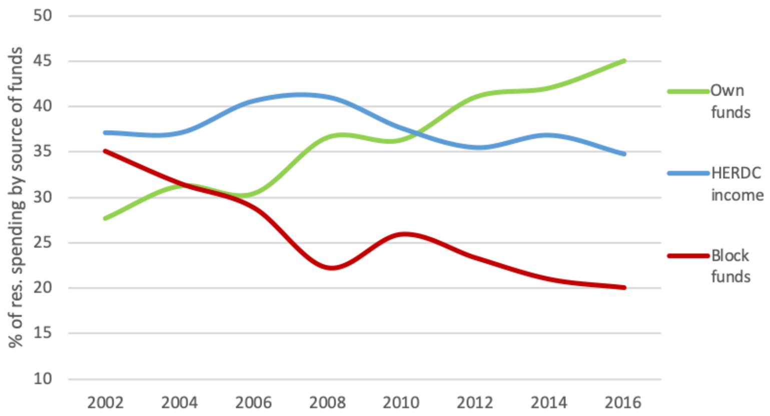
2.2 MAIN SOURCES OF RESEARCH FUNDING

QUESTION: Who will fund Australian university research?

WHY IT MATTERS: Universities have historically funded research via three main sources: from government block grants for research and research training; from research income provided by various external parties for research projects; and from universities' own funds derived from teaching revenues and endowments. Universities that fund their own research can gain strategic independence but must be able to free up resources from other activities to make this happen.

DATA: The extent to which universities must dip into their own funds to support their research (Exhibit 2.2) can be estimated by subtracting HERDC research income (HERDC 2019) and government block grants and infrastructure funding (summarised in HERDC 2019 & SRI 2018) from total university R&D expenditures reported in the ABS R&D survey (ABS 2018).

EXHIBIT 2.2 – UNIVERSITY RESEARCH INCOME BY SOURCE



Note: Derived from ABS 2018, SRI 2018, and HERDC 2019.

ARGUMENT: For 15 years, Australian universities have had to draw upon a steadily increasing volume of their own funds in order to drive scale and success in research. This reflects (a) growing competition in research, (b) a steadily declining appetite from government to provide block funding, and (c) the unwillingness of third-party funders to pay the full costs of research. At some point this trend must stall and the system should reach a new steady state, but the pattern is unlikely ever to be fully reversed.

COUNTER-ARGUMENT: As teaching margins shrink, as students become focused on value for money, and as transfers from teaching revenues to research become a hot political issue, universities could suffer a decline in capacity to invest in their own research. In this case, the significance of block grants would rise again and only universities with substantial endowments would be in a position to maintain strong internal investments.

EXTREME CASE: The Australian Government may come to see nearly all block grant and infrastructure funding as an unnecessary subsidy for a highly successful export industry. Under this scenario, block funding becomes trivial relative to universities' own spending.

20-YEAR BET: There are strong incentives for Australian universities to invest in their own research, and the political competition for government resources is intense. Assuming international education markets continue to provide reliable and growing income streams, this trend towards internal investment will continue. *In 20 years, whilst there will be variation by institution, in aggregate Australian universities will be paying for 50%-60% of their research using their own funds.*

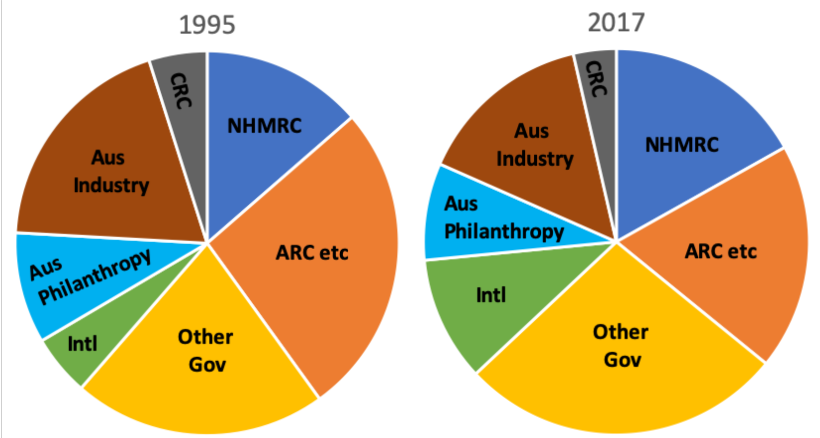
2.3 EXTERNAL SOURCES OF RESEARCH INCOME

QUESTION: Will Australian universities be able to diversify their external project income?

WHY IT MATTERS: Those who pay for research determine which research is funded. Funders have their own disciplinary, social and economic priorities. Different funders will also favour different evaluation processes for selecting among competing projects, researchers, and organizations. HERDC research income is especially influential in this regard because it tends to leverage other internal funds and to influence the selection of other organizational priorities.

DATA: Data on university research income is collated through HERDC (Exhibit 2.3). Here 'ARC etc' includes all category 1 funding except for NHMRC funding. 'Other Gov' accounts for all category 2 funding from federal, state, and local governments. 'CRC' includes income from government and industry. 'Medical Research Future Funding' will shortly lift category 1 medical funding.

EXHIBIT 2.3 – UNIVERSITY RESEARCH INCOME BY SOURCE



Note: Derived from HERDC 2019 data.

ARGUMENT: For two decades, universities have consistently depended on government (NHMRC, ARC, Other Gov, and CRC funding) for around 60% of external research income – i.e. universities have found it difficult to diversify away from a dependence on government income. Within this envelope, moreover, governments have become more prescriptive about what they fund, as exemplified by the neglect of ARC research and the increased focus on medical and 'Other Gov' research. There's no strong reason to expect for these arrangements to unwind.

COUNTER-ARGUMENT: Industry and philanthropic funding have both had a little uptick in recent years, which may signal a shift in opportunity. Moreover, international funding has provided a source of diversification for Australian universities. It tends to be cyclical, and has historically proved sensitive to broader geopolitical trends, but ongoing globalisation could increase Australian universities' access to offshore funds and reduce their dependence on domestic government funds.

EXTREME CASE: A rising governmental preoccupation with political impact could massively unbalance the Australian university research system by producing: (i) further neglect of broad capacity building through the ARC and (ii) the promotion of an even more extreme emphasis on medical research and other politically favoured domains.

20-YEAR BET: The best Australian universities will continue to develop world-leading strengths to grow their international funding and diversify their funding base. Yet the impacts won't revolutionise the sector. *In 20 years, Australian governments will continue to account for a majority (>50%) of Australian universities' research income, and this will magnify the importance of political relationships and of being active in politically fashionable fields.*

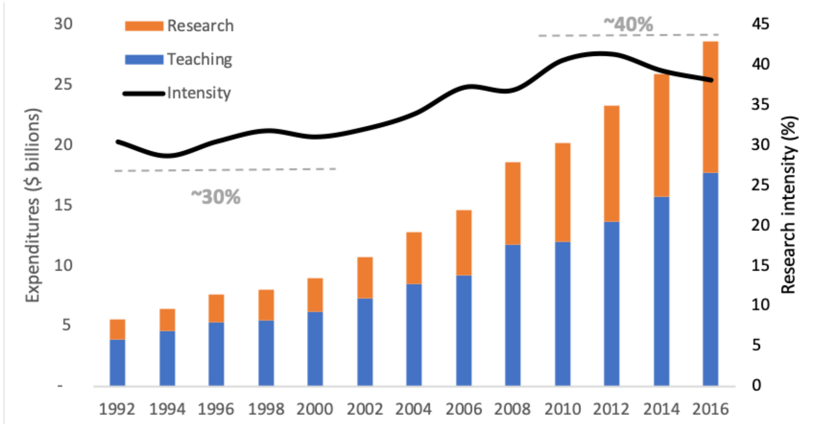
2.4 RESEARCH INTENSITY

QUESTION: How much of a university's portfolio will be taken up with research?

WHY IT MATTERS: Research and teaching have very different revenue models in higher education. They also necessitate different approaches when making hiring decisions. (Historically, top-flight researchers have been more difficult to attract and retain than top-flight teachers.) If universities start to look more like research institutes, this impacts significantly upon their business models.

DATA: A telling estimate of research intensity can be derived by presenting R&D expenditures (ABS 2018) as a proportion of total university outlays from continuing operations (DETa 2018). This is readily done for Australian universities in aggregate over the past 25 years (Exhibit 2.4), revealing that the sector's research intensity has increased from ~30% to ~40%.

EXHIBIT 2.4 – RESEARCH AS % OF TOTAL OPERATIONS



Note: Derived from ABS 2018 and DETa 2018.

ARGUMENT: Collectively, Australian universities have experienced a decisive shift upwards in research intensity, with research reaching a new plateau at ~40% of university expenditures. But some universities have lower intensity and others have higher intensity than the national figure. Leading research universities in Australia and globally are probably already best thought of as 50:50 organizations, and what the best do today is what the rest aspire to do tomorrow.

COUNTER-ARGUMENT: Rising research intensity is a consequence of the long economic boom, strong revenues from teaching growth, the mounting importance of rankings in global league tables, and policymakers' expectations that investment in university research will yield economic fruit. A reversal along any of these dimensions will see research intensity decline as universities refocus on their traditional core teaching obligations.

EXTREME CASE: Teaching has historically been more labour-intensive than research, while research (in many though not all fields) has proved more capital-intensive than teaching. Over time, new technologies will reduce the cost of delivering teaching, while the sophistication and cost of equipment required for frontier research will rise. This will eventually transform universities from teaching organizations that do research into research institutes that teach.

20-YEAR BET: The integration of research into undergraduate teaching programmes will prove an important differentiator for high-status universities as they compete with new models of education delivered remotely via technology. This reflects changing social demands and the impact of new technologies: barriers to entry for competitors in tertiary education are falling, while barriers to entry for competitors in research remain high. *Not every university will be able to make the leap, but in 20 years it's plausible to imagine that the pre-eminent Australian universities will be equally, if not more focused on research, as they are on teaching.*

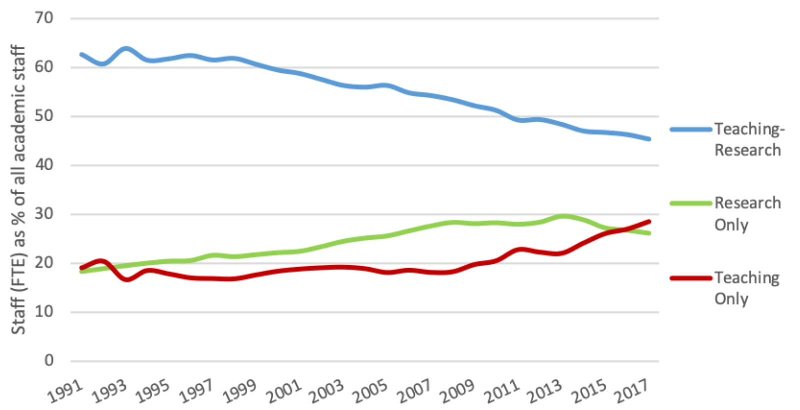
2.5 RESEARCH – TEACHING SPECIALISATION

QUESTION: Is the old teaching-research model finished?

WHY IT MATTERS: In late twentieth century universities, the academic workforce was composed predominantly of staff members each of whom had responsibilities both for undergraduate teaching and research. A model that spawns greater specialisation with more teaching-only and research-only staff would radically change hiring requirements, transform workplace cultures, and engender new practices in relation to promotion and performance management.

DATA: The Australian Government collects data on the Australian higher education workforce (DETb 2018), with staff categorised by work function. The data shown here (Exhibit 2.5) include casual staff, but a similar pattern is observed when one analyses full-time staff only. In both datasets, there has been a steady decline in the proportion of academic staff fulfilling a traditional teaching-research role.

EXHIBIT 2.5 – WORKFORCE FUNCTION



Note: Derived from DETb 2018 and includes casual as well as full-time staff.

ARGUMENT: For two decades from the early 1990s, steady growth in research investment and government initiatives to support research fellowships lifted the proportion of academic staff in research-only roles. More recently, demand for teaching services and the efficiencies that come from using specialised teachers has encouraged universities to create more teaching-only positions. A continuation of either of these effects will continue to erode the proportion of academic staff in traditional teaching-research roles.

COUNTER-ARGUMENT: A bifurcated model is neither sustainable nor desirable. At great universities, teaching and research inform one another and this process is best carried out by individuals who straddle both worlds. As teaching and research become more integrated, the teaching-research role will reassert itself.

EXTREME CASE: Research only became a part of the job description for academic staff in late nineteenth century Germany, and the research-teaching model only became entrenched in the second half of the twentieth century. For hundreds of years prior to this, the vast majority of academic appointments were teaching only. Why shouldn't we return to a largely specialist model?

20-YEAR BET: Australian universities will continue to move down the path towards specialisation of workplace function and current terminologies about work function will end up replaced by new ones like 'teaching-focused' and 'research-focused'. *In 20 years, fewer than a third of university academic staff will be roles that combine both functions.*

3. COMPETITION & COLLABORATION

Research has always been an international endeavour, but over the past 20 years research has been globalised. There has been a massive expansion in the number of research-active institutions and a steady increase in cross-border collaboration. This has raised the stakes for any institution that aspires to excel on the world stage. The following summarises five key speculations about the shifting patterns of competition and collaboration for Australian universities over the next 20 years, along with some implications should these bets prove right.

20-YEAR BET	IMPLICATIONS
3.1 Global Competition: The number of research-active universities will soon exceed 2000, but the more important change will be the number of research-active universities currently operating at low scale that shift to undertake research at high scale.	For global recognition in research, universities will increasingly need to build high scale portfolios while also producing an elite-quality output.
3.2 Research Assessment: The global research literature will double, producing new disciplinary fragmentation, stronger linguistic, national, and regional networks, and increasing use of non-volume-based markers of research excellence such as journal reputations, peer recommendations, and collaboration patterns.	Universities will need to differentiate by research specialisation and by pursuing distinctive research objectives. University researchers will develop new metrics of research quality and aspiring researchers will need to find ways to excel along such metrics.
3.3 International Collaboration: Two thirds of Australian universities' research output will involve an international co-author while Australian research policies will become more closely embedded with those of its allies.	Universities will vie for high-status global partners and for participation rights in international research initiatives. They will also be paying much greater attention to the political and strategic implications of their international collaborations.
3.4 Dominant Regions: North America will still be the leading region for high-impact research, followed by East Asia (particularly in high-tech fields). European institutions will remain influential but with reduced significance on the world stage. India and Southeast Asian nations will have a rising influence.	Universities globally would be advised to deepen relationships (where possible) with high-status partners in North America and Asia, while also trying to identify potential partners in rapidly growing emerging economies.
3.5 Industrial Engagement: Business will account for two thirds of Australian R&D, broadly in line with the situation in Europe, but well behind that in China, Japan, and the USA; consequently, industrial investment in universities will increase to match OECD norms, albeit driven by a minority of universities with industrially-relevant portfolios.	Some universities will actively identify high-growth and R&D-intensive sectors and some will align their disciplinary portfolios with the interests and needs of Australian firms, but most will continue to seek industrial funds in the same way they seek funds from all potential partners: opportunistically.

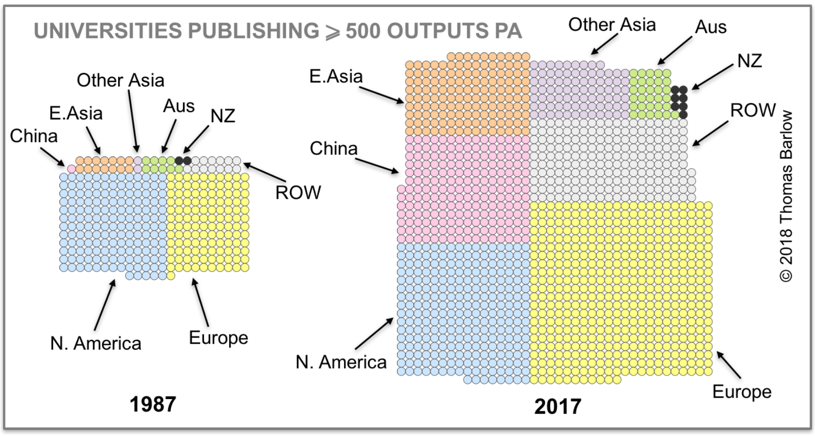
3.1 GLOBAL COMPETITION

QUESTION: Where are Australian universities main international competitors?

WHY IT MATTERS: Research is a global activity and the best research organizations compete and collaborate globally. International competition is especially relevant for universities involved in international education because global research standing has become a critical determinant of institutional reputation. Intensifying competition in research also means an ever-toughening contest for resources, research students, and staff.

DATA: A recent Barlow Report shows the expanding number of universities active in research as measured by a simple publication output threshold (Exhibit 3.1). It suggests that over the past 30 years, the number of research-active universities globally has increased from 320 to around 1400. The number of such universities in Australia increased from 9 to 31, while the number in China increased from 1 to over 200.

EXHIBIT 3.1 – RESEARCH-ACTIVE UNIVERSITIES



Note: Derived from BR 2019 and CA 2019.

ARGUMENT: As economies expand, the number of nations with the desire and capacity to invest in university research will continue to rise. New investment will be especially evident in high-growth nations like Indonesia, Turkey, Brazil, Mexico, Saudi Arabia, Nigeria, Philippines, and Vietnam. With large numbers of universities meeting basic thresholds for research activity, the incentives and advantages that accrue to those able to operate at a distinctively high scale will be magnified.

COUNTER-ARGUMENT: Societies have historically increased their universities in number and research intensity in line with economic growth and demographic effects. The recent trend mirrors prior expansions (e.g. in the late 19th century and following the Second World War). The observed recent rate of increase is not sustainable, has been skewed by China's return to the global economy, and will slow over the next 20 years.

EXTREME CASE: The dramatic increase in the number of research-active universities represents a seed that will germinate a completely new level of competition. Even if no new institutions become research active and join the fray, the global competition among the 1400 institutions depicted in 2017 will increase the pressure for every one of them to stand out in the scale of their research output and to differentiate by quality or some other characteristic of their research portfolio.

20-YEAR BET: The global competitive landscape will continue to add research-active institutions, which in turn will increase the reputational advantage for those able to conduct research at high quality and scale. *Within 20 years, the number of research-active universities worldwide will easily exceed 2000, but the more important change will be the number of research-active universities currently operating at low scale that shift to undertake research at high scale.*

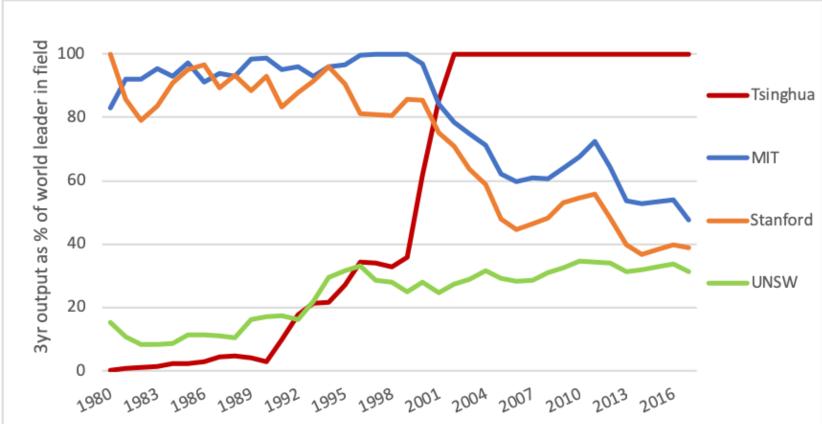
3.2 RESEARCH ASSESSMENT

QUESTION: How will researchers and funders assess research quality and researcher performance?

WHY IT MATTERS: Differentiating good research from bad is absolutely pivotal for funders, employers, peer reviewers, and organisational decision-makers. It is also increasingly essential for researchers themselves who face a vast and growing literature and who must be able to identify what is reliable and good while avoiding contributions to the literature that are distracting, misguided or just plain wrong.

DATA: There are now over 2.5 million research articles published every year in more than 40,000 peer reviewed journals (STM 2018). At the same time, productivity differences between leading institutions as measured by output volumes are narrowing. This is shown for four leading universities in the field of computer science (Exhibit 3.2), but very similar patterns are observed in other disciplines.

EXHIBIT 3.2 – WORLD LEADERS IN COMPUTER SCIENCE



Note: Derived from BR 2019 and CA 2019.

ARGUMENT: Surging output is making it increasingly difficult for researchers to keep up with the literature, and convergence in output among high-status universities has reduced the value of raw volume metrics for benchmarking. In a contest for visibility, few will dare to scale back, but with everyone aiming for volume, its value as an assessment metric looks set to decline.

COUNTER-ARGUMENT: We are in the midst of two revolutions. The ballooning of world output reflects the growth in discovery and the sheer number of new fields and subfields being created. Within each field, the situation is more manageable. At the same time, what looks like convergence among leading institutions is actually a crossing of paths that will see the best Chinese universities eventually dwarfing the output of all global competitors just as US universities did in the late twentieth century.

EXTREME CASE: The annual output of global scientific publications will double, in line with global investment growth, the expansion in the number of research-active institutions, and a competitive environment that forces everyone to strive for scale. The requirements to publish in the top journals will consequently become even more onerous than they already are, which will encourage some publishing of aggregated results, but not enough to stem the underlying drive for volume.

20-YEAR BET: The race for volume is not going to end any time soon. *The global research literature could well double in 20 years producing new disciplinary fragmentation, stronger linguistic, national, and regional networks, and increasing use of non-volume-based markers of research excellence such as citation patterns, journal reputations, peer recommendations, and collaboration patterns.*

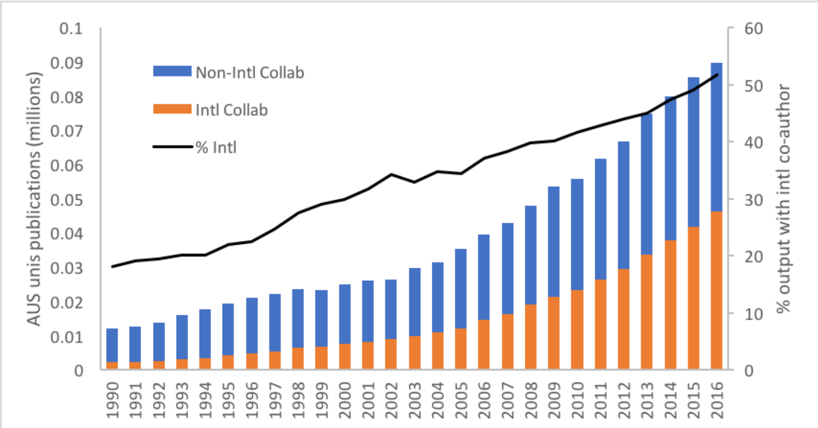
3.3 INTERNATIONAL COLLABORATION

QUESTION: To what extent will Australian university researchers need to be globally connected?

WHY IT MATTERS: Australia accounts for a fraction of the world's research investment and output. International collaboration enables Australian researchers (a) to gain early access to new discoveries being developed elsewhere and (b) to benefit from the ever-widening array of expertise and facilities that is being assembled in other parts of the world. International collaborations also tend to correlate with international funding and with positive responses in international surveys about institutional reputations.

DATA: The scientific literature offers a way of assessing rates of international collaboration. The 2019 Barlow Report showed that international co-authorship as a share of total Australian university research output has been rising since the early 1990s (Exhibit 3.3). Currently, more than 50% of Australian university outputs in science, technology, and social sciences have an international co-author.

EXHIBIT 3.3 – INTERNATIONAL CO-AUTHORSHIPS



Note: Derived from BR 2019 and CA 2019.

ARGUMENT: The best always want to work with the best, and as new technologies facilitate this, researchers will continue to seek out their optimal collaborators, wherever they may be. Moreover, as Australia's share of global research shrinks, and as reviewers increasingly evaluate co-authors as a proxy measure of output quality, the imperative to collaborate globally will strengthen. International collaboration and connectivity will continue its inexorable rise.

COUNTER-ARGUMENT: If the trend of the past 20 years continues, by 2040 three quarters of all Australian universities' research outputs will involve an international co-author. This is not beyond the realms of possibility, but some areas of research do not lend themselves either to large-scale or to cross-border collaboration. Moreover, the world as a whole is turning against globalisation. Consequently, it's reasonable to expect a levelling out of international collaboration rates.

EXTREME CASE: As the research community integrates, we will see not just more collaborative output, but also more internationally funded projects and infrastructure. This is already common in big science initiatives (e.g. astronomy, particle physics, genomics, climate science), but cloud computing and an emerging focus on data science makes this model plausible in other areas too. In time, parts of the Australian research system, including government funding agencies, may integrate much more closely with foreign agencies.

20-YEAR BET: International connectivity will intensify, though with a likely cultural and political bias. *In 20 years, two thirds of Australian universities' research output will involve an international co-author while Australian research policies will become more closely embedded with those of its allies.*

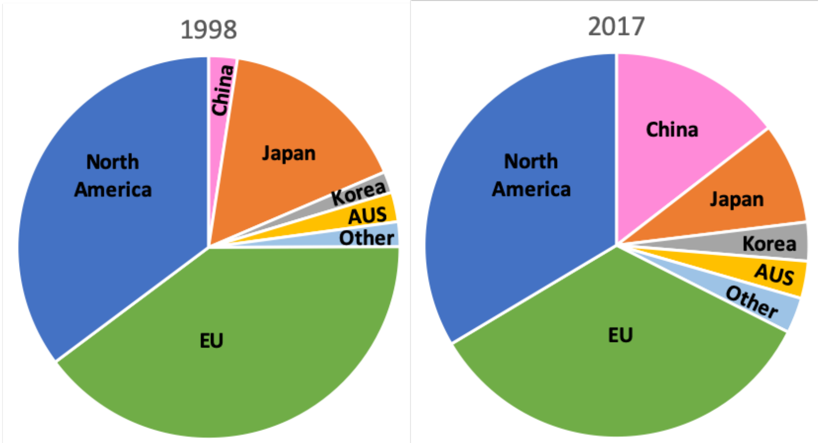
3.4 DOMINANT REGIONS

QUESTION: Where are the global epicentres of knowledge creation?

WHY IT MATTERS: In the early twentieth century, the greatest research discoveries were typically European. In the late twentieth century, the USA emerged as the global research leader. Knowing which countries are in the lead provides Australian university researchers with a useful bias in choosing collaborators, foreign research training placements, and in understanding which literatures to follow.

DATA: Three regions dominate university R&D spending globally: North America, Europe, and the Western Pacific. OECD data enables comparison of spending across these regions (Exhibit 3.4). Over the past 20 years, Chinese activity has displaced European and to a lesser extent Japanese activity. Although not shown here, spending in other regions so far remains modest (in relative terms).

EXHIBIT 3.4 – UNIVERSITY R&D SPENDING BY 3 REGIONS



Note: Derived from OECD 2018. Other means other Western Pacific nations.

ARGUMENT: Investment in university R&D has always been a function of prosperity. The growing scale of Chinese university R&D spending is a testament to this, as is the declining relative scale of Japanese and European spending. Assuming the link between economic activity and university R&D holds, over time we might expect to see enduring dominance from North America and China, strong but declining relative scale of investment in Japan and Europe, and eventually large new university research investments in places like India, Indonesia, Brazil, Turkey, and Mexico.

COUNTER-ARGUMENT: The West has led the world in basic research for centuries. China will rise and fall as Japan did, and it will face too many domestic political challenges to be able to afford a university research system on an American or European scale. At the same time, Europe will rediscover its economic mojo and will exploit a renewed vitality to reassert its old dominance in the discovery of new knowledge.

EXTREME CASE: The continued rise of East and Southeast Asia, the growth of the Indian economy, and an expansion of economies in Africa and Latin America, will see massive injections of resources into university research throughout the world. This will rebalance expenditures and output so that no one country or specific regions will ever again dominate global research production.

20-YEAR BET: National and regional trends in university research investment (and output) will remain a function of economic prosperity. *In 20 years, North America will still be the leading region for high-impact research, followed by East Asia (particularly in high-tech fields). European institutions will remain influential but with reduced significance on the world stage. India and Southeast Asian nations will have a rising influence.*

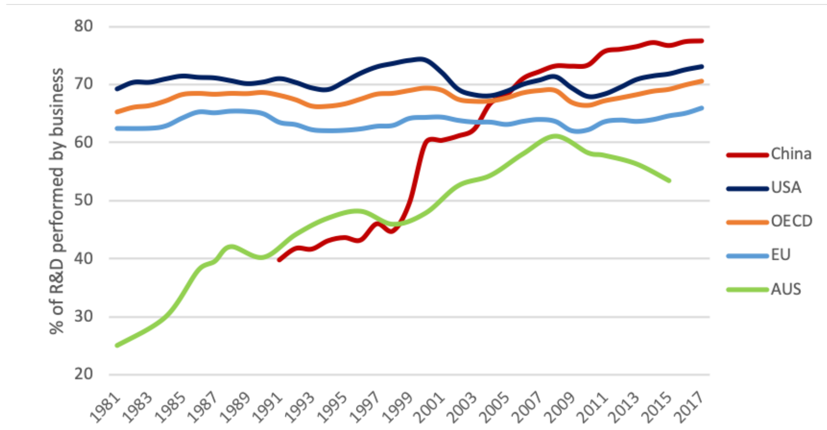
3.5 BUSINESS ENGAGEMENT

QUESTION: Will Australian industry ever be a major funder of Australian university research?

WHY IT MATTERS: Australian policymakers frequently bemoan the lack of connectivity between Australian university research and industry. Industrial funding ought to be a source of diversified income and should provide a mechanism for universities to increase the external impact and the national benefits derived from their discoveries. Yet industrial investment accounts for a persistently lower share of university research spending than is true in other developed economies.

DATA: From OECD data on R&D spending, it's possible to calculate the proportion of national R&D expenditures attributable to industry (Exhibit 3.5). Contrary to the pattern observed in other developed economies, nearly all of Australia's R&D spending has historically occurred in the public sector. R&D spending by Australian business exceeded that of public organisations for the first time only in 2001.

EXHIBIT 3.5 – SHARE OF R&D PERFORMED BY INDUSTRY



Note: Derived from OECD 2018 based on R&D expenditure data.

ARGUMENT: The Australian economy does not favour R&D-intensive sectors and Australian industry has consequently invested weakly in R&D. This has steadily changed (i) as low-tech and service industries have become more knowledge-intensive and (ii) as governments have provided incentives to foster R&D investment. However, there are enduring differences with the rest of the developed world, which will continue to limit private-sector investment available for universities.

COUNTER-ARGUMENT: Over the coming decades, every industry will experience growing investment in R&D, and sectoral differences in R&D participation will diminish. The bigger problem for universities is the diversity of their portfolios compared with industry, where research is massively focused in engineering and computer science. The only way to improve industry-university linkages is to refocus the universities around industrially-relevant disciplines.

EXTREME CASE: By seeding a new culture of high-tech entrepreneurship, Australian universities could conceivably themselves create the R&D-intensive companies that are needed to transform the Australian economy and to deliver a corporate ecosystem that is (a) hungry for new knowledge and (b) keen to connect with universities. If this scenario were to come to pass, the Australian economy would experience a transformation in its R&D intensity and university-business linkages would take off, but there is scant evidence for such a transformation at this stage.

20-YEAR BET: This is an area where Australia will continue to muddle through. *In 20 years, business will account for two thirds of Australian R&D, broadly in line with the picture in Europe, but well behind China, Japan, and the USA; consequently, industrial investment in universities will increase to match OECD norms, albeit driven by a minority of universities with industrially-relevant portfolios.*

4. TRENDS IN KNOWLEDGE PRODUCTION

It is hard to predict where knowledge will advance most rapidly. Recent developments point to an increased global emphasis on technology and medicine, and to striking advances in some enabling technologies. At the same time, political and intellectual fashions will continue to drive research behaviours, and there is uncertainty about multidisciplinary. The following summarises five key speculations about the shifting trends in knowledge production at Australian universities over the next 20 years, along with some implications should these bets prove right.

20-YEAR BET	IMPLICATIONS
4.1 High-Growth Domains: The technological domain will share an equal significance in the literature alongside physical sciences and life sciences, while medical and health sciences will entrench its dominant position, accounting for over a third of total global research.	Australian universities keen to participate in global trends should strengthen their emphasis on technology research and ensure that they have a sizeable capability in health and medical research.
4.2 Technological Drivers: The biggest breakthroughs in every field (perhaps even in the humanities) will be driven by research groups that are most active in seizing and leading a new paradigm based on automation and a compute-intensive approach to experimentation, observation, and analysis.	Universities will need to invest not only in new infrastructure but also in courageous ventures that use technology in order to scale up the impact and speed of discovery in research.
4.3 Political Fashions: Government priorities will include many that are quite different from those of today, inspiring a host of newly fashionable initiatives, and spurring new forms of advocacy from within the research community. This will produce a resurgence of investment far beyond today's popular themes of health and environment.	Universities with strong political leverage and researchers who can articulate political problems and their solutions will have advantages in political game-playing; but it can be as advantageous to create fashions as to follow them.
4.4 Intellectual Fashions: Intellectual trends will come and go with increasing rapidity, so originating or picking high-impact trends will become more important than ever, and the professional judgement and expert intuition required to discriminate in this regard will be more valuable than ever.	Universities should avoid rolling with every latest band-waggon, recognising instead the benefit in having in-house decision-makers with domain-relevant knowledge and an understanding of the competitive landscape.
4.5 Knowledge Fragmentation: Some Australian universities may introduce more over-arching multidisciplinary structures, but all will have greater sub-disciplinary specialisation and the fundamental disciplinary specialties will continue to provide the core organising principles for research.	Universities may continue to discover good publicity in multidisciplinary messaging, but they will need more than ever to maintain disciplinary strengths through focused initiatives built around specialty subfields.

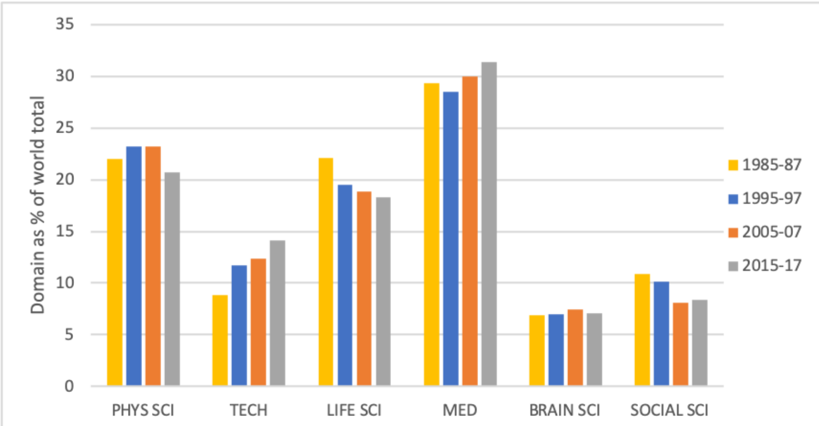
4.1 HIGH-GROWTH DOMAINS

QUESTION: Which will prove to be the growth fields of the future?

WHY IT MATTERS: Knowledge moves at different rates in different fields, shifting as a function of investment, technological possibility, prior discovery, and the perceived attractiveness of different fields among talented researchers. All fields will have their promising lines of enquiry, but a growth field generally presents greater opportunities than a stagnant field.

DATA: Trends in knowledge production are best analysed at the level of subfields, emerging concepts, and recent breakthroughs. However, it's also possible to capture higher-level trends relating to broad research domains (Exhibit 4.1). The 2019 Barlow Report did this by re-categorising Web of Science publication data into six domains, each of which encompasses many fields. Note that these data do not include the humanities or arts.

EXHIBIT 4.1 – GLOBAL OUTPUT BY KNOWLEDGE DOMAIN



Note: Derived from BA 2019 and CA 2019.

ARGUMENT: The elevate expansion in output in technology (engineering, computer science, and material science) and in medicine (excluding behavioural & brain sciences) reflects a heightened intellectual, technological, and societal excitement that currently exists in these fields. If these trends continue, these two domains will account for an increasing share of global output; output in other domains may also expand in an absolute sense, but more slowly.

COUNTER-ARGUMENT: The expansion in technology is not a function of any great revolution in capability or opportunity but is rather a function of where emerging Asian economies are choosing to invest. Likewise, the increasing relative output in medicine reflects the political priorities of ageing societies not any special improvement in the rate of discovery in treating disease.

EXTREME CASE: University research has long encompassed two paradigms: a discovery paradigm and a creative paradigm. While recent technological advances have magnified the opportunities for research along both dimensions, the opportunities for creating and inventing are infinite and will eventually account for a greater share of university research than more traditional discovery work.

20-YEAR BET: Within every domain there will be exciting and important research being undertaken, but the global research system will experience a continuing change in emphasis. *In 20 years, the technological domain will share an equal significance alongside physical sciences and life sciences in the literature, while medical and health sciences will entrench its dominant position, accounting for over a third of total global research.*

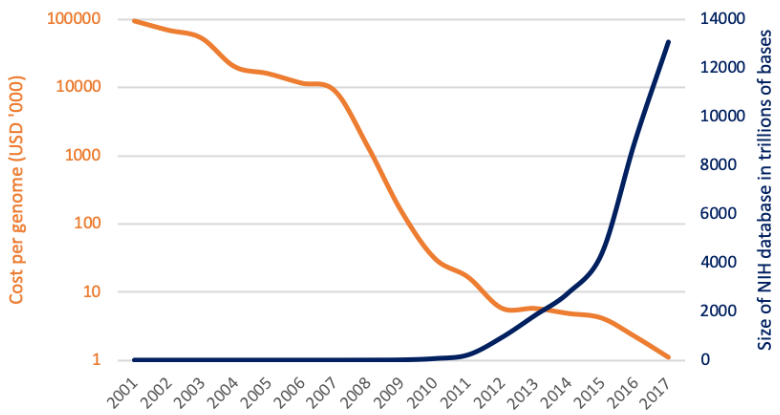
4.2 TECHNOLOGICAL DRIVERS

QUESTION: Will technological change transform research as it is transforming the wider economy?

WHY IT MATTERS: Many of the greatest breakthroughs in research have historically followed on from the development of some new tool or technology. The telescope, the microscope, and the x-ray are well-known examples of technologies that greatly magnified human potential for scientific discovery. A host of new technologies are poised to move entire fields in a similar way today: e.g. artificial intelligence, growing compute power, huge data storage, environmental sensors, biological and medical imaging, genome sequencing, robotics, and so on.

DATA: The National Human Genome Research Institute (NHGRI 2017) publishes data on the cost to sequence a human genome over time (Exhibit 4.2). The cost has dropped from $100m in 2001 to around $1k today, producing a huge uptick in the volume of sequencing conducted (SRA 2017). Few technologies have undergone such rapid cost scaling, but this provides an iconic example of how technology drives research opportunity.

EXHIBIT 4.2 – COST CURVE FOR GENOME SEQUENCING



Note: Derived from NHGRI 2017 and SRA 2017.

ARGUMENT: Technology is driving down cost and increasing the scale of possible experimentation and observation in a host of areas. Over the next 20 years, laboratory and field automation, high-volume data collection and analysis, new capabilities in microscopic, nano-, and atomic imaging, and massively enhanced simulation will enable many universities to shift their research operations onto an industrial scale.

COUNTER-ARGUMENT: Predictions about automation, big data, and industrial-scale research are relevant in select areas like astronomy, genomics, and medical imaging. But the norms of research have survived many technological revolutions and will remain fundamentally unchanged in most disciplines.

EXTREME CASE: Research will become even more capital-intensive than it already is as automation, instrumentation, and computation drive fundamental changes in the way research is conducted. Factory-scale research operations will outperform small teams and become the norm for university research across most areas.

20-YEAR BET: The practice of research will continue to scale up, though the importance of individual insights created from individual minds will be as important as ever. *In 20 years, the biggest breakthroughs in every field (perhaps even in the humanities) will be driven by research groups that are most active in seizing and leading a new paradigm based on automation and a compute-intensive approach to experimentation, observation, and analysis.*

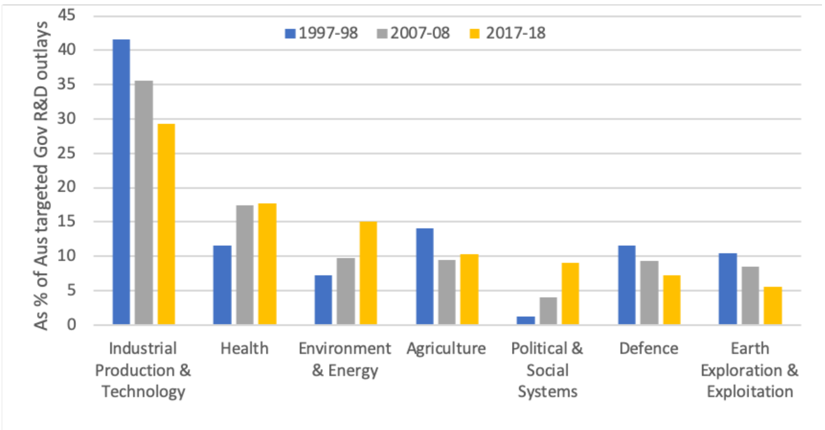
4.3 POLITICAL FASHIONS

QUESTION: In which areas will governments be most enthusiastic about research discovery?

WHY IT MATTERS: Science has become a tool for legitimising policy in almost every area of government, and governments have learned to use research investment both constructively, as a way of solving problems, and symbolically, as a way of appeasing political interests. Policy has consequently become scientised, research has become politicised, and the funding options available to researchers are tending to drift, more than ever, in line with political fashion.

DATA: R&D spending by socio-economic objective is listed in the Australian Government Budget Papers (SRI 2019). Discounting 'general advancement of knowledge' funding and focusing on activity targeting other socio-economic objectives shows decreasing emphasis on defence and industrial development and rising emphasis on health, environment, and society (Exhibit 4.3).

EXHIBIT 4.3 – AUS GOVERNMENT R&D BY OBJECTIVE



Note: SRI 2019 data. Excludes 'general advancement of knowledge' funding.

ARGUMENT: While governments are unwieldy and slow to change, they can dramatically shift their priorities over time. In the coming years, we expect to see continuing political momentum in Australia around themes that are perceived to bring social benefit: health, the environment, and social policy. This reflects both (a) shifting community interests and (b) a realisation that research provides a cost-effective political mechanism for being seen to be addressing difficult problems.

COUNTER-ARGUMENT: A long period of peace and prosperity has enabled Australian governments to expand the pool of funding for research and to shift the broad focus of their research investments. However, a recession or growing strategic threat in the Pacific region would quickly swing the pendulum back towards economic development and defence spending; and researchers working in neglected areas will eventually figure out how to reignite political interest in their work.

EXTREME CASE: While the data show how political priorities can drift in general terms, political decision-makers will become more susceptible to manipulation on shorter timeframes around highly targeted issues. Government interventions will increasingly be made in response to political pressures created by researchers themselves, and often justified on a surprisingly arbitrary basis.

20-YEAR BET: In 20 years, governments will still be funding many of the research constituencies whose interests they already serve, but they will continue to derive political advantages from supporting new research across a widening range of portfolios and objectives. *Government priorities will include many that are quite different from those of today, inspiring a host of newly fashionable initiatives, and spurring new forms of advocacy from within the research community. This will produce a resurgence of investment far beyond today's popular themes of health and environment.*

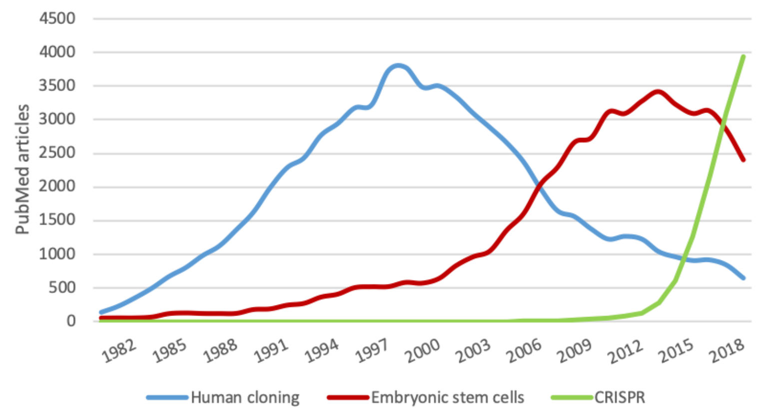
4.4 INTELLECTUAL FASHIONS

QUESTION: Within and across different fields, what will be the hottest topics for research?

WHY IT MATTERS: Intellectual fashions can be stimulated by new discoveries and technologies, or by new ideas or schools of thought. Some intellectual fashions are constructive and help to advance knowledge; others are pernicious both because they are erroneous and because they blinker their adherents from the pursuit of truth. For a researcher it is vital to know the difference between a constructive and a pernicious fashion, and also to know whether a fashion is likely to last.

DATA: Intellectual fashions are a feature of every field of research. Here the PubMed database of medical research outputs is used to illustrate how interest in three different research topics has trended in recent years (Exhibit 4.4). It is evident that the 1990s were the best time to be publishing on 'human cloning', the 2000s were the optimal time to be active in 'embryonic stem cell research' and now is the moment for 'CRISPR' research.

EXHIBIT 4.4 – TOPICAL RESEARCH IN BIOMEDICAL SCIENCE



Note: Derived from PMC 2019.

ARGUMENT: Research will continue to move by intellectual waves. Some waves will have short lives (shorter even than those depicted in Exhibit 4.4), while others will have extraordinary longevity (e.g. feminism, Marxism, climate change, or the theory of evolution). The enduring challenge for decision-makers in 20 years will remain (a) that of distinguishing between a short-term fashion and a wave that will endure, and (b) that of knowing the difference between someone who has merely leapt on a band-waggon and someone who is driving a band-waggon.

COUNTER-ARGUMENT: As the research community becomes more interdependent, its members will also become more consensual and more orthodox in mindset. This could institutionalise a herd mentality, increase the longevity of intellectual fads, reduce the risks associated with being a fashion-follower, and potentially even diminish the need for discernment in evaluating fashions.

EXTREME CASE: An alternative viewpoint suggests that as discovery rates increase, the waves of intellectual fashion will come and go ever more quickly. This would imply (a) that valueless and pernicious trends will be winnowed rapidly, (b) that even the benefit of being associated with a constructive fashion may prove short-lived, and (c) that the value of originality will be magnified.

20-YEAR BET: It is impossible to predict what will be perceived to be the most exciting areas of enquiry 20 years from now. But it does seem likely that intellectual fashions will come and go with increasing rapidity – especially in highly technological fields. *In 20 years, originating or picking high-impact trends will be more important than ever, and the professional judgement and expert intuition required to discriminate in this regard will be more valuable than ever.*

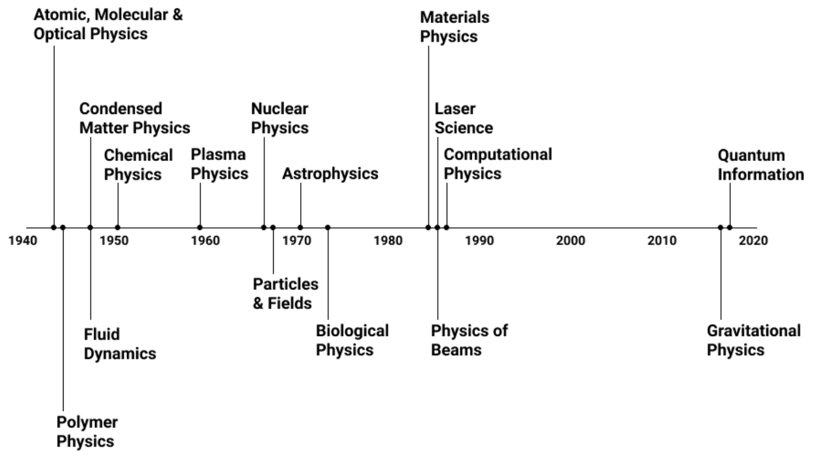
4.5 KNOWLEDGE FRAGMENTATION

QUESTION: Is knowledge fragmenting or aggregating?

WHY IT MATTERS: The quest for new knowledge has always involved two complementary processes. On the one hand, a reductionist process fragments knowledge into component parts and encourages specialisation within disciplines. On the other hand, a systematising process integrates knowledge into a synthetic whole, encouraging connectivity across disciplines. Whenever diverging or converging tendencies begin to outweigh the other, the optimal way of structuring research by organisational unit will change.

DATA: Data on citation patterns and the titles of newly established journals suggests that knowledge is continuing to fragment into new substructures, even as many existing fields collide or converge with one another. Even learned societies that advocate for multidisciplinary work and for 'theories of everything' show an ongoing appetite for creating new subdisciplines, as evidenced by the American Physical Society (Exhibit 5.5).

EXHIBIT 4.5 – AMERICAN PHYSICAL SOCIETY DIVISIONS



Note: Illustrates founding dates of APS Divisions (APS 2019).

ARGUMENT: Within most disciplines it has become impossible to stay abreast of an exploding and fragmenting literature. Researchers have specialised to the point where experts even from related subfields can find it difficult to communicate. This trend is not going to unwind for the foreseeable future. Consequently, new communities of interest will continue to evolve, leading to the periodic creation of new subfields, and to ongoing Balkanisation of the research community.

COUNTER-ARGUMENT: The growing divisions in the research system actually increase the importance of multidisciplinary work – a development that becomes especially critical where researchers try to translate their work into practice, policy or commercial outcomes. At some institutions, this is already leading to a renaissance in multidisciplinary structuring.

EXTREME CASE: As more and more institutions seek to build scale in specialised subdisciplines or in ways that target transdisciplinary problems, the system will eventually abandon its old disciplinary structures altogether.

20-YEAR BET: Many of our disciplinary knowledge structures have remained surprisingly unchanged since the nineteenth century, and it's a big bet to assume that this is all going to change anytime soon. *In 20 years, some Australian universities may introduce more over-arching multidisciplinary structures, but all will have greater sub-disciplinary specialisation and the fundamental disciplinary specialties will continue to provide the core organising principles for research.*

5. HOT TOPICS

From the previous discussion, aggregating across multiple bets, one might conclude that an Australian university that wants to excel in research in 2040 should aim to be:

Empowered – high in scale, more research-intensive, and better equipped to invest its own resources and make its own strategic choices in research;

Globally-facing – deeply networked internationally, and engaged most especially with partners in countries with strong economies on both sides of the Pacific;

Selective – about the subfields in which it specialises, and about how and where it publishes, so as to maximise global perceptions about the quality of its output;

Technological – active both in developing breakthrough technologies and in adopting new technologies to transform research practice;

Persuasive – not merely relying on its fashionable capabilities (e.g. in environment or health), but able to create compelling cases for investment in other areas too; and

Adaptable – able to adjust positively and opportunistically to technological, scientific, social, political, and geopolitical changes.

Such a summary is useful, but it omits specifics about which areas of research will take off in 2040. Unfortunately, the history of discovery suggests few reasons for confidence in anyone's predictions about what will be the hot topics for research in twenty years. Nonetheless, it is certainly possible to identify areas that are regarded as exciting in the present.

Listing such areas is useful, even in thinking about 2040, because although many other novel developments are bound to emerge, and although many of today's topical themes will fall from favour, some will still prove to have lasting impact 20 years from now. Research is path-dependent: its future vitality is built upon things happening today. Indeed, the safest way for any research organisation to position itself for the future is simply to make sure that its work is as close as possible to the frontiers of the present – whatever they may be.

There are many ways to identify topical research. One can study trends in the literature, such as trajectories in output and citation impact by field or subfield. One can read review papers. One can trawl through the various roadmaps, decadal plans, and future-scoping reports prepared by disciplinary societies, learned academies, industry groups, and funding bodies. A comprehensive analysis would do all these things systematically.

It can also be instructive, however, to take a more impressionistic approach. Building upon a recent study of trends in the research literature (BR 2019) as well as many years spent reviewing research strategies for Australian and East Asian universities, it is straightforward to identify some of the areas that seem to have momentum at the moment (Exhibit 5.1). This eclectic list of 'hot topics' may not be comprehensive, but it does facilitate a higher-level synthesis.

EXHIBIT 5.1 – SOME 'HOT TOPICS' IN CONTEMPORARY RESEARCH

- *ageing*
- *artificial intelligence*
- *automation*
- *behavioural ecology*
- *biodiversity*
- *bionics*
- *blockchain applications*
- *brain imaging*
- *business data analytics*
- *climate science*
- *computer modelling of complex systems*
- *cybersecurity*
- *data science*
- *deep earth resource exploration*
- *defence & strategic studies*
- *digital culture*
- *digital marketing*
- *drones*
- *earth systems science*
- *education technologies*
- *electric vehicles*
- *energy storage*
- *gene therapy*
- *genetic modification*
- *genomics*
- *geological-biological interactions*
- *health data systems*
- *health economics*
- *high-performance materials*
- *human evolution*
- *immigration*
- *immunotherapy*
- *Indigenous languages*
- *intelligent infrastructure*
- *medical devices*
- *medical imaging*
- *mental health*
- *microbiome science*
- *molecular machines*
- *nanotechnology*
- *oncology*
- *planning & urban studies*
- *personalised medicine*
- *precision medicine*
- *preventative health*
- *quantum information science*
- *radioastronomy*
- *rare diseases*
- *repurposed pharmaceuticals*
- *robotic surgery*
- *smart materials*
- *social media*
- *solar power generation*
- *space science*
- *spatial imaging*
- *synthetic biology*
- *systems biology*
- *trade economics*
- *transportation*
- *telemedicine*
- *tissue engineering*
- *tissue regeneration*
- *virtual reality*
- *waste transformation*

Taking the topics listed in Exhibit 5.1 as our starting point, it seems reasonable to bet that 12 key themes will help to bridge the pathway to the hot research of 2040. These should not be seen as predictions about the future, but rather as speculations about the key pathways that will be travelled to get there.

5.1 Statistics, data science, and visualisation: Across a host of disciplines, advances in computing, data storage, and automation are increasing the data-intensity of research and the value of statistical method, complex modelling, and new techniques in visualisation.

5.2 Applied quantum physics: New technologies for the manipulation of matter and light at extremely small length scales have created the possibility of exploiting quantum effects in the macroscopic world in areas like computing and communications security.

5.3 Next-generation materials: There has been a proliferation of approaches for designing high-performance materials, intelligent materials, and waste-transforming materials for an extremely diverse range of applications.

5.4 Surveillance and sensor technologies: sensors, spatial imaging, and drones are revolutionising our capacity to design intelligent transportation networks, novel defence capabilities, smart buildings, and responsive environmental and agricultural systems.

5.5 Artificial intelligence and automation: The combination of compute power and data availability has transformed our capacity for automated pattern recognition, signal processing, and the creation of unmanned and voice-activated technologies with likely ubiquitous consequences.

5.6 Energy breakthroughs: Recent investments in energy research have spurred innovations in new materials, plants, systems, manufacturing processes, and software for energy storage, generation, distribution, and utilisation.

5.7 Imaging technologies: In areas as disperse as physics, cell biology, medicine, and neuroscience, a revolution in imaging technologies is transforming researchers' capacity to study the world on new length and time scales.

5.8 Genome revolution: Transformational technologies for genetic sequencing and genetic modification are revolutionising biology and agricultural breeding, supplying new insights in psychology and health, and stimulating the invention of powerful gene therapies.

5.9 Push for personalisation: Whether in medicine (via new molecular and genetic understandings) or in manufacturing (via 3D printing and control software), a new research paradigm is facilitating highly individualised products and services.

5.10: Medical devices: A convergence of engineering, wireless technology, physics, chemistry, medicine, and neuroscience has opened new possibilities for active mechanical and electronic devices to be connected to human biological systems.

5.11 Digital world: The invention of online worlds and virtual realities has created an entire cosmos of new research in business, management, marketing, psychology, sociology, economics, and cultural studies.

5.12 Quantification in the humanities, arts, and social sciences: New data sources and enhanced computing capabilities are provoking mathematical and data-based disruption in fields that have traditionally been ambivalent about methods based on quantification.

This list is idiosyncratic. It has a strong focus on the impacts of computing in all its manifestations. A different author would no doubt have constructed a different list. Nonetheless, it illustrates the diversity and excitement that exists at the research frontier – a diversity and excitement that is likely to be magnified in the future.

6. THINKING ABOUT THE FUTURE

Although the future of research may be difficult to predict, there are benefits in thinking seriously about it. Decisions taken by policymakers, institutional leaders, and researchers will often have long-term consequences. Being aware of likely future trajectories does not guarantee success, but it should enhance the capacity of organisations and the people within them to plan and to adapt to changing circumstances.

In the absence of serious thinking about the future, decision-makers tend to obsess over whatever is most fashionable in the moment. The Australian research system today places a high emphasis on: (i) research impact and translation; (ii) grand challenges; (iii) multidisciplinary work; (iv) health; and (v) environmental sustainability. These all attest to a voguish desire for political relevance, for doing research that is socially beneficial, and for thinking big.

To many people working in research, this orientation would seem self-evidently sensible. However, it can also lead to surprisingly undesirable outcomes. When organisations become preoccupied with big, socially relevant goals, they often become highly responsive to the fads of a given moment – fads that do not always last, leading to unwanted legacy capabilities and under-utilised infrastructure. Chasing the latest bandwagon can also be counterproductive if it inspires institutions to neglect other areas in which they have genuine comparative advantages, or disciplines in which students have a stronger desire to study.

Perhaps most pernicious of all, the desire for relevance will often stimulate enthusiasm for research missions that seem important irrespective of their odds of success. There is an infinite number of pressing and important problems that the world needs addressed, but many of them will remain intractable no matter what resources or efforts are expended, simply because the knowledge base and the state of current technology are not yet sufficiently advanced for a breakthrough.

A similar cautionary observation can be made about the current passion for multidisciplinary initiatives. A dynamic university must be willing at times to adjust its disciplinary structures, but this can be beneficial in more than one way. Certainly, where a new synthesis is made possible by combining expertise from different areas to create a new systems-based discipline, a university may do well to aggregate in a multidisciplinary fashion. But it's equally true that where new subfields emerge, and a university has a strong position in the area, it can still make a lot of sense to nurture a specialised disciplinary capability.

Unfortunately, chasing an abstraction like 'multidisciplinary research' will sometimes lead to the pursuit of very bad ideas (simply because of their relevance to multiple disciplines) and to the neglect of very good ones (due to the supposed defect in their having too narrow a disciplinary focus). In practice, both models are viable. However, it's critical not to be constrained by any particular conceptual model, but rather to have the ability to spot, evaluate, and respond to specific opportunities, in whatever form is most appropriate.

One of the wonderful things about human knowledge is its rich complexity. Collectively, we know more than ever before. We have access to technologies of unprecedented power. This should enable our researchers to ask questions and develop new ideas at a new level of scale and intensity. The opportunities for exploration should also be broadening. In such a complex and vast landscape of possible enquiry, there should be many different options opening up for exploration – and different organisations should be seizing these opportunities in vastly different ways. The challenge for universities lies in deciding where they can make their own most effective contributions. This is where thinking about the future becomes most valuable and difficult. To some extent, those who are embedded in a shared institutional context cannot help but develop common understandings and expectations, to which they will inevitably respond with remarkably consistent plans. But the future, when it comes, always hits different organisations slightly differently, and it is in preparing for these differences that the most effective strategies are laid.

This report has covered a lot of ground. The emphasis has been on the structure of the Australian university research system, the global competitive landscape, the drivers that might make some areas of research more fashionable than others, and the contemporary platforms from which researchers will create the future. Such a brief overview necessarily misses a lot. A more comprehensive analysis would explore all the issues we've touched upon in greater depth. It would also look at other dimensions.

For example, will group sizes continue to increase in scale? For decades, the number of authors per paper has steadily increased. This reflects the incentives in the research system, which encourage researchers both to pursue collaborative research and to get their names on as many papers as possible. It also points to a steady increase in the size of research groups. It seems credible to bet that new technologies will generally increase the advantages that accrue to larger-scale groups.

Another question is will outstanding research require mounting investment per unit of output? Some fields are renowned for their ever-increasing capital intensity. Particle physics and astronomy are pin-up examples of this phenomenon. To succeed in these fields, it has become essential to connect with major international initiatives, and publications (particularly in the former domain) can involve thousands of co-authors. If it is true that where physics leads other disciplines follow, then rising capital intensity may become ubiquitous. Our bet is that not every discipline will inspire 'big science' initiatives, but capital investment will become increasingly important in a widening array of fields.

Finally, to what extent will universities shift from the traditional 'investigator-driven' model to other modes of operation such as the 'mission-driven' approach favoured by industry and, to a certain extent, government agencies? Over recent decades, universities have supplanted government agencies as the main location for not-for-profit research in most developed economies. Whether this trend will continue depends upon the extent to which universities can take on roles traditionally fulfilled by government agencies (e.g. as custodians of national infrastructure and repositories for strategic expertise), and on the extent to which they are prepared to support research that does not produce traditional academic outputs. Our bet is that their capacity for the former is quite high, but that their scope for embarking upon the latter will remain limited.

Serious thinking about the structure of research groups, the capital intensity of research, the point at which scale reaches its beneficial limits, the motivations of researchers, likely trends in student numbers and behaviours, and the scope for governments to introduce new policy mechanisms would all be valuable in making more detailed estimations about where the Australian university research system is headed. A longer analysis would also look more deeply at the history of discovery and would provide a more systematic study of where the frontiers are currently moving most rapidly within specific fields. Yet even the most carefully crafted predictions along these lines are likely to prove unreliable. To speculate about the future of research is to peer down a microscope with gauze over the lens.

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