Professor Richard Holden
June 2024

The Economic Contribution of Science at UNSW

Acknowledgement of Country

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The Uluru Statement

Contents

Foreword
Dean UNSW Science

UNSW Science has a long and proud history of delivering societal, economic, and academic impact. This legacy has been made possible through meaningful collaborations with our partners.

We are facing some of the most challenging macroeconomic and environmental issues of our time, and the ongoing success of our world-leading university sector is critical to the Australian economy.

Our collaborations with partners in business, industry, NGOs, and government are essential to advancing scientific understanding and addressing society's grand challenges. For our research ecosystem to thrive, we must secure our role in Australia's future, maintain our legacy, and achieve societal and economic prosperity.

UNSW Science is committed to acknowledging and measuring the breadth of impactful scientific research and the generation of ideas that drive economic growth and societal change.

This year, we launched the Pact for Impact – an Australian-first, collective commitment to create and measure the impact of science on our society. From fundamental discovery science through to implementation, Pact for Impact encompasses the entire research life cycle, stimulating scientific curiosity and generating impactful ideas.

Research conducted for UNSW Science in 2024 found that over a quarter (26%) of Australian businesses are not investing in scientific research. However, 60% acknowledge that scientific research is crucial for their organisation to achieve societal impact.

Both government and industry are seeking ways to invest in science and measure their impact beyond traditional metrics of scholarly output and revenue growth. As such, UNSW Science has committed to a set of Impact Indicators. These indicators evaluate the complex and meaningful ways we are making real-world impact with our partners – this paper explores their role further.

Under the leadership of the UNSW Business School, UNSW Science has collaborated on this research paper to encapsulate the significant role science plays in creating economic and societal impact. Such collaborations highlight the broad impact of this co-created research beyond discipline boundaries. The projects and advancements referenced in this paper demonstrate the breadth and depth of UNSW's work, all contributing to important business outcomes and the global stock of knowledge.

I wish to acknowledge all those who have contributed to this paper, particularly its author, Professor Richard Holden, Professor of Economics at UNSW. Richard's insights and expertise are incredibly valuable. His findings on the economic output of science at UNSW are profound, offering a means to continually demonstrate the real-world impact of science.

Scientia Professor Sven Rogge

Dean UNSW Science
UNSW Sydney

Foreword
Dean UNSW Business School

At UNSW Business School, we prioritise big ideas that address societal challenges. One way we are doing this is by partnering with the faculty of Science to develop insights that can be translated into action to accelerate productivity and growth.

When we partner with other UNSW disciplines, we have the ability to apply co-created research to current and future challenges, and equip our stakeholders to tackle complex problems.

We believe that business is the critical link for Science to generate future social and economic prosperity. We need business to invest in innovation and translate science into commercial opportunities, to create new products and technology, and attract talent and create jobs.

The findings in this paper produced by Professor Richard Holden, underscore the pivotal role and impact of scientific research, which is advancing knowledge and driving productivity and economic growth. The paper outlines how and why scientific research is not just a pursuit of knowledge, but a significant driver of productivity and a contributor to economic and social prosperity.

Science, with its rigorous methodologies and innovative breakthroughs, is a catalyst that transforms curiosity-driven research into tangible outcomes that benefit all sectors of the economy. Business, with its ability to leverage research to create new commercial opportunities, is a catalyst that transforms research into revenue-generating products and services that shape our daily lives.

The paper describes the economic impact of scientific research and identifies a further five indicators that provide a multi-dimensional measure of research impact: Commercialisation, Sustainability and Environment, Lives Changed, Policy and Influence, and Scholarly Outputs. These indicators not only highlight the diverse contributions of our scholars but also emphasize the tangible benefits of scientific research.

Businesses have a unique opportunity to invest in scientific research to boost productivity and innovation. By partnering with UNSW Business and Science, businesses can leverage cutting-edge research to develop new technologies, improve processes, and create sustainable solutions. Such collaborations can lead to significant advancements in various industries, fostering economic growth and enhancing global competitiveness.

This report not only celebrates the achievements of our exceptional researchers but also serves as a call to action for businesses to invest in scientific research, driving innovation and economic prosperity.

Professsor Frederik Anseel

Dean UNSW Business School
UNSW Sydney

Executive Summary

UNSW is leading Australian universities in science. Based on traditional measures of output, UNSW produces more scientific knowledge than any other university. However one slices it, UNSW leads. In number of papers, number of papers in top 5% or top 1% outlets, in citations, in field-weighted citations, UNSW leads.

There is intrinsic and unquantifiable value in this. It's at the core of what a great university does—create knowledge. But there's also a quantifiable economic value to this contribution. For more than three decades economists have emphasised the importance of ideas as a key driver of economic growth. And as a great economist once said: "the secret sauce of economics is arithmetic."[1] Modern economic theory and a little arithmetic can put an annual dollar value on UNSW's scientific contribution to global stock of knowledge. It's big: $2.2 billion a year.

All this is made possible by a diverse group of exceptional researchers. Ten of those researchers are profiled here. Their work covers everything from chemistry and materials science to quantum computing and climate science. And although a short profile cannot do justice to a lifetime of scientific work, it's more than enough to illuminate the scientific and social value of these remarkable scholars.

And these scholars help highlight the new UNSW Science Impact Indicators which incorporate five dimensions of impact: Commercialisation, Alignment with the UN Sustainable Development Goals (SDGs), Lives Changed, Policy and Influence, and Scholarly Outputs. These new Indicators highlight the different dimensions on which different scholars make different contributions. And they help give an even broader picture of the impact of science at UNSW.

Overview

The economic value of ideas

Beginning in the 1990s economists developed a formal framework for articulating the economic value of ideas. Paul Romer was at the forefront of this and was awarded the 2018 Nobel Prize in Economic Sciences for his contribution.[2]

This area of economics has become known as *endogenous growth theory*. Rather than taking the rate of technical progress as being given, or exogenous (as then standard "neoclassical" model of economic growth did), Romer emphasised that the rate of technological process is determined by the generation of ideas and scientific knowledge.

Romer's key observation was that knowledge can be an important driver of long-run economic growth in a market economy. Before Romer, economists thought of economic growth as being determined by physical capital and labour.[3] Romer expanded this to include knowledge, and noted the stock of knowledge is determined by research and development activities broadly constituted. This includes what universities refer to as both *basic* research and also *applied* research.

There are two things about "ideas" that are different from physical capital (like machines). First, they are "non rival." If one person is using Pythagoras's Theorem it doesn't prevent anyone else from using it. In other words, once discovered, there is no monopoly on finding the length of the hypotenuse of a triangle. This is very different from standard economic goods. If one person is eating a salad it precludes other people from eating the salad. Second, some ideas can be made "excludable"—in the sense that others can be prevented from using them through policies such as patents, or through technologies like encryption.[4]

The production of ideas often involves large fixed-costs—such as the initial research and development—and low marginal costs for the subsequent production of each unit of the good or service. Economists refer to this as *increasing returns to scale*. Excludability, such as through patents, is important for allowing firms to recover their initial fixed costs. Otherwise ideas may never be developed in the first place. Balancing non-rivalness and excludability has been a major focus of economist's work on economic growth.

One important insight is that decentralized, market-based solutions will not always lead to the right balance of excludability and non-rivalness. This points to a role for different forms of knowledge production. Romer himself emphasised the importance of universities.[5] Universities have long been, and continue to be, a major source of basic and applied research. This makes university research a fundamental driver of economic growth.

In fact, endogenous growth theory is essential in explaining some basic empirical facts about economic growth. These facts only started to emerge in the mid 1980s with the rise of large, cross-country datasets on economic growth over time. The neoclassical growth model could not explain persistent differences between countries in the rate of economic growth. It also predicted that poorer countries would grow faster than richer countries because of decreasing returns to physical capital. This wasn't true in the data either. Endogenous growth theory provided a parsimonious explanation of the essential empirical facts about economic growth.

Nobel-prize-winning economist Robert Lucas once observed that "once you start thinking about economic growth it's hard to think about anything else."[6] Anyone who doubts that would do well to compare and contrast the relative fortunes of Japan and the United States over the past three decades. In 1995 Japan's GDP per capita—a good measure of living standards—was $44,198 per capita (in 2022 US dollars). United States GDP per capita was just $28,691 in 1995. So Japan's living standards were 54% higher than those in the United States. Fast forward to 2022 and the U.S. had grown to $76,330 per capita. Japan, after a series of "lost decades", had actual shrunk to $34,017 per capita—or 55% *lower* than the United States. The US had grown at 3.7% per annum while Japan had shrunk at 1% per annum.

So it's not an overstatement to say that generating and applying knowledge is the cornerstone of rising living standards. Countries that consistently do it better can provide their citizens with more public goods like healthcare and high-quality education, more opportunities for social mobility, and better lives.

This report shows how a combination of the insights from endogenous, along with some basic arithmetic, allows us to quantify the economic impact of science at UNSW and their contribution to global stock of knowledge.

Before that we profile ten of UNSW's scientists and their contribution. And we demonstrate the value of the Impact Indicators as a lens for thinking about those contributions.

Researcher Profiles

Pall Thordarson

Fundamental Chemistry is the key to everything from zero-carbon-footprint sneakers to improved mRNA vaccines.

Pall Thordarson made headlines during the COVID-19 pandemic for his leading role in establishing domestic mRNA vaccine manufacturing capability in Australia. But that's just one part of his rich agenda. Talking to him, it's clear that he sees himself as a Chemist through and through.

The RNA agenda is exciting. Traditional vaccines inject either some harmless virus or viral protein into our bodies to trigger an immune response. mRNA vaccines basically instruct our cells how to make a viral protein, which then triggers the response.

"mRNA works great as a vaccine," says Thordarson, "however it still has some side effects. We need less than 30-40 micrograms per dose to get an immunoresponse. But if we could somehow use less, then there will be less potential side effects."

The key is what's known as the "escape efficiency." Right now, the escape efficiency of mRNA vaccines is 1%. So 99% of what goes into our cells doesn't do anything. Increasing escape efficiency decreases side effects. But it's also cheaper because it uses fewer active ingredients. And it makes it less likely there will be acute shortages of these active ingredients in times of extremely high demand—like during a pandemic. Thordarson and others at UNSW RNA Institute are working on this issue.

Thordarson also sees a path to decarbonisation of the plastics industry through basic research.

Changing oil into plastic isn't just about how many carbon atoms one is converting, but also about how many carbon atoms are used in the process. But there is basic research going on around the world to how to reduce the use of carbon in the process.

That could lead to "carbon-net-zero sneakers" he says, but if we don't undertake the R&D in chemistry in Australia then the opportunity will be lost to those overseas. And what's currently the most likely country to benefit at Australia's expense if we don't boost R&D in chemistry? Saudi Arabia.

For Thordarson it comes back to fundamental science, and how it guides the search for better solutions to practical problems. "We just need to understand better some of the fundamental of chemistry and biology, and then we can improve things. We see this across the science fields.

Often industry wants to improve a catalyst to decarbonize, or the pharmaceutical industry wants to reduce the side effects of a drug. On one level, it's almost engineering. But on another level, normally the only way you can actually improve the best practice is through new scientific knowledge. So, it's not that a chemist comes up with a new catalyst that Orica will use in their plant, or a chemist or a biologist comes up with a better understanding of how RNA gets to the endosomal membrane. It's just the new knowledge that's published in a scientific paper allows them to work out in which direction to optimize the catalyst they already have. Otherwise, they're searching blindly. And AI won't solve that problem."

> "From a chemist's perspective, carbon in the ground is too valuable as a feedstock for essential materials for modern life to be simply burned for energy production."

Emily Oates

Advances in genetic sequencing technologies have transformed the diagnosis, treatment and prevention of genetic neuromuscular disorders.

Clinical geneticist and medical researcher Emily Oates works with families whose children have potential or confirmed genetic neuromuscular conditions.

These are conditions that impact the muscles of our body that allow us to move and breathe, or the peripheral nerves that feed these muscles. But they can also involve other organs, for example the brain, spinal cord, eyes, or heart.

There has been a revolution in computer-based technologies that enable our gene 'recipes' to be 'read' (sequenced) over the last decade. Dr Oates says that because of these advances "our job has actually transformed dramatically." Dr Oates and her colleagues are increasingly involved in analysing large amounts of genetic sequencing data to try and find genetic diagnoses for their families, many of whom have been waiting years for a diagnosis.

She says "Having a genetic diagnosis is so important for families. It means that we can provide them with much more accurate information about why their condition has happened, how it might change over time, whether we need to be on the lookout for additional health problems, and who else in the family might be at risk of additional health complications. It can also open the doorway to treatment options, either now or in the future."

One option for potential parents who are at risk of having children with a serious genetic condition is preimplantation genetic testing (PGT). Once a genetic diagnosis has been made in a family, IVF technology can be used to generate embryos. These embryos can then be be tested for the causative gene spelling mistakes (genetic variants) that have been identified in other family members. Embryos that don't have the variants can then be transferred to the mother to start a pregnancy. Prior to PGT, families would need to rely solely on testing during the early stages of a pregnancy through chorionic villus sampling (CVS) or amniocentesis. Some couples don't want to undergo such tests as they pose a small risk to the pregnancy. And couples who do proceed with this sort of testing who then receive a result that indicates that their baby is affected by the condition then face a heart wrenching decision about whether to stop the pregnancy.

Pre-implantation genetic testing avoids this. For Dr Oates "it's all about empowering families with information about all available options so that they can make the best possible decision for their family in the context of their own belief system."

As powerful as testing is, Oates says that increasingly her work will, in addition to diagnostic testing, focus on the development of new treatment technologies. She modestly points to the work of her colleague, paediatric neurologist Michelle Farrar, and others in the neurology field for their work in treating spinal muscular atrophy. The therapies that are now being used in this patient group have led to extraordinary results. Dr Oates says: "I attend neuromuscular clinic every Friday and we're seeing children running up the corridor who, without treatment, would not have been expected to survive beyond their first year of life."

Many of these advances wouldn't have been possible without the dramatic advances in computational-based sequencing technologies. For instance, "recessive titinopathy" is emerging to be perhaps the most common early onset muscle disorder, caused by genetic "spelling mistakes" in the titin gene (*TTN*) . Titin is the biggest protein in nature and the gene that provides its protein recipe is so long that it couldn't be sequenced routinely in the diagnostic setting before these recent computational advances." Now it can be screened for gene spelling mistakes routinely.

One exciting area "exon skipping therapy" development. Within our cells, genes are copied into RNA recipes that tell the cells how to make specific proteins. These RNA recipes are made up building blocks called "exons" which are a bit like separate sentences of the of the recipe. Often a genetic spelling mistake is within a specific exon. If the exon that contains this spelling mistake can be removed (skipped) without scrambling the overall protein recipe then a little bit of the protein is lost (the bit of the recipe provided by the skipped exon) but most of the protein is still produced in the normal way. You end up with a protein that's close to normal in size but is missing a small segment. As Oates says: "for many disorders that's going to be a far better outcome than having that spelling mistake which results in little or no protein at all being produced."

Does Oates have any regrets? "I teach undergraduate science and medical students as well as members of the broader clinical community. I love this field but the opportunities that are available to students just starting out now in this field are enormous because of these recent advances. The world is their oyster. Why would you not want to do this? It's incredible. So, I just wish I were about 20 years younger."

> "In the last 10 years everything that we could offer our patients has been absolutely transformed in a way that no one could have anticipated."

Andy Pitman

Understanding climate extremes like wind and solar droughts, or major hailstorms, is central to our net zero strategy and to economic resilience.

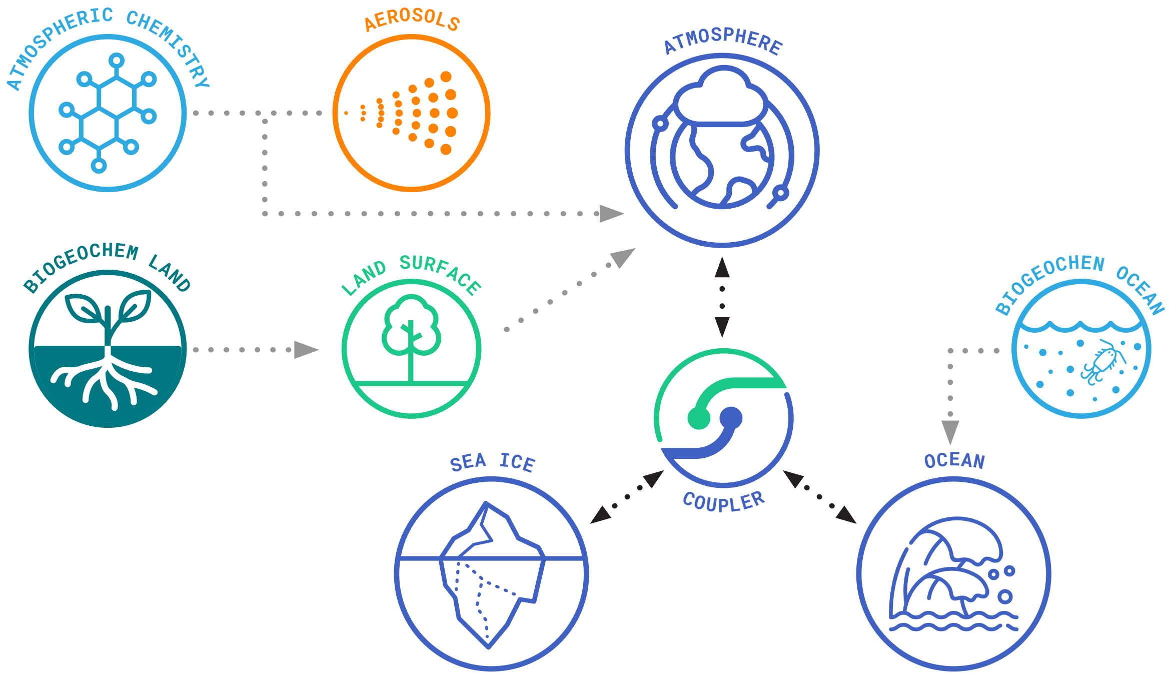
> “Energy, water and carbon exchange between the surface and the atmosphere and things that influence that exchange and how we can describe them mathematically more robustly.”

Andy Pitman is a climate scientist and Director of the ARC Centre of Excellence for Climate Extremes.

It’s fundamental science—at its heart concerned with “energy, water and carbon exchange between the surface and the atmosphere and things that influence that exchange and how we can describe them mathematically more robustly.”

But it’s hard to overstate the social and economic impact that comes from reducing Australia’s vulnerability to climate extremes. And while there is rightly a lot of public attention on average temperatures, and how they’ve risen, Pitman and his colleagues work on understanding the entire distribution of outcomes—especially the tails. It’s the link between the tails of the distribution and, as he puts it “extremes that actually threaten the resilience of a business, or material extremes as in rather important things like wind and solar droughts occurring with a particular geographical footprint feeding into things like a net zero strategy.”

Figure 7:
Climate Models



Source: https://climateextremes.org.au/climate-modelling-an-overview/

Climate models are a mathematical description of physical laws stemming from fundamental physics that govern “the flow of air in the atmosphere, water in the ocean and heat and moisture in the land surface.”[7] This produces a large system of equations that can be solved by powerful computers to provide simulations of our climate in the future, including temperate, rainfall, moisture in the soil, and the flow of ocean currents. The following figure depicts these interactions.

These models help us understand the range of future climate outcomes and how these will impact the world socially and economically. Extreme climate events can have a major impact on people living in certain regions, on national economies, and on specific industries or businesses.

Pitman is more skeptical of new regulatory requirements around disclosure of climate risk in financial reports. In principle businesses should make financial provisions for climate risks—just like banks make provisions for bad loans. And Pitman thinks “there is an avenue for big agricultural companies to be able to assess their risk to, for instance, extreme temperatures.” But we discuss whether say, a supermarket chain, could do a similar thing. Here Pitman says “that business runs by sourcing products, bring those products into a single location and then moving them from that location to a second location along a road, usually. The capability to predict whether a material extreme event will hit any single piece of that infrastructure is at least a decade or two away. [Right now] there is no skill in doing it. And if you stop and think about that for a second, you would not trust a weather forecast that said there was going to be a catastrophic extreme event over your house in three weeks time. It’s mathematically impossible to do that. But we think we can for 2050? This is sort of a false precision that they’re asking for.”

In fact, current climate models run at 100 x 100-kilometre pixels. So there’s a single value of rainfall for an area the size of the entire Sydney basin. Pitman sums it up succinctly: “It’s probably 20 years work ahead of us to produce 10-kilometre information. But the disclosure of climate risk needs to be done by, from July 1.”

One area where climate modelling is extremely useful for businesses is in financial services such as banking and insurance. Says Pitman: “we’re working with Commonwealth Bank, NAB, Aon, and other companies…for them to understand what they can and can’t know about future risk.”

At the heart of Pitman’s work is computing. Running modern climate models involves storing and accessing exabtyes of data (1 quintillion—i.e. 1,000,000,000,000,000,000—bytes) and integrating those data into a high-performance compute environment. Australia’s National Computational Infrastructure (NCI) is powerful, and it is powered by renewable energy, but there’s a very real risk of falling behind. The NCI has less than 1% of the computing power of the world’s most powerful supercomputer (at Oak Ridge National Laboratory in the United States), and Australia’s leading supercomputer (the Pawsey Supercomputing Centre in Perth) comes in at around 2% of power of the Oak Ridge facility.[8]

Veena Sahajwalla

The interplay of materials science, engineering, and supply-chain economics are a critical part of Australia's green energy future.

Growing up in Mumbai, India, Veena learnt how to fix things. "It was always knowing if things did break, we can fix them," she says. "You can repair your shoes and your clothes and, yes, part of it was out of necessity. You grew up in a situation where you're going to fix things until they are beyond repair, and then you think about how these materials can be put to further use. So I guess in that sense, I see the full circle coming back."

Full circle, indeed. Sahajwalla is now a global leader in recycling science and developing technogies that reform hard to recycle wastes into new products and feedstock materials for manufacturing. As founding Director of the Sustainable Materials Research and Technology (SMaRT) Centre at UNSW, she is pioneering a new generation of green materials made from waste. The Australian Research Council Industrial Transformation Research Hub she leads collaborates with industry on "green manufacturing" initiatives that translate recycling science into technologies and processes that deliver practical economic, social and environmental benefits. SMaRT's MICROfactorie™ Technologies now reform various hard to recycle wastes, such as mixed glass, textiles, matresses, hard plastics and e-waste.

It's not just talk. Five minutes into our conversation she pulls a "green ceramic" tile out of her briefcase. "It's made of waste glass and waste textiles," she tells me. Working with industry partner Andrew Douglas, CEO and founder of Kandui Technologies, they developed the first commercially operated and UNSW SMaRT Centre licensed Green Ceramics MICROfactorie™, which is successfully growing and producing a wide range of ceramic tiles.

It might sound simple, but it's actually a sophisticated mix of materials science, engineering, and manufacturing capability. Recycling and green manufacturing actually involves quite a bit of lateral thinking. "It's not about saying, well, I've got a plastic bottle and it's got to come back to life as another plastic bottle. When I've got a hybrid mixture of different kinds of fabrics, old clothes, textiles, different kinds of glasses, it's about thinking 'what happens to this glass? What happens to architectural glasses?' Glass is not just one standard thing. So that chemistry and the materials science and then ultimately the engineering that leads to all of this."

It's about "the fourth R," she tells me. We've all heard of "Reduce, Reuse, Recycle". The fourth R is Reform for the reforming of waste into useful and valuable resources. So rather than melting down glass—which uses a lot of energy—to make another glass bottle, glass might be used as a binding agent in a ceramic tile.

The logic extends to recycling solar panels. They're layered structures with solar cells, polymers, aluminium and glass. So part of the challenge is peeling off all they layers, not just shredding the panels as often happens. Sahajwalla says "part of it is getting people to stop their bad habits…like oh, well, if I just shred it, that's easy but its use now is very limited. You just put in a crusher or a shredder and then let somebody else worry about it."

And that process means getting things right at a local level. As our solar rollout continues, recycling of waste into feedstock materials will become a crucial component of the ongoing energy transition. After 20 years most solar panels need to be replaced, if not sooner. Extracting the materials from the existing panels is economically valuable if those materials can be reformed. But it's also about preserving the embedded energy in the materials. The key is grasping "how much energy it cost me to make that silicon in the first place and realising that I don't have to go back to the start, I don't have to go to the mine." Or, referring to the pile of materials from existing solar panels, she says "my *pile* is my new mine."

This process needs to start locally. 70% of the weight of a solar panel is glass, so it makes no sense to ship all that weight around for the 30% that might need to go to a specialised facility for processing.

It gives a whole new, and exciting meaning to "think global, act local"

As founding Director of the Sustainable Materials Research and Technology (SMaRT) Centre at UNSW, she is pioneering a new generation of green materials made from waste.

Matthew England

Ocean temperatures fundamentally change our climate and weather patterns. But the way the oceans circulate is changing, and it's changing our climate in important and concerning ways.

Matt England liked mathematics enough at high school to do lots of it in his undergraduate degree. To the point where "I was going down the rabbit hole of a pure maths career," he tells me. Then serendipity struck.

"By pure accident I discovered a course in physical oceanography which is about the physics of the oceans and it was clear that maths was a major prerequisite for that. There were only like six of us, four of whom hated the mathematics side of it and only a couple of us were kind of happy to see everything written up in equations. It was just a magnificent discovery for me to understand that there was a field of science that was basically the mathematics of the oceans."

Just as England was beginning his PhD, a paper came out in *Nature* which showed that climate projections are fundamentally altered by taking account of oceans in a serious way. Before that climate models assumed an ocean that doesn't move. It could absorb heat and radiate heat back into the atmosphere, but the ocean was static.

"That 1989 paper showed that there are absolutely first-order changes to our projections by having a dynamic ocean," says England. Syukuro Manabe would go on to win a Nobel Prize for this contribution. The paper brought oceans to the fore, showing that our changing climate depends fundamentally on how much the oceans absorb heat and how they move this heat around the planet.

So how does the movement of ocean currents affect global temperatures? England explains that oceans absorb a lot of heat in the tropics where there's a lot of heat coming from the Sun being directly overhead. This warm water gets moved towards Antarctica, the North Atlantic, and the North Pacific in what are known as "gyres". These basin-scale gyres move heat from the tropics to high latitudes where that ocean heat gets released into the atmosphere. This moderates the climate of the mid latitudes. As England puts it: "Western Europe is warmer by 10-15 degrees Celsius on average" because of this process.

The gyre circulations are driven by winds and thought to be relatively stable, but "overturning circulations" are also an important driver of this heat transport process. This is where cold, salty water sinks at high latitudes because it's so dense. That dense water flows to the bottom of the ocean and then recirculates back up into the tropics. This is an important way in which the oceans affect our climate system. But these overturning circulations can collapse with enough warming. When water off the ice caps melts it desalinates the water to a degree and makes it more buoyant. If fresh enough this water won't sink and the circulating currents begin to slow down. Or eventually stop. When this happens the oxygen that's taken down from the surface to the seafloor starts declining rapidly. "It's like the world's ocean lungs are collapsing," England says.

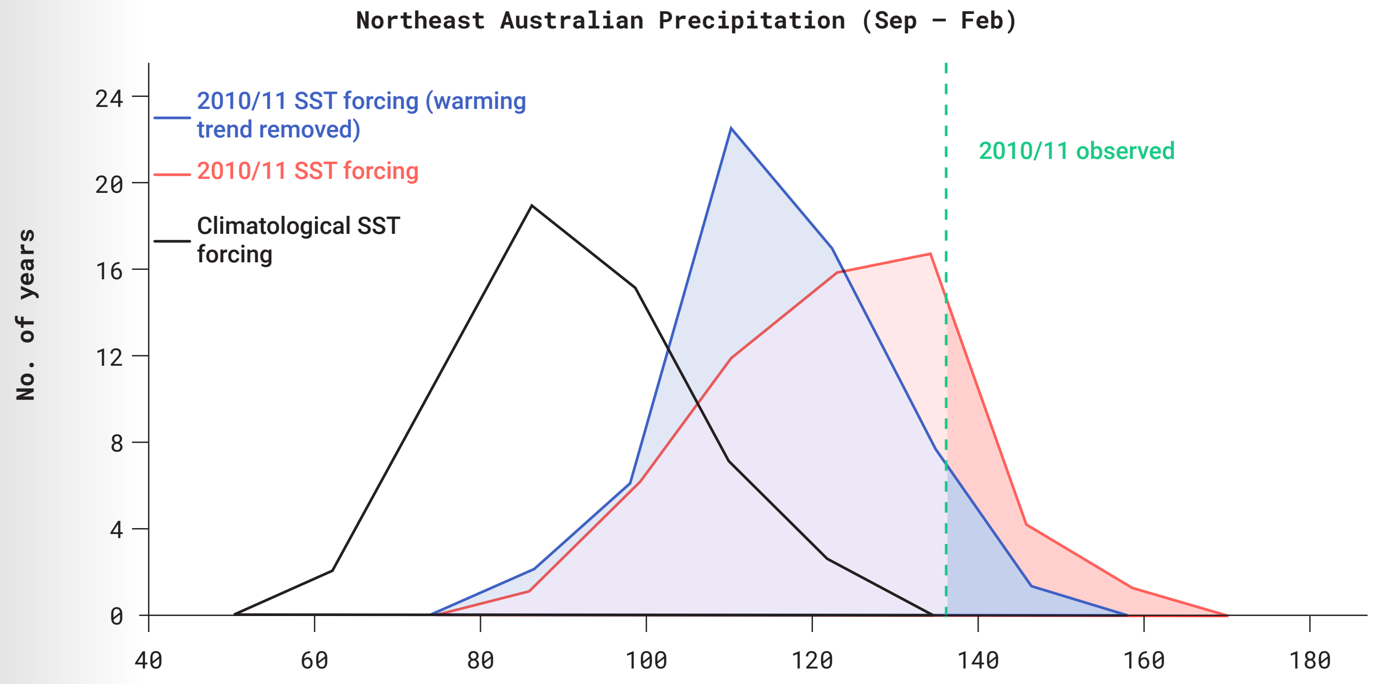


Figure X:
Rainfall Distribution with and without surface ocean warming

Compared to two decades ago, we've already seen a 20-30% reduction in these overturning currents. And that's already having an effect on how heat and oxygen are distributed in the oceans. In addition, the surface waters of the ocean are warming at an unprecedented rate, and this is already impacting climate extremes. Some of England's work illustrates this with the 2010-11 Brisbane floods. He ran a climate model with and without surface ocean warming, and the whole distribution of expected Queensland precipitation shifted (see Figure X). The odds of floods went way up, and as it turned out, floods occurred.

This work depends crucially on computational power. Even now, these models can't factor in Antarctic flows because of computational limitations. More computing power would help, but also crucial is to have software engineers to take advantage of that. It's possible to put better physics in the model, but without high-quality software engineering this can make the models much more computationally intensive. Good coding can ensure that better physics doesn't make the models grind to a halt.

Getting the most up-to-date physics into these climate models is vital to understanding what's happening to the oceans, and our planet as a whole.

> "By pure accident I discovered a course in physical oceanography which is about the physics of the oceans and it was clear that maths was a major prerequisite for that"

Kaarin Anstey

Kaarin Anstey is Director of the UNSW Aging Futures Institute. Some of Anstey's research is complex. For instance, MyCoach is an intervention for people who have concerns about their cognitive functions.

As Anstey puts it "some older adults are concerned that there's something wrong but tests haven't actually been able to find anything objectively wrong with their memory or thinking. They just sense that there's something changing."

MyCoach is designed for that group suffering from "subjective cognitive decline" and another group who have clinically verified "mild cognitive impairment", but not dementia. It's a randomised controlled trial for people living independently in the community who are computer literate. People self-refer to the study via social media. The control group gets information about dementia risk factors and how to reduce risk. The treatment group enrols in an online course with chapters that teach them about the brain and memory and lifestyle modifications to improve brain health. These include things like physical activity, diet, and social interactions. They have online sessions with an exercise physiologist who works on an exercise program for them, and a dietician who provides dietary advice. Participants are subsequently given online cognitive tests at 0, 3, 6 and 12 months.

"Experts believe that you've got to modify multiple risk factors at once—you've only really got one chance, and you want to give people the best opportunity to improve their cognition and reduce their risk," says Anstey.

And some of Anstey's research addresses seemingly simpler, but also vital problems—like driving. The Better Drive program is about improving drivers' skills as they age. People get their drivers' license at age 17, but never really do any upskilling. "What else do you do in life where you do no training to keep up?" Anstey asks. "Where you could kill a bunch of people if you're not doing it right," I add quickly.

It seems like a no-brainer that with some lessons, drivers are going to improve their skills and safety. But what works best, and what delivers the most bang for the buck? Anstey and colleagues have conducted a randomised controlled trial to answer exactly those questions. One group of drivers get classroom education through an online webinar. A second group get the webinar and also get video feedback where drivers are recording actually driving and shown video clips of unsafe moves like not taking enough time with turning right or not stopping at stop signs. The third treatment also get tailored driving lessons that focus on the errors they're making and how to correct the errors.

The pilot studied showed that the intervention works. This has the potential to make the difference between people losing their license as the age, and with it part of their independence and dignity.

The common thread across Anstey's research is building a strong, causal evidence base to inform policy. And to make sure that people age well.

Jes Sammut

An impact journey that started with the science of diseased fish and dead prawns has now become a means to rehabilitating prisoners and reducing tribal violence in Papua New Guinea.

Jes Sammut is a marine scientist who began his career working on fish pathology to understand environmental factors that caused Red Spot disease and fish kills.

> "I was tasked to help re-invigorate aquaculture in PNG, with The National Fisheries Authority as the major partner, to address protein shortages in people's diets."

One puzzle called in early on was why shrimp farms were being abandoned in India. Sammut immediately recognised the problem from something he had already worked on in Australia. "The problem you've got is that the soils produce acid when they're disturbed…that's what I'd been working on in Australia as a trigger for fish disease and a cause of fish kills." This led him to help solve similar problems in Indonesia in the late 1990s.

That led to training staff in laboratory and field methods after a tsunami killed two-thirds of the fishery staff in Aceh. That capacity building gave Sammut a sense of the impact he could have, and an extraordinary opportunity emerged in 2009 to do just that with the National Fisheries Authority (NFA) in Papua New Guinea (PNG).

As Sammut puts it: "I was tasked to help re-invigorate aquaculture in PNG, with NFA as the major partner, to address protein shortages in people's diets." With NFA and ANSTO, he worked on improving fish production by reducing the cost of feeding fish; this was achieved by improving fish feed formulations, and trialling different fish feeding strategies. "People were passing off stunted fish as juvenile fish for sale; the stunting was mainly caused by a lack of feed and fish putting their energy into reproduction rather than growth. People didn't know how to manage their ponds and separate male and female fish to prevent breeding. Nile tilapia, the main species farmed in PNG, can produce thousands of unwanted offspring that compete for the food. So NFA funded training for our project team to produce monosex fingerlings using environmentally-safe hormones to create all males." This revolutionized fingerling production, and helped farmers to grow fish to table size at a lower cost.

Perhaps UNSW and the NFA's greatest impact was with some of the most disadvantaged members of society.

For ex-prisoners fish farming has proved to be a path to reintegration into the community. One such person, Moxie, "had done some pretty terrible things," says Sammut. "When he went back into the community…they didn't want him back; they were scared of him." But he got into fish farming by applying the skills from the training program in prison, and because it was next to a main road people in the community could see what he was doing. And people in the community began to ask him what he was doing, and he explained that he was farming fish. "People could see he was making money," Sammut explains, "and they asked if he could teach them. His status in society shot up…it was just incredible. He's really well respected now." The program, run by NFA, is supported by the inland aquaculture research project led by Sammut and his colleague from NFA, Jacob Wani, the brainchild of the Fish for Prisons Program.

It's not just one person. A number of existing prisoners are involved in fish farming. 8 prisons are involved. Prisoners tell Sammut "we no longer sit around idle and bored and feeling hopeless. We enjoy farming fish and have hope for a better future when released. We enjoy coming down to feed the fish. We enjoy harvesting and eating the fish." And they've got fish as part of an otherwise rather bleak prison diet.

Martina Stenzel

Nanoparticles are the key to solving medicine's "last-mile problem" of getting drugs to the right cells, and not the wrong ones.

Martina Stenzel always loved chemistry, but it was in her early university days in Germany that she discovered polymer chemistry. She was fascinated by "how we can actually make these materials and give them so many different properties just by changing the building blocks."

And so began a career focused on the interface of polymers and medicine. She points to implants and sensors to detect diseases, but much of her focus is on how polymers can enhance the delivery of drugs. She reminds me that "a little-known fact among the board population is that mRNA vaccines are delivered with nanoparticles. So most of the world have now got little nanoparticles in their body, and they're totally benign." In order to make mRNA vaccines work, these nanoparticles underwent years of development to work the way intended to with the immune system.

A major focus of Stenzel's work is using nanoparticles to enhance cancer treatment.

The basic idea sounds simple enough. Lots of new drugs are either not water-soluble, or they are not stable in the bloodstream for very long. So they don't get into the cells where they need to go. Stenzel says: "so you basically package them—you put them inside what's almost like a sponge. And now it's protected." This sponge-like nanoparticle is then not detected by the immune system so it can circulate for a long time.

Metal-based drugs have great promise in treating cancer, but the delivery mechanism is complicated. They need to go into the cancer cell and bind to DNA and then destroy the bad cells. But metal-based drugs are very reactive, so they bind to almost anything. So less than 1% might actually go into the tumor. The other 99% might get cleared by the kidneys, but they might accumulate elsewhere in the body and cause large side effects. Think of chemotherapy. It kills the cancer, but it attacks the rest of the body as well.

As Stenzel puts it "by putting into a nanoparticle, what we're really trying to do is make sure that platinum drug does not start binding to all these proteins in your bloodstream and gets circulated a little bit longer until it eventually finds the tumor." In fact, Stenzel is going further than that, by coating the surface of the nanoparticles so that they target only the cancer cells.

Once this works, the issue is how to scale up to production of nanoparticles. For animal studies, for example, only a few grams might be needed. But scaling up from there can be complicated. Stenzel notes: "what works on the milligram, it might, let's say, give you a particle of 50 nanometres, and then you want to upscale it, and suddenly it gives you broad size distribution, or you get mainly 100 nanometre particles that aren't useful." To scale up means going from a beaker and pipette to a nano assembler. From at $2 setting to a $200,000 setup.

All of this is turbocharged by having top-flight medical and engineering schools at UNSW. It lays the foundation for truly interdisciplinary work. To have the kind of collaborations that lead to breakthroughs.

But at its heart is the basic research. As Stenzel says: "People need to understand the importance of science, that things that are made today, they might not have any commercial value next year. But they might have a huge commercial value in 10 years-time. And until then, you really try to get your foundations right, you're really trying to optimise the system, you try to understand the system. And then when it's needed, you're ready to go."

> "People need to understand the importance of science."

Ben Newell

Making good decisions is all about understanding the cognitive process. And that's true for medical, financial, and even environmental decisions.

Ben Newell is a behavioural scientist in the school of Psychology at UNSW. He's also the Director of the UNSW Institute for Climate Risk & Response (ICRR).

At first glance this might seem like an unusual combination, but as Newell explains to me that understanding people's perceptions of risk and their decision-making processes are at the heart of tackling climate change.

His work is extraordinarily interdisciplinary. He's collaborated with researchers across numerous UNSW faculties. In talking to me—an economist—he immediately adopts the sensibility and vernacular of a behavioural economist. We talk at length about the impact that psychology has had on economics in recent decades—particularly the work of the late Amos Tversky, (the now late as of this writing) Danny Kahneman, and Dick Thaler. They are often credited with documenting some of the deficiencies in human decision-making and how some of our biases are "systematic".

Newell has a penetrating take. "I think the overall view—and this is something that Danny Kahneman often tries to stress—that the whole point of their enterprise was to say that most of the time people actually make really good judgments and decisions their heuristics are very effective and efficient."

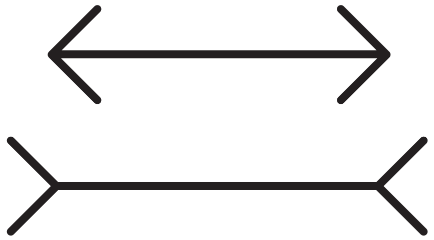
Why all the emphasis on biases, I ask. Newell says: "everyone picked up on the biases because they're easier to illustrate and laugh at people because they're wrong. It's become more of a currency because it also puts the psychologist or the behavioral economist in this exalted position where they can say you think you know how you think but you don't.

The whole *homo economicus* versus *homo sapiens* distinction, it short-changes how smart people actually are…it's kind of remarkable how good the heuristics are, how they're efficient and adaptive."

What's most interesting for Newell is not how people can be shown to make mistakes in "garden path" situations which almost invite people to make errors. That's why *systematic* biases are interesting—because people haven't learnt, they haven't responded to incentives to improve their decision-making. It leads him to ask "what's your benchmark for perfection? You want a topology for thinking about how far away from perfection you are."

He points to the famous Müller-Lyer illusion. Most people estimate the stick with two open fins is longer, even though the sticks are actually the same length.

Figure X:
The Müller-Lyer illusion



"You can say well, yeah your perceptual system is judging something incorrectly for you and therefore it's wrong. But you could also interpret that as as being an extremely adaptive way for your visual system to operate and so it's not that it should be seen an error. It should be seen as useful."

This kind of thinking is important for big issues like medical and financial decisions, and for our response to climate risk. The latter, in particular, involves huge numbers of decisions by different companies, individuals, and governments. Focusing on how to harness what's good about our cognitive processes is the key to making progress.

Newell's work has tremendous social impact, and he's widely sought after as a media commentator. But he emphasises that impact is an outcome of serious academic work. It's reminiscent of how good medical, financial, and environmental outcomes stem from good decisions, which are in turn the product of good decision-making processes.

Michelle Simmons

A lifetime of focused research on creating new technologies and processes places Michelle Simmons in a commanding position to win the race to a quantum computer. Being up against giants with incredibly deep pockets is "an advantage", she thinks.

There are few accolades that Michelle Simmons has not received. But you wouldn't know it when talking to her. She's both extremely down to earth and incredibly focused on her scientific mission.

When working at the famous Cavendish Laboratory at Cambridge University on making very fast, high-quality transistors she became aware of quantum computing. As she tells it:
"I realized that to be able to make a quantum computer, you have to have a reproducible methodology that can make the same extremely small device twice, particularly since the device behaviour is exponentially sensitive to its' dimensions At the Cavendish, we were using the latest tools to try and achieve this. And we were finding that it was very hard to do." She realised that what was needed was a new way to make devices with "atomic precision", which didn't exist at Cavendish or anywhere else in the world. But Australia was thinking about getting into quantum computing from a standing start, and she realized atomic precision manufacturing was going to be essential.

"So we came up with a whole process about how you would make devices with atomic precision and then designed the tools – large scanning probe microscopes and crystal growth systems to be able to do this. That process took all the skills that I'd learned at the Cavendish, along with new concepts of atomic manipulation and brought them to Australia to establish a team to be able to do this. We have then pioneered a globally unique manufacturing process to be able to build devices with atomic precision ever since and established a company called Silicon Quantum Computing that is the only company in the world that can manufacture with atomic precision."

Here, we make devices using a technique where we grow the device layer by layer with atomic precision. Instead of trying to create small devices by whittling away material from a large crystal or putting metal on the surface and trying to make it small by applying voltages we create the device with precision from the start.

What material works best to build a computer where you need to create and control the quantum states with high precision? A paper by Bruce Kane (then at UNSW) showed that choosing the right material makes a big difference. Simmons says: "Ironically silicon was proposed as one of the best materials to make precision high quality quantum processors (not just classical computers) since it is a very pure, non-magnetic crystal and has already been demonstrated to be manufacturable at scale. Using phosphorus atoms as qubits would further benefit from the extremely long coherence times creating a simple, clean elegant platform to scale quantum computers.. And I guess the irony was that at the time nobody in universities was looking at silicon , because it was owned by the semiconductor industry. So as a consequence, Australia got in at a time to look at silicon when nobody else was looking at it."

This is crucial, Simmons says, because "if you adapt a poor material, there's a very little chance you're going to make it a good material. If you start with the material that's the right one at the beginning, then you build on that."

Rather than have the baggage of people stuck with an existing approach that they might be reticent to ditch, Australia was a greenfield site which allowed for a coordinated approach. Combined with her ARC QEII research fellowship, this was a powerful platform. "As a young fellow, I had a five-year program, so I could be ambitious." Simmons tells me.

At the heart of a quantum computer is a quantum bit or "qubit." The more "high quality" qubits one has, the more powerful the computer that you can build. A high quality qubit has to have a combination ofa long coherence time—to last in the state that you want for as long as possible, and fast operation. Since qubits interact with the environment, making them fragile, ideally they would be hosted in a high quality, clean material that doesn't cause them to lose their state. In the perfect world this would be a vacuum, but this is hard to manufacture at scale. The good thing about silicon is that it acts much like a solid-state vacuum because it is a high purity crystalline material. But it's also a material that the semiconductor industry has been working with for decades. Combined with our ability to manufacture with atomic precision, we can make them very small, and very close together, which makes them fast.

That's the case for building a quantum computer in silicon: long coherence times and fast operation times.

As for competing against some of the world's largest corporation in the race for the first quantum computer? "I think that can work to our advantage. If you have too much money too quickly it can cripple you as you grow too fast. This is a highly interdisciplinary field where you have to grow teams organically to ensure high quality outputs."

Traditional Quantitative Measures

Publications and Citations

To assess the quantitative impact of science at UNSW we downloaded data from the SCOPUS database on all publications between 2018 and (mid-March) 2024 with authors affiliated with Australian institutions. In all instances we calculate an "institutional contribution" associated with each publication, given that most publications have multiple (often many) authors from a number of different institutions. Further details of how these measures are constructed can be found in the Appendix. The Appendix also contains a comparison of various Australian universities on these measures.

Taken together these figures provide compelling evidence of the relative contribution of science at UNSW to knowledge generation by Australian Universities. But we can take this a step further. By utilizing the endogenous growth theory framework discussed earlier, we can translate these scientific outputs into economic value.

The Economic Value of Science at UNSW

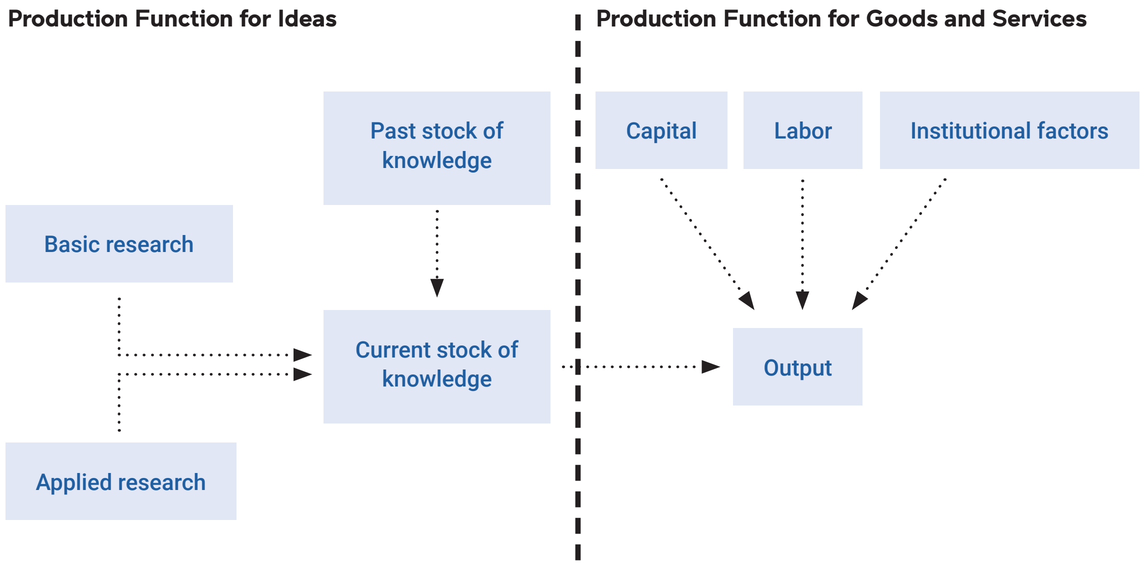
To calculate the economic value of Science at UNSW we utilise work from the International Monetary Fund ("IMF"), reported in their *World Economic Outlook*.[9] The IMF approach is based on endogenous growth theory, discussed above, and can be summarised by the following diagram.

The IMF focus on research citations in patent applications across countries from the Reliance on Science ("RoS") of PATSTAT databases. RoS links 38 million patents from the United States and European scientific publications, and PATSTAT has global coverage of 105 million patent applications from 190 countries.

To understand how knowledge diffuses *across countries*, the IMF authors estimate what international trade economists call a "gravity-model" to estimate international knowledge flows. To understand how knowledge diffuses over time the IMF authors look at the age of scientific articles cited in patent applications. They show that basic knowledge has a long-lasting effect, and longer than for patent-to-patent citations.[10]

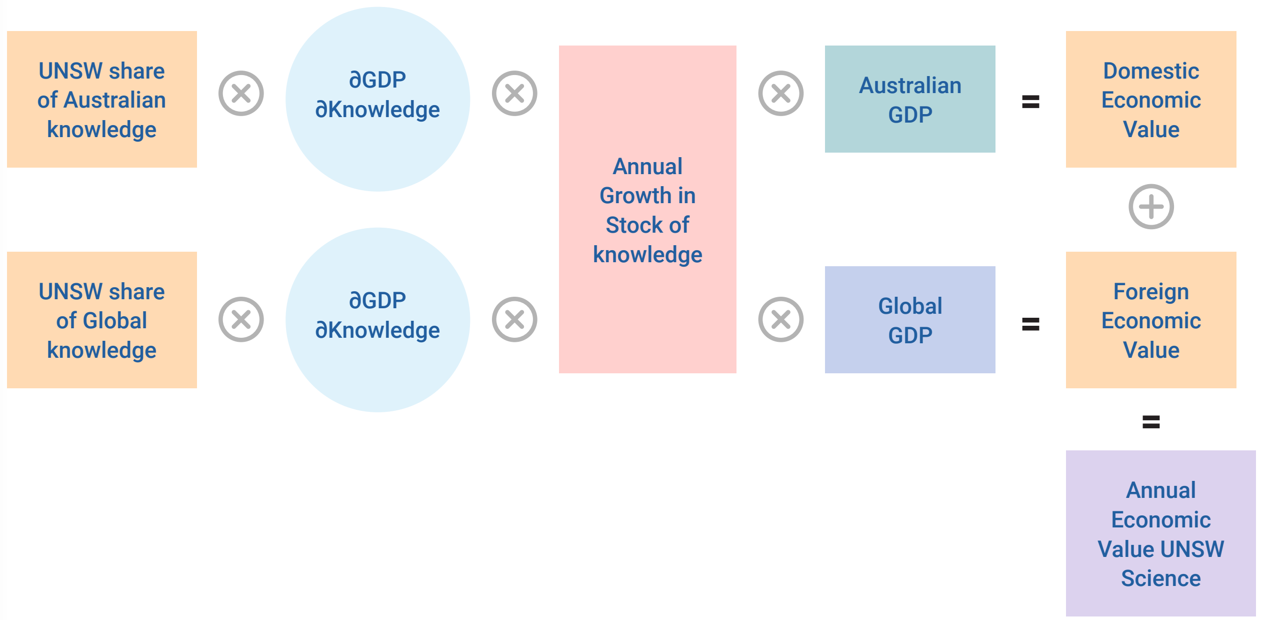
Putting the spatial and time dimensions together, the authors establish the size of the link between innovation and productivity. This allows the IMF to calculate the impact of a 10% increase in the stock of basic research on GDP per capita. They find that such an increase in own basic research increases GDP per capita by 0.3%. For foreign basic research this figure is 0.6%.[11]

Figure 3.2:
Stylised Conceptual Framework



Source: IMF staff illustration

Figure 5:
Calculating the Annual Economic Value of UNSW Science



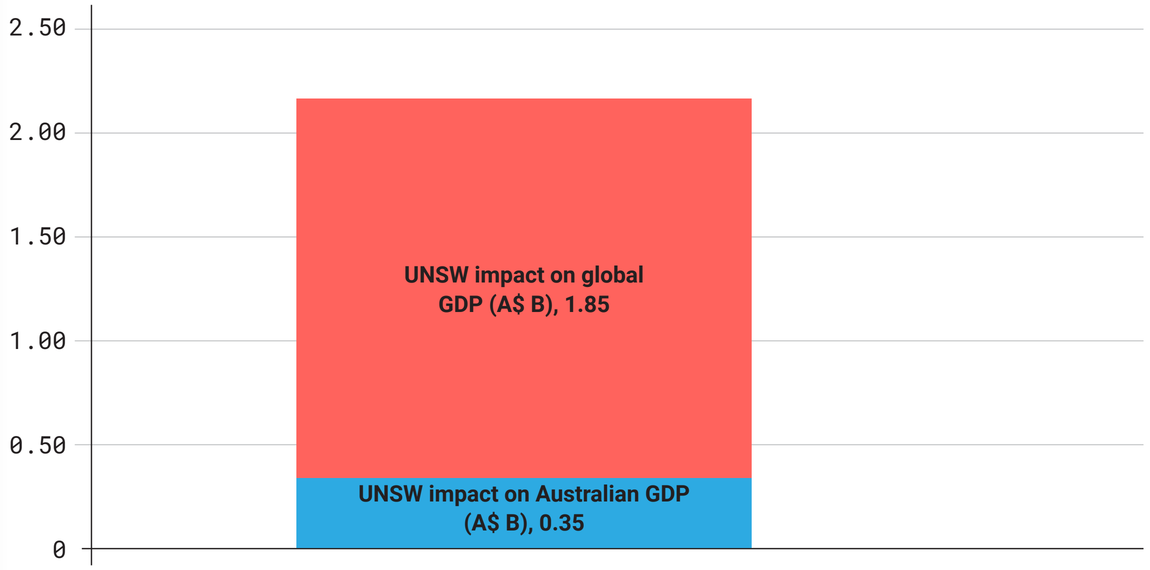
Armed with this we can calculate how research from UNSW Science translates into economic output (GDP per capita) in Australia and around the world.

Australian GDP is approximately A$2.9 trillion and global GDP (excluding Australia) is approximately US$99.6 trillion. The best estimates of annual growth in the stock of knowledge range between 3% and 5%. For instance, global R&D spending grew by 4.8% per annum between 2000 and 2018, and the annual growth in scientific articles has been as high 8% per annum[12]. We use a conservative estimate of 4% as the annual growth rate of the stock of knowledge both in Australia and globally.

Using SCOPUS publication data for the past 10 years for Australia and also the past 10 years globally, we estimate that UNSW's share of the increase in the stock of Australian knowledge is 9.00%, and for global knowledge is 0.503%. Putting this all together, the annual economic contribution of UNSW Science is $2.20 billion.

It is worth noting that 16% of this value is created in Australia and 84% is created by the global power of UNSW ideas. UNSW Science's impact is truly global.

Figure 6:
The Annual Economic Value of UNSW Science



From Ideas to Social and Economic Value

There's a terrific exchange between a Senator, a Presidential staffer, and a Princeton physics professor in screenwriter Aaron Sorkin's *The West Wing*. It goes like this.[13]

Senator Enlow

I'm a Democrat, Sam. How's a 20 billion dollar astronomy lecture gonna help the President get elected?

Sam Seaborn

It won't. "We've discovered a seamless, intellectual framework for the universe" isn't a good 30-second spot.

Enlow

If only we could only say what benefit this thing has, but no one's been able to do that.

Professor Dalton Millgate

That's because great achievement has no road map. The X-ray's pretty good. So Is penicillin. Neither were discovered with a practical objective in mind. I mean, when the electron was discovered in 1897, it was useless. And now, we have an entire world run by electronics. Haydn and Mozart never studied the classics. They couldn't. They invented them.

Great achievement has no road map, but it can be nurtured.

Top global universities play a crucial role in this because they are one place where great, fundamental ideas can be generated. Universities are not hostage to quarterly earnings targets like publicly listed companies are. They are not subject to the whims of venture capitalists. They are one of the few remaining institutions capable of thinking long-term.

The profiles of the ten scientists in this report are revealing. They highlight the breadth and intensity of ideas being generated at UNSW Science. They are scientists devoting a lifetime of research to some of the most fundamental questions facing the world.

How and why is our climate changing? How can people's cognitive processes drive better decision-making? How do we get more of a drug into the cells we want to target? Can we help people age well? Can we avoid or treat some of the most debilitating neuromuscular disorders. Might the global race to an entirely new type of computer be won in Australia? Can teaching men how to fish—literally—reduce tribal violence? And can global value chains be reorganized to make better use of the embedded energy in what we've already made?

But not only are they making extraordinary progress on these pressing questions from the perspective of basic science, they are a central part of the journey to translate and even commercialise them.

Perhaps one of the ideas will lead to a breakthrough akin to mRNA vaccines. Famously, the work of Katalin Karikó led not only to a Nobel Prize, but was central to the success of BioNTech and its US$20 billion market capitalisation. Indeed, the path from some of the UNSW scientist's work to tens of billions of dollars of stock market value is not too hard to see.

But as modern economic theory has taught us, whether the path is direct or more circuitous, ideas are at the heart of economic growth. It is ideas that drive productivity—allowing us to get more out of less. It is ideas that allows humanity to thrive indefinitely. And it is ideas that make for infinite possibilities in a seemingly finite world.

Moving Beyond Traditional Measures

Economic value is one important measure of impact. We've shown how traditional indicators of scholarly outputs such as citation counts and numbers of publications in top-ranked journals can be translated into a dollar value.

But it's also possible to provide a multidimensional measure of research impact.

That's why UNSW Science's Pact for Impact Initiative has developed a richer framework for assessing impact. These Impact Indicators incorporate 5 dimensions of impact: Commercialisation, Alignment with the UN's Sustainable Development Goals (SDGs), Lives Changed, Policy and Influence, and Scholarly Outputs.

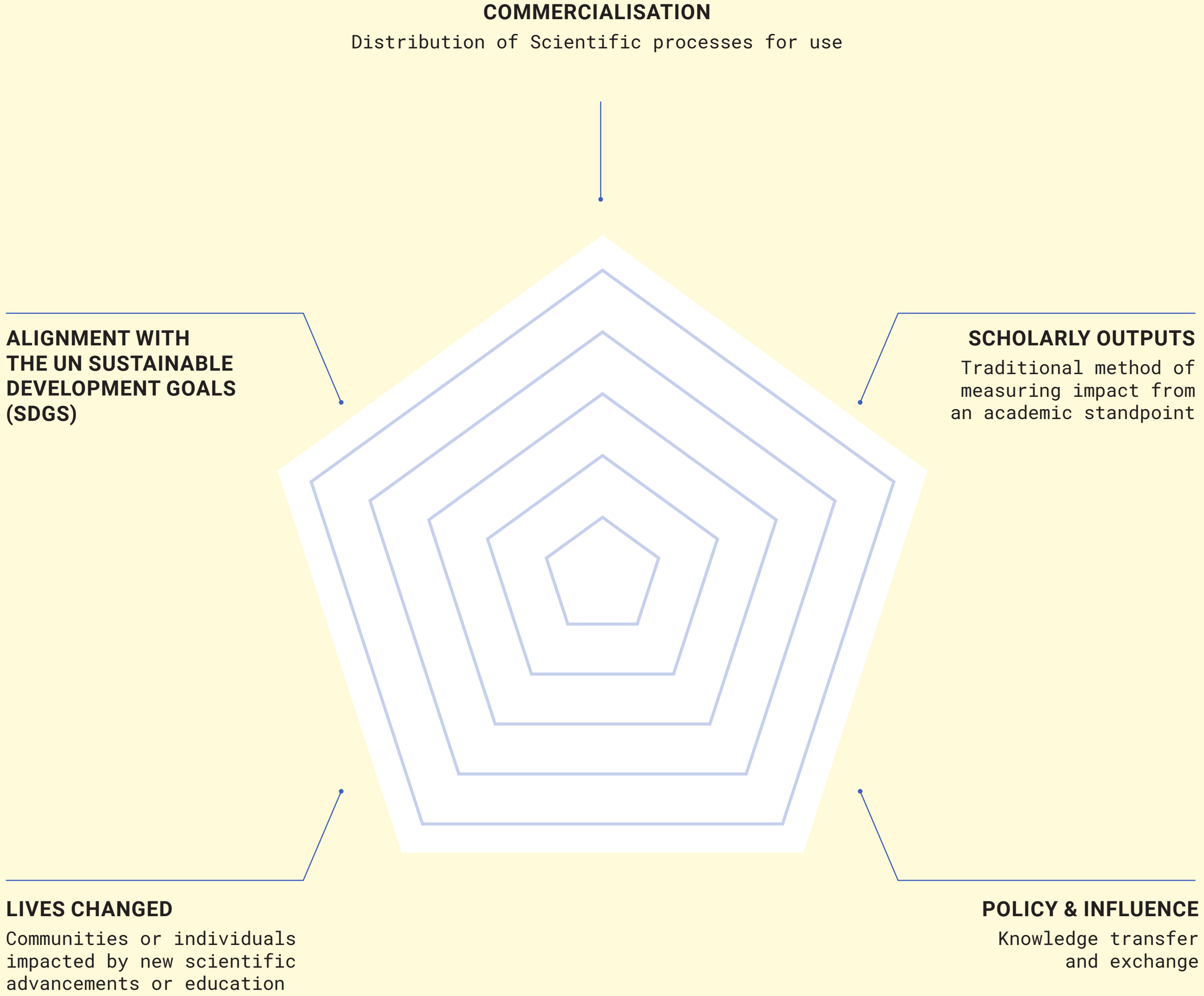
These new indicators highlight the different dimensions on which different scholars make different contributions. And they help give a broader picture of the impact of UNSW Science.

For instance, some scientists might score very high on traditional scholarly outputs, but quite low on policy influence or commercialisation. And, of course, we shouldn't expect everyone to be able to do all these things at the highest level. One of the concepts underpinning modern economics is the *division of labour*. Indeed, it has been described this way:[14]

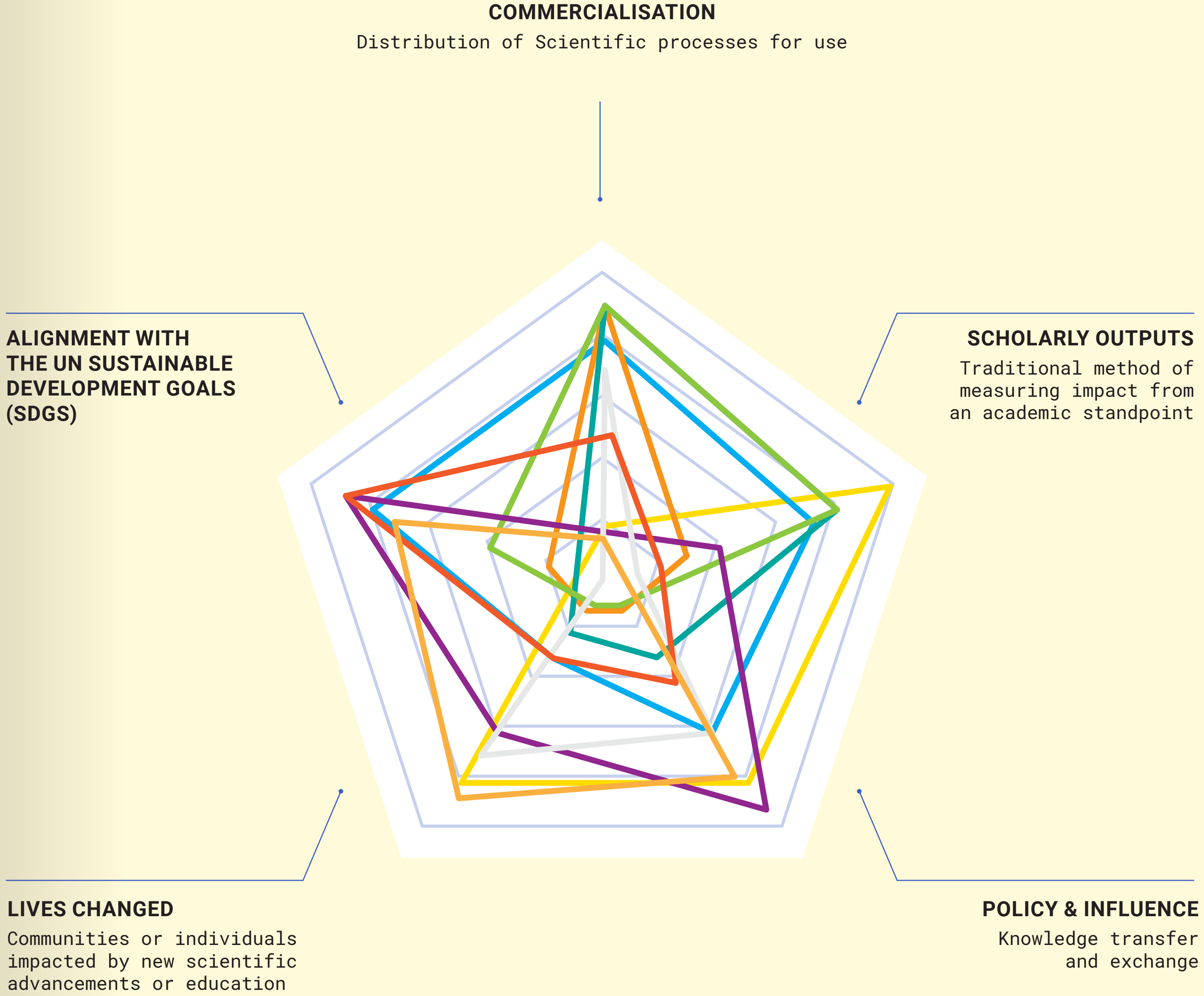
> The idea that there are gains from the division of labour with people specialising their efforts across tasks is an old one—dating to around 2,400 years ago in Plato's *Republic*. It was, of course, expanded into one of the cornerstones of modern economics by Adam Smith in *The Wealth of Nations* where he emphasised the benefits of breaking down tasks in his hypothetical pin factory.

UNSW SCIENCE
IMPACT INDICATORS

The Impact Indicators help us to understand the breadth and depth of our impact across science's broad range of research areas and collaborations. They also highlight why there is a need to move beyond traditional metrics and measures of impact.



One needs to look at the whole picture — the combination of each of the individual contributions. And when one does this for UNSW Science the result is striking. Each different colour in the below figure represents a specific UNSW Science researcher. Each one of them scores extremely high on at least one dimension — often more than one. But when combined they span all of the five dimensions of the Impact Indicators several times over. It also highlights the benefits of moving beyond traditional measures of impact.



Appendix

Publication Data and Approach

We downloaded data from SCOPUS on publications between 2018-2024 (up to 18 March 2024) with authors affiliated with Australian institutions. The following SCOPUS SciVal fields are included:

Agricultural and Biological Sciences

Biochemistry, Genetics and Molecular Biology

Chemistry

Chemical Engineering

Computer Science

Earth and Planetary Science

Energy

Engineering

Environmental Science

Materials Science

Mathematics

Neuroscience

Psychology

We create an "institutional contribution score" or "weights" for every entry in the dataset which is the proportion of Australian institutions to the total number of institutions on a given paper. For example, if a publication has 10 authors across 6 different institutions, and two of these institutions are (say) University of Sydney and UNSW, then both University of Sydney and UNSW would receive a weight of 1/6 for this publication.

We remove all "Retracted" types (but kept Erratum). We remove all duplicate entries within a given university (i.e. if there are two of the same papers listed but with different universities then we keep both). The resulting dataset contains 522,713 entries. This is the number of publications between 2018-2024 that have authors affiliated with at least one Australian institution, counting a paper twice if it had two authors from two different institutions. If we remove duplicates across universities, the total number of papers written in part by (possibly multiple) Australian authors between 2018-2024 is 395,475.

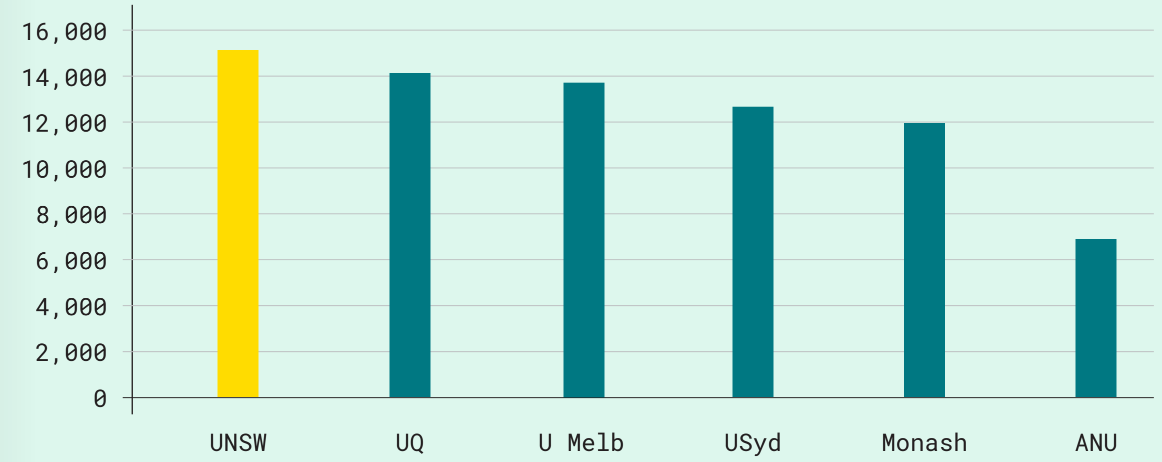
SCOPUS includes SJR percentile more often than raw SJR so we filter the dataset by those entries which contain an SJR percentile. i.e. the 4th best applied math journal in the world has no SJR but has a 1% in the percentile column. Once we filter by entries which have a valid SJR percentile, we are left with 463,810 rows (and 346,639 unique scholarly outputs).

The "Field-Weighted Citation Impact" (FWCI) is a metric which takes into account that different disciplines receive different citation numbers on average. A groundbreaking work in quantum physics may only have a handful of citations despite being of equal or greater importance than (say) a paper introducing a new software package which might be more accessible to a general audience. Scopus groups together publications with the same publication year, type, and discipline, and the average citations in that group are normalised to 1. An article with FWCI = 1+x has x% more (or, if x<0, fewer) citations than the average paper in its "group."

Traditional Output Measures

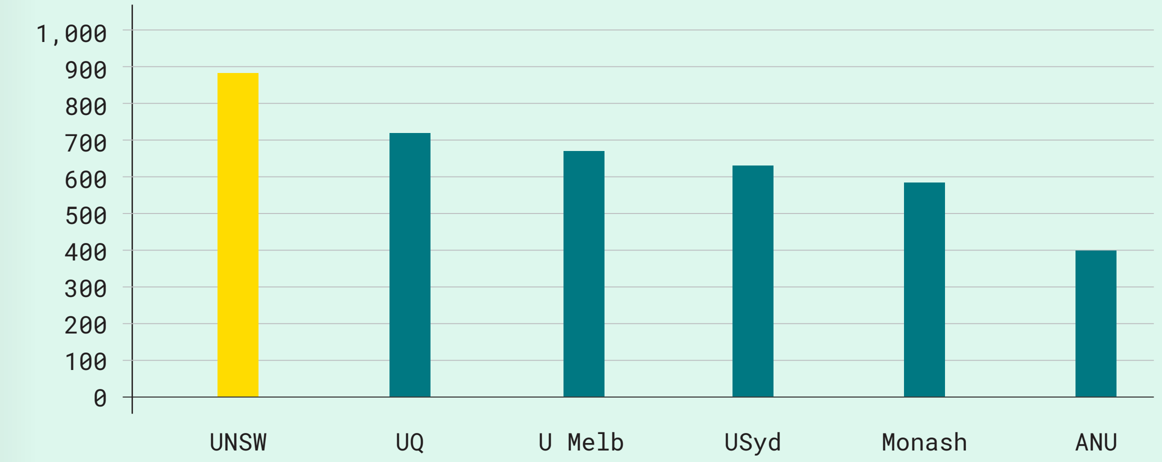
We first consider total publications. Figure 1 shows this for the six highest-publication Australian institutions: UNSW, University of Queensland, University of Melbourne, Monash University, and the Australian National University. UNSW is the clear leader with more than 15,200 institution-weighted publications over the period, nearly 1,000 more than the second-place UQ, over 2,500 more than University of Sydney, and more than double the ANU. UNSW's unweighted publications are more than double this number, at more than 30,000.

Figure 1:
Publications 2018-2024



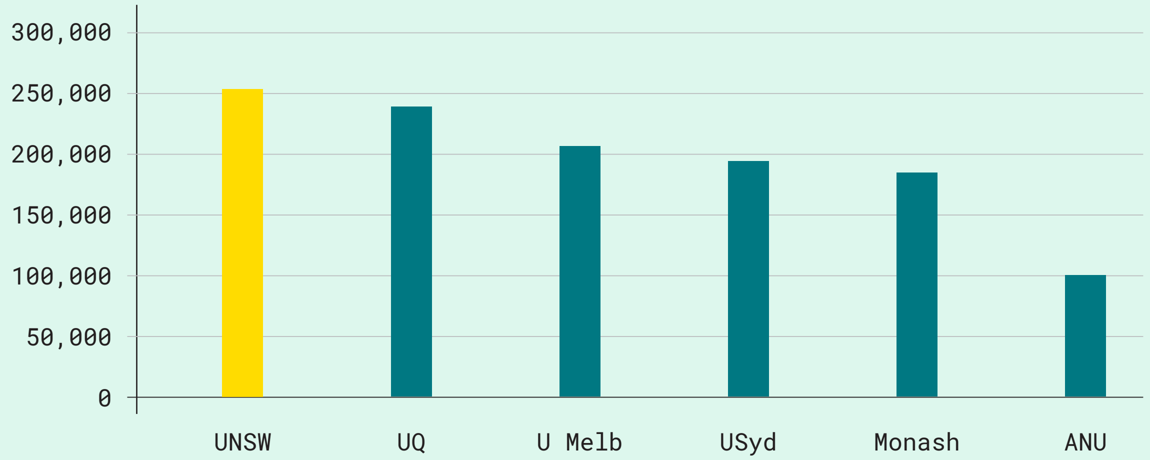
When we restrict attention to the very highest-ranked journals—those in the top 1% as measured by the widely-used Scimago SJR—the picture is even starker. UNSW has 20% more top publications than the nearest-ranked UQ, 31% more than Melbourne, 38% more than Sydney, 50% more than Monash, and a remarkable 116% more than the ANU.

Figure 2:
Top 1% SJR Publications 2018-2024



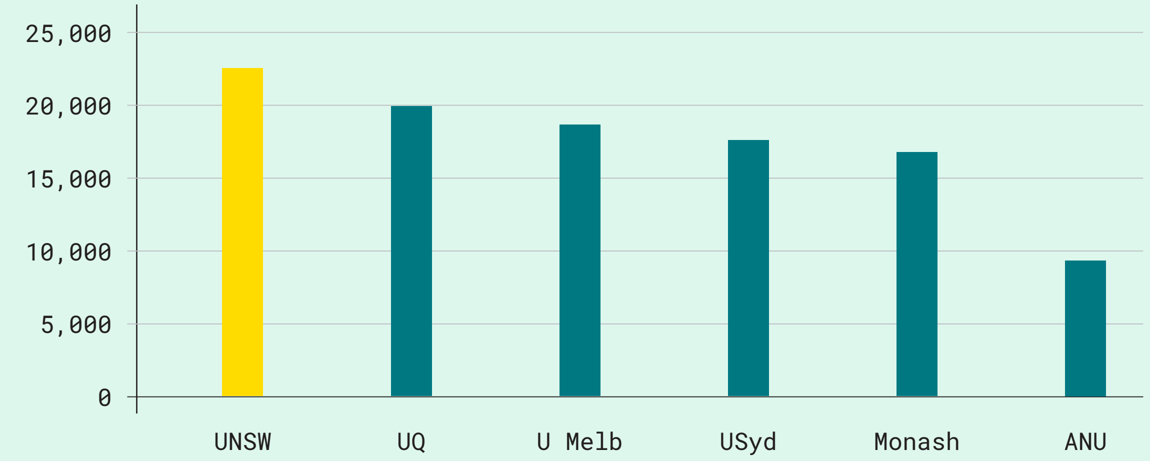
Of course publications—even those in the very top journals—are an imperfect measure of the impact of research. Citations provide an alternative perspective on idea generation. Here, too, UNSW is the top Australian University. UNSW has 8% more citations than the nearest-ranked UQ, 28% more than Melbourne, 29% more than Sydney, 34% more than Monash, and 156% more than the ANU.

Figure 3:
Citations 2018-2024



Some scientific fields tend to be more highly-cited than other fields, perhaps due to citation norms rather than actual impact. To account for this we we used SCOPUS's "field-weighted citation impact" metric to construct our own measure of field-weighted citations." This only amplifies UNSW's relative citation count with 13% more such citations than UQ, 19% more than Melbourne, 25% more than Sydney, 33% more than Monash, and 141% more than the ANU.

Figure 4:
Field-Weighted Citations 2018-2024



IMF Knowledge Flow Model

As discussed in the text, the IMF authors estimate a gravity-type model of international knowledge flows to determine the economic impact of increases in the stock of knowledge. The econometric specification is, as the authors note, as follows:

The outcome variable is the number of citations from one country to another. For example, for basic research, this would be the number of citations by, say, Malaysian inventors to scientific articles with Spanish authors (for applied research, the citations are to other patents). The explanatory variables are: whether the two countries share a border, whether they have a common official language, how specialization in their economies differs (scientific specialization for science citations, technological for patent citations), and geographic distance in kilometers. Citing and cited country fixed effects capture differences in the knowledge mass, intellectual property rights, and other factors that may influence a country's propensity to patent or to cite other patents.

When putting together the cross-country and time-series effects to pin down the link between innovation and productivity, the IMF authors note that they measure the stock of innovation using cumulative patent flows with an annual depreciate rate of 10%. Their empirical specification involves 138 countries from 1980-2017. It assumes constant returns to scale and includes controls for capital per worker, human capital, and includes both country and time fixed effects. It also "includes interactions between innovation and institutional factors to allow institutions to affect the transmission from innovation to productivity."

Endnotes

1 See Larry Summers quoted at *https://www.thefp.com/p/larry-summers-on-inflation-and-the*

2 The classic paper by Romer to which the Nobel Committee pay particular attention is Romer, Paul M. "Endogenous technological change," Journal of political Economy 98(5), Part 2 (1990): S71-S102.

3 Solow, Robert M. 1956. "A Contribution to the Theory of Economic Growth," Quarterly Journal of Economics 70(1): 65–94.

4 This description is based on Richard Holden, "Nobel Prize recognises two fixers of market failure," Australian Financial Review, 9 October 2018. Available at *https://www.afr.com/policy/economy/nobel-prize-recognises-two-fixers-of-market-failure-20181009-h16e17*

5 In particular, see Paul Romer. "Two Strategies for Economic Development: Using Ideas and Producing Ideas," Proceedings of the World Bank Annual Conference on Development Economics (1992): 63–93; Paul Romer." (1993).

6 Lucas Jr, Robert E. "On the mechanics of economic development." Journal of monetary economics 22.1 (1988): 3-42.

7 See *https://climateextremes.org.au/climate-modelling-an-overview/*

8 *https://www.top500.org/lists/top500/2023/11/*

9 See chapter 3 of *https://www.imf.org/en/Publications/WEO/Issues/2021/10/12/world-economic-outlook-october-2021/#Chapters* for details and a summary blog post at *https://www.imf.org/en/Blogs/Articles/2021/10/06/blog-ch3-weo-why-basic-science-matters-for-economic-growth*

10 As the authors put it: "Basic knowledge displays a long-lasting impact, with the density for the age of cited scientific articles reaching a peak at about eight years versus three years for cited patents. This evidence suggests that scientific ideas can still be economically influential for long periods of time."

11 The IMF authors use an elasticity of 0.674 for patents with respect to own basic research and 1.358 for patents with respect to foreign basic research. And they use an elasticity of 0.044 for productivity with respect to the stock of patents.

12 No single measure fully captures annual growth in the global stock of knowledge, but reasonable proxies include annual growth in research & development spending (see *https://uis.unesco.org/en/topic/research-and-development*); and the annual growth of scientific publications (see Bornmann, Lutz, and Rüdiger Mutz. "Growth rates of modern science: A bibliometric analysis based on the number of publications and cited references," Journal of the association for information science and technology 66.11 (2015): 2215-2222.).

13 See *http://www.westwingtranscripts.com/wwscripts/3-15.txt*

14 "Incentives to Discover Talent" (with *Tobias Brunner, Guido Friebel and Suraj Prasad*), Journal of Law, Economics and Organization, 38(2), 2022, 309-344.

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