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Editorial: paradigm shifts

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This issue includes the 14 papers presented at the 2018 Forum, "Towards a prosperous yet sustainable Australia — what now for the Lucky Country?", a submitted paper by Ann Moyal[1] on the reception of Charles Darwin's *The Origin of Species* among scientists in nineteenth-century Australia, six Ph. D. dissertation abstracts, and an obituary on the late Distinguished Fellow, Noel Hush (1924–2019), by Don Hector.

Darwin's argument that the emergence of new species from old occurs through the mechanism of natural selection — evolution — was an archetypal paradigm shift, to use Thomas Kuhn's (1962) term: a paradigm shift is a fundamental change in the basic concepts of a scientific discipline. But paradigms are not easily shifted: "A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it." according to Max Planck (1858–1947).[2] And the evidence of the reactions amongst the establishment scientists in Australia suggests that Max Planck's observation was correct. The scientists' birth and death dates are included in Moyal's paper to emphasise Planck's point.

For a paradigm shift to occur there must be an existing paradigm. A paradigm is a way of thinking or seeing, not so much a way of doing. This rules out such new technologies as sound recording and television and radar with no antecedents, and also such revolutionary technologies as double-entry bookkeeping in 1494 (single entry), steam engines (horse power), photography (painting), and the telegraph (semaphore etc.). The following list for the most part does not include new technology.

Examples of other possible paradigm shifts	
628–1202	the formulation of zero as the tenth symbol in the Hindu-Arabic decimal numerical system with positional notation, promoted in Europe by Fibonacci, replacing Roman numerals (although perhaps this is new technology)
1543	from Ptolemaic to Copernican cosmology
1610	using the new technology of the "telescope," Galileo observed the moons of Jupiter which disproved the belief in the immutability of the heavens of Aristotelian cosmology, and also led to the adoption of Copernicus' heliocentric view

[1] Ann Moyal was a veteran historian of science and inaugural winner of the RSNSW History and Philosophy of Science Medal in 2014. Les A. Murray, the late poet, dedicated his poem, "The Tube," to Ann, as I found in my copy of Murray (1993), after his recent death. Ann died on 21 July 2019, aged 93.

[2] "Eine neue wissenschaftliche Wahrheit pflegt sich nicht in der Weise durchzusetzen, daß ihre Gegner überzeugt werden und sich als belehrt erklären, sondern vielmehr dadurch, daß ihre Gegner allmählich aussterben und daß die heranwachsende Generation von vornherein mit der Wahrheit vertraut gemacht ist," in Planck (1949).

Examples of other possible paradigm shifts	
1686	Newton's three laws of motion (and his earlier theory of gravity) built on work by Galileo and Kepler, against Aristotle's notions
1783	Lavoisier's theory of chemical reactions and combustion in place of the phlogiston theory
1826	the discovery of non-Euclidean hyperbolic geometry by Gauss and Taurinus
1859	Darwin's theory of the evolution of species through natural selection
1866	our own William Stanley Jevons[3] (and, independently, Carl Menger and Léon Walras) derived neoclassical value theory in which individuals maximising utility is the way of understanding market behaviour: the marginalist revolution of microeconomics (against Mill's and Marx's classical approach)
1905	quantum mechanics replaced classical mechanics at microscopic scales (Planck and Einstein)
1876–1905	the transition from luminiferous æther pervasive in space to electromagnetic radiation in spacetime (Einstein)
1919	from Newtonian gravity to Einsteinian general relativity
1929	the expanding universe, the Hubble-Lemaître Law[4]

[3] See Castles (2016) and Marks (2016).

[4] See Burton (2018).

Examples of other possible paradigm shifts	
1935	John Maynard Keynes argued against Say's Law (which implied that under-employment and under-investment were virtually impossible) and derived effective demand, and counter-cyclical fiscal policy (macro-economics)
1953	the discovery by Crick and Watson of the double-helix structure of DNA[5] — they used simulations[6] of physical models (their "stereochemical experiments") — against Pauling's triple helix
1964	the discovery by Penzias and Wilson of cosmic microwave background radiation (the residual of the Big Bang) led to the demise of the steady state theory (Hoyle, Gold, and Bondi)[7] and the triumph of Lemaître's and Gamow's Big Bang theory in cosmology
1964	the proposed existence of Gell-Mann's quarks, and the Standard Model of particle physics[8]
1965	the acceptance of Wegener's continental drift as plate tectonics in geo dynamics
1998	the accelerating universe, Brian Schmidt DistFRSN: the expansion is speeding up, not slowing down

[5] They celebrated their discovery in The Eagle, my local in Cambridge.

[6] As they were well aware, simulation can derive sufficiency, but not in general necessity: was theirs the *only* possible structure?

[7] I remember Thomas Gold and Herman Bondi with Harry Messel on the televised International Science School in the 1960s; I met Thomas Gold at the Santa Fe Institute decades later, and reminisced

[8] Although this took some years and many experiments. At the Santa Fe Institute in March 1993 Murray Gell-Mann (1929–24 May 2019) was not amused at a lunch-time quip of mine.

In the future, the eventual reconciliation of quantum mechanics with general relativity (and gravity) may well need a paradigm shift, when it is devised.[9]

You might agree or disagree with this selection, not meant to be exhaustive.[10] Two earlier developments might also stand as paradigm shifts: the inventions of writing systems and particularly the invention of the alphabet (using symbols to record the sounds, phonemes, of words, rather than the whole word or phrase), but their details and impacts are lost in prehistory. And anyway we might look on the alphabet as a new technology.

A good topic for dinner conversation (at least in some circles) is what developments of today will be remembered as paradigm shifts after the dust settles: complexity theory? computational biology? "wet" (biological) quantum phenomena? quantum computing? But I digress.

The Forum includes two papers dealing with AI (Artificial Intelligence), a topic which is generating much discussion. A recent McKinsey Global Institute publication includes at least one article of interest in applying AI for social good (Chu et al. 2018). See Mitchell (2018) for another view. John Quiggin (2019) updates his Forum talk.

A note: the Forum committee invites the Forum participants to address the Forum, and for the most part they convert their addresses into papers for the *Journal*. As invited papers, these are not sent out for review, but are accepted without further scrutiny. Nor am I involved in the selection of the speakers. This might sometimes result in papers from the Forum being published which, as editor, I would not myself have included in the *Journal*, for various reasons.

In recent news, we have observed the "shadow" of a black hole,[11] and we have continued to monitor gravity waves from the LIGO/Virgo observatories. There is now an app, Gravitational Wave Events,[12] that will notify you when a new observation is confirmed, using its GW chirp on your smart phone. And recent DNA analysis has shown that grapes used by the Romans 2,000 years ago are strongly related to today's pinot noir and syrah varieties, meaning that the same lines must have been carefully tended and propagated through the Dark Ages to now. In monasteries?

Two other recent events are the sesquicentenary of the presentation by Mendeleev (1834–1907) on 6 March 1869 of his periodic table of the elements (which correctly predicted several new elements), and the demise on 20 May 2019 of the old definition of the kilogram, defined by the mass of a man-made artefact, the Grand Kilo, in Paris, which has been superseded by a definition based on Planck's constant via a Kibble balance.[13] Is our moving from physical artefacts to define our units of mass, distance, and time etc. (now complete, with the demise of the rôle of the Grand Kilo) also a paradigm shift?

When the back issues of the *Journal* were scanned and placed in the on-line repository at the Biodiversity Heritage Library, one was overlooked: Volume 115, parts 3 & 4 (Parts 325 & 326). I have recently added this issue

[9] See Powell (2015) for a clear discussion of the issues.

[10] What of Mendelian genetics? What of Bayesian probability? What of Freud's insights into psychology? Other psychological schools?

[11] See https://www.vox.com/2019/4/10/18302343/first-picture-black-hole-eht-photo-event-horizon

[12] See https://itunes.apple.com/us/app/gravitational-wave-events/id1441897107

[13] See Hibbert (2017).

to our Contents web page. Our collection from 1867 is now complete.

I should like to thank Ian Wilkinson, Louise Young, John Spence, Len Fisher, and the Editorial Board for discussions about this editorial, and Ed Hibbert, Rory McGuire, and Jason Antony for their help in preparing this issue.

Balmain, 9 June 2019.

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John Quiggin (2019), Australia isn't doing its part for the global climate. Sooner or later we'll have to pay our share *The Guardian*, May 27. https://www.theguardian.com/commentisfree/2019/may/27/australia-isnt-doing-its-part-for-the-global-climate-sooner-or-later-well-have-to-pay-our-share

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The scientists and Darwin's *The Origin of Species* in nineteenth century Australia. A re-evaluation

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Abstract

The arrival in Sydney of a copy of the first edition of *The Origin of Species* early in March 1860, purchased and annotated in pencil by a botanically aspiring colonist, William Woolls, yielded a significant insight into the reception of Darwin's theory of evolution at a remote outpost of the scientific world. A Christian "creationist," Woolls, rejected the theory, and his pencilled objections and questioning marked an attitude that would predominate among Australian naturalists for almost four decades. British institutional approaches coloured the development of colonial science. The personal and research influence of the great British palæontologist, Sir Richard Owen, and his concept of a "final cause" held prevailing sway, and it was not until the mid to late 1880s that a new breed of trained pro-Darwinian scientists from the United Kingdom percolated the teaching posts in the three Australian universities and promoted a paradigm shift in Australian biological science. Darwin's long consideration of the platypus (first sighted in 1836 on his visit to the Cox's River, New South Wales) as a key aberrant species in the evolutionary chain, finds relevance in this re-evaluation. Evolutionary ideas won widening acceptance at the Royal Society of New South Wales following the creation and award of the Clarke Medal in the late '80s as the first scientific award in Australia.

The Origin arrives in the Colonies

In December 2009 the National Library of Australia acquired a copy of the first edition of Charles Darwin's *The Origin of Species,* the earliest to reach the Australian colonies. Published by John Murray, London, in a small edition of 1,250 copies on 24 November 1859, it arrived in Sydney by ship on 10 March 1860 and a week later it was proudly inscribed by one of its first purchasers — "Parramatta N.S.W. William Woolls March 17 / 60". Defined in library terms as an "association copy,"[1] its singularity was marked by the pencilled annotations made by its owner across some one hundred of its pages denoting the earliest known commentary offered in Australia on a work that was destined to transform scientific thinking and promote a new understanding of the biological world. Titled fully *On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life*, Darwin's book would both confound and challenge opinion in the Australian colonies across the next four decades.

Fertilized by his *Beagle* journal (Darwin 1839) from his four years as a travelling naturalist and his subsequent experiments and research, *The Origin* was stocked with new biological data drawn from sources across the globe, its wide compass offering a detailed proposal for the progressive development of species and a positivist biological framework for man's understanding of the natural world. It was launched into an audience already exposed to Lamarck's theory of the evolution of species through the process

[1] NLA.cat-vn4591931

* Ann Moyal died on 21 July 2019, aged 93.

of adaptive change and the amateurish, but popular, *Vestiges of the Natural History of Creation* published anonymously by Richard Chambers[2] (Chambers, 1844) advancing a theory of progressive evolution instituted by a Creator working down the ages to produce an unending series of adaptive change. Yet centrally it was Archdeacon Paley's book, *Natural Theology* (Paley[3] 1802–70) with its thirty-odd editions, set as a standard text at Oxford and Cambridge universities, that had the most sustained influence on public opinion: "There cannot be design without a designer; contrivance without a contriver; order without choice…subserviency and relation to a purpose, without that which could intend a purpose; means suitable to an end…without the end ever having been contemplated, or the means accommodated to it. Arrangement, disposition of parts, subserviency of means to an end…imply the presence of intelligence and mind" (Paley, 1833, p.259). "I could almost," Darwin himself once remarked, "formerly have said it by heart"[4] (Darwin, 1859b).

For Australia itself Darwin had early followed the published journeys of the Australian explorers, Thomas Mitchell and Alan Cunningham, was acquainted with the work of the renowned British botanist Robert Brown in Australia, (Moyal, 2017) and, during his own visit to New South Wales — recalling that "wonderful" animal (Darwin, 1836), the platypus, seen in the Cox's River — had jotted in his Journal on 19 January 1836, "An unbeliever in everything beyond his own reason might exclaim, 'Surely two distinct Creators must have been [at] work'"[5] (Darwin, 1836a). Now in early 1860, an eager Australian reader approached Darwin's book and, addressing it with his pencil, provided a rare historical record of the impact of this seminal work on the mind of an aspiring colonial botanist.

William Woolls' commentary

William Woolls (1814–1893) was born at Winchester, England, the last of nineteen children. His family enjoyed close association with the Established Church and, while he received no formal education, he was tutored by several Anglican clergymen, including his godfather, a master at Westminster College, and his own older brother, the Rev. Charles Woolls at Pembroke College, Oxford, both of whom contributed to his education in literature, classics, theology and verse. Orphaned at 16 and lacking prospects in Britain, he was advised to emigrate to Australia and arrived in Sydney in April 1832 carrying a passport to colonial society with a letter from Viscount Goderich to Governor Bourke. In Sydney Bishop Broughton, impressed by the young man's skill as something of a literateur, appointed him as an assistant master to the Rev. Forrest, the first headmaster of The King's School, Parramatta. Woolls quickly published his epic poem *The Voyage: A Moral Poem* (1832), contributing other poems to the *Sydney Gazette* and *The Colonist,* and in 1841 opened his own school, Mr Woolls Academy, at Parramatta, where he educated the sons of colonists for some twenty-four years. He took an early interest in church matters, became secretary of the Parramatta Bible, Tract and Religious Book Society in 1842, and in 1844 published *A*

[2] Richard Chambers (b 1802–d 1871)

[3] William Paley (1743–1805)

[4] https://www.darwinproject.ac.uk/letter/DCP-LETT-2532.xml

[5] http://darwinbeagle.blogspot.com/2011/01/19th-january-1836.html

Short Account of the Character and Labours of the Rev. Samuel Marsden, followed by *A Tract for the Times: addressed to the laity of New South Wales* in 1849. He was also influenced in these early ears by the Rev. James Walker, a later headmaster at The King's School, who fostered his interest in botany. Collecting plants around Parramatta between 1845 and 1856, he began to hone his understanding of the principles of systematic botany,[6] develop an interest in "the natural system" of Jussieu[7] (adopted by Brown in his *Prodromus Floræ Novæ Hollandiæ et Insulæ Van-Diemen*) and the works of William and Joseph Hooker, and to publish material in the *Sydney Morning Herald* on the derivation of scientific names, the promotion of local plants, and information on species of the Parramatta region. He would publish his second paper, "A glance at the Botany of the North Shore, Sydney" in 1861.[8]

William Woolls comes to *The Origin of Species* with botany on his mind. He proves an attentive and confident reader. He embraces the book's four leading chapters 'Variation Under Domestication', 'Variation Under Nature', 'Struggle for Existence', 'Natural Selection,' and enters the discussion on natural selection in Chapter 5, 'Laws of Variation'. There, Darwin, having declared after several allusions to environment and the direct action of the conditions of life that induce "variability; and natural selection will then accumulate all profitable variations,"[9] Woolls notes, "All the examples [of environmental condition] "seem to prove to me the premise [of their influence]…all the author's deduction to deny it" (Darwin 1859, pp. 133–4). At Darwin's assertion that "Natural selection, it should never be forgotten, can act on each part of each being, solely through and for its advantage,"[10] Woolls asks, "By what process is a part to develop by itself?" and writes, "God determines" (Darwin 1859, p. 149). With Darwin's criticism of "the logic of attributing accommodations in domestic situations of each species having been independently created" rather than "to the *vera causa* of community of descent,"[11] Woolls scribbles, "Why not?" (Darwin 1859, p. 159).

"Our ignorance of the laws of variation", Darwin sets down, "is profound. Not in one case out of a hundred can we pretend to assign any reason why this or that part differs, more or less, from the same part in the parents. But whenever we have the means of instituting a comparison, the same laws appear to have acted in producing the lesser differences between varieties of the same species, and the greater differences between species of the same genus[12]… Whatever the cause may be of each slight difference in the offspring from the parents...it is the steady accumulation, through natural selection, of such differences, when beneficial to the indi-

[6] His paper, Remarks on the botany of Parramatta, was read at the Linnean Society, London, communicated by Dr. Ferdinand Müller, on December 15, 1859. See *J. Linnean Soc. Zoology*, v. 5, p. iii, 1861. https://www.biodiversitylibrary.org/item/35035#page/11/mode/1up

[7] A. L. de Jussieu (1748–1836)

[8] Read at the Linnean Society, London, on February 21, 1861. See *J. Linnean Soc. Zoology*, v. 6, p. v, 1862. https://www.biodiversitylibrary.org/item/39615#page/223/mode/1up

[9] http://darwin-online.org.uk/content/frameset?pageseq=152&itemID=F373&viewtype=side

[10] http://darwin-online.org.uk/content/frameset?pageseq=167&itemID=F376&viewtype=side

[11] http://darwin-online.org.uk/content/frameset?pageseq=177&itemID=F373&viewtype=side

[12] http://darwin-online.org.uk/content/frameset?pageseq=185&itemID=F373&viewtype=side

vidual, that gives rise to all the more important modifications of structure by which the innumerable beings on the face of this earth are enabled to struggle with each other, and the best adapted to survive"[13] (Darwin 1859, p. 167, 170). "*Structures!*" writes Woolls, "There can be no structural change of 'like begetting like'" (Darwin 1859, pp. 170).

When Darwin reflects directly upon the question of squirrels and how they "work" and notes that "it does not follow … that the structure of each squirrel is the best that it is possible to conceive under all natural conditions,"[14] Woolls again scribbles in the margin, "Does this not call into question the Creator's wisdom?" (Darwin 1859, p. 180). Darwin, earlier, has argued that it was improbable that shared characters of three related species were the result of three separate acts of creation, and not of common descent, Woolls asks, "Why not?" (Darwin 1859, p. 159). Against Darwin's judgment on "one general law leading to the advancement of all organic beings, namely, multiply, vary, let the strongest live and the weakest die,"[15] Woolls questions, "Who gave this law?" (Darwin 1859, p. 244). And when, turning to "disuse" in nature, Darwin suggests that the wingless condition of beetles in Madeira is a possible case due to the action of natural selection, these beetles having "the best chance of surviving from not being blown out to sea,"[16] Woolls sets down: "Ingenious dismissal of their Creator's intention" (Darwin 1859, p. 136).

Woolls' credulity is increasingly exercised in other natural history fields when Darwin, addressing 'Organs of Extreme Perfection' on the structure and graduated diversity in the evolution of the eye (Darwin 1859, p.187), and the difficulty of explaining electric organs in fish, Woolls notes, "separate creation" at margin points (Darwin 1859, p.193) and, faced with the question of parasitic bees pollinating bees of another kind, he observes, "surely this is a design by the Maker" (Darwin 1859, p. 218 & p.250). The imperfection of the geological record offers further challenge. Here Darwin's comment, "We have no right to expect to find in our geological formations, an infinite number of those fine transitional forms, which on my theory assuredly have connected all the past and present species of the same group into one long branching chain of life"[17] [where] "all the species of the same genus have descended from some one species"[18] (Darwin 1859, p. 301, p. 341), elicits Woolls' heavy underlining, as does the author's assertion that "The extinction of old forms is the almost inevitable consequence of the production of new forms"[19] (Darwin 1859, p.343). Throughout the chapter 'On the Imperfection of the Geological Record', Woolls' attention and interest is evident; his exclamation marks and underscoring, a strong show of his questioning and dissent.

On "Classification" he is directly engaged. At Darwin's remark that, "it has often been

[13] http://darwin-online.org.uk/content/frameset?pageseq=185&itemID=F373&viewtype=side

[14] http://darwin-online.org.uk/content/frameset?pageseq=198&itemID=F373&viewtype=side

[15] http://darwin-online.org.uk/content/frameset?pageseq=262&itemID=F373&viewtype=side

[16] http://darwin-online.org.uk/content/frameset?pageseq=154&itemID=F373&viewtype=side

[17] http://darwin-online.org.uk/content/frameset?pageseq=319&itemID=F373&viewtype=side

[18] http://darwin-online.org.uk/content/frameset?pageseq=359&itemID=F373&viewtype=side

[19] http://darwin-online.org.uk/content/frameset?pageseq=361&itemID=F373&viewtype=side

asserted, but the assertion is quite incapable of proof, that the amount of variation under nature is a strictly limited quality."[20] "Why if man can by patience select variations most useful to himself, should nature fail in selecting?...I can see no limit to this power in slowly and beautifully adapting each form to the most complex relations of life. The theory of natural selection even if we looked no further than this, seems to me to be in itself probable"[21] (Darwin 1859, pp. 468 & 469). Woolls firmly lines the margins of the text adding a large question mark. When, ultimately, Darwin offers his conclusive dismissal of "the doctrine of final causes" as espoused by Professor Owen, "Nothing can be more hopeless than to attempt to explain this similarity of pattern in members of the same class, by utility or by the doctrine of final causes,"[22] Woolls is there, expressing his objection with his underlining and large question mark (Darwin 1859, p. 435). Moving towards his conclusions, Darwin writes, "I have attempted to show that it is the widely ranging, the much diffused and common, that is the dominant species belonging to the larger genera, which vary most. The varieties, or incipient species, thus produced, ultimately become converted, as I believe, into new and distinct species"[23] (Darwin 1859, p. 411). Once more Woolls leaves his signifying question mark.

Yet despite his questions and rebuttals, Darwin's richly argued treatise undoubtedly claimed Woolls' close attention: he read the volume to the end. His pencilled comments are at times obscured by time or smudged by the book's two subsequent owners.[24] His participation is sporadic, yet his continuity and sense of commitment is clear. Darwin may set down in his final pages that "all true classification is genealogical; that community of descent is the common bond which naturalists have been unconsciously seeking, and not some unknown plan of creation"[25] (Darwin 1859, p. 420), Woolls remains cautious and intense. However, when Darwin, concluding, acknowledges outlooks "directly opposite to mine" and looks with confidence to the future "to young and rising naturalists, who will be able to view both sides of the question with impartiality,"[26] Woolls leaves a final cryptic comment, "No doubt" (Darwin 1859, p. 482).

William Woolls' pencilled response to the 1859 *The Origin of Species* has produced a significant artefact (Moyal, 2018). The author is revealed both as a Christian who views the natural world through the Paleyian concept "thro Nature up to Nature's God" and as a creationist and a separate creationist. On the matter of the progressive evolution of species, he emerges as a fastidious rejecter and unwilling recruit. His historical relevance, however, is clear. With his rare and detailed reading of Darwin's landmark book, he appears as a pertinent signifier of what became a prevailing Antipodean reaction and attitude to one of the most influential scientific concepts in the history of human thought.

[20] http://darwin-online.org.uk/content/frameset?pageseq=486&itemID=F373&viewtype=side

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[25] http://darwin-online.org.uk/content/frameset?pageseq=438&itemID=F373&viewtype=side

[26] http://darwin-online.org.uk/content/frameset?pageseq=500&itemID=F373&viewtype=side

William Woolls would go on to develop a vigorous commitment to Australian botany and to become an influential educator and public spokesman on the country's flora. In 1868 he founded the Cumberland Mutual Improvement Society and, throughout the '60s and '70s, gave numerous lectures and despatched frequent letters to the *Sydney Morning Herald* informing the community of plants and his own wide-flung field explorations in New South Wales. His *A Contribution to the Flora of Australia* (1867) was a compendium of miscellaneous notes, data and short papers relating to the Parramatta district, the North Shore, the botany of the Berrima district and Mittagong, Kurrajong, Tomah, Ash Island, Darling and the Castlereagh district; his *Lectures on the Vegetable Kingdom with special reference to the flora of Australia* (1879) yielded another dense collection of papers to carry forward his botanical mission. His *Plants indigenous in the Neighbourhood of Sydney, arranged according to the System of Baron F. von Mueller,* (1880) was followed by his introduction and occasional notes to Mueller's *The Plants of New South Wales* (1885), which was praised as an important "floristic" work.

Woolls' early forays into public communication brought him into contact with Ferdinand von Mueller (1825–1896), the Government Botanist of Victoria, to whom he sent specimens and one thousand letters across his career.[27] It was a connection that brought him frequent attributions in Mueller's published work and carried Woolls to the attention of the British botanists, George Bentham and Joseph Hooker. Hooker noticed him early in his *Floræ Tasmaniæ* (1859) as "a zealous Australian botanist," while Bentham, employed on preparing the multi-volume *Flora Australiensis* at Kew, acknowledged Woolls' large contribution of specimens and information in 500 mentions in his collective work. He was elected a Fellow of the Linnean Society of London in 1865 on the recommendation of Mueller and the two British botanists. Woolls, however, never became a botanical systematist; he published no description of new species, deferring to the taxonomic decisions of the professionals and adhering in his work on species to Mueller's cortical system. His most important paper "The Progress of Botanical Discovery in Australia" given initially as a Lecture to the Cumberland Mutual Improvement Society on 13 July 1869,[28] was included together with *A Contribution to the Flora of Australia* in his submission (on Mueller's urging) to the University of Göttingen, which won him a Ph.D. from the university in 1871.[29]

William Woolls' position on evolution, however, held firm. Reviewing the third volume of Mueller's *Fragmenta Phytographiæ Australiæ* in the *Sydney Morning Herald* of 7 July 1863, he wrote, "I have no faith in Dr Darwin's origin of species, nor in the process of hybridization by which some would attempt to clear away part of the difficulties, yet I am sensible that in certain species the amount of variation is astonishing."[30] The fundamental questions of variation and distribution remained at the core of his puzzle.

[27] Mueller had communicated Woolls' 1859 paper to the Linnean Society, London.

[28] *Sydney Morning Herald*, 15 July 1865, p. 5. See https://trove.nla.gov.au/newspaper/article/13185201

[29] Gilbert, 1985; *ADB*, 1976, Moyal, 2003, 2. p.903). "The Progress of Botanical Discovery in Australia" was published in *Lectures on the Vegetable Kingdom* (1879, pp. 25–60).

[30] W. Woolls, "Dr Mueller's *Fragmenta*," a letter to the *Sydney Morning Herald, 7 July 1863*. https://trove.nla.gov.au/newspaper/article/13081158

But as he told members of the Cumberland Mutual Improvement Society, "the Great Architect of the Universe created nothing in vain." If Man "had not discovered a plant's especial purpose in the economy of nature," he argued, it was due to his current state of ignorance, and not, "to any other cause" (*A Contribution*, p. 138, quo. Gilbert, p. 60). Nonetheless, Woolls took a persistently forward view: "Our knowledge…is simply progressive," he maintained, "the more we know, the more remains to be known." "[In] the study of the Creator's works, there is no finality."[31] For Woolls, science and the scientist had a sacred duty "to replace ignorance with enlightenment and to reveal God's plan to Man."

Aware of his own "amateur" status, the scribbling colonist remained essentially a botanical missionary eager to share knowledge of Australian plants and to draw the public into citizen botanical science (Gilbert, p. 84). In this his influence proved far stretching. As his scholarly biographer, Lionel Gilbert, writes, for some fifty years members of the Cumberland Mutual Improvement Society, Horticultural and Agricultural Societies, the Young Men's Friendly Society, and the great company of newspaper readers, together with the boys he taught in various schools, were "treated to a seemingly never-ending feast of lessons, addresses, articles, papers and book reviews" (Gilbert p. 63). "The boys learnt most of their botany' from Woolls." In 1873 Dr Woolls was ordained priest in the Anglican Church and appointed incumbent at St Peter's Church, Richmond. He is commemorated in the genus *Woollsia* (Epacridaceæ) and the names of six species.

William Sharp Macleay

In 1839 two naturalists arrived whose work in England had placed them in the mainstream of scientific ideas and whose emigration to the Colony gave particular impetus to colonial science. William Sharp Macleay (1792–1865), a Cambridge graduate who had studied under Cuvier in Paris and associated with Lamarck and Geoffroy Saint Hilaire, had already played a prominent part in the debate on the classification of species with his treatise *Horæ Entomologicæ* in which he espoused the Quinary or Circular system of classification founded on affinity and analogy. "One plan," he wrote there, "extends throughout the universe, and this plan is founded on the principle of a series of affinities returning into themselves, and forming as it were circles" (Macleay 1819, p. 459). A Fellow of the Royal Society of London, Macleay gathered a considerable following in Britain. T. H. Huxley,[32] reading the *Horæ* on his return from service on *HMS Rattlesnake* in Australian waters, wrote to him in 1851, "I am every day becoming more and more certain that you were on the right track thirty years ago in your view of the order and symmetry to be traced to the true natural system" (8 November, 1851, Huxley, p. 100). Macleay's own belief was that the true "natural system" was the very "plan of Creation itself, the work of an all-wise, all-powerful Deity" (Fletcher, quo p. 594). As a senior scientist in Australia he was averse to embracing Darwin's evolutionary conclusions. With access to *The Origin* early in 1860, he set down his position in a letter to his friend Robert Lowe in London. "The naturalist finds himself," he wrote in May, "on the horns of a dilemma. For, either from

[31] *Sydney Morning Herald*, 15 July 1865, op. cit.

[32] Thomas Henry Huxley (1825–1895).

the facts, he must believe in a special creation of organised species, which creation has been progressive and is now in full operation, or he must adopt some such view as that of Darwin, viz. that the primordial material cell of life has been constantly sprouting forth of itself by 'natural selection' into all the various forms of animals and vegetables. … The theory is almost a materialistic one, nay, even so far atheistic that, if it allows a deity at all, He had been ever since the institution of the primordial type of life fast asleep. I am myself so far a Pantheist that I see God in everything; but then I believe in his special Providence, and that He is the constant and active sole Creator and all-wise Administrator of the Universe"[33] (Patchett, p. 207, Moyal 1986, p. 145). Nevertheless he allowed that "Charles Darwin is an old friend of mine and I feel grateful to him for his work." His own opinion, however, remained unaltered. Three years later when Huxley's exposition of Darwin's theory was in current debate in Britain, he confided to his friend the Rev. W. B. Clarke, "I am utterly opposed to Darwin's, or rather Lamarck's theory, and no one had done greater harm to Genesis than Darwin, Huxley and Lyell."[34]

Macleay and Clarke's friendship had drawn them into early discussion of the relationship between science and theology, Macleay writing to his clerical friend in July 1842 to give his view on the Mosaic chronology and the possible relationship of the seven days of creation to an understanding of the geological epochs which Clarke was early examining in New South Wales (Letter 4 July 1842, Moyal, 2003, 1, pp. 115-9). Clarke had also delved deeply into the subject lecturing as a young parish priest in Dorset on the relationship between the Mosaic chronology and geological science and arguing for a clear distinction between the claims of the Scriptures and science (Moyal, 2003,1, p. 52). While at Cambridge he had combined his degree in divinity with training in geology under the foundation Woodwardian Professor of Geology, the Rev. Adam Sedgwick. Increasingly, Clarke was influenced by Lyell's writings on uniformitarianism and the vast changes these works suggested on the passage of forms over infinite eras of geological time (Lyell, *Principles*). Launching his Australian fieldwork in the early 1840s, he envisaged making the country "a new earth for geology."

William Branwhite Clarke

The Rev. William Branwhite Clarke (1798–1878) was an avowed admirer of Darwin's *Voyage of the Beagle* which, as he wrote to Sedgwick, had given him great pleasure and which he judged "a truly philosophical work" (Letter to Adam Sedgwick 13 August 1840, Moyal, 2003, 1, p. 80). He was also familiar with Darwin's other writings including his work on coral reefs and his *Geological Observations on the Volcanic Islands Visited during the Voyage of H.M.S. Beagle* (1844), but, engaged in his busy parish at St Thomas's Church, St. Leonards, his public role as a government geological surveyor in the 1850s, and his wide fieldwork and reportage on gold and mineral resources, he communicated for the first time with Darwin on *The Origin* in August 1861. His tone was positive. Although the first page of Clarke's August letter is missing from the Charles Darwin Correspondence in Cambridge (Moyal, 2003, 1, pp. 551–2), he cordially noted the

[33] http://darwin-online.org.uk/content/frameset?pageseq=8&itemID=A350&viewtype=side

[34] Mozley, 1967, p. 422, Letter 27 June 1863, Moyal, 2003, p. 621). The remainder of this letter, held originally at ML MSS 139/42, pp. 421–4, is missing.

author's treatise, had read the book in full and, alluding to Darwin's remark (Darwin 1859, p. 373) of "direct evidence of glacial action in the south-eastern corner of Australia,"[35] observed that it came from one of his own reports to government from Eden, N.S.W. Clarke accordingly enclosed "a minute slice of the surface" of the granite evidencing glacial "polish" and "a stereoscopic view of the locality" which led Darwin to include information on Clarke's discovery of glacial action in New South Wales in the third edition of *The Origin* in 1869. Darwin's swift response to Clarke's letter is dated 25 October 1861:[36] "I thank you cordially," he wrote, "for your very kind expressions towards me & for your letter which has deeply interested me. Your name has of course been familiar to me for years." "There are great difficulties," he continued, "in believing in a mundane cooler period; but it would throw a flood of light on Geographical distribution. … No subject interests me more than the Glacial period." He also added his congratulations on Clarke's "new discoveries of Secondary fossils in N. S. Wales," noting, "I have for some time thought that the geology of distant countries would help in the progress of the Science more than anything else; and in this, you have been an earnest worker. Most cordially do I wish you success" (Letter 25 October 1861, Moyal, 2003,1, pp. 560–61). Concluding, he sought Clarke's assistance in a "little" biological experiment on bees. "You have attended to so many branches of Nat. History," he urged, "that I daresay you are a Botanist" and invited Clarke "to cover up any species of the Goodeniaceæ under a net so as to prevent any other bees or insects visiting it, & observe whether it sets seeds as well as an unprotected plant." Throwing his biological net wide, Darwin was securing another assistant in the face of Ferdinand von Mueller's declining to aid him in this.

Clarke and Darwin's relationship was set in their first exchange. Clarke wrote to Darwin four times between August 1861 and September 1862 seeking his help for guidance to a British palæontologist for his Carboniferous fossils, informing on the behaviour of local bees, and subsequently transferring the Goodeniaceæ experiment to the Director of the Botanical Gardens in Sydney to subject it to more "rigid trial" (Moyal, 2003,1,Letters, pp.574–5; 576; 587–8; 599). Darwin rewarded Clarke with a copy of his *The Fertilization of Orchids* (1862) and, notably in 1876, became one of three sponsors for Clarke's election to the Fellowship of the Royal Society of London. Within the context of their collegial links and commitment to his Christian faith, Clarke, as the most strategically placed savant in New South Wales, took the opportunity to give a rare public expression of open-mindedness to *The Origin of Species* in his Inaugural Address as Vice-President of the newly formed Royal Society of New South Wales in 1866. Warning the members against nervousness on the fate of the Scriptures and urging that we "should wait for further evidence and a wider range of experiment," he declared: "We must strive to discern clearly, understand fully and report faithfully, … adjure hasty theory and unsupported conjectures; where we are in doubt, not to be positive; to give our brother observer the same measure of credit we take to ourselves; not striving for mastery, but leaving time for the formation of the judgment which will inevitably be given, whether

[35] http://darwin-online.org.uk/content/frameset?pageseq=391&itemID=F373&viewtype=side

[36] https://www.darwinproject.ac.uk/letter/DCP-LETT-3298.xml

for or against it, by those who come after us." In this, he noted, Australia's continent, afforded "much to excite man's curiosity and intellect" (Clarke, 1867).

In geological and palæontological matters, however, from his own exposure to the giant marsupial *Diprotodon* found in the Wellington Caves and *Dromornis* in Queensland, on which he corresponded with Richard Owen, Clarke announced in a letter to the *Sydney Morning Herald* on 11 June 1869[37] that he could not subscribe to the doctrine "that recent animals are *the offspring of the older forms*. I believe that species as such were made by the Creator, and that they are not the result of accidental conditions, but however related are independent of their predecessors." In this field of knowledge he aligned himself as a separate creationist.

Most of Clarke's colleagues held to similarly cautious views. While Charles Lyell's[38] uniformitarianism and his later *Geological Evidences of the Antiquity of Man* (1863) had exposed men's minds to both the vast spanning reaches of geological time and man's possible antiquity, the Government Inspector of Coalfields in New South Wales, William Keene,[39] proudly proclaimed his distrust of both theories. "Better evidences … are needful," he wrote tartly to the *Sydney Morning Herald* in 1863,[40] "before geologists can pretend to set aside the prevailing belief in the Jewish chronology" (Keene, 1863). At the same time, one of the most visible of Sydney's men of science, Dr John Smith,[41] foundation Professor of Chemistry and Experimental Physics at the University of Sydney destined to become a prominent public analyst, educator and legislator, while ready to concede that there might have been a race of pre-Adamite men, concluded "that these had been entirely destroyed to give place to the present race of which we now had record" (Smith, 1863).[42]

Charles Moore

On the institutional front, the Government Botanist and Director of the Gardens in Sydney, Charles Moore (1820–1905), trained at Kew and serving as director in Sydney from 1848 to 1896, carefully labelled plants for his herbarium showing the Natural order, scientific name and authority and country of origin; exchanged specimens of plants and seeds, corresponded widely, and served as an established representative of science in the Sydney community. Yet, as a rare recipient of a presentation copy of Darwin's book,[43] he avoided public discussion of the evolutionary principle, issuing 'A Catalogue of Plants in the Government Botanic Gardens, Sydney' 1895 which, without introduction, listed all plants held providing names, family and country of origin "to facilitate exchanges with all those interested in Botany and Horticulture." Moore published *A Census and the Plants of New South*

[37] "Extinct Species," a letter to the *Sydney Morning Herald* from W. B. White, p. 2. https://trove.nla.gov.au/newspaper/article/13187620

[38] Charles Lyell (1797–1875).

[39] William Keene (1798–1872), http://adb.anu.edu.au/biography/keene-william-3931

[40] Letter to the *Sydney Morning Herald*, after a meeting of the Sydney Philosophical Society, 19 November 1863, p. 8. https://trove.nla.gov.au/newspaper/article/13094245

[41] John Smith (1821–1885), http://adb.anu.edu.au/biography/smith-john-4608

[42] Cooper (2018) argues that Smith was trying to reconcile his faith with the scientific data.

[43] Moore's presentation copy of *The Origin* is held by the Daniel Solander Gallery, Botanic Gardens of New South Wales

Wales (1884) and *A Handbook of the Flora of New South Wales* (1893) (*ADB*,1974, 5). As Finney notes, men such as Moore at the Australian Museum were "users of classification schemes rather than devisers of them."

Ferdinand von Mueller

The most eminent and resolute anti-Darwinian in the Colonies, however, was the doyen of Victoria's scientific community, the Government Botanist and subsequent Director of the Royal Botanic Gardens Victoria, Dr Ferdinand von Mueller (1825–1896). Born in Schleswig-Holstein, a Ph.D. scholar from the University of Kiel who emigrated to Adelaide in 1847 and began his botanical investigations in South Australia, was appointed Government Botanist of Victoria in Melbourne in 1853, and, extended his knowledge of Australian flora by joining A. C. Gregory's North Australian Exploring Expedition as expedition botanist in 1855. He became a prominent and authoritative figure in the colony, the most honoured of Australia's nineteenth century scientists, the "von" being bestowed on him by the King of Würtemberg in 1869 and the hereditary title of Baron from the same source two years later. An intense collector and researcher, Mueller developed a network of willing workers who contributed specimens to his herbarium and built a large international and local set of correspondents. Raised as a strict Lutheran and adhering to the faith all his days, he might privately acknowledge that Darwin's early writings had influenced him as a young man and given plan and direction to his life (Kynaston, p. 175). But with the arrival of *The Origin* he fiercely resisted the theory of evolution and clung tenaciously to his belief that species were fixed and immutable. As he wrote to Richard Owen in August 1861, "during less than 22 years of observations of the forms of vegetable life in free nature, I had during travels extending in Europe and Australia over nearly 30,000 miles, never cause to entertain any doubt, that we are surrounded by species clearly defined by nature, all perfect in their organization, all destined to fulfil by unalterable laws those designs for which the power of our creating god called them into existence" (24 August 1861, *Regardfully Yours*, 2, p. 113).

Mueller, rather strangely in light of his wide excursions in Australia, chose to set down his own views on species in a small book on an isolated group of islands east of New Zealand, the Chatham Islands. There he wrote of "the wonderful adaptability of species to sometimes singularly different circumstances" but added that "analytical dissections in his museum and the field of hundreds of thousands of plants" had "convinced him of the great truth, that the Supreme power to which the universe owes its existence, called purposefully forth those wonderful and specifically ever unalterable structures of symmetry and perfection… from the morn of creation to the end of this epoch" (Mueller 1864, p. 8).

As the Australian authority, Mueller hoped to be invited to prepare the proposed official flora of Australia; but the prize went to the eminent George Bentham (1800–1884) at Kew upon whom he at once pressed his firm belief: "I cannot help to differ from you in the sentiments, which you so decidedly express in reference to the non-fixity of species," he wrote in 1862. "I think I had in Australia, where physical conditions are more widely different within limited space than perhaps in most parts of the globe, an opportunity to study the laws of variation of species more carefully in the field & under the most varied circumstances, than

any other, or at least than most Botanists. And the result of investigations has *invariably been*, *wherever I had a fair opportunity of completing observation that species are permanent & unalterable*." "I think you will forgive me," he added, "if I boldly uphold the great principle, on which the formation of species rests… but I consider it a duty which I owe to science, that I should not withhold my views on this important question which agitates now the naturalists of the day" (24 September 1862, *Regardfully Yours*, 2, pp. 167–168). As Bentham was in the van of British botanists in accepting the impressive weight of Darwin's evidence, Mueller's entrenched adherence to the fixity of species proved a complication in their collaboration on *Flora Australiensis*, 1863–1878. For his part replying by letter on 26 October 1862, Bentham advised Mueller, "Whatever may be one's opinion of the speculative part of his work, it is very certain that the numerous facts he has observed must cause naturalists to consider their previous opinions" (Willis, p.74, Mozley, 1967, pp. 422). Mueller, however, determined to keep ahead of Bentham by publishing his description of new taxa in fascicles of his *Fragmenta phytographiæ australiæ*. In the event Bentham and Mueller were able to collaborate, Bentham noting in the text of his seven volumes of the *Flora* where Mueller disagreed (*Regardfully Yours, 2,* pp. 24–26).

Frederick McCoy

At the University of Melbourne, the occupants of the foundation chairs of science were equally uncompromising in their attitudes to evolutionary ideas. There the inaugural Professor of Natural Science, Frederick McCoy (1817–1899), a dedicated Anglican, while holding no degree, was a palæontologist with several works of systematic reference behind him and a close colleague of the anti-Darwinian Professor of Geology, Adam Sedgwick, at Cambridge. A forceful and dogmatic figure, McCoy rapidly gained eminence in Melbourne, convinced from his palæontological and zoological findings in Victoria that species were immutable and that Australian mammals were the subjects of separate creation. He went so far as to oblige his undergraduate students to take a strong stand against Darwinian theory, declined to have a copy of *The Origin* in the Museum's library, and prevented student exploration of other evolutionary scholarship (Finney, p. 99, Frame, p. 102). In two published lectures, *The Order and Plan of Creation,* delivered in 1869 and 1870 shortly after the publication of T. H. Huxley's 1869 essay *On The Physical Basis of Life*, McCoy severely castigated Huxley proclaiming, "There was no authority, either in Scripture or science, for belief in the gradual transmutation from one species to another, or passage from a low creation into a higher one" (Frame, p.102, Finney, p. 107). Rather, he too saw the living world as "a part of one great, complete, universal and perfect plan whose separate parts were brought into existence at His own different times, following laws some part of which we may dimly perceive."

Eager for visual proof to encourage rejection of the idea about a relationship between man and ape, McCoy imported a stuffed gorilla for exhibition in Melbourne's National Museum of Natural History and Geology in 1865 informing the public, "It is well for the inhabitants of a country so remote … from the chance of seeing actual specimens of the greatest and most manlike of the anthropomorphic apes, to see how infinitely remote the creature is from humanity, and how monstrously the writers

have exaggerated the points of resemblance" (Finney, p. 107). McCoy also became a notable exploiter of the taxidermist's art, his own zoological collection, the largest in the country, displaying animals, he claimed, "from six centres of creation" expressly aimed to counter Darwin's evolutionary argument (Moyal, 1986, p. 94, 100-101).

George Halford and J. E. Tenison-Woods

Melbourne's Foundation Professor of Anatomy, Physiology and Pathology, George Britton Halford (1824–1910), a nominee of Richard Owen's for the colonial post, also weighed in with a public lecture series briskly titled, *Not like Man, Bimanous and Biped, nor yet Quadrumanous*, to rebut Huxley's man and monkey theme, a position stoutly supported by the *Australian Medical Journal*.[44] There were other serious-minded contributors. The respected Jesuit, Rev. Julian Edmund Tenison-Woods (1832–1889), blending his pastoral and rural duties with his palæontological studies in several colonies, presented his record of geological fieldwork to an audience of the Royal Society of Tasmania to undermine the Darwinian perspective. "My researches in Australian tertiary geology," he recorded in 1876, "have now extended over twenty years, and during that time, as I have helped somewhat to create its literature, I may say, probably without arrogance, that I have as good an opportunity of becoming acquainted with its palæontology as any one…in all my examinations of our fossil and living fauna, I have carefully sought for any reasonable evidence in favour of evolution or clue to its mode of operation, and have found none — none whatever. I must add that Australian geology, whether reluctantly or not, must admit that she can urge nothing in favour of that theory being true, the true explanation as we find it" (Tenison-Woods, 1876, p.78).

At root, however, McCoy's and Halford's respective appointments to the new University of Melbourne, and John Smith's earlier posting in Sydney, were illustrative of the official commitment of the two senior colonies to the British structure of science and to the entrenchment of a vision of the scientific enterprise as "a creationist vision," (Butcher, 1988, pp. 140–141). A sense of the British scientific structures was further underpinned by the Philosophical and Royal Societies rising in the separate colonies and endorsed by the colonial governors, who lent their patronage and influence as the societies' Presidents. Vice-regal figures enjoyed high prestige among the scientific community, and alert to their Imperial status, aired their anti-Darwinian view in public and private. Victoria's Governor, Sir Henry Barkly (1815–1898), an active President of the Victorian Royal Society and himself a student of geology and natural history, early urged members to refute by every scholarly means a theory "so pernicious to the very existence of Christianity" (Barkly, 1865, pp. xxvi). In New South Wales, the eminent Governor-General of the Colonies, Sir William Denison (1804–1871), a supporter of science in general, wrote privately to his sister that, although he had not actually read *The Origin,* he took his lead from the curator of the Australian Museum, Simon Pittard (1821–1861) , who considered that "natural selection was contrary to natural processes" (Frame, p. 99). In South Australia, the highly active Richard Hanson (1805–1876), serving successively as lawyer, premier and Chief Justice of South Australia, became governor

[44] *Australian Medical Journal* 1863–68; Finney, p. 102

from 1872–3. As an articulate Christian and a jurist he had given a series of closely argued papers before the Adelaide Philosophical Society in the early 1860s in which he espoused the view that the Bible "was God's great instrument for the education of the world…if read with the spirit of enquiry instead of infallible authority." Hanson, a positivist in his thinking, came to uphold the view that "theology must respond to Darwinian insights or risk becoming irrelevant" (Frame, p.95, *ADB*, 1972, 4).

While attitudes to Darwinian theories were largely confined to leading figures in science, the reaction of two of Darwin's close associates from *Beagle* days reflected a view popularly held by many colonists. Phillip Gidley King, a midshipman on the *Beagle* now settled in New South Wales who retained a long friendship with Darwin, wrote to his old friend, "Your work the Origin of Species has a prominent place in my library & was read with much interest. I think you are thought by many to be right who will hardly allow it. I feel in the small scope of my expression that there is much truth in yr deductions, but the question is where do they lead us to — or what is their limit?" (19 September, 1862, Nicholas, quo p. 200; Finney, p.104),[45] while another one-time shipmate writing from Sydney, the artist Conrad Martens, playfully covered his ground. "Your 'book of the season' as the reviewers have it, I must own I have not yet read [he wrote] altho Mr Clarke offered to lend it me, I am afraid of your eloquence, and I *don't* want to think that I have an origin in common with toads and tadpoles" (*ibid.*).

Gerard Krefft and Robert Fitzgerald

It was not, then, until the 1870s, more than a decade after *The Origin of Species* reached Australia, that direct expressions of support for Darwin's ideas on progressive development were publicly heard in the colonies. At the Australian Museum in Sydney, Gerard Krefft (1830–1881), Simon Pittard's successor as curator, was an active zoologist with a serious interest in fossils. Emigrating to the Victorian goldfields in 1852, the German-born Krefft had been a member of Blandowski's expedition to the Murray River, had worked on its collections in Melbourne's National Museum, and, appointed assistant curator at the Australian Museum in 1860, became its Curator in 1866. With his zoological studies, *The Snakes of Australia* (1869) and *The Mammals of Australia* (1871), and his part in the retrieval of the fossils of the Wellington Caves, Krefft was a sophisticated Australian researcher who gained international reputation. He claimed to have been converted to Darwinism by reading *The Origin*, but his public commitment to the evolutionary principle first appeared in the 1870s, when he communicated his views on Darwin's works and theory through a column in the *Sydney Mail*.[46]

Krefft corresponded with international scientists, became a critic of the dominant Richard Owen, and exchanged letters and data with Charles Darwin. "I have long respected your able and indefatigable labours in the cause of Natural Science," Darwin wrote to him on 17 July 1872. "Your conclusion also agrees with Prof. Flower and others. It is lamentable that Prof. Owen shd. shew so little consideration for the judgment of other

[45] https://www.darwinproject.ac.uk/letter/?docid=letters/DCP-LETT-3727.xml;query=;brand=default

[46] See also his papers presented at the Philosophical Society of New South Wales at https://royalsoc.org.au/council-members-section/91-phi;soc1856-65#1862

naturalists, and shd. adhere in so bigoted a manner to whatever he said"[47] Creative and nonconformist, Krefft was disdainful of the Museum Trustees' concentration on collecting and classifying natural history specimens and acquiring pieces for their personal cabinets but he fell foul of the Trustees on the grounds of his public commitment to evolution. As Butcher records, Krefft "was a theoretically sophisticated naturalist whose contribution to the zoological literature of Australia was substantial and of lasting value." He won an international reputation beyond Australia; his letters to Darwin reveal him as a colleague and fellow scientist rather than a colonial informant. He was brought down by the entrenched, personal interests of the Museum Trustees and was forcibly expelled from office in 1874[48] because, as he told Darwin, of his "rejection of the God of Moses as the Creator;" his livelihood destroyed (Letter to Darwin, 15 May 1872, quo Finney p. 113). Corresponding later with a colleague, Richard Lydekker, Krefft perceptively observed, "here in Australia you must follow the footprints of those ancient gentlemen who still follow Cuvier."[49]

The second conspicuous figure to emerge in favour of Darwin in New South Wales was the colony's deputy-surveyor, the botanist Robert D. Fitzgerald (1830–1892), who raised orchids. Trained as an engineer in Ireland, he emigrated to New South Wales in 1856 and joined the Department of Land where he rose to become deputy surveyor-general in 1873. His initial spur to prepare a multi-part work, *Australian Orchids* (1882), came from Darwin's book on *The Fertilization of Orchids* and, working critically from his personal investigations outside the institutions, Fitzgerald became, as Butcher notes, one of the first Australians "to turn to Darwinism both as an alternative to orthodox religious doctrine and as a potential source of inspiration in interpreting the natural productions of the continent" (quo Frame, p. 94). Fitzgerald sent the separate finely illustrated parts of his work from 1875–82 to Darwin, who absorbed many of the Australian's observations in the second edition of his orchid fertilization work. It proved a fertile two-way interchange. Writing to Fitzgerald in July 1875, Darwin was moved to express astonishment "that such a work could have been prepared in Sydney".[50] While Fitzgerald had some reservations about Darwin's theory that the structure of orchids was "a design for cross-fertilization" and advanced his observations on pollination and the self-fertilization of many Australian orchids, he saw Darwin as "the greatest naturalist of the age" and used his research results both to challenge Darwin's concept of a fertilizing "design" and to give his support to the progressive development of species, "happy," as he put it, to add "a single stone to the very great pile constructed by the boldest speculator of the age." The two men's correspondence again marked a collaborative exchange of equals. With Darwin's permission, Fitzgerald dedicated his completed seven-part *Australian Orchids* to Darwin's memory in 1882 (Mozley, p. 429; Frame, p. 94).

[47] Letter 17 July 1872, quo Finney, p. 111, p. 171 fn 99; Butcher, 1988, pp. 146-7. https://www.darwinproject.ac.uk/letter/?docId=letters/DCP-LETT-8416.xml

[48] The Trustees' forceful treatment of Gerard Krefft prompted the swift resignation of the two naturalist trustees, the Rev. W. B. Clarke and Dr. George Bennett (1804–1893).

[49] Letter to Darwin, 15 May 1872 and Richard Lydekker, 8 December 1880, quo Butcher, 1988, p. 146–147, *ADB*, 1974, 4.

[50] Mitchell Library Ref. No. A2546, quo Butcher 1988, p. 157. Fn.33, p. 152–3

The presence of Gerard Krefft and Robert Fitzgerald marked a changing disposition in the sociology of colonial science that suggested an emerging shift away from the creationists to the tenets of scientific naturalism. But Krefft's allusion to Cuvier had pertinence. For fifty years from the 1830s, the commanding presence of Professor Richard Owen (1804–1892), Britain's leading comparative anatomist and palæontologist and Superintendent of the Natural History Department of the British Museum, had loomed significantly over Australian zoology and palæontology, where his vast output of papers and monographs on extinct and living fauna defined the expanding outlines of knowledge. Macleay, Clarke, McCoy, Tenison-Woods, Mueller, and Krefft were his correspondents or local investigators, despatching specimens and data for his research. Owen published his composite *Researches on the Fossil Remains of the Extinct Mammals of Australia* (1877). Much influenced originally by Cuvier, Owen had begun his career as a separate creationist but saw himself increasingly as "a successive and continuous creationist" who considered that, while each species had been created only once in time and space, its diffusion was the result of its own law of reproduction influenced by external circumstances.. While his theory was short on the evolution of adaptive mechanisms, Owen was an ardent anti-Darwinian who saw a unity of plan in the animal kingdom attributable to a beneficent Sovereign and "the irrefragable evidence of 'Creative foresight' and 'Final Cause'" (Mozley Moyal 1975, p. 47). Both Richard Owen's scientific reconstructions and philosophical ideas had a strong currency in the colonies.

Thus in 1876 as President of the newly formed Linnean Society of New South Wales, the eminent Sir William Macleay[51] could affirm in his Inaugural Address that all evolutionary theories since Lamarck "could be dismissed with the Scottish version of 'Not Proven'" (Macleay, 1877, p. 96), while the renowned independent astronomer at Windsor, John Tebbutt (1834–1916), was wont to repeat his 1878 lecture on "The Testimony which Australia Furnishes to the Attributes of the Creator" (Bhathal, 1993, p. 35).

And there too in 1879 is the Rev. William Woolls, addressing a public audience on "Variation of Species in Relation to the Variations of Language"[52] partly in response to Darwin (1874), and insisting; "Those, who are content to receive the Bible as a revelation from heaven, reject the absurd notion of fortuitous combination and gradual development" (*Lectures on the Vegetable Kingdom,* p. 126). "Is it not sufficient [he asked] for us to know that, for three or four thousand years, species have undergone no visible change? And does not that simple fact tend to show that they were the result of some creative act, not the result of gradual development?" (p. 129).

Yet emergent change was in the air. In the colonial press Charles Darwin's death in 1882 ushered in cautious public praise. "Even if [his theory] were conclusively disproved tomorrow," said *The Age*,[53] "it will still retain an important place in the history of thought,"

[51] William John Macleay (1820–1891) was a cousin of William Sharp Macleay (1792–1865).

[52] Presented at the Horticultural Society of N.S.W. on July 3, 1878. Reprinted in the *Sydney Morning Herald*, July 15, 1878, p. 3. https://trove.nla.gov.au/newspaper/article/13412164

[53] See Trove, at https://trove.nla.gov.au/newspaperarticle202528339/18355504

while Melbourne's *The Argus*[54] agreed that the theory of evolution had brought a revolution to science: "he [Darwin] will be recognised as the originator of the most fruitful idea of the present century and at the same time the most revolutionary." It was quite simply "the most fruitful idea of the present century" (*The Argus*, 22 April 1882, p. 13; Finney, p. 113).

William Caldwell's discovery

Pervasive change would reveal itself in the thrusting new biological sciences. In April 1884, William Hay Caldwell (1859–1941), a young Scottish scientist, trained at Cambridge in embryological studies and reared on the works of Darwin and Huxley, travelled to Australia on a British Balfour Scholarship and arrived at the Burnett River, Queensland, to investigate species reproduction among the monotremes. After several weeks, aided by a large company of Aborigines, he shot a female platypus that had laid one egg and held a second egg at the mouth of the uterus, a hit which confirmed that the platypus was a clear intermediary link between reptiles and mammals. Caldwell's terse cable to the outside world — in this case the British Association for the Advancement of Science meeting in Montreal that year — *monotremes oviparous, ovum meroblastic* (monotremes lay eggs, their large egg yolk is absorbed as food by the developing young) made scientific and telecommunication history and conveyed the knowledge that the platypus was an explicit player in Darwin's ideas on isolation and species diversity.

Caldwell's breakthrough discovery both cancelled out Richard Owen's fifty-year claim of an *ovoviviparous* birth for the platypus, a view stoutly reinforced by his close associate in New South Wales, collector and naturalist, Dr George Bennett (1804–1893), with his consignment of thousands of platypus specimens to Britain, and Owen's long domination of Australia's biological science. As Caldwell later informed his audience of predominantly separate creationists at the Royal Society of New South Wales (Caldwell, 1884), his results were "facts," not theories; they could not be argued. Thus, recognizing as an evolutionist that each living form had descended "from some differently constructed ancestor," Caldwell became the first in the wake of Darwin to attempt to fit the monotremes into the evolutionary frame (Moyal, 2001, pp.151–157).

Darwin had been laid to rest with honour in Westminster Abbey when this critical scientific news broke, but remembering the curious animal in the Cox's River in New South Wales in 1836, he had written about the *Ornithorynchys* in *The Origin,* where he saw the animal as "aberrant genera" and noted that "The more aberrant any form is, the greater must be the number of connecting forms which on my theory have been exterminated and utterly lost"[55] (Darwin 1859, p. 429). Speculating on it later in letters to Hooker and Lyell, Darwin held the platypus as a ripple in his mind and returned to it in 1874 in the *Descent of Man*. There he heralded it as "a key exemplar of natural selection" and "as a diversified link" in the organic chain of mammals rising up to man. These "eminently interesting"[56] Monotremata, he wrote of the two Australian species — the platypus and echidna — "were

[54] See Trove, at https://trove.nla.gov.au/newspaper/article/11538553

[55] http://darwin-online.org.uk/content/frameset?pageseq=447&itemID=F373&viewtype=side

[56] http://darwin-online.org.uk/converted/published/1874_Descent_F944/1874_Descent_F944.html

structural precursors of the marsupial, placentals and on to man." And "if any single link in this chain never existed," he added, man "would not have been exactly what he now is" (Darwin, 1874, pp. 158, 165; Moyal, 2001, p. 114).

New men in the universities.

It was time for the new men in the universities of Australia. Among them at the University of Sydney was Edinburgh-trained J. T. Wilson (1861–1945), appointed in 1887 as a demonstrator in anatomy in the new Medical School, soon to hold a foundation chair, who, introducing the study of physiology and embryology, went on with his two brilliant British assistants, physiologists James P. Hill (1873–1954) and Charles Martin (1866–1955), to apply the theory of natural selection to the study of Australian marsupials and monotremes and to shift the centre of monotreme research to Australia. (Moyal, 2001, Morison, 1997). At the University of Adelaide, the diversely qualified Ralph Tate (1840–1901), geologist, palæontologist, botanist and zoologist was appointed to the first Elder Chair of Natural Science in 1874, bringing rigorous new teaching and research methods to these fields (*ADB*, 1876, 6, Finney, p.113). At Sydney University, Professor William Haswell (1854–1925), a former pupil of T. H. Huxley, appointed demonstrator in comparative anatomy early in the `eighties and rising to fill the foundation Challis Chair of Biology in 1890, characterised the vital transformation that was occurring in scientific education in the colonies.

Addressing the Biology Section of the Australasian Association for the Advancement of Science in 1891, Haswell sketched the upward intellectual thrust. "It is, it need hardly be said, mainly to the influence of Darwin's writings that a very important change has come over biological research. … This change has been, in great measure, in the nature of an illumination, and the illuminating influence has been theory, and more especially the theories of descent and modification by natural selection. And this illuminating influence, which has lent tenfold interest to the work of every investigator of animated nature, has also shown to him many new lines of study, in the following of which he is conscious that, while not leaving his particular corner of the field, he is doing work that is of interest to a comparatively wide circle of thinking men" (Haswell, 1891, pp. 173-4). It was a testament to a fundamental change in the institutional structure of science in Australia.

This testament was early expressed in the appointment at the University of Melbourne in the appointment in 1887 of Walter Baldwin Spencer (1860–1929), an evolutionary biologist trained at Owens College, Manchester, as the foundation Professor of Biology. An active and influential figure, Spencer infused new life into the teaching of natural science in Victoria; removed McCoy's outdated tuition, and established a modern laboratory for the new department of biology, that became a major research centre on Australian biota by the century's end (*ADB*, 1990; Mulvaney & Calaby, 1985).

At the old societies of science, there were also regenerating signs of change. At the Royal Society of New South Wales, Australia's first scientific medal was struck in 1878 to honour the research and scientific legacy in the natural sciences of the Rev. W. B Clarke, who died in 1876. It was awarded in its augural year of 1878 to Richard Owen, to George Bentham in 1879, and to T. H. Huxley in 1880. Charles Darwin was made

an honorary member of the Society in 1879.[57] Throughout the 1880s the recipients of the Medal — Frederick McCoy in 1881, Ferdinand von Mueller in 1883, and Joseph Hooker in 1885 — reflected the landscape and the history of Australian science.

Conclusion

As the century turned, it fell comprehensively to the universities in the Colonies to inculcate a new generation of students in a wide and diversifying experience of Darwin's intellectual heritage. As historian Tom Frame concludes in his large overview of the extending sweep of *Evolution in the Antipodes*: "The status of evolutionary theory as scientific orthodoxy … in Australia, had been achieved within four decades."

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[57] See Kelly (2009).

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Towards a prosperous yet sustainable Australia — What now for the Lucky Country?

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Patron of the Royal Society of New South Wales

Abstract

This is the opening address given by His Excellency General The Honourable David Hurley AC DSC (Ret'd), Governor of New South Wales, to the *Royal Society of New South Wales and Four Academies Forum* on *Towards a prosperous yet sustainable Australia — What now for the Lucky Country?* on Thursday, 29th November 2019.

Let me begin with an Acknowledgement of Country. I acknowledge and pay respect to the Gadigal people of the Eora Nation and to their Elders, past and present, who are the traditional owners of this beautiful part of our country here in Sydney on which we meet today and the custodians of knowledge and learning going back 60,000 years.

Thank you and, ladies and gentlemen, and, a very warm welcome to Government House Sydney this morning. I'm delighted to be here for our fourth Royal Society Forum with the four learned Academies and to continue, I hope, in the quality of rich discussion we've had over the last three years.

For those who have not been to a Royal Society Forum in the past, you may be wondering: Why are we here? When I became Governor four years ago, and I was considering the question: how does the Governor value-add to the community, to the people of New South Wales, I sat down and I developed my strategic plan, my thinking about the next five years, and the areas that seemed to me to be in need of some attention. The number of the areas I looked at included: rural and regional sustainability and the development of rural and regional New South Wales; our youth development endeavours; many of the social issues that confront us at the present time; the mental health concerns we have in our community; and what's happening in our Indigenous communities. I sort of knitted those together, but I saw there were many cross connections. I think one of my strengths lies in identifying patterns and joining dots. During my time as Governor and as I've travelled around New South Wales communities, I could see many great endeavours, but many disconnections.

Having served in the military for 42 years, despite what you read about the Army, Navy and Airforce not liking each other, that is incorrect. We do like each other in a way but I also know that you produce your most effective combat capability out of a joint force. It must integrate; it must collaborate; it must coordinate. And I kept seeing the same need writ large across so many areas of activity in our community. And I thought: am I able to take a this a step further? And can I help develop useful ideas to assist in making progress on these issues? I looked at a number of my roles and patronages,

including Patron of the Royal Society and I'm the University Visitor across the state. Of course, not now in the old sense — the concept of Visitor has moved on — but I take a real interest in what's happening in our tertiary institutions across the State. And I thought: is there some way of bringing the Royal Society and the universities together to look at some of these issues in a non-political space, in a place where we can talk about big issues facing Australia without having to worry about being on the front page tomorrow? Can we talk about collaboration, integration, coordination? Can we bring these great minds in our country together to talk about a particular issue from different perspectives?

And, as luck would have it, as Patron of the Royal Society I met with Don Hector for the first time. He was re-building, working on building the Royal Society, I was looking for a vehicle, and at that meeting we decided on this forum. We agreed that the Royal Society would determine the topic, I would provide the location and the next step was to ask the Academies to contribute, which thankfully they did. And for those representing the Academies today, thank you for doing that and thank you for keeping to your commitment and allowing us this opportunity to speak, as I say, in a way in which we can bring together different perspectives on the same problem. And, relevant to today's topic, perhaps come up with an understandable definition of "sustainability" that we could all walk away with and share. We were just talking about that before we came in. If you throw that word out there, you will get many different responses as to what it means to people. And so that will be an interesting discussion as we run through that our program today.

Where are we going in the future? We'll hear many responses to that question today but I was talking to Catherine Livingstone in her Chancellor of UTS role yesterday afternoon and she pointed out that in 2030, the HECS bill, the tertiary education debt, in our country will be $230 billion which, at that time, it will have a material impact on the national economy, and our budget, to the degree that it could threaten our triple A credit status. We might be educating a large number of people but we haven't paid the bill yet, and I see that theme running through some of the presentations today.

We see that 40% of students, in a recent survey at our universities, do not support democracy as a form of government that we should continue with into the future and perhaps, therefore, if we draw a link, nor do they support the economic principles, philosophies, that underlie democracies. So where is the next generation thinking we should be heading?. Today, I hope, we will receive some food for thought about different options, alternatives and, themes, lines we should work further on, and about how to present those ideas to our decision-makers in a way that engages them and enables them to make decisions rather than pushes them into corners, which is often the way things play out today.

While we're looking at the topics today, and as you run through them — as would be the way when you're looking at how to we solve a problem, you look at problems and ask questions about possibilities, this is a particular issue, how do we tackle it? — please remember in the back of your mind that, at least from my observation of the last four years, our society is very rich: rich in a non-material sense. There is enormous commitment to community, there is enor-

mous commitment to each other, and there is — Hugh might say a few things about this today — this enormous richness in our communities. Travel through the drought-stricken communities of New South Wales at the present time. They're a bit down. But they are enormously resilient. They look out for each other; they create opportunities; they re-invent their communities. Go through rural New South Wales … everything from the Elvis Presley Festival to the Deni Ute Muster, they're still running events to bring communities together.

This is not a "wringing of the hands" exercise about where we are in Australia today; the Forum is about how do we use that enormous love for country, energy and desire to help each other, and channel it into a positive force for the future of our country.

I think that's there's a tremendous opportunity out there, let's use it. So no more from me; let's hear it from the people who know what they're talking about on the subject. And I'll declare the fourth Royal Society of New South Wales and Four Academies Forum open: let's look at this question of how we move towards a prosperous yet sustainable Australia — what now for our "Lucky Country"? — and really look forward to the day.

One note of apology, which I was taught I should never do in an opening speech, I will leave at some time today to go and visit one of the SES headquarters following yesterday's downpour and the death of one of their members but I'll be back my late afternoon so if I disappear for a while it's simply to do that duty, not because I've seen who's up next. But thank you all. It is my pleasure to now declare the fourth Royal Society of New South Wales and Four Academies Forum open.

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Sustainability — setting the scene

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I love a sunburnt country, a land of sweeping plains,
of ragged mountain ranges, of droughts and flooding rains.
I love her far horizons, I love her jewel-sea,
Her beauty and her terror — The wide brown land for me![1]

We should think about this today. We live in a very beautiful country. I've just spent two years away and I often looked at this poem and thought of home for me, Australia, very different from England. I also looked at it and thought how lucky we are in this country, and we are indeed very lucky. I want to echo many of the things that the Governor has just mentioned. We are hugely impressive in terms of where the economy has gone in the last 24, 25 years. Certainly the entire time I have been in Australia, it has been on a growth path unlike any other economy in the world. I think it's more than just the growth — which is averaging 2.9% p.a. in the last couple of years when you compare it to Europe or, indeed, many other places in the globe — it's also incredibly resilient. It's not just mining or agriculture or any one field. Twelve of the main 19 major sectors expanded by more than 3% last year. This is really an amazing feat that's going on in Australia.

Having spent two years away living in the United Kingdom, spending a lot of time in the United States and in Europe doing various things, I see that we don't know how lucky we are. I look at the social and political troubles in Europe and in the US, and really across the globe — not just the sort of issues around population and emigration — and I think the threats that are out there are growing threats. And we're very much hidden from that sort of thing.

The ways in which this country fends for itself, works together, and does a lot of things that really make us a very, very resilient society. It's interesting coming back again and seeing how well the society supports itself relative to what's going on elsewhere in the world. So I think we've got to take one step back and say: we're doing well, but we also need to understand what the future holds, what the problems are, what we need to address, and we need to understand Australia's role in a global world in which we are increasingly playing a much, much larger part. That's something that's come home to me. When I was first in Australia, back in 1995, Australia's role was we were in Asia and we were the supporter of everyone, but now, actually, we're considered a major player in a lot of areas and I think there's a lot that we have to think about in terms of where this country is going, not just in a prosperity sense but in thought leadership around areas like sustainability.

I've got a whole list of things which — when I was trying to write what I should say — I thought I should try and get this community to think about today. I want

[1] Dorothea Mackellar (1885–1968), *My Country*, 1904.

to really try and set the scene a little bit. I think the first thing for me is the environment and it's one of these things that sort of creeps up on you, I guess. Twenty years ago and earlier, I'm not sure I thought about environment in a particular way. But now we begin to see what I think are genuine climate-change issues affecting the environment in which we live. About five years ago I bought a property out in the country and you get a much closer view of all of these different areas: how climate change is affecting the levels of dams, the types of livestock, and these sorts of things. I also look at the work in the government. I was at DPI, the Department of Primary Industries, a couple of weeks ago, and there they're working on how to design crops that will grow anywhere any time in any condition, the sorts of things that we really need to view in Australia.

There are associated issues. Tomorrow we have a workshop on the circular economy: what do we do with all this waste and recycling? Do we even have any plans as to how this is going to become sustainable in the future in any kind of way? I also worry particularly now, having property out in the country and lots of other things, about what's happening with our wildlife. Again, do we really have a plan for how that's going to work? I think what's interesting in my role in the New South Wales Government is that a very, very large part of what we do now is providing advice to Government on all of these issues. When I look at the projects — and we have about a dozen different projects we're currently doing for different departments across Government — they are all to do with pollution, what's happening with plastics, what's happening with wildlife, all of these sorts of things, with watering associated with mining and all these issues and really trying to manage these sorts of things in a sustainable way. I have to say, one of the challenges that we face in general is often we take a step back from doing anything positive because generally we actually don't have the data, we don't understand what's going on, we don't have the models, we are not in a position to really make positive commitments to alternative *X* because we just don't have the information.

And so, typically, we kind of move backwards and backward and backwards, and that's not a bad thing if you're in an uncertain world, to not make those sorts of commitments: should I mine here, should I bottle water over here, should I do this? But what it says to me is that we need a bit more of a sustained program to understand the environment in which we live, by getting data, by building models and using those models to make evidence-based policy decisions in government. I think there needs to be a sustained effort in that area.

A second thing that does worry me, and I guess I see it also from the European perspective, is the issue of a booming population. You know, I'm not going to get into the debate of how much is enough in Australia. The reality is that almost all the world, excluding Africa, has already passed peak birth. We are already not on a replacement trajectory. So the idea that we should start aiming to restrict population growth is not there. The reason population is still growing is the fact that we're all living longer. That's a big issue.

There is still an immigration thing and it's not just Australia. Europe is grappling with this and you look at it and it is truly scary actually, some of the things that are going round, and it's causing political change, it's causing real challenges and, of course,

I should mention America in this context as well. Emigration is a major issue and it's not a sustainability issue, it's a political issue around these sorts of things. So, again, this is a challenge in small part which Australia really is going to have to deal with and it's a *now* issue, rather than a 20-or-30-years-from-now issue.

Moving to more prosperity-related things, I think the other thing that's quite noticeable, coming back from Europe and seeing the U.S. is, to be honest, how uncompetitive Australia is. We are an expensive place for doing business. There are high housing costs. We make things difficult. We are not very good at getting involved in the international supply chain and I'm particularly grappling with defence at the moment. We are about to expend a lot of money on defence. Truthfully, we don't really have the industries to actually take advantage of that. We don't have a way of sustainably building business in these areas. We've got to think carefully about what we want to do in the future in terms of business sustainability, in terms of being competitive on the world economy and there's a whole range of issues there. It's about teaching and training, it's about the skill sets we have, it's about the way that we do business, it's about the way we need to develop technology, it's the understanding what our role is in the bigger ecosystem of what's going on in the planet and I think we have so many issues to deal with in that.

I'm going to bring out just one which I'm sure is going to be controversial. We — the Chief Scientists from different states and the Federal one — have lots of conversations about things like STEM.[2] And I rather controversially brought out the article that was in the *AFR* about two or three weeks ago that said only 32% of science graduates in full-time jobs say that their skills are actually being used in their employment.[3] So there we are. We're graduating all these scientists and we go round and we say, "More, more STEM, guys. We want more and more," and yet, actually, we're not providing jobs for the scientists that we graduate. Engineering is better, but even that's not great.

The problem in my view is that we're not building the industries that can actually make good use of science and mathematics skills in a way that genuinely will attract people, that will start growing things, that will really start building something new. I will tell you, it's a bit of a controversial thing to say because all my fellow Chief Scientists are busily out there selling STEM to schools, and my view is, at the moment, the problem is not that, it's the fact that we don't have industries which are really able to drive that sort of thing.

So, again, as Chief Scientist, one of the big things I've started — and I'll recognise at this point my predecessor has left me something that, frankly, doesn't need to be changed at all because she did such a wonderful job of getting engagement with government and everything else — is what I'm talking about as the prosperity agenda and this is something that, again, I saw overseas. It's where Chief Scientists and the science community and academia and everyone are concerned not just about the science of the problem but also how that science gets translated into outcomes, whether that's through a business outcome, whether that's through

[2] Science, Technology, Engineering and Mathematics.

[3] See also "Bringing relevance to STEM education," *ATSE Focus*, 147, December 2007, at https://www.applied.org.au/wp-content/uploads/2019/02/Focus-issue-147.pdf and Michael Anft, The STEM-Crisis Myth, *The Chronicle of Higher Education*, Nov. 15, 2013.

a societal outcome, whether that's through any other form of engagement. I have to say, we are not good at that in Australia. We think our job is done when we've written the paper and we've graduated the student, but our job has only just started. We really need to be creating prosperity outcome, creating the future for this country in terms of the types of jobs, the types of roles, the types of thinking that we should do.

I gave a talk recently for the Engineers Australia Awards[4] and I said, "We need to think of ourselves as we used to think of ourselves in the 19th century in some senses. We need to be makers and thinkers and doers." And I think a little less talking and more doing is perhaps somewhere where I'd like to go on the agenda. So certainly I'm putting a lot more support and a lot more funding into those kind of areas. How do we translate things into outcomes?

Where are we going in this state? I would say I look outside here, it is beautiful. We have a wonderful country. I will reflect on the poem that I told you earlier. We should all be very proud to be here. What I think we do need to be concerned about is thinking in the 10, 20, 30 year time frame, sustainability. Energy is another area that I hesitate to get into. Energy for our Federal government is like Brexit for the UK government, it's the kind of thing that just destroys parties. We are beginning to realise it is a complex issue, but it's a solvable problem and I think that we need to get on with that.

I urge people in this room to think about those sorts of problems. I think that we have the wherewithal to solve them. We have the community to solve them. I think also, from my position, one thing that's been very positive and something that Mary has left as a great legacy is the fact that this government — and not just this government but the secretaries, the ministers, this process — now trust science in a way that I don't think they did probably a decade ago because of the sorts of things that Mary — and, indeed, my office before I arrived — managed to deliver and managed to achieve.

I think within this state we have an opportunity to influence the outcomes of what New South Wales might actually do. So I'll be listening today to try to get some of those ideas and try to draw them in and try to influence government, at least at a state level, to really make those changes. I'll be very interested to hear what everyone has to say and thank you for inviting me to speak today.

[4] See https://www.engineersaustralia.org.au/News/celebrating-success-harricks-oration-and-bradfield-awards

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Why social cohesion is our greatest challenge

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In this Forum, we will be tackling some big issues — ecological, technological, economic, cultural — within the context of this highly ambiguous word "sustainability". My perspective is societal: however else we approach the idea of sustainability, let's not forget that society itself — the way we actually live, the way we interact, the kind of institutions we establish to preserve our values and to do cooperatively and collaboratively the things we can't do individually — must also be sustainable.

In many respects, we're doing well. Perhaps chief among the things we can be proud of is the fact that we have set an example to the world of how to create a harmonious society out of extraordinary ethnic and cultural diversity. We've brought people here from 200 different birth places around the world and made it work so well that if there are occasional outbreaks of racism or ethnic tension — as there inevitably are — they are reported as news, because they are not characteristic of us.

Multiculturalism is in our DNA. When the first fleet arrived here in 1788, about 60 nationalities were represented on board those 11 ships, and they arrived on a continent where between 300 and 400 Indigenous nations were already co-existing.

But I believe our social harmony — our social cohesion — is under threat, and any threat to social cohesion represents a threat to the sustainability of our very way of life. The threat I am referring to can best be described in terms of two key facts about contemporary Australia, both of them deeply uncomfortable for us to confront, but necessary for us to confront in any honest discussion of social sustainability.

The first of those key facts is that we are experiencing a mental health crisis. The Beyond Blue organisation has told us that last year alone, two million Australians were suffering from an anxiety disorder. Another two million were suffering from depression and another one million from other mental illnesses — so at any given moment, about five million of us are dealing with mental illness.

The second key fact is that we are becoming more socially fragmented. In spite of all the wonderful things that many local neighbourhoods and communities are doing to preserve social cohesion, the factors impelling us towards fragmentation are now very apparent — and none of them, by the way, has anything to do with immigration or, indeed, cultural diversity.

Let me remind you of just six of the many social changes that are putting pressure on the stability and cohesiveness of our local communities and heightening the risk of social fragmentation.

Our shrinking households

In the last 100 years, our population has increased fivefold and the number of dwellings has increased tenfold. So we've been creating households at twice the rate we've been growing the population, and have now reached the point where the average Australian household is 2.5 people — heading, the Australian Bureau of Statistics (ABS) pre-

dicts, for 2.2. The fastest growing household type in Australia (as in the US) is the single-person household. Already accounting for one household in four, the ABS is projecting that will reach one household in three. A society in which every third or fourth household contains just one person is a very different place from the one we all grew up in. Not everyone who lives alone feels socially isolated, of course; many solo householders relish their sense of freedom and independence. But *The Australian Loneliness Report,* recently published by the Australian Psychological Society and Swinburne University of Technology, tells us that one in four Australians report suffering feelings of loneliness for more than half of every week, and the trend towards ever-smaller households clearly increases the *risk* of isolation.

Our rate of relationship breakdown

Approximately 35-40 percent of contemporary marriages and other relationships are expected to end in separation or divorce, with obvious emotional and social consequences for the couples who are splitting, their families, their friendship circles and neighbours. It's also disruptive for any children caught up in the process — and many are. One million dependent children now live with only one of their natural parents and half of these are involved in a mass migration, once a week or once a fortnight, from the home of the custodial parent to the home of the non-custodial parent. Particularly in the early stages of these arrangements, this can be hugely disruptive and fragmenting not just for the families that have found themselves in this situation but for the micro-communities they're moving in and out of.

Our falling birth-rate

The post-war baby boom sent our birth-rate to 3.6 babies per woman. Our present birth-rate, at 1.7 babies per woman, is way below replacement rate. Relative to total population, we are now producing the smallest generation of children we have ever produced. Why mention this in the context of a discussion of social fragmentation? As any parent knows, when a family moves into a new neighbourhood, it's usually the kids who get to know each other first — on the school bus, in the playground, on the sports field, wherever it might be — and social networks gradually evolve from those connections. Today, that social lubricant provided by kids is in shorter supply than ever. We compensate, of course. It's amusing to compare the graph of Australia's falling birth rate with the graph of rising pet ownership. It's pretty obvious — even from the names they are being given — that many of those pets are child substitutes, particularly the dogs. (I mean no respect to the President of your Society when I mention that I recently met a dog called Ian.) Maybe taking your dog to the dog walking park is a bit like taking your kids to the playground, but I personally think there's a huge difference!

Our increasing busyness

When we greeted each other, we used to say, "G'day" or "How are you going?" Now our standard greeting has become, "How are you going — *busy?",* reflecting a revved-up way of life that leaves us less time and energy for the nurturing of personal relationships, especially with neighbours. Our busyness often serves as a barrier between us and that, too, erodes social cohesion.

Our increasing mobility

On average, we move house once every six years and, thanks to almost universal car ownership, most of us live in drive-in/drive-out suburbs and towns where footpath traffic has declined and there are fewer opportunities for the incidental social contacts that build a sense of community trust. You wave at your neighbour's car. You assume that your neighbour is driving but that's not quite the same as stopping and saying hello on the footpath.

Our increasing reliance on information technology at the expense of personal interaction

The IT revolution is brilliant, seductive, efficient, convenient … and paradoxical: it connects us like never before while making it easier than ever to stay apart. (No wonder that, among young people, the heaviest users of social media also report the highest levels of loneliness and anxiety.)

None of this means that we are inevitably going to become a more socially fragmented society or that social cohesion is inevitably going to be lost. But the threat is real and the level of social fragmentation is already disturbing.

The two key facts I mentioned at the beginning of this paper — our mental health crisis and the increasing threats to social cohesion — aren't really two facts at all. They are not independent of each other; they are merely two sides of the same coin. In any society, in any human setting, if you increase the level of social fragmentation you will increase the incidence of social isolation and, over time, raise the level of anxiety and associated forms of mental illness.

Of course, there are many triggers of anxiety in individual cases — relationship breakdown, job insecurity, rent stress, loss of faith, insufficient contact with the natural world — and some people are simply genetically predisposed to anxiety. But when you're looking at this at a societal level — when you're faced with an epidemic of anxiety — we have to go beneath those individual causes and ask what's happening in society itself. And that's where it seems to me social fragmentation is emerging as the villain.

Many negative health consequences flow from social isolation. In October 2018, the *American Journal of Epidemiology* published a paper reporting that "social isolation directly affects health by causing changes in the body such as inflammation, cognitive decline, hypertension and poor immune functioning" and that's on top of the mental health issues we've already mentioned. Socially isolated people are also more likely to have sleep disturbances, to smoke, to make less use of health-care services, and are more likely to be exposed to the health risks arising from over-reliance on information technology.

It's not surprising, therefore, to learn that social isolation is now looming as a greater threat than obesity to public health. We are, after all, members of a social species. We humans need each other; we need a sense of belonging to communities that nurture us, sustain us, protect us and even give us a sense of personal identity. (A lot of nonsense is talked about this question of personal identity as though it's something that people could discover by staring in the mirror or gazing at their navel. You don't discover personal identity by introspection; you discover personal identity by looking into the faces of the people who love you, the people you work with, the people who are your neighbours, the people who need you, the people who'll put up with you. For

an individual, as for a nation, identity needs a context.)

We're herd animals and when a herd animal is cut off from the herd, negative health consequences are bound to follow. In our criminal justice system, solitary confinement is the worst punishment we can inflict on a prisoner because, for a member of a social species, solitary confinement *is* the worst punishment most of us could imagine. Living alone — or any experience of social isolation — is by no means the same thing as "solitary confinement", but when people start to feel as if they don't belong anywhere, as if they are socially excluded, overlooked, powerless, or simply not being acknowledged and listened to, that is a dangerously unhealthy state for them, and an anxiety disorder can be the first sign of that danger.

There is a circularity here for people whose anxiety is induced, or increased, by social isolation: anxiety itself tends to make us more self-absorbed, less sensitive to others, tougher in our social attitudes, more obsessed about the concept of control, more vulnerable to fear (including fear-based propaganda, political and otherwise) … all of which is likely to *increase* the sense of social isolation.

We are not mere bystanders to these trends and their consequences, and I urge you not to be "mere scientists" in your response! This is *our* society I am describing. These are *our* communities. These are *our* local neighbourhoods. The places where *we* live are the places where social cohesion is under threat; the places where a growing number of people are experiencing loneliness; the places where social isolation is becoming a public health issue.

We ourselves are participants in the social changes that have increased the risk of social fragmentation. We ourselves have driven the divorce rate up. We ourselves have driven the birth-rate down. We have shrunk our households; we have allowed ourselves to become addicted to our information technology devices; we have embraced busyness as a way of life. The health consequences that flow from all these disruptions are therefore our collective responsibility. To be dispassionate and analytical about it is important in understanding the social science, but we must never forget that we are also humans ourselves, we are citizens, we are neighbours.

The tragedy for us, as a society, is that we are not always living as if we understand that our own health, especially our mental health, depends on the health of the communities we belong to, though it does, and the health of those communities depends on our willingness — person by person, street by street, neighbourhood by neighbourhood — to engage with those communities.

There's no simple answer to a complex, evolving problem like the threat to social cohesion. But if we value social cohesion — and we should, since social cohesion builds social capital, and social capital builds strong societies — then the key word for us is the word "compassion." By that I don't mean some bleeding-heart, emotionally-charged condition: on the contrary, I regard compassion as a tough mental discipline, and the only rational response to an understanding of what it really means to be human. Once we acknowledge that, being members of this species, we depend for our survival on the maintenance of healthy, sustainable communities to support us, then the only way to ensure the sustainability of those communities is to treat each other with kindness and respect. Think of compassion as the high-octane fuel that drives the machinery of social cohesion.

Compassion is a deeply civilising discipline. Indeed, our willingness to treat each other kindly and respectfully — even when we don't like someone, and especially when we disagree with them — is the test of how civilised we can claim to be.

In essence, I'm talking about a very small-scale response to a very large-scale problem. I'm proposing — as so many people in the past have proposed — that it is our personal, individual ways of living that determine the kind of society we will become. We need to acknowledge that "neighbour" is one of the most important dimensions of our role as citizens. Yes, we have other dimensions: we are members of families, we have friends, we have professional colleagues and we might belong to a range of other communities. But we *also* live in a street or an apartment block, and that implies some responsibility to engage with the life of that neighbourhood.

We all know how to act like neighbours when there's a flood, a fire, a storm or some other catastrophe. What a tragedy it would be if we became the kind of people who needed a catastrophe to galvanise us into acting like neighbours.

In cities like Sydney and Melbourne "we don't know our neighbours" has become a kind of urban cliché, yet no one ever says that with pleasure or pride. It's always said wistfully, as if we know there's something wrong with a situation in which the people who live right next-door, or even in the same street, are strangers to us.

If you accept, as I do, that the health of any society can best be measured by the health of its local neighbourhoods and communities, then the task of preserving social cohesion is an urgent one. In practice, it involves some very simple strategies: get to know your neighbours; be alert to the wellbeing of anyone in your street, or your apartment block, who is at risk of social isolation; don't pass someone in a local street, or stand with them at a bus stop, without acknowledging them with a smile and a greeting; give the gift of listening, generously and attentively, to those who need it.

As I said at the outset, this Forum is addressing some very big issues and some very big challenges, but let's not forget the small, local, personal challenges as well. We may be scientists, economists, IT strategists … but we are also neighbours. We may be called on to show leadership within our professions, or in society-at-large … but true leadership entails setting a good example in every aspect of our lives, including our local neighbourhood.

When we exercise compassion in all our dealings, and when we take our responsibilities as neighbours as seriously as our grander and more professional responsibilities, we will be helping to slow the process of social fragmentation, and to minimise the risk of social isolation. That's how we'll help preserve social cohesion and, in the process, help curb the rising epidemic of anxiety.

In the end, that's what prevents any society, any community, from descending into the chaos of rampant individualism. It's not a matter of luck, but of a disciplined commitment to helping create the kind of society we all want to live in.

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Australia's progress against the UN's Sustainable Development Goals

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I'd like to start by acknowledging that we're on Gadigal country and pay my respects to elders past and present. It's a great honour to be in front of such an illustrious audience and, as we've already heard, the need for the conversation that we're having has never been greater. We wake up to learn that there are over a million people in rental stress in Australia today, a result of unemployment, rental increases and housing stress. And, of course, we live in a world where we can see before us the environmental and climate issues, particularly in northern Australia at the moment with unprecedented fires. We had unprecedented fires on the south coast of NSW in October, never seen before, and we're entering into a summer that will be one of our hottest, the continuing trend of extreme climate.

I was very fortunate that in September 2015, I was sitting in the General Assembly of the United Nations when the Secretary General gavelled the sustainable development goals to the world. They were released at a time when I think the parties, the member states of the UN, had a very strong view that what the world needed was a bold and ambitious plan that was time-bound to 2030. These goals are the Global Goals for 2030 and they were promulgated at a time when the world believed in multilateralism, believed in the global compact to solve some of our biggest issues. I think it's really significant to offer to you the fact that it was Australia's foreign affairs officials who helped drive many of the very important components of those goals. They're often not thanked for their work and Australia is often not acknowledged as driving the goals, but our foreign officials throughout the UN and around the world were doing exceptional work to play Australia's role, particularly in the insertion of disability into every one of the goals.

Disability wouldn't have been mentioned but for our officials who sought to make sure that we think about disability in the same way we think about anything else under the goals, which I'll describe to you in a moment. And it was also our officials who worked with smaller countries such as Timor Leste to deal with the inclusion of Goal 17, which was for peaceful and transparent institutions. Again, we should be very proud of our officials who were helping those smaller nations to ensure their voices were heard.

So the Sustainable Development Goals', or SDGs', development was very serendipitous. We would not be able to secure this kind of agreement in the world we live in today. I don't need to tell you why. It involves certain personalities on the world stage but also a changing view about the role of the UN and the notion of multilateralism, but was unique at the time. We had come out of the Millennium Development Goals, or MDGs, which were about lifting half the world out of poverty and the MDGs did very,

very well. They met their targets about lifting the poorest out of poverty around the world.

The SDGs, however, took a different course. They weren't simply the work of the UN thinking about our poorest nations, they were the most widely debated and consulted goals that the UN has ever completed. They included the broadest consultation with every member state, with civil society and, importantly, with business — which had never been at the table for the MDGs and which we now see playing an extraordinary role through the actions of business and the private sector in helping to lift us to meet many of the goals. These goals actually act as a blueprint for a sustainable future. I encourage you to have a look at them. I will leave you with some information about how you can look at them yourself and understand why they're not simply a group of 17 goals with 169 targets that are baffling and impossible to meet. There are actually some very simple truths within the goals which I hope I leave you with a sense of optimism about.

What I find fascinating, following on from Hugh Durrant-Whyte and Hugh Mackay, is that the most success that the goals have achieved to date has come from the work of local communities, local governments and business, and it's been national governments that have actually lost their way and not made these goals a feature of their leadership. It staggers me today to think that our Prime Minister, the leader of our Opposition and many of our state Premiers don't talk about the global goals as a framework and a blueprint for Australia when most of our local governments do, most of civil society does, most communities are uplifting parts of the goals to make a statement about what a prosperous, inclusive, dynamic, sustainable future could look like by using the goals as their blueprint.

You'll see the work of the goals in communities all around the world but particularly in Australia. I think it speaks to the desire of people wanting to come together as communities and neighbourhoods and using a framework that has a measurement system that tells us we're doing well to actually get on with the work. I keep imploring national leaders to pick up the goals the same way communities have because the language of the goals is about a future that we can all engage with.

Interestingly, recently in Singapore the former New Zealand Prime Minister and former head of the United Nations Development Program, Helen Clark, called for a dramatic stepping up of actions under the goals. She warned that now that we're three years into the program, we're nowhere near on track to meet many of the goals. Climate change targets in particular have been badly missed, the Paris Agreement compromised by those who would seek to walk away and much else that is contained within the goals. In essence, Clark points to the largest disconnect that I could imagine and I think, again, builds on the two Hughs' comments that we're actually living in a time where we're seeing the largest disconnect between the reality of our looming challenges, and they are getting much closer, and how we sustain humanity and our societies with an acceptance of the need to address them. That collision is causing us delay and a potential crisis.

A quick reminder about what these goals are. As I've already said, there are 17 goals under which there are 169 targets. It sounds like a lot but actually they're easy to deploy across a country like Australia. I want to read you something from the 2030 agenda which

sets the tone for how the goals work. Targets are defined as aspirational and global, with each government setting its own national targets guided by the global level of ambition but taking into account national circumstances. Each government should decide how these aspirational and global targets should be taken and incorporated into national planning processes, policies and strategies. That's the prescription for national governments. As I said, many countries have done that, many countries, particularly the Scandinavian countries, but others have built these goals into their national aspiration plans for their nations and are working towards meeting them. Australia is not one of those countries, I'm sad to say.

By signing up to the goals, as all member states or almost all member states did, there's an obligation to follow up and review. There'll be review mechanisms that will actually hold governments, national governments and member states to account as to how they're progressing. So what are we dealing with on a macro scale, picking up on the comments already made about what our sustainability challenges are? At a global level, those challenges are, unlike Australia, the rapid population rise. We'll have global population at nearly 10 billion human beings by mid-century, driving a massive demand for food, for land, for jobs, for energy and water, let alone for a sense of community.

The biggest mass urbanisation program in the globe's history is underway. Most of our population growth and movement will be in cities by the middle of the century. You know already about climate change and environmental degradation. These are already harming human and ecological health and are threatening our future in many respects. There is a need to think about how economic prosperity and decent jobs fit within the context of these challenges. I think that goes to the question as to what the measurement might be of what prosperity is rather than GDP. Is it gross national happiness, is it about a different kind of function of how we exist as societies and how we will live?

And, most importantly, the SDGs acknowledge that we are an interconnected and collaborative world and that we must connect and collaborate. One of the goals is all about that. Goal 17 talks about partnership, and without partnership none of the other goals can actually be reached. These are all interdependent goals that require a commitment and a belief that doing things will lead to a better outcome and they are all measurable. Many people scoff at a process like this just as they scoff at the United Nation or multilateralism, but I think the critics ignore the very real and positive impact that concrete goals can have on governments, on businesses and on communities.

I've spoken to the chairman of our group, the National Sustainable Development Commission, chaired by John Thwaites, a previous deputy premier of Victoria. John brought us back together as a National Sustainability Council after we were sacked by a particular government when we were first created. We've come back together as a group of volunteers to keep doing the work on our own progress. And John makes the point that, for politicians, the only way other than going to the ballot box that governments can be held to account is to have measurable outcomes. And he points to things like water conservation targets that have been met by governments suffering severe drought consequences or lowering of dams, that without a framework for measurement, things

just don't get done. So having a goal with a plan for the future lends itself to the kinds of work that, at the community level, we want to do but also what we should be doing in our businesses and in our governments.

There are some positive stories to tell. The SDGs, as I said, came out of the success of those Millennium Development Goals and they looked just at poverty, health and education in developing countries and they applied from 2000 to 2015. And during that time, poverty was almost eradicated in the way the then goals were measured in those developing nations. Primary school enrolment in sub-Saharan Africa during that time increased from 60 to 80%, disparities in primary school enrolment between boys and girls were eliminated in those countries at the time. Many gains were made under the MDGs but, as we've heard already this morning, the world is going backwards in a number of areas. Inequality inside countries, within most nations, is increasing. It's a global phenomenon. The top 20 households in Australia now own 62% of total wealth and the bottom 20% of Australian households own less than 1%. It's a staggering figure.

We've gone backwards on climate change and the environment. Conflict remains the biggest threat to human development. Sixty million people are currently displaced across our world, the highest level since the Second World War and we see a national response to that not only in our part of the world but around the world when we think about the discussion of borders and how we treat migrants and refugees. These challenges affect all countries, they affect us and I think it's why the SDGs provide us with an antidote to some of those problems that we can act on collectively because all of the SDGs are interlinked and they provide us with a framework of thinking about what a more successful world might look like.

I have mentioned the Sustainable Development Council which was created in 2012. At the time, it was supported by a government which believed there was a need to provide an independent assessment of how we were going against our sustainability criteria. Then we were sacked, as I said, and decided that, with the challenges ahead, that we would come back together as a group of volunteers. I'll give you the reference to our website but we stand as a group of people, concerned citizens, if you like — from economics, from climate change, science, the humanities, from education, from politics — wanting to actually share with the general community how we're going on these issues. And our first report was called *Conversations With the Future*, to try to encourage people to use our data to think about that future. And in September 2018, we put a lot of our data up on our website for you to look at that actually tracked Australia's progress against the 17 goals. And we have a very simple vision, which is for a smarter, more inclusive and sustainable Australia, believing that our culture of pragmatic problem solving, particularly when it comes to our young people who are desperate to get involved in this problem solving, should actually unleash the potential and our capability to address the big challenges not just facing Australia but challenging the region that we live in.

I'll give you a little bit of a backdrop as to where Australia finds itself against some of the goals and I'll leave you to have a look at our website so you can read that for yourself. You've already heard that Australia has seen 27 years of uninterrupted economic growth. It's longer than any other advanced economy.

We've had a 29% growth in real household incomes since 2000, although almost no growth since 2012, which might tell you something about those wealth disparity and inequality numbers I've already quoted. Yet when the Council for Economic Development in Australia, CEDA, this year polled the broadest base of Australians ever asked this question about how they felt about their place relative to 27 years of unbroken economic growth, only 5% of Australians said they have been the beneficiaries of that growth, 5%. And 40% of those surveyed, in our representative sample of the country, said that the only people who have benefited from economic growth have been big business, big companies and executives who work within them, 40% of the country.

They're quite extreme numbers and they speak to Hugh's comment, I think, about how, as a society, we look to these big trends and how we feel and it is the case that a much larger cohort of Australians have done well out of economic growth. We know that to be the case, we know that it has done many good things for Australians. But to have 95% of those surveyed say they don't feel that they've had any of that advancement in the same way that the top end of town has tells us how people are feeling. But in the middle of that, where business has done well, business investment in research and development, and I could add education to that, which should help us drive future growth, has actually declined since 2008 and it's getting worse. Collaboration between industry and research and academia could be a lot stronger. We have the capacity to do that but we're not very good at it in a consistent way. Our research is generally funded by industry, lower than the OECD average and our investment in knowledge-based capital is declining.

Our unemployment is lower today. I'm not going to open up the entire conversation about this but we must all think about underemployment. There has never been a time of greater underemployment than we're suffering today and underemployment in our younger people is at crisis levels. In some parts of the western suburbs of Sydney, Melbourne, Perth and Adelaide, unemployment for younger people is sitting between 20, 30 or 40% and underemployment — that is the number of people who are doing many jobs just to get by but still don't earn enough income to really have a good life — is growing rapidly in this country.

And our underemployment figures don't collect that data in the way that you hear about the unemployment figures. These are people who want to work more hours, be paid a good wage and want to actually have a good quality of life but feel that the volume of part-time work they're doing on low salaries is not getting them ahead and not helping them advance and they're feeling that pain very deeply.

You already know that the cost-of-living pressures are real. We see that in the energy debate and electricity prices have risen, and while our wages are 25% higher than they were in 2000, as I've already said, there's been no real wage growth since 2012. So the cost-of-living pressures felt by households have probably never been greater and now we're seeing greater pressure coming on with the decline in house prices and house values so people are beginning to feel the stress.

What does that say about our society? We've heard a bit from Hugh Mackay about health. In this country, we've had great gains in life expectancy. We have one of the high-

est life expectancies in the world. It used to be 70 years, and now 82.5 years is the average life expectancy, but a high proportion of Australians are obese, as Hugh pointed to, and our tertiary qualification levels, whilst rising, are not being deployed into our society in the way that they best could be put to work to help solve our issues. Investment in early childhood education and care is low at a time when we should be focusing heavily on early education and our childcare systems. It has almost never been lower. And, as I've already indicated, income inequality in Australia remains relatively high. Our wealth inequality is rising, as I've already indicated, and the Productivity Commission is right to let us know that growth has benefited people not across the full range of incomes. So we've got a very big task ahead of us with reducing that income equality.

A topic close to my heart and to half of this room almost is the gender pay gap. We haven't talked about women specifically here but Australia's gender gap remains substantial and stubbornly at a rate that is hard to shift, despite some good activity in some businesses. And the statistics around violence against women are truly shocking. Sixty-three women have been murdered this year, most in their homes by a previous or current intimate partner, 63 dead women.

Hugh mentioned our health impacts. It is true to say today that violence against women is now a greater health risk factor for women than smoking, drinking or obesity because of the prevalence numbers. One in every two women in this country, half of all women, will experience or has experienced sexual harassment at work or on the street and one in four women will experience or has experienced domestic violence from an intimate, current or previous partner. It's a national epidemic. Let alone the fact that our superannuation balance for women is 42% lower than for men and we're now seeing the rise of women living on the streets and being very poor in their old age but caring for others.

I could take you through the numbers on the scale of our carbon emissions challenge but I think there are enough scientists and climate experts in the room to know this to be an enormous problem for Australia. We are way off track to meet the 26% Paris targets. We've become much more water efficient, we're doing a lot of good things in the environment but on the essential issue of our carbon management, we have a huge job ahead of us. So, despite a history of really strong economic growth, our children and grandchildren do now face the prospect of being worse off than we were and than earlier generations were and we are at the point of passing a burden on to them of fixing climate change, inequality, gender equality and the like and we're also saddling them with high debt. You've heard about those numbers already, unaffordable housing and an exclusion from our society. What we're not doing is positioning ourselves properly to thrive in this changing dynamic economy.

On behalf of the council that I represent, we think that we can identify trends to do better. We think the goals actually provide the best way for us to do that and that's why we have labelled our report *Transforming Australia*. To achieve our goals, we're going to have to overcome collectively the short-term focus that currently dominates our political landscape particularly, less so in our business world. Our business world is getting better and many businesses now use the Sustainable Development Goals as the measure of their performance for their shareholders,

much more so than national governments. We think we can actually use some of the vernacular — our Prime Minister likes using the vernacular — so we just think we need a fair go for the next generation and not pass on all these burdens and help make this transition and transform Australia.

Hugh mentioned that we need compassion, kindness and respect. I would also add that what the goals give us to do, properly deployed, properly understood, shared amongst our community and particularly led by large institutions including government, will give us a sense of an old-fashioned principle called stewardship. We don't see enough stewardship. We see lots of people claiming to be leaders, claiming to be taking us in some direction, but I think good old-fashioned stewardship, to be a steward of this country, to be stewards of our communities, stewards of our institutions, stewards on behalf of our younger people, is the way in which I like to interpret the goals, underpinned by compassion and kindness and neighbourly aspiration.

So I'll leave it there for the moment. Look at https://www.sdgtransformingaustralia.com You can find our full report there. It really is just an SDG progress report. It gives you all the data that you need to know about what's going well, what's not going so well, how you might use the data yourself in your institutions, how you might lobby governments to use this framework to achieve better outcomes given our good economic growth and I commend it to you.

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Is a sustainable future possible?

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Abstract

Simulations of the real economy at both global and national scales highlight the unsustainable path we're on — modelled respectively in *The Limits to Growth* (LtG) and the Australian Stocks and Flows Framework (ASFF). Global data on actual developments for 1970–2010 support the LtG scenario for business-as-usual that results in near-term collapse. Nationally, the calibration of the ASFF with historical data over six decades depicts how Australia's growth has led to tangled environmental and economic dilemmas. Explorations of Australia's future in the ASFF show that a sustainable pathway would require massive changes to infrastructure (for sweeping efficiency gains and renewable energy), a stabilised population (with fertility rates halved and zero net immigration), and transformed lifestyles (with consumption rates and the working week halved). Considering why sustainable pathways have not been adopted, a review is presented of analysis into the collapse of historical societies. This leads to a summary of recent innovative modelling by others on the critical role of social resistance to change associated with control by a powerful cohort.

Introduction

Every few years or so the question of Australia's population and future economic and environmental sustainability arises in the public domain. The author became involved in this 18 years ago after joining a CSIRO modelling project analysing Australia's sustainability. Almost from the very beginning the CSIRO project was tarred with the brush of the Club of Rome's 'Limits to Growth' (LtG). Critics had claimed that this well-known work from the 1970s had been shown to be wrong, and tried to discredit the Australian work by connection. However, a detailed examination of the LtG shows clearly that the critics were outright lying or regurgitating a myth (Turner, 2012; Turner, 2008). The LtG is worth briefly revisiting in the following section before delving into some key findings from the detailed Australian modelling. The section on Australian sustainability first summarises the historical path that has led to Australia's challenging contemporary position, then documents the impacts of future alternative population trajectories under 'business-as-usual' conditions, and subsequently explores a range of strategies aimed at achieving long-term sustainability. Finally, this paper considers analysis of collapse in historical societies, which leads to the importance of understanding our social system, since resistance to the changes required to achieve sustainability has proved so powerful despite the clear and much repeated evidence for change.

Global sustainability

A quantitative, modelled account of the global predicament was first promulgated by the Club of Rome in the 1972 publication "The Limits to Growth" (Meadows et al., 1972). Their 'System Dynamics' approach covered global population, agriculture, industry, services, resources and environ-

ment linked through various responses, sometimes with delays. The model was calibrated with data over 1900 to 1970 (Meadows et al., 1974), and then various scenarios simulated to the end of the 21st century.

A key scenario was their "standard run" or 'business-as-usual' which basically continued the same policy and development settings as evident in the calibration period. In summary, over the historical calibration period (to 1970) and continuing to about 2010 in their BAU scenario (Figure 1, left to right):

- the industrial revolution leads to growth in industrial output per capita (and consequently, material wealth);
- which supports the so-called "green revolution" in agriculture, so that food per capita increases;
- as well as supporting exponential growth in services per capita, such as health and education;
- and consequently natural resources are drawn down, to about half the original endowment;
- while at the same time pollution, such as GHG, increases but from a very low level;
- so that the death rate falls because of better food and services;
- and increasing wealth leads to a fall in the birth rate;
- but population grows because births exceed deaths.

From about now onward (to the end of this century):

- resources continue to be extracted;
- but increasing extraction difficulty diverts capital away from the industrial system, so the industrial output per capita falls;
- pollution grows for a few decades;
- and the combined effect of pollution and weakening industry undermines both the per-capita food and service outputs;
- so that both birth and death rates reverse their trend and grow;
- leading to a collapse in the population later in the century.

Since the modelled scenarios start in 1970, there are decades of reality that we can compare with the simulation (Figure 1). Overlaying four decades of data from 1970, shows that the agreement with the modelled scenario is remarkably good. There were many other LtG scenarios modelled — such as comprehensive, adaptive technology and a stabilised world — but comparison of the data with these is poor. While this doesn't prove beyond doubt that the LtG BAU scenario is unfolding, it certainly refutes the critics and says we should take the work seriously. Still, acceptance of the LtG has been hindered by the complex 'spaghetti and meatball' nature of their model, and its very coarse resolution.

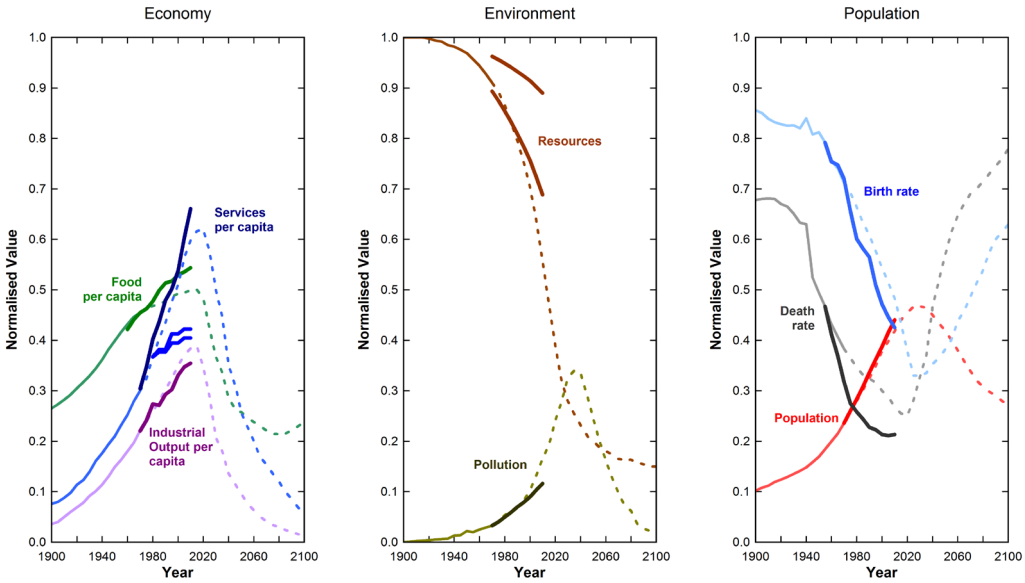

Figure 1: LtG BAU (Standard Run) scenario (dotted lines) compared with historical data from 1970 to 2010 (solid lines) — for demographic variables: population, crude birth rate, crude death rate; for economic output variables: industrial output per capita, food per capita, services per capita (upper curve: electricity p.c.; lower curves: literacy rates for adults, and youths[lowest data curve]); for environmental variables: global persistent pollution, fraction of non-renewable resources remaining (upper curve uses an upper limit of 150,000 EJ for ultimate energy resources; lower curve uses a lower limit of 60,000 EJ [Turner 2008a]).

Australian sustainability

In order to study the sustainability question, and in contrast to the System Dynamics approach of the LtG, CSIRO adopted a 'Stocks and Flows' approach (originally developed in Canada) that models the physical activity (effectively via mass and energy balance) of the vast array of economic and environmental processes across the nation (Turner et al., 2011). In the Australian Stocks and Flows Framework (ASFF), scenarios of the future are explorations of the physical implications of settings for lifestyle choices, technology developments and policy directions, similar to modelling of climate change scenarios. The ASFF is a massive framework now comprising about 1700 variables, most of which are large data cubes, and is calibrated with a huge volume of historic data.

How did we get here? — the historical picture

The historical calibration of ASFF has produced a detailed complete and coherent quantitative account of Australia, reproducing the historical data and filling in the gaps, from the end of the Second World War through to about 10 years ago (Turner, 2016 (draft)). The graphical picture of the State of Australia over some six decades paints a disturbing story.

The Australian economy has grown enormously over the six decades, driven by population growth and increases in productivity (in roughly equal share). Economically we

appear exceptionally wealthy compared with our forebears, but inequality is accelerating. Further, our international financial position has steadily deteriorated, with the trade balance continuing to head in an unhealthy direction. This is despite massive flows of export commodities, most recently iron ore, first to Japan and now to China, and natural gas. Paying off international debt — which is mostly private debt — would involve unprecedented changes to our economy and lifestyle.

A transition in the composition of the economy is evident from about 1970, with a move away from industrial manufacturing toward ever increasing services (principally health and commercial services), and construction (along with agricultural employment continuing to decline, mirroring the demographic shift toward the coast). Consequently, the Australian economy is already largely a service economy, indicating that there is little scope for environmental salvation by suggestions of further structural change. We are also increasingly reliant on imports of value-added goods, with obvious implications for our trade balance, as well as decreasing our resilience to international shocks.

Despite the past structural shift, the growth in wealth, and ongoing efficiencies and productivity improvements, dramatic impacts on the natural resources and environment have occurred that leave us exposed to future shocks. This is a result of population growth combined with per capita consumption.

Increasing rates of per capita consumption of materials and energy have occurred through the recent housing boom, high levels of travel, and purchase of goods and consumable items. This combines with steady population growth to produce escalating volumes of resource use, as well as wastes and greenhouse gas emissions. These rates of consumption have been financed by apparent accelerating growth in national and household wealth, though in reality this has been founded on borrowed money, which has grown even faster than GDP.

Our contribution to global greenhouse gas emissions has grown steadily in hand with the size of our economy. Through further climate change, this is likely to exacerbate dramatic reductions in water availability already seen in the SW and SE of Australia, with serious implications for many capital cities, food production and electricity generation.

Australia's apparent growth in wealth has been built on escalating debt that is mostly private (not public). Australia's environment and resources have been degraded to an extent that already impacts on the economy. Crop land degradation is reducing yields and requiring higher intensity of inputs for farmers, though expansion of area has helped to mask this in the past. Fish stocks have fallen to levels where many species remain under serious pressure. Natural water resources for many capital city catchments are seriously threatened through the combined effects of increasing extractions converging on the falling volumes of rainfall and runoff. These pressures are likely to worsen due to ongoing climate change, fuelled by rising greenhouse gas emissions. Domestic oil resources have passed the point of peak production, so that Australia is increasingly reliant on international supplies for this crucial commodity that underlies the movement of people and freight. Having let our manufacturing industry deteriorate constrains our ability to create alternative strategies (e.g., electric vehicles).

These resource pressures constrain the Australian economy. When combined with the demise of the domestic manufacturing sector, the ability for the Australian economy to increase its productive capacity in order to pay off its debt is seriously compromised. Instead of investing in a more self-reliant productive economy and transitioning to renewable energy forms and more diversified transport, we have used borrowed money to fuel a housing boom and consumptive lifestyle habits.

Rescuing Australia from our predicament of a high level of debt and environmental degradation will not be easy. Due to the inter-related nature of the economy and environment, unintended consequences typically arise from traditional strategies. Physical realities must be observed: you can't have your cake and eat it too (although some economists believe that this physical law can be ignored).

Attempting environmental remediation using just technological fixes would require rates of progress well beyond any historical precedent, confirmed in the detail of the Australian National Outlook (Hatfield-Dodds et al., 2015a). Even if these were achieved, greater efficiencies lead to lost jobs. Creating new jobs through growth of consumption and the economy undoes the intended environmental gains. Additionally, depending on imports of expensive equipment worsens our international debt.

Trade balance and international debt issues would be alleviated somewhat by a major turnaround in Australian manufacturing — back-tracking from the service economy. However, Australian-made products would be more expensive, not simply in dollar terms, but also in energy, material and water costs locally.

Alternatively, relying on further expansion of the service economy for lower environmental impacts may be naive. Many services have hidden or indirect environmental impacts, sometimes of a substantial nature. The financial sector, for example, supports investment in physical infrastructure.

Even substantial reductions in population growth and consumption rates would be insufficient on their own to achieve sustainability. Lower consumption demand directly threatens jobs, leading to further inequality and possible social unrest.

Australia's challenging contemporary predicament discussed above suggests that any solution would most likely have to involve a comprehensive suite of strategies. The Australian Stocks and Flows Framework (ASFF) was designed for exploring such futures, and has been used in a wide range of studies (summarised in Turner et al., 2011), and most recently in food security (Turner et al., 2017; Candy et al., 2019).

What does business-as-usual entail?

A convenient reference case for exploring alternative futures in ASFF was developed from a study of the environmental impact of alternative population trajectories for the Department of Immigration and Citizenship (Turner, 2010) — though this report was effectively buried. The scenarios involved a business-as-usual future, without substantial change to lifestyles, behaviours and policies. (Hence it generally employed projections of historical trajectories for many of the ASFF inputs, and therefore obviating modelling of prices.)

The population trajectories reproduced the Australian Bureau of Statistics projections (ABS, 2008) based on different immigration and fertility rates (Figure 2). Higher immigration and contemporary fertility

rates are in the upper curve, leading to 40 million Australians by mid-century. Australia is approximately on that trajectory now. But it's quite possible to stabilise and even reduce Australia's population as the lower curve shows. This will be investigated in the next section.

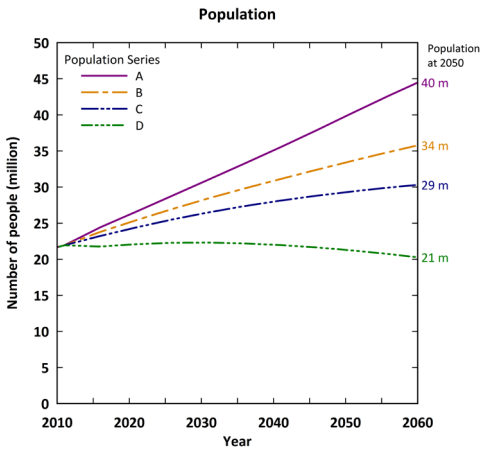

Figure 2: Population trajectories reproduce the ABS series based on different immigration and birth rates.

The scenarios included some ongoing productivity and efficiency advances; a transition toward cleaner electricity generation; and some climate change impacts on water resources. The scenarios also targeted an 'optimal' unemployment rate of 5%, via endogenised economic growth (which is discussed later in this section).

Interestingly, all scenarios produce economic growth, even the stabilised population, as shown by growth in GDP (Figure 3a). Critically though, as shown by per capita GDP (Figure 3b), average wealth is essentially the same irrespective of the population scenario.

There are however, somewhat different environmental outcomes. For example, GHG emissions (Figure 3c) are higher for bigger populations, and rise for all population scenarios, except for a modest reduction in the stabilised population. This is despite all of these scenarios employing greener power and wide-spread efficiencies.

In terms of fuel security, our reliance on overseas oil (Figure 3d) increases dramatically as Australia's domestic production falls. That could be a challenge depending on availability and price.

Water security is increasingly threatened with larger populations. Water use (Figure 3e) actually begins to be dominated by urban consumption in the higher population scenarios. These pressures combined with some climate change, force some river flows, such as the Murray-Darling, into the red (Figure 3f) — their average flow would be negative if we kept trying to extract.

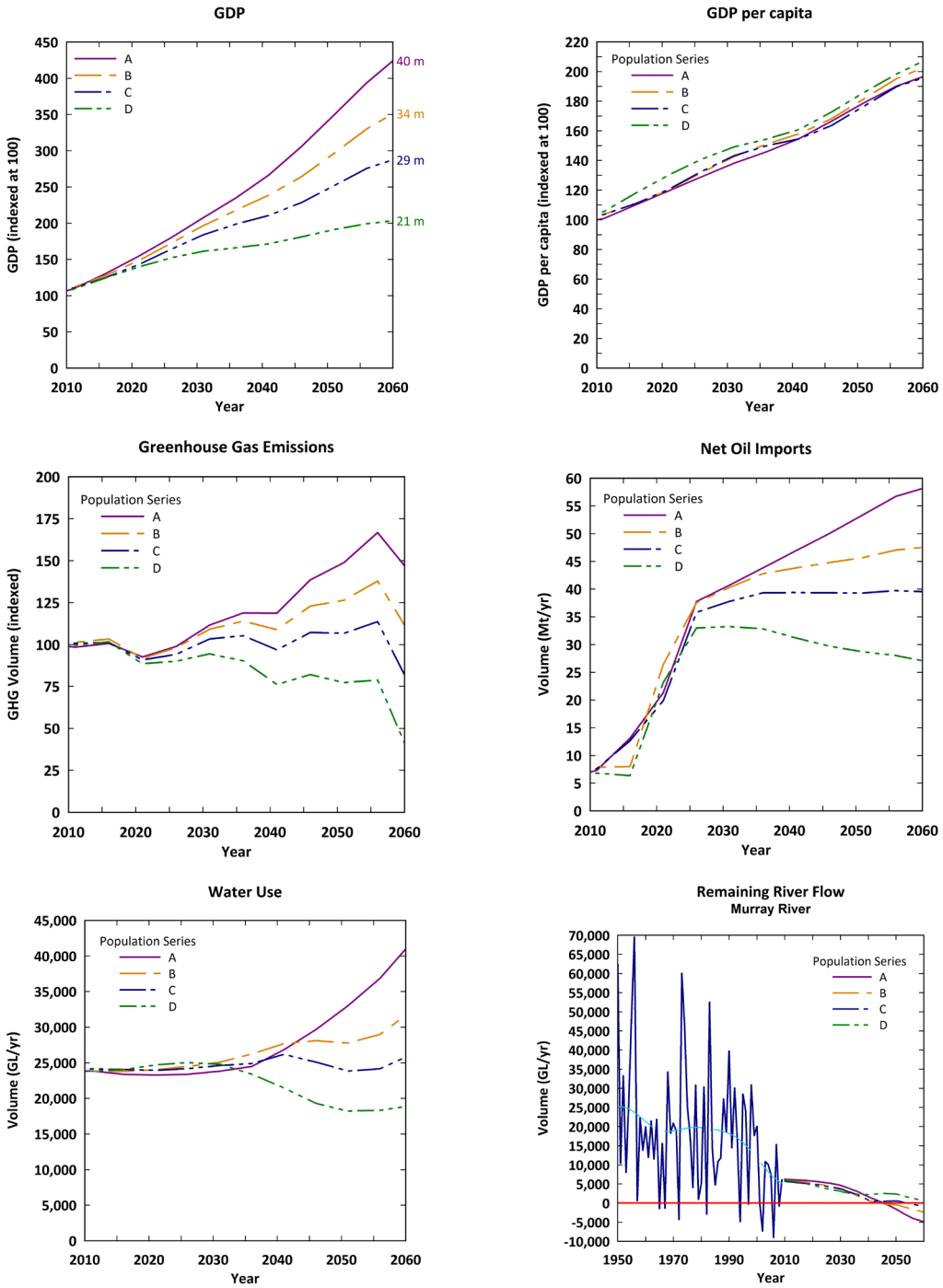

Figure 3: Several key economic and environmental outcomes under BAU conditions for four alternative population trajectories (see Figure 2).

These and other impacts come about despite technological improvements. In particular, the Carbon intensity for the economy (i.e., volume of GHG emissions for the whole economy per dollar of GDP) over time for each of the population scenarios falls significantly (from approximately 0.65 kg/$ to 0.25 kg/$). That is, Australia becomes cleaner in a *relative* sense, but our total GHG emissions increase, so Australia becomes dirtier in an *absolute* sense.

This apparent paradox is not an artifact of the modelling or something peculiar to Australia. Over the past 1–2 centuries, carbon intensity for the world economy has decreased (i.e., efficiency increased) (Grubler, 1998), while GHG emissions have simultaneously increased, at an exponential rate. This is just one aspect of technology as a double-edged sword, and the apparent paradox can be understood by considering the focus of modern developed economies, like Australia's, on achieving economic growth of typically 3% pa.

Such economies target 3% — and not other rates — because our populations typically grow at about 1.5% pa, and technological progress and productivity advances also at about 1.5% pa. If there were no other change made, both of these factors combined would create unemployed labour at the rate of 3% pa, and lead to massive unemployment levels within decades.

To prevent such social disruption, we have traditionally adopted the growth model — grow the economy through investment and increasing consumption at 3% pa to create new jobs for those that would have been unemployed. This growth mechanism was employed in the ASFF modelling of business-as-usual to maintain an optimum unemployment level (5%). As the system-wide outcomes of the modelling and historical evidence clearly show, we've undermined the environmental gains we thought we'd get from technology. Unfortunately, this mechanism is not well understood or acknowledged (e.g., even the Chief Scientist for Australia openly adopts an optimistic position regarding impacts of technology (Finkel, 2015)).

Pathways to sustainability

Nevertheless, human societies are inherently innovative. Consequently, to examine the possible strategies for alleviating the environmental/resource stresses identified above, ASFF was used to model ambitious technological, population and lifestyle changes in succession (Turner, 2016):

- sweeping efficiency gains are made, across every sector of the economy;
- the power sector was also transitioned to mostly renewables;
- population was stabilised by halving the fertility rate and imposing a zero net immigration rate — so the number of people entering Australia matches those leaving; on the lifestyle front, in order to avoid unemployment:
- personal and household consumption rates were halved, and;
- crucially, the labour force shifts over decades to a 3-day working week, though the four days of "leisure" would be quite different from contemporary experience.

The modelling shows it takes the whole collection of ambitious strategies to achieve meaningful change (Figure 4). For GHG, the upper rising curve shows the growing emissions from the earlier scenario with population growth and economic growth

(Figure 4c). The lower green curve incorporates all of the strategies (of the "alternative" scenario) and gets GHG emissions down to approximately recommended levels for climate security (assuming a similar global response). Our oil security is much better with all of the strategies, though not complete (Figure 4d). Clearly, water use is reduced dramatically (Figure 4e), and the Murray-Darling average river outflow is by-and-large prevented from drying up (Figure 4f).

Other strategies would be needed for some other environmental challenges, like moving to regenerative agriculture to tackle land function degradation (Turner et al., 2017; Turner et al., 2016; Larsen et al., 2011).

The implications of this alternative scenario (with all strategies implemented) in the ASFF modelling contrast in many ways with the recent CSIRO Australian National Outlook 2015 report (Hatfield-Dodds et al., 2015a). The message promulgated by the ANO report's authors, including an article in the prestigious journal *Nature*, explicitly suggests that a sustainable environmental outcome can be achieved without sacrificing a consumption-based lifestyle and continuous economic growth (Hatfield-Dodds, 2015; Hatfield-Dodds et al., 2015b). Their research uses a collection of interacting models to produce a large number of scenarios at both the global and Australian level. Key elements for achieving the outcome (of their "Stretch" scenario) are:

- escalating price on carbon;
- large dependence on carbon capture and storage (CCS);
- huge transfer of agricultural land to forestry plantings for bio-sequestration and biodiversity; and
- unprecedented growth in energy/resource efficiency.

The ANO modelling has been criticised (including by a co-author) on a number of grounds, many of them related to the extreme or unsubstantiated nature of key assumptions such as those above (Lenzen et al., 2016; Alexander et al., 2018). Such criticism has validity in terms of questioning the likelihood of the scenario and the ANO authors' suggestion that a transformation in public values is not needed (criticised by Diesendorf (2015)). However, it does not necessarily invalidate the modelling per se.

In terms of the validity of the ANO scenarios/model — and of the contrast with the alternative ASFF scenario above — it appears that the ANO modelling omits the effect on unemployment from exponential growth in efficiency, perhaps due to missing links between the ANO models dealing with labour and resource efficiencies. The importance of this relationship was demonstrated in the ASFF modelling: first, in the business-as-usual scenario, where consumption (and investment) increased to generate new jobs that mitigated the unemployment created through efficiency gains (and hence endogenised economic growth); and second, in the alternative scenario where a three-day working week was imposed (and consequently growth is unnecessary).

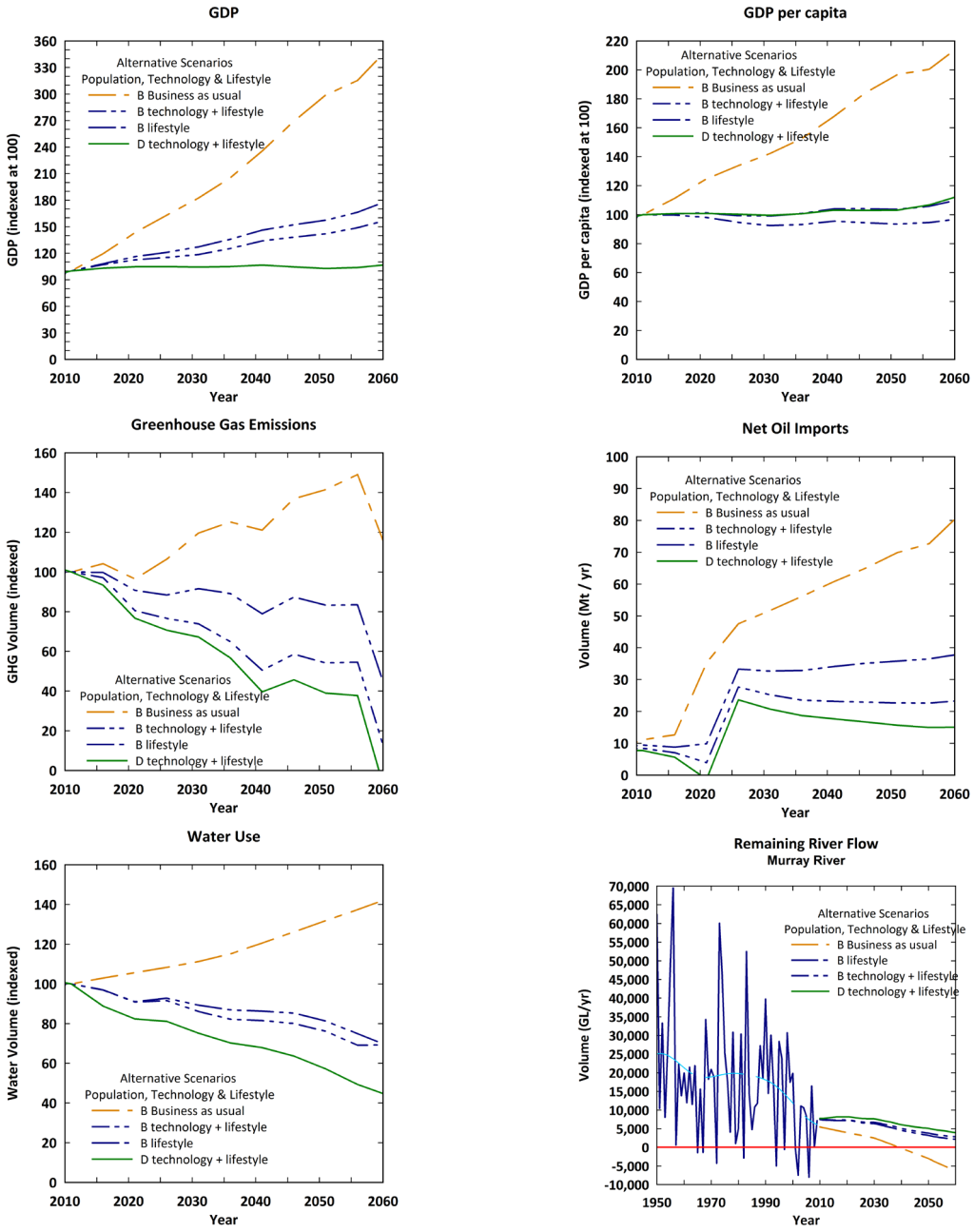

Figure 4: Effect on key economic and environmental outcomes of changes in population, technology and lifestyle. BAU with modest population growth (B) (orange single dash line) provides a reference (see Figure 3). Only the combination of stabilised population (D), sweeping efficiencies, renewable power, reduced household consumption and shorter working hours (green solid line) approaches a sustainable future.

The lack of such a relationship between efficiency and unemployment in the ANO creates an erroneous decoupling of economic growth from environmental impact. Additionally, the decoupling argument (Schandl et al., 2016), and associated conclusion of ever-growing consumption-based lifestyles is based on growth in GDP per capita, and is questionable since a large but unspecified part of GDP should be attributed to investment in new capital/infrastructure (at least partially funded by the high price of carbon), and hence not available as income to labour (see comment on ASFF below).

Compared with the view of the ANO report, the alternative ASFF scenario (above) could sound draconian to growthists, but it does not mean going back to living in a cave according to the simulated GDP figures. Under all of the imposed strategies GDP (Figure 4a) remains constant, and since population is also stabilised, the per capita average also flat-lines (Figure 4b). Although not an aim of the explorations, the scenario has effectively produced a sustainable "Steady-State Economy".

There are of course issues with using GDP as an indicator of wealth, and the per capita average hides questions of inequality and distribution. For instance, the stabilised GDP per capita outcome (Figure 4b) appears to contradict the lifestyle changes of the scenario, where household consumption rates and the working week have been halved. The paradox is explained by recognizing that a growing segment of GDP is associated with the capital investment that supports the technological change also embodied in the scenario. Consequently, a reduced portion of GDP is associated with income to workers. This reduction in average wealth is consistent with the lifestyle setting of the scenario, and could mean that households would have to return to mid-20th century wealth levels.

So, technically, we know how we could be sustainable, and it does involve truly massive transformation, but it doesn't necessarily involve living in a cave. (That said, the scenario simulation hasn't dealt with the problem of growing international debt, which might be required to fund the technological capital investment.) Despite the sociological and economic challenges, such a potential approach to achieve sustainability has been known for decades, at least from the time of the LtG — and hence raises the question why sustainable pathways have not been adopted despite the evidence for catastrophic environmental degradation.

Possible insights from history

Other researchers have sought to shed light on our failure to take sustainably pathways through the use of historical analysis. Substantial literature exists on the study of collapse and instability of past societies, and naturally the overwhelming majority of this has focused on agrarian societies. Some notable reviews summarised in Table 1 have been made on ensembles of past social collapse/instability, seeking to draw more general conclusions on causation than can be afforded by studies on single cases (Diamond, 2005; Goldstone, 1991; Goldstone and Bates, 2010; Tainter, 1988; Tainter, 2006; Turchin, 2003b; Turchin, 2009; Turchin, 2012).

Table 1. Summary of key historical reviews of societal collapse, conflict and instability

Societies		Method	Type of Societal Collapse	General Thesis
A. Western Roman	-300–500	Review of archaeological evidence for detailed case studies (from tens of cases overviewed)	Rapid change from complex to simple society with deleterious effects.	Increasing societal complexity (in response to earlier stresses) yields diminishing returns, which reduces or eliminates resilience to shocks.
Classic Maya T	-100–900			
Chacoan	500–1300			
Collapse avoided:-				
Byzantine	???			
Europe	???			
B. Classic Maya	-250–900	Comparative assessment of archaeological evidence	Extinction or dramatic fall of population and societal conditions.	Poor decision-making and mismanagement of environmental problems can be categorised as failure to: • be aware; • recognise (denial); • respond at all; • respond correctly; • respond early enough
Anasazi (SW NthAm)	600–1200			
Greenland Norse	1000–1400			
Easter Island	700–1700			
Polynesian Pitcairn Is	800–1500			
Haiti	1800–2000			
Rwanda genocide	1900–2000			
Collapse avoided:-				
Tokugawa-era Japan	1600–1870			
Tikopia (Pacific Is)	-900–2000			
New Guinea highlands	1400–2000			

Table 1. Summary of key historical reviews of societal collapse, conflict and instability (continued)

Societies	Method	Type of Societal Collapse	General Thesis
C. England 1500–1640 Ottoman 1500–1650 Ming-Qing 1500–1650 France 1700–1790 Global (141 episodes) 1955–2003	Statistical analysis of political, social, and economic factors	Violent conflict, adverse regime shifts, and genocide/politicide.	Short-term prediction of instability through a combination of: • political regime (e.g., partial democracy with factionalism), • infant mortality, • neighbouring conflict, and • state-led discrimination.
D. Rome (Republican,Principate) -350–285 France (Capetian,Valois) 1150–1660 England (Plantagenet,Tudor-Stuart) 1150–1730 Russia (Muscovy,Romanov) 1460–1920 China (E & S Asia) 1780–2010	Mathematical modelling and statistical analysis	Fall of the state	Demographic-structural model interplay between: a) the state's resources, b) elites, and c) commoners, and the existence of diminishing returns produces approx. 200-year secular cycles of rises and falls (with 50-year bi-generation cycles of civil unrest superimposed).

A Tainter (1988, 2000); B Diamond (2005); C Goldstone (1991), Goldstone & Bates (2010); D Turchin (2009, 2003b, 2012).

Perhaps due in part to the abundance of cases, analysis of common cases represents a relatively short list. Considerable differences in the methods employed are also obvious. Recent availability of electronic databases on historical variables has enabled statistical analysis to dramatically extend the spatial and temporal coverage and rigour of analysis (e.g., Goldstone, and Turchin). Attention has only more recently moved toward modern societies of the industrial revolution era. Additionally, definitions of what constitutes societal collapse/instability also differ in detail. Despite these points of difference (and perhaps in view of them), it is valuable to compare these reviews due to their focus on finding generalised laws of societal collapse/instability.

At one level, the generalisations reached appear unrelated, and some researchers view alternative proposals in an explicitly competitive light. This is probably an artefact of inappropriately searching for ultimate causes of collapse within a system resplendent with feedbacks.

For example, Tainter (2006) is critical of Diamond and others ascribing environmental causes to collapse, instead conjecturing that societies have coped with environmental and other stresses by (technological) adaptation, which increased the complexity of the society and subsequently yielded diminishing returns. Consequently, according to Tainter, the society may succumb to a new environmental or other shock because effectively the low-hanging fruit has already been exploited. Tainter (2000) suggests that some societies avoided collapse, such as the Byzantine Empire, through a strategy of simplification; or through substantial innovation and geographic expansion, such as the Industrial Revolution of the late 18th century, when Europe transitioned from an agrarian society based on wood and animal power to an industrial society dependent on coal (combined with the steam-engine).

Diamond (2005) also conjectures that societies may avoid collapse, but that many fail due to poor decision-making and mismanagement of environmental issues, which he suggests are a common but not universal problem (noting also trade issues and cross-border conflict). The hierarchy he proposes of five levels of failure to manage environmental stresses effectively includes Tainter's (as a failure to respond correctly), even though Diamond evidently criticises Tainter (p. 420).

In contrast to these largely agrarian-based studies, Goldstone et al (2010) utilised extensive databases on conflict in modern states to undertake a comprehensive statistical analysis of a suite of social, economic and political variables. Environmental factors were not directly incorporated in the analysis, evidently because earlier research indicated that these factors had an insignificant contribution to violent conflicts (Goldstone, 2001; Goldstone, 2002). (This is in contrast to other research e.g., indicating the influence of climate on human conflict (Hsiang et al., 2013).) The statistical analysis showed that initiation of conflict within states could be predicted a few years in advance at about 80% accuracy by four socio-political factors, namely: the type of political regime (based around the degree of democracy and factionalism), the presence of conflict in multiple neighbouring states, the existence of state-led discrimination, and the extent of infant mortality. This socio-political model contrasts with that of Tainter and Diamond (although a common theme is political mis-management) by abstracting

environmental conditions even further away as potential driving factors. Crucially, it is also essentially a static perspective compared with the alternative multi-century timescales considered by Tainter and Diamond. The static model leaves open the question of interaction between the polity, population and environment, and how each of these may be bound up in long-term dynamics of mutual influence (and hence not actually independent variables).

The dynamics of denial and the role of power

Recently, two separate and innovative modelling efforts address the issue of static analysis by modelling social dynamics of whole societies linked to resource and environmental status. The quantitative nature of the mathematical modelling provides an opportunity for rigorous testing and deriving insights. Crucially, both approaches incorporate modelling of demographic structure, specifically the influence and control that powerful cohorts have over the general populace. While one study (Harich) is on contemporary society, and the other (Turchin) is more based on analysis of historical societies, both models produce dynamics that see societies grow over some 200 years beyond a sustainable level and then collapse.

Harich has constructed a System Dynamics model (among other analyses) to investigate societal resistance to change when faced with potential environmental problems (Harich, 2010; Harich, 2012). Although the model incorporates substantial detail, the crux of it involves two competing processes that seek to influence a general populace to different views of environmental issues. One process involves a dynamic loop that models academics, activists and virtuous politicans attempting to educate the general populace by promulgating facts about forthcoming environmental problems. The second process models "degenerate" politicans, corporations and vested interests that create "false memes" about the problems, and if the falsities are not detected by the general public (which may include a degree of denial), then no change occurs to mitigate the environmental problems.

Exploring the dynamics of this system by varying parameters shows that the second process based on false memes inevitably dominates, resulting in environmental problems growing to critical levels. This is because "you can always tell a bigger lie, but you can't tell a bigger truth." The truth is just that, but false memes come in many forms and extents, such as: spreading fear; confusing the issue; exaggeration; demanding certainty from science; hiding the truth. In the model, a dramatic transformation occurs in public understanding when environmental reality eventually bites so hard that it can't be ignored or denied, though too late for effective change.

In the other innovative modelling, Turchin's work sheds further light on the transformation, based on historians' insight that revolutions by the populace are typically quelled while the powerful cohort remain united, but revolutions erupt when the hard times force the powerful to clash among themselves and consequently lose control over the populace. By using dynamic modelling, Turchin (2003b); (Turchin, 2003a) has avoided the static and qualitative nature of historical analysis (summarised above). Turchin takes Goldstone's (1991) insights about the involvement of "elites" i.e., the cohort with power, and incorporates processes involving diminishing returns on state resources, into a dynamic "demographic-

structural" model of state rise and fall (summarised below).

The diminishing returns concept parallels that of Tainter's, and is essentially a Malthusian view of population effects. This model and its variants, which has population, polities and state resources (ultimately an environmental factor) influencing each other, has mostly been applied to the understanding of a wide range of agrarian societies. With appropriate parameter settings it produces state collapse and periods of state rise and fall with "secular cycles" (Turchin, 2009) of about 200 years, in keeping with much of the historical accounts. The model may be extended to modern industrial societies, as Turchin's (2013) analysis of the US from 1780 to 2010 suggests. Criticism of Turchin's model appears to focus on points of detail (Tainter, 2004) rather than acknowledge the more general understanding generated, including ironically, the importance of diminishing returns in state collapse.

In Turchin's demographic-structural theory, the extent of total resources produced in a society, such as food from land (particularly in agrarian states), increases with growth in population because more people are available to work the land. However, the rate of increase with population is likely to slow i.e., there are diminishing returns, due to crowding for example, particularly as the "carrying capacity" is approached (which is a function of state geography and technology, potentially advanced through state support). The resources needed by the population grow at least linearly with the number of people, so that surplus production should initially grow, peak and then fall to zero as population grows toward the carrying capacity. Surplus production supports more rapid population growth through higher fertility rates. Further population growth can lead to "persistent price inflation, falling real wages, rural misery, urban migration, and increased frequency of food riots and wage protests". This is the demographic or Malthusian part of the theory involving environmental factors, which alone is insufficient to explain the rise and fall dynamics.

During this period of growth, the state assets are enlarged through taxes on the production of surplus resources, and this initially exceeds the state expenses. These expenses, such as the maintenance of the military and bureaucracy, scale linearly with the population. Likewise, the "elite" cohort of the population (this being the "structural" and crucial part of the theory) extract rent from the commoners, and expand in numbers and wealth due to growth of the population, over-supply of labour and resource surplus. This leads to depressed wages and un- or under-employment for commoners, as well as a golden age for elites rapidly accumulating wealth, attracting more to this cohort.

Subsequently, over-production of elites encourages rivalry and factionalism among that cohort. Meanwhile, the state attempts to increase revenues (taxes) to offset escalating expenses, but falling surplus production leads to state fiscal crisis, bankruptcy and loss of military control. As conditions deteriorate, popular discontent among the commoners is harnessed by competing groups of elites. Competition among elites allows or even fuels popular uprisings, breakdown of central authority, potential conflict and state collapse. The deteriorating environmental/resource and social conditions during this period of descent force population numbers and growth rates down i.e., a collapse (in

effect allowing the dynamic system to return to the conditions at the start of the cycle).

An important implication of the demographic-structural model is that an ultimate cause does not exist for the collapse, since the factors involved interact through feedbacks. This lack of independence has implications for any statistical analysis of societal conflicts, and may explain why different studies come to conflicting conclusions about the role of the environment. Nevertheless, societal inequality (in terms of a hierarchy of economic/political power) appears to be a necessary ingredient for collapse. Further, a critical point in the dynamics is reached when surplus production (due to diminishing returns) has peaked, since subsequent attempts by the state to maintain the system perpetuate the problem by increasing pressures, rather than decreasing them, thereby leading to rapidly deteriorating conditions. This dynamic is present in the Limits to Growth model, e.g., when increasingly difficult resources are extracted, as is the case in the business-as-usual scenario presented above.

Conclusions

This paper has examined the question of whether a sustainable future is possible, by drawing together a range of different analyses. Historical analysis by others was summarised covering past societal collapse, as well as the modern development of Australia that depicts the interacting dilemmas we currently face. Modelling was also described at the global level (Limits to Growth) and for Australia (ASFF), which highlight that a business-as-usual approach (such as economic growth and reliance on technology) appears destined to lead to collapse. Indeed, control systems theory shows that in a system with positive (accelerating) and negative (restraining) feedbacks, overshoot and subsequent collapse is inevitable when delays are present in the negative feedbacks. A modelling exploration of an alternative future for Australia demonstrates that sustainability may be feasible, but only if massive transformations occur in virtually all economic/societal aspects — technological, population, lifestyle (and probably also financial).

The sheer breadth, rate and scale of change required for sustainability appears far too much of a challenge to be realistic given historical and recent experience. This view is strengthened by innovative modelling of social dynamics by others that explains the resistance to change. In light of the comprehensive evidence presented, the most rational course of action is to prepare as best as possible for a collapse of some nature. Ironically, if such preparations were broadly adopted, synergies with sustainable strategies might provide some hope of avoiding collapse.

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The trophic theory of money: principles, corollaries, and policy implications

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Abstract

Perhaps the greatest controversy in sustainability science is whether GDP is a reliable indicator of environmental impact. Yet the trophic structure of the human economy is such that GDP — in concert with real money supplies — is an excellent indicator of biodiversity loss, pollution, ecological footprint, and other aspects of environmental impact. The trophic structure of the human economy reflects that of the economy of nature, where producers (i.e., plants) support primary consumers (herbivores), which support secondary consumers (omnivores and predators) and service providers (e.g., scavengers). In the human economy producers (i.e., farmers) support primary consumers (heavy manufacturing), which support secondary consumers (light manufacturing) and service providers (e.g., transportation). The annual amount of human economic activity — GDP — is measured with monetary flows of expenditure and income. The trophic theory of money is that money originates via the agricultural surplus that frees the hands for the division of labour unto manufacturing and service sectors, and therefore reflects the environmental impact of human activity. The primary corollary is that the quantity of money — and GDP — indicates the amount of agricultural surplus and related activity at the trophic base of the economy (i.e., mining, logging, commercial fishing and other extractive activity) and the environmental impact of such activity. Inflation, technological progress (a function of GDP), and international trade affect the precise relationship of real money supplies to environmental impact in any given country, without affecting the underlying trophics. Purely financial activity, such as speculation in derivatives, does not affect GDP or real money supplies.

Keywords: agriculture, environmental impact, GDP, money, trophic levels

The trophic theory of money: principles and policy implications

Perhaps the greatest disagreement in sustainability science and policy stems from the question: Does GDP invariably indicate environmental impact? Some say yes it must, while others adamantly say no, but a great many respondents neither proffer nor accept anything definitive. Their general sense seems to be that GDP has indicated environmental impact, ever since its measure was taken (1934 in the USA), but that, theoretically, if the economy was structured a "new" way and incorporated certain technologies, GDP could grow without concomitant increases in throughput and/or environmental impact.

The trophic theory of money is that, due to the fundamental, ecological structure of the human economy, real GDP (and real money supplies) must indicate environmental impact, invariably and inevitably. This is the theory of money most congruent with the biological sciences. It helps to delineate the paradigm of sustainability science from that of conventional economics.

In order to explain the trophic theory of money I will here summarise: 1) the concept

of trophic levels in nature; 2) the trophic structure of the human economy; 3) why the trophic structure of the human economy entails a particular theory of money, and; 4) precepts and corollaries of the trophic theory of money. I will conclude by exploring some implications of the trophic theory of money for sustainability science and public policy.

Trophic levels in the economy of nature

The word "trophic" is defined as "of or relating to nutrition" (Merriam-Webster online dictionary) and connotes especially the energy derived from food. The word is seldom used outside of the ecological sciences, where it is almost invariably coupled with the noun "level." A trophic level is a set of species that occupy a similar position with regard to the flow of energy (derived from feeding) in the economy of nature (Ricklefs and Miller 2000). The concept of trophic levels is used to summarise two major fields of ecological study: the energy pathways associated with the sustenance of species, and the relative biomass of major categories of species.

A typical ecosystem has three basic trophic levels: producers, primary consumers, and higher-level consumers (Fig.1). The producers are plants, which produce their own food through the process of photosynthesis. The photosynthetic growth of plants is called "primary production."

All animal life depends on the plant community for nutrition. Some animals eat plants directly; these are the primary consumers. Higher-level consumers eat primary consumers. Finer distinctions among higher-level consumers are uncommon and not usually dealt with in terms of trophic levels, but rather in the more detailed terms of food webs and energy pathway diagrams.

The primary consumers are also called "herbivores." Consumers at secondary or higher levels are "predators." However, many if not most predators supplement their diets with plants; enough such supplementation warrants the label "omnivore." *Homo sapiens* is a classic omnivore (Pollan 2006).

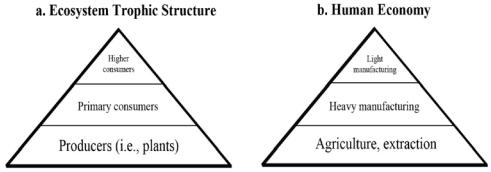

Figure 1: Trophic structure of: (a) economy of nature and (b) human economy (from Czech 2013).

Although the basic trophic levels comprising the economy of nature are simple to understand, it can be challenging to categorise particular species. A fox living in one ecosystem, or at a particular time of year, or at a particular age, may subsist primarily on plant materials (as with a primary consumer), while a fox in different circumstances may subsist primarily on small animals (as with a secondary consumer). Few ecologists would classify a fox as a primary consumer, however. Taken as a whole, fox species — as well as most other canids — are classified as predators that happen to be somewhat omnivorous.

Some species are not readily categorised into trophic levels. Scavengers, for example, are neither plant eaters nor predators most of the time. Yet they do eat primarily animal tissue, so are categorised as secondary consumers in trophic terms. The fact that they "clean up" the ecosystem of rotting flesh leads us to also call them, somewhat anthropomorphically, "service providers." Numerous other services are performed in the economy

of nature such as pollination, decomposition, and the provision of hiding or thermal cover. As members of the economy of nature, service providers may be designated in the trophic structure as necessarily interacting with the "regular" members. Their lives of service would not be sustained without the other species and, as with the regular consumers, they are ultimately dependent upon the photosynthetic activity of plants.

Trophic structure of the human economy

As emphasised in ecological economics and sustainability studies, the human economy is a subset of the economy of nature. In terms of trophic levels, which theoretically range up to 5.5 for large carnivores, human trophic levels range from approximately 2.04–2.57 (Bonhommeau et al. 2013), reflecting not only an omnivorous tendency but substantial variation among cultures. Yet humans also occupy and dominate the apex of the trophic structure in the sense of consuming virtually every other species that is edible, palatable, and economical to harvest (Czech 2000, Roopnarine 2014). These species include numerous highly predaceous fish, reptiles, and mammals, many of which are systematically harvested in various cultures. Conversely, only in extremely rare instances do nonhumans hunt and consume humans.

As a mammalian species, *Homo sapiens* follows the same natural laws that apply to the other species in the economy of nature. In addition to residing in the trophic structure, humans must abide by the laws of thermodynamics and the principles of ecology. What distinguishes humans most, in ecological terms, is the breadth of the human niche, which reflects the unique mental and physical capabilities of *Homo sapiens* (Kingdon 1993).

The human niche is so broad — human activities are so variable — that the human economy itself has a well-developed trophic structure (Fig.1). Farmers are the producers. As with the plants in the economy of nature, farmers produce their own food, and their surplus production is then available for consumers. This was emphasised by the 18th-century French physiocrat, Francois Quesnay, in the Tableau Economique.

However, within the human economy, most members do not make their living by literally eating the members of lower trophic levels. The "living" made by humans goes far beyond mere feeding to encompass the production and consumption of a great diversity of goods and services, and we may also include loggers, miners, ranchers, oilmen, and fishermen as "producers" in the human economy. Each of them "produces" goods needed by themselves and others in the human economy, although technically they extract such goods directly from stocks of natural capital such as timber, minerals, and forage. Farmers still come closest to being true producers — in the physiocratic and ecological sense — because instead of extracting per se, they participate closely with the process of photosynthesis, the ultimate production process for life on Earth.

Manufacturers use raw materials extracted by the producers to manufacture goods. They range from a heavy manufacturing base (such as mineral refining) up through the trophic pyramid to the lightest manufacturing sectors (e.g., computer chip manufacturing) (Fig. 1). Heavy manufacturing requires the rawest of materials, whereas much of the light manufacturing is performed with refined or manufactured materials flowing from lower in the trophic structure.

As in the economy of nature, service sectors in the human economy are not readily placed in particular trophic levels. Cashiers, cab drivers, janitors and other service providers do not produce or consume in a systematic fashion that proceeds upward from one trophic level to the next. A truck driver may deliver a load of logs from forest to sawmill one day, and a load of lumber from sawmill to farm the next. The banker may lend to the farmer or the capitalist. Professional athletes entertain farmers, industrialists, and bankers. Each contributes in some way to GDP, yet none would contribute in any way without the producers, as there would be no one to service.

A theory of money for sustainability science

There is no authoritative source for establishing precisely what is required of a theory of money, but myriad "theories" have been proffered pertaining to the following questions:

- How does money originate?
- How does the quantity of money relate to the quantity of real economic output?
- How is the quantity of money related to prices?
- What influences the velocity of money in circulation?
- What is the proper authority over money supplies and other monetary policy?

The trophic theory of money is primarily concerned with the first question: the origins of money. This is an appropriate question to prioritise, for, as Aristotle said, "He who thus considers things in their first growth and origin … will obtain the clearest view of them" (Aristotle 2008:26). Indeed, the view we get from a trophic perspective provides insights to several of the other issues as well, and goes beyond to address the question at the heart of this paper: Do GDP and money supplies invariably indicate environmental impact?

The trophic theory of money is that money originates as a matter of agricultural surplus, and that the generation or flow of real money ("real" meaning adjusted for inflation) is a real measure of — not just a variable affecting — economic output. The trophic theory of money also posits that the quantity of real money — and/or economic output as measured by GDP — must indicate environmental impact, including biodiversity loss, pollution, and ecological footprint. We can go so far as to posit that GDP is such a fundamental, reliable indicator of environmental impact that it may be considered a "measure" per se. In this sense, GDP is analogous to the volume of engine displacement, which is such a reliable indicator of horsepower that it has overtaken that somewhat esoteric measure. Engine displacement offers the substantial advantages of being easy to measure and being one of the specifications ("specs") invariably provided with the product. With such advantages, few people are required or compelled to purchase an expensive and cumbersome dynamometer to measure horsepower per se.

Unlike engine displacement, GDP is not necessarily easy or simple to measure. However, calculating GDP is relatively straightforward given the principles of national income accounting, including the fundamental identity thereof: Production = Income = Expenditure (Lequiller and Blades 2014). More importantly, GDP is carefully and consistently measured pursuant to the policies and procedures of the U.S. Bureau

of Economic Analysis (and by analogous bureaus in other countries). It is an already available "spec" that, if indeed a reliable measure of environmental impact, makes it largely unnecessary to develop alternative, costly, and cumbersome metrics.

The trophic theory of money suggests that GDP may be viewed as "the" measure of environmental impact — especially in aggregate contexts such as the environmental impact of a nation — more than any other single indicator of environmental impact per se. A natural corollary is that the quantity of money is a negative indicator of sustainability.

The origins of money — trophic and historical

Money may be defined as anything that functions in society as a medium of exchange, unit of account, and store of value (Davies 2002). In the scholarly literature many commodities are cited as historic forms of "money," but Seaford (1994) insisted that, to qualify as money per se, the item in question must be the exclusive medium of exchange (and unit of account, and store of value). This qualification rules out the vast majority of barter commodities that preceded minted coins and paper currency. Therefore these barter commodities, when portrayed as "money," are usually done so with the qualifier "commodity." In societies with enough surplus and division of labour to barter, long periods of using commodity money nearly always preceded the use of money per se (Weatherford 1997).

The phrase "origins of money" connotes these conceptual, historical, and linguistic considerations of money. Sometimes the phrase is used in discussions of who or what actually creates the physical money per se — as in the printing of bills or the minting of coins — and who authorises its creation. Although this issue is relevant to ecological economics, particularly the theme of wealth distribution, it is not our concern with the trophic theory of money.

Another use of the phrase "origins of money" is in historical or evolutionary context, where the line of inquiry is, "When was money first used, and how did such usage come about?" The trophic theory of money has much to offer in this context, as we will see.

However, with the trophic theory, "origins" is also used in a more fundamental, ecological, and ontological sense. Just as the laws of thermodynamics are more fundamental than conventional economic "laws" pertaining to the real sector (Say's Law, for example), trophic theory is more fundamental — more grounded in the natural sciences and first principles — than conventional economic theories pertaining to the monetary sector. In fact, trophic theory itself rests on a solid foundation of thermodynamics. Put in plainest terms, trophic theory may be summarised as: You can't get something from nothing (first law of thermodynamics), and you can never achieve 100% efficiency in the production of biomass (second law of thermodynamics). Therefore, of all the theories of money, the trophic theory of money is most congruent with the natural sciences.

Agricultural surplus and the origins of money

Why does real money originate as a matter of agricultural surplus? In the simplest of terms, because without agricultural surplus there is no division of labour, and neither the need nor even the opportunity to develop a monetary system. In fact, given the trophic theory of money, one would expect the following, and only in the following order:

1. development of agriculture, successful enough for ongoing surplus production
2. division of labour into numerous agricultural and non-agricultural pursuits
3. development of a money supply and system (almost invariably preceded by widespread bartering and proto-money)

Adam Smith briefly alluded to this natural sequence in Chapter 4 of the *Wealth of Nations*, and likely his study of Quesnay's Tableau guided his thinking (Czech 2013).[1] The sequence seems to emanate a certain cultural and political orderliness, but more fundamentally is pre-ordained by ecological reality. Any other sequence of the three stages is virtually prohibited by the principles of ecology. The evolution of the human trophic structure, starting with agricultural surplus, is what makes money a meaningful concept and "authorises" the development of a monetary system.

The development and use of money in the absence of agricultural surplus is so inconceivable and nonsensical that it evidently never occurred in the long arc of human evolution. As Ferguson (2008:20) observed, "Hunter-gatherers do not trade … Nor do they save, consuming their food as and when they find it. They therefore have no need of money." That is a bit of an oversimplification, but if money was used in pre-agricultural settings, it was so limited in scope and functionality as to go undocumented in the archeological record. Furthermore, it would have occurred where some other form of food surplus was relatively widespread and long lasting; i.e., under conditions highly analogous to agricultural surplus per se. Shell, for example — most notably cowry — was first used as commodity money in coastal societies (Davies 2002). Given the trophic theory of money, we readily note that fish harvesting must have been sufficiently productive in these circumstances as to be analogous to agricultural surplus, and this indeed is borne out in the archeological literature (Kingdon 1993). It is no coincidence, then, that widespread, long-lasting, systematic use of money — certainly coinage — did not occur prior to the domestication of plants and the development of agricultural crops during the Neolithic Revolution.

Similarly, it is no coincidence that money is not known to have circulated far outside areas of agricultural surplus during the Neolithic Period. This may come as a surprise to some, because misinformation on this topic is prevalent. For example, a stylish article, "When — and why — did people first start to use money" (Kusimba 2017) appears in the "Science and Technology" section of The Conversation (an online journal advertising its "academic rigor" in its subtitle). Kusimba's (2017) article will be one of the first articles located using internet search engines and the search phrase, "first use of money," and its second sentence provides "…the history of human beings using cash currency does go back a long time — 40,000 years." This astonishing claim is undermined a mere six paragraphs further, where we are reminded of the closest thing to consensus in numismatics, "The Mesopotamian shekel — the first known form of currency — emerged nearly 5,000 years ago." Nothing in the article remotely supports the notion of "cash currency" at any time during the Paleolithic Period (i.e., the "Stone Ages" including 40,000 BP). Rather, there is only mention

[1] Quesnay, it should be noted, was a Renaissance man in the king's court of post-Renaissance France, and was especially an expert in agricultural production and economics.

of bartering for "flint weapons and other tools" among hunters.

The trophic theory of money provides an ecologically rich explanation for the transition from barter through "commodity money" to money per se. The development of a thorough, economic trophic structure including a diversity of manufacturing sectors from heavy to light — and supporting a diversity of service sectors — is essentially the story of human evolution from hunter/gatherers to modern actors in the industrial and computerised economy (Kingdon 1993). The intermediate ages of transition from hunting/gathering to widespread agricultural surplus brought to a certain fruition the producer trophic level and set the stage for divisions of labour, both within the producer level (including unto the many extractive trades and specialties) and beyond to manufacturing and services.

This transition did not occur overnight — indeed it comprised "ages" — which explains why there was such a lengthy, hard-to-delineate transition from barter to money per se, which did evidently span the ages from approximately 40,000–5,000 BP.

The gradual nature of this transition is reflected in the best-documented examples of commodity money (Table 1). Shell was noted above; its commodity value was primarily as jewelry. The shell of *Cypraea moneta* ("money cowry") in particular, was durable, convenient, recogniisable, and divisible, so it was naturally selected as currency (Van Damme 2007). The use of shell lasted so long, it hasn't entirely died out on the Indonesian archipelago.

Some scholars have considered cattle in herding societies to be the first form of "money," yet cattle "cannot be properly considered as money because, being such a 'heavy' or expensive unit of account and standard of value, they were not very suited to performing the other more mobile functions of being a good means of payment and medium of exchange, which apparently demanded something much smaller than, say, a cow" (Davies 2002:42). As Davies (2002) pointed out, cattle are more accurately designated as an early form of working capital. As with shell in coastal economies, however, the use of cattle in exchange would hardly be an exception to the trophic theory of money, because surplus cattle in pastoralist cultures were analogous to crop surplus in agrarian cultures.

Non-necessity of money

The trophic theory of money does not imply that agricultural surplus must result in the use of money; only that the use of money is predicated upon agricultural surplus. There were evidently ancient cultures — perhaps most famously Mayans and Aztecs — who developed relatively long-lasting agricultural surpluses and yet never developed monetary systems with exclusive currencies (Table 1).

Even the Mayans, though, used cacao beans and greenstone beads as common means of exchange (Sharer 2009). Furthermore, it seems likely the Mayans would have developed a monetary system if not for their mysterious demise (circa 800-900 AD) and later devastation by the Spanish. With their use of beans and beads, the Mayans were clearly on the brink of using money per se, but then evidently exceeded their ecological capacity, a process exacerbated by a devastating drought (Diamond 2005). The population declined sharply and Mayans retreated into peasantry, with very little surplus or division of labour. Some Native American tribes in North America, especially in the ecologically productive river valleys of the

Table 1. Origins of agriculture and money; highlights of well-documented and widespread scenarios. All dates Before Present (i.e., years before 1950 AD)

Neolithic Region	**Origins of Agriculture**	**Commodity Money**	**Money Per Se**
Mesopotamia	10,000-9000 (especially barley; Jones 1952	Pre-3100, barley grains (Powell 1996)	5000-2500, silver shekels (Powell 1996)
Ancient Greece (including Lydia)	9300-9000 (Halstead 1996)	≥3000, oxen (Mundell 2002)	2490-2480, Lydian coins of electrum (a gold and silver alloy; Weatherford 1997)
China – Yellow River Basin	≥7450 (most notably millet; Crawford et al. 2005)	3950-1950, cowrie shell and imitations, knife and spade proto-money (Yang 2011)	≥2170, copper coins (Smith 1926)
Ethiopia	~ 7000 (Ehret 1979)	≥1200, salt blocks, "amole tchew"	250-150, Maria Theresa thalers
Mesoamerica	6000-4000 (most notably corn and beans; Johannessen and Hastorf 1994)	2000-900, cacao beans, quachtli (cotton cloaks), beads, shells (Sharer 2009, Weatherford 1997)	No money per se among ancient Aztecs and Mayans.

https://blog.continentalcurrency.ca/ethiopian-birr/ https://en.wikipedia.org/wiki/Ethiopian_birr

East, produced large agricultural surpluses (most notably with the "three sisters" of corn, beans, and squash) and developed complex economic societies (Stannard 1992, Park et al. 2016). Prior to European contact they used wampumpeag, or "wampum," as a means of exchange (Davies 2002). Wampum — most commonly from the widespread freshwater clam *Venus mercenaria* — had some medicinal value, being useful in the stopping of nosebleed (Francis 1986). It was kept as beads and accumulated in strings, and was therefore readily stored in various quantities, including common amounts often used in exchange (analogous, for example, to ten-dollar bills today).

As with the Mayans, some of the North American tribes were on the verge of using money per se. However, conquest by Europeans, and more importantly widespread smallpox, decimated many tribes and severely impacted the rest (Stannard 1992). While the earliest colonists apparently used wampum and Native American commodities as often as English coinage, distinctly "American" forms of money developed rapidly as the great expanse of rich American ecosystems was highly conducive to agricultural surplus and wide open for business in multiple trophic levels, having been vacated by the smallpox-ridden tribes. Wampum was eclipsed by pieces of eight (Spanish *reales*), New England schillings, revolutionary "continentals," Civil War "greenbacks," and finally dollars and cents.

As Weatherford (1997:59) postulated,

> Prior to the invention of money in the form of coins, the chapters of history overflow with stories of many civilisations on different continents speaking different languages and worshiping different gods, but

> we see in virtually all of them a common pattern. Whether we consider the ancient Egyptians or the Aztecs, the Hittites or the Babylonians, the Cretans or the mysterious people of Mohenjo-Daro, we see that they all appear to have risen only to a similar level of civilisation. It is almost as though each of them encountered the same invisible wall, which they were unable to penetrate. They developed their own architecture and religion, science and commerce, poetry and music only so far before they stagnated. The Greeks, however, broke through this barrier. Suddenly, architecture, philosophy, science, literature, and the other arts and sciences soared to a level of attainment unknown to any earlier civilisation. Some scholars would have us believe that this breakthrough arose from some superior quality of the Greek mind, psyche, race, or culture…

Weatherford went on to ascribe the "breakthrough" to the Greeks' proximity to Lydia, where the first known coins were minted (Table 1). In his opinion, the Greeks took the Lydian invention and brought it to new heights, along with all the activities it was exchanged for.

No doubt the availability of a widely accepted, easily accounted, and durable means of exchange allowed for efficient, swift transaction. In a sense, a reliable currency reduced transaction costs, as economic actors of all kinds could quickly exchange their goods and services and get on with life (including production and consumption of more goods and services), rather than struggling to measure, agree upon, or even recognise the various forms of proto-money. It was as if the adoption of currency lifted an unspecified tax previously inflicting Greek society.

That said, given the trophic theory of money, Weatherford's attribution to money of such a profound "breakthrough" in Greek civilisation is unfounded. There was no "invisible wall" mysteriously preventing the Greeks from flourishing. Rather, they shared a common ancient history with other peoples who underwent the long gradual process of agriculture. It was their eventual achievement of substantial surplus that allowed for significant division of labour as well as for the use of money in exchanging the fruits of their labour.

It is somewhat remarkable that the Greeks did not have the benefit of a "breadbasket" such as the American plains or Ukrainian steppes. On the other hand they did benefit tremendously from a Mediterranean climate and diverse ecosystems superior for agricultural (and pastoral) purposes to those of the Mayans, for example. Meanwhile abundant coastline allowed them to supplement their terrestrial production with protein and fat intake from fish. Furthermore, there is nothing about the trophic theory of money to deny the relevance of raiding, warfare, and eventually regional trade to increasing food surpluses and trophic development. The long history of Greek warfare — largely successful prior to the Roman Empire — brought with it the spoils of war, including Persian goods. These goods added to what the Greeks produced themselves and had the effect of increasing Greek agricultural surplus, freeing the hands for a further division of labour and the exchanging of additional money.

Agricultural surplus and the quantity of money

If the origins of money are in agricultural surplus pursuant to the trophic theory of money, then it is not far-fetched to hypothesise that the quantity of money — and/or the level

of GDP — is proportional to agricultural surplus. There is in fact plenty of evidence to support this hypothesis. The shekel, for example, originated as literally 180 grains (or "she") of barley (Acton and Goldblatt 2010). One can hardly find a better example of money supplies tracking with agricultural surplus! (Barley reserved for exchange, and therefore not consumed as food, represents a surplus.) The salient point, though, is that the grain of barley could have instead been a gram of silver, nickel, or lead. Although each of these metals was also useful as a commodity, none would have been useful as money per se if the barley (and other food) surplus hadn't allowed for the division of labour and the subsequent exchange of goods and services.

Indeed shekels evolved to become measures of barley in terms of silver equivalent. The weight of the original shekel (i.e., the she of barley) became the weight in silver that was worth one gur (a type of container, hauled on an ass) of barley. In other words, a gur of barley cost a silver shekel, and vice versa (Cripps 2017). Evidently for much of Mesopotamian civilisation, as documented most assiduously in Assyrian cuneiform bookkeeping, this was the case, and these units of barley and silver comprised the primary forms of Mesopotamian proto-money (Cripps 2017). Ultimately, however, barley gave way to minted silver coins — money per se — if for no other reason than coins were far more durable as a store of value. This giving way to silver coins also hints at increasing agriculture surplus, because there is little need for durable storage when grain surplus is a year-to-year concern.

Another indicator of agricultural surplus highly relevant to the trophic theory of money is the percentage of farmers in society. This indicator of surplus is straightforward. If it takes one farmer to support two individuals (including the one farmer), we have 50% farmers, and little demand for exchange. Money is extremely unlikely to originate in such a scenario, although it might be used to some extent if it flows in from adjacent regions where agricultural surplus is high. (Money might also originate if the small surplus is predictable and reliable for lengthy periods of time, but that is notoriously rare in agriculture). Conversely, if one farmer supports 10 economic actors, we have 10% farmers, and palpable demand for exchange. Money is likely to originate in such a scenario; alternatively, if money circulates in adjacent regions, it is likely to be adopted.

As a variable affecting the origins of money and money supplies, the percentage of farmers offers insight into why the Mayans never quite "advanced" to the stage of money per se. As Diamond (2005:164) described, "At least 70% of Maya society consisted of peasants… because Maya agriculture suffered from several limitations." These limitations included low yields, low protein production, and difficulty storing crops due to a humid climate. Each of these limitations would have precluded substantial division of labour or the development of a thorough trophic structure. What little division of labour occurred was primarily into soldiering and slavery (for serving soldiers and nobility).

In sharp contrast is the modern United States, where farmers comprise approximately 2% of the population and each farmer can feed "on the average 125 other people" including Americans and among foreign trading partners (Diamond 2005:164). This is a level of agricultural surplus capable of supporting a thorough and rich (in several ways) trophic structure, conducive to a

tremendous amount of exchange, which in turn calls for a means thereof; i.e., money.

Agriculture, money, and environmental impact

Pursuant to the trophic theory of money, the human economy — the size of which is measured by GDP — proliferates in proportion to agricultural surplus. Meanwhile agriculture has environmental impacts (Bodley 2012). Primitive agriculture would have had slight impact, but as agriculture intensified toward the levels required for divisions of labour — and the use of money — so too did its impact. Mesopotamia again provides an early example. The amount of barley (proto-money) cultivated in Mesopotamia — the "land between the rivers" — was a function of the amount of land irrigated along the Tigris and Euphrates Rivers and tributaries. But as Bodley (2012:52) described, "There is clear evidence that intensive agricultural practices in ancient Mesopotamia, where irrigation causes the gradual accumulation of salts in the soil, were also contributing factors in the fall of Sumerian civilisation after 2000 [BC]."

Obviously, too, the mining of silver and gold has pronounced environmental impacts. The fact that these metals have long been the primary metals used in coinage is symbolic of the fact that all extractive activities near the base of the economic trophic structure have a heavy footprint on the environment. Yet the obviousness of these impacts should not obscure the effects of all economic sectors throughout the trophic structure of the human economy. All sectors have direct environmental effects, but more profoundly, all are portions of an economy that grows as an integrated whole. Due to the tremendous breadth of the human niche, this trophically structured economy grows at the competitive exclusion of non-human species in the aggregate (Czech et al. 2000). The staggering loss of biodiversity is perhaps the greatest indicator of environmental impact (Wilson 2017).

Indeed most if not all the areas associated with the early use of money are also associated with early episodes of ecological degradation and limits to growth. For example, the Yellow River Basin is the "cradle of Chinese civilisation" (Feng et al. 2006:125) where Chinese agriculture and money originated. There, too, millennia of trophic buildup have led to an environmental crisis of equally historic proportions. It is no coincidence that the Loess Plateau (along the Yellow River) is the first region identified in assessments of Chinese environmental history (see for example Maohong 2004). The plateau "had been over-cultivated and overgrazed, resulting in soil erosion and a criss-cross network of gullies, following the development of civilisation in the Yellow River valley" (Maohong 2004:480).

Circular flow of money

In conventional economics and business textbooks, the economy is often modeled as a circular flow of money, with factors of production flowing in one direction and payments thereto in the other. In circular flow diagrams, the factors of production are often limited to labour *L* and capital *K*. Money certainly does flow between labour and capital. Capital pays wages; labour turns around and purchases from capital, and there is an obvious circularity to the process.

Unfortunately the circular flow of money depicted in textbooks typically leaves out the ecological context, as well as a crucial factor of production. While the circular flow displays labour and capital as the factors of production, it typically leaves out land, which is at once an essential factor of production and a boundary within which labour

and capital must operate. This omission is wholly conducive to the broader neoclassical propensity to ignore limits to growth. In a sense, the omission reflects the "landless production function" of output $Y = f\{K,L\}$ (Czech 2013:158). With the circular flow of money and the landless production function in mind, the student can hardly avoid envisioning the economy growing outward into boundless space.

The trophic theory of money alleviates this problem because merely including money in the circular flow diagram accounts for agricultural surplus and environmental impact. With the trophic theory of money, the circular flow can hardly be considered without recognising limits to growth. The circular flow suddenly becomes a demonstration of how money cannot become unhitched from the real economy. It must indeed reflect the flows between capital and labour. These entities are readily recognised as actors in the trophic structure of the real economy. If the trophic structure is not more heavily drawn upon (i.e., without additional surplus at the agricultural base), the injection of more money fails to reflect what is happening in the real economy. Instead, it is simply an episode of inflation.

Money, GDP, and finance

It is a common misunderstanding outside the world of monetary policy and national income accounting that the traffic in recent years of financial products such as rainbow derivatives with iron butterfly options purchased online, perhaps even with Bitcoin, somehow represents a "new economy." This misunderstanding, which even afflicts environmental and ecological economics, readily morphs into the notion that we live in an "information economy" unrooted or decoupled from biophysical throughput. In reality financial speculation itself has no effect on GDP or real money supplies, although it is suspected of having an effect on nominal GDP (Sipko 2011).

Speculation itself should not be confused with the services of the brokers, agents and bankers who earn an income for assisting customers fulfill their speculations. This distinction — service vs speculation — helps clarify the real nature of GDP. Speculation is similar to gambling whereby the speculator "bets" (presumably with some analytical insight) on the chances of particular trends in interest rates, stock prices, insurance claims, and a wide variety of other financial data. Nothing in the trophic structure of the economy is produced or consumed in the act of speculation. However, the placing of bets requires transacting, recording, and accounting, performed by brokers, agents and bankers. These are real people using real energy and material (e.g., office equipment and supplies) to provide a real service accounted for in GDP. The key point, vis-à-vis the trophic theory of money, is that none of the brokers, agents or bankers would be operating in the absence of agricultural surplus. Their income required real surplus at the trophic base of the economy.

Perhaps an even better example is of gambling per se. If a gambler "spends" a million dollars at a casino and returns with a thousand dollars short of that, GDP doesn't increase by a million; rather by somewhat less (accounting for casino depreciation) than the one thousand that went toward the wages of casino employees and the profits to the casino owner and creditors. The approximately $999,000 difference was but a whirlpool outside the circular flow of money, a sort of sideshow the gambler paid to watch, with the services of casino employees.

Likewise, the trophic theory of money says nothing about purely financial (or gambling) activity; only the real labours of those hosting and administering such activity. Therefore flow variables such as "volume of transactions" are not particularly relevant for assessing the trophic theory, because many transactions occur in purely speculative settings. These transactions divert money from the circular flow, similar to play diverting an animal's energy from feeding or reproduction. The trophic theory of money is focused on the origins and quantities of real money supplies and productive flows accounted for in GDP, as reflected for example in the activities listed in the North America Industry Classification System (Office of Management and Budget 2017).

Meanwhile, in managing the money supply, the Federal Reserve System (and analogous monetary authorities in other countries) is focused primarily on staving off high rates of inflation (Axilrod 2013). Although the Fed is hardly known for an ecological background, economists at the Fed (as well as accountants in the Bureau of Economic Analysis) have developed a feel for keeping the money supply in balance with the real sector and its trophic structure. For the money supply to accurately reflect the production and consumption of goods and services in the aggregate is the essence of the phrase "real GDP."

The trophic theory of money under scenarios of recession and collapse

As a basic rule of ecology, any species that uses continuously more energy and resources — as *Homo sapiens* does in the process of economic growth — will reach or breach its carrying capacity. Pursuant to the trophic theory of money, the distinction between reaching and breaching capacity (which may be referred to synonymously as ecological or economic capacity) can be assessed with GDP. Reaching capacity will amount to a stabilization of GDP, or a steady state economy. Breaching capacity will result in declining GDP; i.e., recession or degrowth. If the recession is abrupt and substantial, the scenario may warrant the label "collapse."

Therefore, when economic growth is continuously prioritised, there comes a time when real GDP declines while the environmental impact of economic activity continues to grow. Environmental impact continues to grow due to ecological momentum (such as ecosystem unravelling as a function of climate change), anachronistic efforts to stimulate the economy (such as loosening environmental protections), and the getting by of millions or billions of people, many of whom are now (by definition of collapse) attempting to grow their own food on a crowded and exhausted landscape. This by no means refutes the trophic theory of money. Rather, the dissipation of GDP under these circumstances is analogous to a chemical reaction culminating at a titre level. Instead of being refuted by collapse, the trophic theory of money provides insight to foresee (and potentially obviate) collapse. For example, when a nation's fiscal, monetary, environmental and social policies are designed increasingly for GDP growth, without the desired effects, leaders should recognise that real fundamentals are no longer conducive to growth. Pursuant to the trophic theory of money, these fundamentals include the agricultural and extractive resources available for further capitalization at the trophic base. Conversely, without the trophic theory of money, it is easy to envision policy makers pursuing wispy notions of "dematerialised" GDP.

Variables affecting the relationships among trophic levels, GDP, and environmental impact

The trophic theory of money does not imply that nothing except agricultural surplus affects GDP and real money supplies. We have already noted inflation and accounted for it with phrases such as "real money" and "real GDP." Two other variables are worth mentioning: technological progress and the propensity to use money as a means of exchange.

The effects of technological progress on GDP and real money supplies are relatively straightforward, even if not widely understood. Technological progress is not manna from heaven. Rather, it occurs as a function of research and development (R&D), which in turn is a function of economic growth based upon pre-existing technology (Czech 2008). This latter aspect is overlooked in Pollyannaish visions of dematerialisation. With a firm grasp of the relationships among economic growth, R&D, and technological progress, there is nothing surprising about the declining rates of total factor productivity that seem to perplex many economists and economic journalists (see for example *Economist* 2017). The natural resources available at the trophic base have been heavily harvested over millennia, and many natural capital stocks have been liquidated. The low-hanging thermodynamic fruits (e.g., concentrated minerals lying close to the ground, abundant fisheries, oilfields with high energy return on investment) have been picked. Meanwhile new technologies do nothing to change the trophic demands of the economy. Water, for example, cannot be substituted for. The trophic structure of the economy is fully fleshed out as congruent with Daly's concept of a "full-world economy" (2007:76). R&D is inching to the limits of its capacity to produce new technologies that increase productivity, not for any lack of human imagination, but rather for lack of the real resources required for economic growth. Therefore, technological progress is having less of an effect on GDP and real money supplies than it did in the 20th century. As total factor productivity reaches its limits, so too will the effects of R&D on GDP and real money supplies.

The propensity to use money as a means of exchange self-evidently affects real money supplies. In-home provision of services or widespread reversion to bartering, for example, would lessen the demand for and necessity of money. Nothing about the effect of this variable affects the trophic theory of money or the validity of its corollaries.

Linguistic and rhetorical considerations

The phrase "trophic theory of money" offers substantial linguistic advantages. First, it is clear and concise. It is as it sounds; i.e., a theory of money based upon the trophic principles of ecology. The emphasis on trophic principles is warranted as described in the preceding sections for, without trophic maturation, money does not originate. Although the word "trophic" is somewhat academic, the clarity, concision, and appropriate emphasis of "trophic theory of money" is superior to "money as a function of agricultural surplus" or other less efficient phrases.

"Trophic theory of money" also offers the rhetorical advantage of communicating, emphasising, or reminding readers and audiences of the ecological basis of the economy. As such, it offers the field of sustainability science its own theory of money; a theory most congruent with an emphasis on the

laws of thermodynamics and principles of ecology. It serves to belie the unsubstantiated proposition that real GDP may somehow be de-linked from environmental impact.

Conclusion: the generation of money

Nothing, perhaps, should grate the senses of the sustainability scholar more than the loosely issued phrase "X generated millions of dollars of income," where X might be golfing, shooting, or even gambling. The only activity that clearly qualifies for the title of "generating" money is agriculture. It is agricultural surplus that frees the hands for the division of labour, even unto the entertainments of golfing, shooting, and gambling. Money is spent on these latter activities, not "generated" therefrom.

Not even construction, auto making, or steel refining has a legitimate claim on "generating money." The only activities that might qualify for consideration, other than agriculture, would be those analogous activities that may produce a predictable, widespread surplus of food under conducive ecological conditions. These activities are primarily commercial fishing and domestic livestock production.

With the trophic theory of money we can readily recognise that real GDP and money supplies indicate the amount of agricultural surplus, and in turn environmental impact. Lots of agricultural surplus generates lots of real money; no surplus generates no real money. Limits to agricultural production, therefore, mean limits to real money and real GDP. Long before such limits may be reached, major environmental impacts occur and accrue.

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The circular economy: international case studies and best practices

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What now for the Lucky Country?

The paradox that titled this forum implies movement towards a new future but admits significant uncertainty about the direction and the final destination. In his 1964 critique, Donald Horne felt that Australia was still a place where arriving immigrants and perhaps the whole nation was still "making life anew". Over half a century later, a fresh and furious impulse of nation building is still underway in Sydney and Melbourne, but there is ample evidence of a Britain-like transition to a post-industrial services economy where China supplies so many of the goods purchased. As an American who arrived in Sydney after long periods living in Britain and Shanghai, this author observes a bifurcated society with one half rapidly realising how consumption orientation and consumerism are incompatible with the fundamental value many Australians assign to the social amenity of natural beauty, the continent's uniquely fragile flora and fauna, and the national 'fair go'. "Towards a prosperous yet sustainable Australia — What now for the Lucky Country?" It's a well-aimed question. This author sees a rising generation of young people who reject the consumerism that was imported from America in the '50s and '60s. Older societies like Britain, continental Europe and even China are offering new views of a future economic model, the so-called Circular Economy. The ageing architects of 20th century industry are being overtaken by a new generation of business leaders and consumers who consciously balance ecology with economy and self-convenience with the preservation of the commons.

This paper and its presentation at Government House in November 2018 offer an answer to the "what now" question posed at the forum. Australians and many others in the world are reacting emotionally to evidence that their personal microeconomic behaviours aggregate to contribute to the decline of planet Earth. This realisation creates the "what now" question. One answer is a transition towards Circular Economy concepts. This paper showcases some of the emerging ideas about what the "Circular Economy" means. It also examines social discourse in 2018 that changed perceptions, created a sense of urgency and may drive Australia over a tipping point of economic and political resistance towards taking action.

Human-centred design

Basic science informs fundamental engineering. When engineers turn their minds towards human needs and practice Human Centred Design, new technologies leap out from laboratories to cross the threshold of successful commercial innovation. Superior new products and processes serve the market of the 25 million people of Australia and then move overseas to build economic impact in the global market of 7 billion

people. This cycle of innovation builds wealth and prosperity for Australians. It builds a high quality of life. Experts who study systems of innovation know that the communities that practice this well build competitive economies that spiral upwards in the global knowledge economy, providing sustainable jobs, strong local enterprises and prosperity.

Human Centred Design yields solutions that support human health and acknowledge that humanity depends upon the health of the entire planet. Sustainable designs support long term cycles of innovation and growth. As basic science has informed the modern understanding of climate change, human impact on flora and fauna, and the role of persistent molecules in the environment such as perfluorinated alkyl substances, there is a demand on engineers and entrepreneurs to acknowledge new science and to develop new designs and new business methods. Engineers and entrepreneurs have a vital role of economic renewal in the innovation cycle.

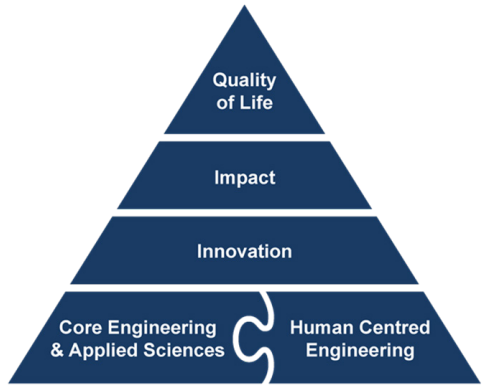

Diagram 1: How engineers and scientists innovate to deliver high quality of life

The Accumulation Problem

The first and most fundamental law of chemical engineering governs material flows in a system: mass in minus mass out equals accumulation. Chemical engineers, and indeed all industrial engineers from the 20th century, have created a problem that can be called the Accumulation Problem.

Societies are accumulating waste. Electronic waste and defunct consumer goods accumulate. The standard 20th century supply chain and production process is a linear process (Brocklehurst 2015). Goods producers extract raw materials, build parts, assemble machines, and sell to consumers. When goods are no longer useful or when consumer preferences change, consumers and societies landfill the obsolescent goods.

Diagram 2: The Accumulation Problem: e-waste. Curtis Palmer / CC-BY 2.0

Diagram 3: The Accumulation Problem: plastic. Shutterstock, licensed to the Warren Centre

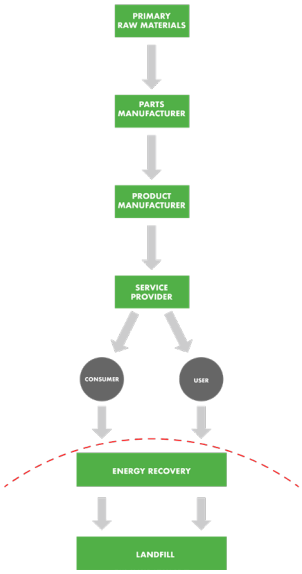

Diagram 4: The Linear Economy: Take, make, use, dispose. ©The Warren Centre, permission granted to reproduce. Adapted from World Economic Forum.

The profitability equation for this manufacturing is also linear. Increased sales revenue requires more raw material extraction, faster product redesign cycles and faster product obsolescence. Existing manufactured goods deployed and functioning perfectly well in the economy must be discredited, superseded or made unfashionable to drive demand for premature retirement from use to drive sales of new models. Incremental new functionality features and trivial changes in form factor and visual cues communicate between goods owners who has a trendy mobile phone, the newest automobile and the latest smart watch. In this linear economic system, increased profit is correlated to increased extraction and landfill waste.

Plastics that were engineered for the remarkable chemical stability of their polymer molecules are accumulating in oceans and on beaches. An often-cited statistic warns that the rate of accumulation of plastic in the oceans will lead to a day in the middle of the century when the mass of all the plastic in the oceans is greater than the mass of the fishes in the oceans. The Accumulation Problem is real.

The Circular Economy alternative

The Circular Economy is an idea that the linear process should be turned into a cycle of distribution, use, re-use, repair, collection, sorting, and recycling. However, the Circular Economy is much more than just recycling. A fundamental re-design revolution is required for products and production processes. This is not a small task, and in many sectors, it is not an incremental task.

The concepts that constitute the Circular Economy are emerging but are not presently exact and definitive. In different countries and among different thinkers, there are multiple conceptions.

Diagram 5: The Circular Economy—Raw materials to residual waste. ©European Union, used with permission

Some concepts present separated biospheres of agriculture, fresh water systems, sanitary waste and fertilisers connected to

industrial production processes that produce energy, use water, produce chemicals and manufacture goods in urban, suburban and industrial land use environments.

Diagram 6: Connected urban, industrial, agricultural and nature segments.
© WWF Bioplastic Feedstock Alliance, used with permission

The Share Economy: "Why buy a car when you can Go Get?"

Within these conceptualisations, recurrent themes broadly define the Circular Economy. The Re-Manufacturing Economy refurbishes, upgrades and re-deploys used goods. Instead of owning the photocopier, hardware is serviced continuously by the copier company. Instead of purchasing consumable ink cartridges, the contract supplies photocopies on demand at a variable cost. Ownership transforms towards a services orientation. New business models of the Share Economy are increasingly relevant. Why buy a car when the passenger can call a taxi? Why dedicate capital to a yellow taxi if car owners share their capital on Uber, Lyft or Ola or if drivers share in Car-Next-Door or GoGet schemes?

Reddy Go, oBike, MoBike and Lime mobile phone apps enable on-demand use of dockless bicycles and e-bikes. Local manufacturing, local remanufacturing, distributed manufacturing technologies like 3D printing, and local food production are themes within the broader Circular Economy discussion.

Diagram 7: oBike at Putney Bridge, London, by EdwardX / CC-BY-SA 4.0

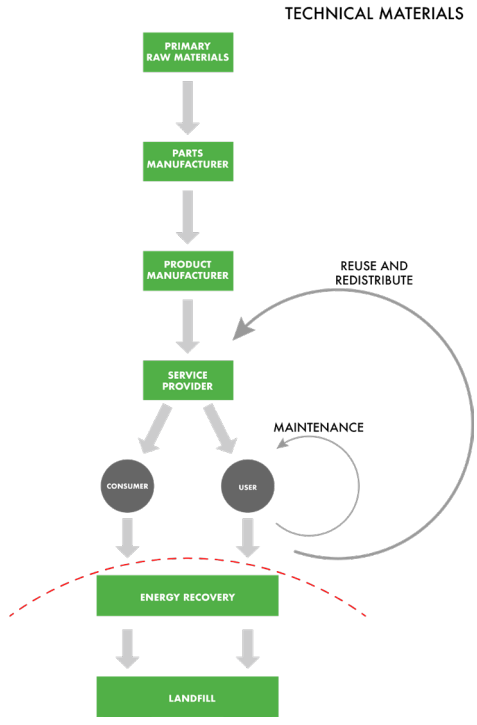

Diagram 8: Service Systems ©The Warren Centre, permission granted to reproduce

Industrial aggregation and Denmark's experience

The first step is industrial aggregation. From head to tail, in the bio and techno-spheres, integrated suppliers and consumers can be co-located to gain economies of scope and economies of scale in materials and energy efficiency.

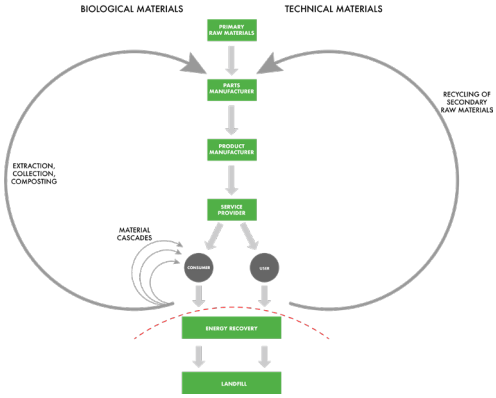

Diagram 9: Industrial Aggregation in biological and technical spheres ©The Warren Centre, permission granted to reproduce

Diagram 10: Kalundborg Power Station in Denmark, CC0

The case study of the Kalundborg Denmark Eco-Industrial Park demonstrates advantages of industrial aggregation (IISD 2013). The Kalundborg Park developed between the 1960s and the early 1990s. A 1.5GW coal-fired power plant supplies electricity and steam. Statoil Petroleum Refinery supplies natural gas and uses waste steam for reboilers. Pharmaceutical supplier Novo Nordisk integrates with fresh water fish farms, yeast processing and the City of Kalundborg sanitary waste water processing to supply fertiliser sludge to offsite land agricultural users.

Gyproc is integrated with the coal-fired power station, and fly ash from the power station feeds an Eco Park Portland cement manufacturer. Elements of head-to-tail recycling are being tested in Australia, but the scale of Kalundborg's industrial integration is far beyond domestic Australian industrial co-location and integration.

Professor Ali Abbas at the University of Sydney School of Chemical Engineering has demonstrated a coal fly ash cement technology that incorporates flue gas carbon dioxide into cement carbonates to reduce CO_2 emissions yielding cement with compressive strength substantially equivalent to conventional cement kiln products. In late 2018, Professor Abbas and colleagues hosted the Australian Circular Economy Conference at Kooindah Waters, Central Coast NSW. Nanyang Technology University Singapore, Tsinghua University, Shanghai Jiaotong University, University of California Santa Barbara and UTS participated. NSW Dept of Industry, IChemE and Engineers Australia participated. The World Economic Forum Beijing and from industry Suez, Downer and Dow Chemical participated. Following the Australian Circular Economy Conference, Professor Abbas said, "It's not just recycling. We've got to redesign *everything*. Everything you see around us, it ALL has to be re-designed." The technical discussion in Australia must shift from just recycling to design, Advanced Manufacturing, longevity of product life, re-use and re-purposing.

Carbonate trapping cement pellets are an example of tail-to-head industrial agglomeration and recycling. In Scotland, MacRebur company is replacing petroleum tars in asphalt with pelletised recycled plastic. Several domestic Australian innovators are demonstrating plastics recovery processes to convert ploymers to olefins, diesel fuel or clean hydrogen gas. These steps are substantive and important, but they are not enough. Recycling is necessary, but not sufficient, to address the scale of the Accumulation Problem.

China's approach to the Circular Economy

Multiple, successive Five Year Plans by China feature increasing commitment to the Circular Economy (Su et al., 2012). President Hu Jintao, an electrical engineer, led the People's Republic of China from 2003 to 2013. President Xi Jinping, a chemical engineer and lawyer, has led the country since 2013. There is absolute alignment between the government and the single political party. On matters of industrial development, for most of the past 20 years, the Chinese Communist Party acted as an evidence-based, scientifically driven technocracy.[1] When Shanghai banned free plastic shopping bags, the change was immediate, with high compliance, and no turning back. The speed of industrial reform is fast. Integrated industrial aggregation features prominently in the Suzhou Industrial Park and Tianjin Park.

In 2017, China's National Sword Policy prohibited the import of plastic waste starting in 2018. That policy caused shocks in the US, Japan and Germany. Indeed, it shocked Australia. Plastics are diverted to Malaysia, Thailand and Vietnam, but hundreds of millions of tonnes of plastic are stranded globally. Local solutions are urgently needed. Today's supply chains are global. Manufacturing, consumer purchase, and ultimate recycle/recovery geography are not generally local and not integrated-agglomerated due to distance. Global supply chains can appear to be economically efficient in the linear economy if externality costs are zero. However, sprawling supply chains create intermediate stockpiles that can temporarily hide the Accumulation Problem. Disruption in those chains, such as the National Sword Policy, can create shocks.

Europe's Circular Economy design and manufacturing approach

Re-design is critical. The economy must be restructured from a linear economy to a Circular Economy as the European Commission Vice President Frans Timmermans stated in 2015, "Our planet and our economy cannot survive if we continue to pursue the throw-away approach. We must conserve valuable resources and fully exploit their economic value. A circular economy reduces waste accumulation and protects the environment; but it also means a fundamental change in the functioning of our economy" (UNGCNG, nd). Mercedes-Benz, and indeed the whole German manufacturing industry, is redesigning products for maintenance, service, refurbishment, re-manufacturing and redeployment. Germany's DIN Standards are a leading influence upon the development of ISO Standards that are influencing nations adopting the Circular Economy.

A few examples of the thinking and standards follow. DIN 14040 and ISO 14040:2006 are standards for environmental management using life cycle assessment principles and frameworks. The standards

[1] See for example, Zhou (2017).

were formally adopted by ISO in 2016. DIN EN ISO 14044 is closely related. In the automotive industry, ISO Standard 22628 — "Road vehicles — Recyclability and Recoverability — Calculation Method" is an example used by Mercedes Benz. ISO TR 14062 covers the integration of environmental aspects in product development. ISO 14001, ISO 9001 and ISO 14006 are part of a European style design approach alongside environmental certification in accordance with ISO TR 14062.

Industrial design reform

The first older phase of reform, as demonstrated in Kalundborg, was industrial aggregation. The next two newer phases are industrial design reform and the transition from product sales towards lease, service and share economy business models. Each year the Warren Centre features a prominent Australian innovator in the annual Innovation Lecture. Professor Andrew Harris of University of Sydney developed one of the world's largest 3D printers, an invention conceived in Australia and deployed in England to produce mass customised wax forms for concrete acoustic tiles in the London Cross Rail project. Professor Harris stands with one foot in industry, leading Laing O'Rourke's Engineering Excellence playground of new technologies, and one foot in academia at the University of Sydney. At the 2017 Innovation Lecture Professor Harris described how digital design tools yield infinitely and easily customisable production with sensors built into products and infrastructure to allow machine learning and to capitalise on the efficiencies of artificial intelligence. The plastic printer car by Local Motors is an example of digital customisation and local manufacturing. Distributed manufacturing and re-manufacturing further enable refurbishment in situ and new share economy and lease business models like the photocopier example described previously. Some industrial reformers in Europe believe that jobs displaced by robot factory automation might be supplemented by new labour demand in maintenance and refurbishment.

Diagram 11: Apple's Daisy robotic iPhone cracker (Apple press release, 2018b)

Apple has a different idea about maintenance, refurbishment and materials recovery. On a market capital basis in February 2019, Apple is the second most valuable company on the planet behind Amazon. CEO Tim Cook is a leading proponent of sustainable electronics manufacturing. Apple is powered with 100% renewable energy (Apple press release, 2018a). The company's iPhone XR contains 32% bioplastic (Bioplastics News, 2018). In May 2018, Apple announced co-financing for a zero-carbon aluminium smelting pilot process with Rio Tinto Alcan (Ker and Ludlow, 2018). With two billion iOS devices produced, Apple is part of the e-waste accumulation problem. To address this in 2016, Apple demonstrated Liam, a robot that disassembles iPhones for recycling parts. Apple demonstrates not only robotic factory assembly, but now product disassem-

bly by robots. Liam's daughter robot is Daisy, the next generation of phone crackers (*Tech Crunch*, 2018). Daisy is recovering sufficient tin metal that Apple hopes it can close loops and discontinue tin mine extraction in the future.

Thought leadership, influence and the role of public sentiment: a convergence?

Presently, the Circular Economy is an idea being promoted. Some elements are clearly already being demonstrated, but other elements are still hopeful thinking and may even be poorly defined. In the UK, the Ellen MacArthur Foundation catalyses thought leadership on the Circular Economy.[2] The various universities are active in New South Wales, and it is easy to observe engagement and aspirations by tech companies like Apple. Ecological cooperation reached an international pinnacle at the 2015 Paris Conference. Perhaps this forum, "Towards a prosperous yet sustainable Australia", is an indication that aspirations continue to rise.

It appears that a convergence of thought is coalescing. That convergence is social, political and technically led, perhaps "tech sector" led, within the long established environmental and sustainability discourse. Today's technologists are increasingly politically active, and they skilfully use digital media platforms to influence social attitudes.

Students aspire to align careers to sustainable goals. At the University of Sydney, Professors Maryanne Large, Andrew Harris and Ron Johnston built a program called "Invent the Future". Ph.D. candidates from science, engineering, business and design faculties collaborate to imagine a new product or service innovation to commercialise. The Biochite/Carapac team developed a bioplastic film. Company co-founder and agriculture PhD candidate Michelle Demers hopes to sell this plastic made from polymerised, recycled seafood shells to mushroom farmers to displace petroleum plastics. This rising generation of students and researchers has the aspiration to solve the so-called wicked problems inherited from the last century.

Diagram 12: Carapac bioplastic film © Carapac, used with permission, and permission granted to re-use by Royal Society

Based on solid science and the precautionary principle, a significant, influential segment from the professional technical community sees the impact of the accumulation problems of e-waste and plastics. They use social-political-technology convergence to influence public opinion and business decisions. On June 8, 2018, the Thailand Department of Marine and Coastal Resources uploaded photographs of a whale autopsy onto Facebook. Eighty plastic bags were removed from the belly of the dead whale and displayed for a photograph showing some of the blood of the whale (Sriring, 2018).

Three weeks before the Thailand whale incident, McDonald's USA shareholders met and voted down a proposal to discontinue single-use plastic straws (Meyer, 2018). Four weeks after the whale autopsy social media

[2] https://www.ellenmacarthurfoundation.org

Diagram 13: Plastic bags removed from Thai whale. Placed in the public domain by Thailand Department of Marine and Coastal Resources

furore, Starbucks announced a phase out plan for single-use plastics.[3] A long-time environmentalist, Sir David Attenborough, is increasingly using his public persona to leapfrog over today's business leaders and engage directly to the new generation of children and, of course, to their mothers who are the next generation of consumers. This consequential social media and traditional television media influence on young family consumers is a new force indirectly influencing corporate shareholders and boards of directors. "The David Attenborough Effect" via Facebook and digital media shapes public opinion and influences business decisions. Mothers and children love whales. The Thai whale photograph unmistakeably associates plastic bags with death.

On June 9, 2018, social media feeds were inundated with images of floating plastic from a garbage patch at the Dominican Republic in the Caribbean (Kratz, 2018). #StrawsSuck began trending in June 2018.

[3] "Starbucks" (2018).

While US President Donald Trump tweets that climate change is a hoax, a rising generation of young people is pushing back with a response that is socially conscious, political, tech-enabled and increasingly technologically sophisticated. It is visible globally and supported locally by campaigns such as the ABC's *War on Waste* and student support at Australian universities.

Diagram 14: Student appeal at a USyd café outside the Chemical Engineering School. Photo by author, public domain

On November 20, 2018, photographs of a 9.5-metre dead whale from Wakatobi National Park in Indonesia were distributed. Six kilograms of plastic from hundreds of cups and plastic bags were in the dead animal's belly. The cause of death was unknown, but associations of marine life deaths with plastic have become irresistible on social media platforms.

What next on the science?

Plastics are appearing in numerous unintended environmental locations, and the images frame spoiled natural beauty, ruination of the ocean and death to fishes. It is a public relations challenge for the plastics industry.

Diagram 15: Dead whale filled with plastic waste, Wakatobi National Park, Indonesia. Public domain, Twitter, WWF Indonesia

As the anti-vaxxer phenomenon has shown, science and conspiracy theories on internet platforms can intensify or distort public perceptions of risks, especially where there is a significant scientific question with an absence of reliable research or where there is weak research combined with deficient science communication from the media (e.g., commercial television breakfast shows featuring the cancer cure of the week stories). Through product stewardship and extensive toxicity testing, there is general industry and scientific community acceptance that plastic materials in macro form are not toxic to humans. However, eroded microplastics are appearing in the human food chain, and new questions are being asked. Table salt (Yang et al., 2015), fish (Karami et al., 2017), saltwater oysters and fresh water mussels (Rochman et al., 2015) have shown microplastics contamination. Strict curb side waste segregation and recycling in Germany is recovering kitchen vegetable and fruit wastes to municipal composting programs, but plastics are entering that compost and appearing in fertiliser supplied to German farms (Weithmann et al., 2018). A small scale feasibility study by a Medical University of Vienna researcher included tests from six European countries plus Japan and found microplastics in eight out of eight human faeces samples tested (Schwabl, 2018). The FTIR pilot study showed plastic particles in the size range of 50–500 µm, especially polypropylene and PET. The Science Advice for Policy by European Academies organisation issued a report in January 2019 concluding, "The best available evidence suggests that microplastics and nanoplastics do not pose a widespread risk to humans or the environment, except in small pockets. But that evidence is limited, and the situation could change if pollution continues at the current rate" (SAPEA, 2019). A recent broad review of scientific literature and a critique from an industry viewpoint were provided by *Chemical & Engineering News* in early February 2019 (Scott, 2019). *C&EN* highlights the current concerns of microplastics as: preferential adsorption and concentration of organic pollutants like benzene compounds due to lipophilic surface tension; collection of microbes such as *E. coli* on microplastics in shellfish; and the possibility of transmitting plastic precursor monomers or plasticisers such as bisphenol A into human food chains. It is hotly debated science. However, as the saying goes, "We are what we eat", and clearly people are unintentionally digesting micro-plastics and anything attached to the plastics. Connection of marine and bird deaths attributed to macro plastics obstructing gut function is extending to human health concerns for micro-

plastics. This logic extension will occur with or without validated causation, especially on internet and social media platforms that connect to viewers first on an emotional level based on shock and fear and then later on an intellectual level after the cognitive bias has already been activated.

What next on public policy?

Looking forward, the convergence of social-political and tech factors could yield sufficient alignment to trigger a tipping point. This will be obvious when governments begin to use the words of economists to justify legislation and regulation to implement Circular Economy reforms. Governments are themselves massive purchasers. Secondary materials markets are presently insufficient for recycled materials, but governments could create markets using their procurement powers.

In late 2018, NSW Government released a Circular Economy Policy Statement. In early 2019, a Circular Economy Innovation Network was initiated prior to the State's 2019 election season.

In early 2018, the Warren Centre released a report on the Circular Economy. In its conclusions, that report describes the legislation, logistics, technology and linear economy inertia barriers needed to achieve change. These actions were also identified as important steps towards the circular economy:

- Pricing of negative externalities through taxation or trading schemes
- Support for businesses transitioning to circular economy concepts
- Further research and development in materials science for more efficient identification and separation of plastics
- Information systems to create databases of secondary raw materials
- Establishment of secondary raw materials commodity markets

Conclusion

"What now for the Lucky Country?" There is strong evidence for the case for re-designing industries and products to align towards the Circular Economy. Increasingly, public opinion in Australia aligns towards support for Circular Economy concepts, especially due to social-political-digital technology influences. A new generation of young Australians connect as global citizens on worldwide digital media platforms, experiencing in real time environmental incidents that occur anywhere in the world. This generation questions the consumerism of the 20th century and appears keen to adopt a new Circular Economy. Some businesses are already re-engineering themselves to align with the aspirations of a new generation of consumers and customers. Governments are also taking action.

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Unearthing a new frontier: the ABS Environmental-Economic Accounts

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Abstract

Environmental-economic accounting, utilising the System of Environmental-Economic Accounting (SEEA) as a framework, is a field that is rapidly beginning to show its importance around the world. This paper provides a brief introduction to the SEEA and outlines its importance, also addressing issues around big data and data integration.

Why the SEEA was developed

"A country could exhaust its mineral resources, cut down its forests, erode its soil, pollute its aquifers, and hunt its wildlife to extinction, but measured income would not be affected as these assets disappeared" (Repetto et al., 1989). The development of the SEEA was driven by a desire for more complete and integrated information on the economy and the environment and the interactions between the two. This is due to the increasing realisation that economic prosperity is dependent on the ability of the environment to supply natural resources and to absorb pollution (and to support life on the planet), and that environmental policies can impact the economy and vice versa. Natural assets and the services they produce are not fully quantified in the System of National Accounts (SNA) — this means that decisions are not always informed about the long-term implications of depleting non-renewable assets.

Gross Domestic Product (GDP) is one of the key indicators presented in the SNA, which includes estimates of the value of natural assets where they fit the definition of an economic asset. An economic asset must have an identifiable owner and the owner must be able to hold or use these assets for economic gain. It has been recognised that there is a need to consider a broader range of benefits, and this gave rise to the SEEA. Through experimental application of the SEEA Central Framework and its companion, the guide to Experimental Ecosystem Accounts, countries are starting to explore the possibilities of this approach. An example is China's interest in developing a measure of Gross Ecosystem Product (GEP), proposed by the Chinese Academy of Sciences, as an indicator for natural capital.

What is the SEEA?

The SEEA is a measurement framework that can provide a range of metrics that link information on the environment and the economy. This integration is achieved through the use of common formats, classifications and standards. It is effectively a series of accounting tables that seek to record, as completely as possible, the stocks and flows relevant to the analysis of environmental and economic issues. The SEEA has the great advantage of being one of only two international statistical standards, having the endorsement of the IMF, World Bank and United Nations. This imprimatur and standardisation encourages the development of comprehensive and consistent datasets over time. Importantly, SEEA accounts are structured in monetary and *physical* terms. It is difficult to compare accounts simply using physical units of measurement (e.g. megalitres, petajoules), so monetary measures are required.

SEEA was endorsed as an international standard in 2012. Although SEEA has been around since the early 1990s it is still in its infancy compared to the SNA, which was first published in 1953.

Challenges the SEEA was designed to address

The fragmentation of information in silos and data "puddles" is a major barrier to achieving integrated decision-making. The high degree of specialisation in scientific fields, and the tendency to study specific problems at a point in time, or commission one-off consultancies, creates dense "puddles" of data that can be difficult to connect, and do not offer capacity for time series analysis, which is so critical to understand the implications of potential decisions. A vast field of information puddles is therefore lying dormant, unconnected and isolated after the heady media attention on day one, and perhaps the odd citation in the academic press. There have been efforts to pull the puddles together through initiatives like the State of the Environment Reports that collate a range of environmental metrics, however these are not inclusive of the economic perspective. By bringing all these elements together in accounts under a broad framework, the SEEA provides a platform that enables visibility of environmental data to decision-makers in non-environmental portfolios.

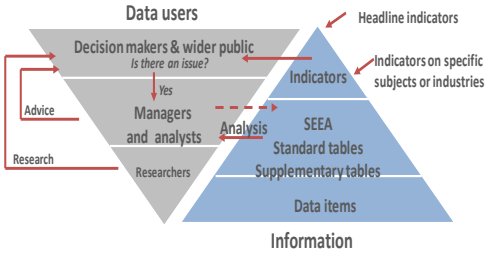
Secondly, as discussed above, there are barriers around values, languages, and philosophical approaches. At the moment it is often the case that there are two distinct narratives competing, each with their own proponents: one for economic development and the other for environmental protection. As long as these two narratives remain separate, competing, and speaking different languages with different value systems, then it is the decision-makers who must take on the burden of somehow evaluating the relative strengths of these arguments, and choose to be swayed either one way or the other. Many of the decisions that affect the environment are made in the economic sphere. Unless we institutionalise frameworks like the SEEA, these decisions will not automatically be made with the full picture in view.

One of the strengths of environmental-economic accounting systems is that they work well even when not all of the required data are available. Because the components are designed to sum to a whole, an account can reveal what is missing and help to make assumptions or hypotheses about the missing pieces. In the case of environmental-

economic accounts, it can inform those assumptions through knowledge of what is going on in the economic sphere — this may help explain the changes in the physical environment, and vice versa. Investing in a system of accounts, rather than separate puddles, also allows for that all-important longitudinal view.

There exist differing viewpoints around the challenge of placing a value on nature — these are presently on the research agenda of the UNCEEA. "One of the softer but still tangible results of doing accounting is that we now have ecologists and economists talking the same language. I feel quite a sense of achievement when I hear ecologist colleagues referring to assets and services and the need to monitor both in a more holistic way, treating the ecosystem as a whole as the asset and the components of the ecosystem (biodiversity, soil etc.) as indicators of the quality of the ecosystem." (Rocky Harris, from the UK Department of Environment, Food and Rural Affairs).

The figure below presents an idea of how the different levels of accounting are utilised by different parts of the professional community to meet their needs:



For example, researchers and modellers are more likely to be interested in the detailed source data, but, as you make your way up the line, policy analysts and managers are likely to look for more synthesised information, and policy advisers and decision-makers are more likely to focus on distilled indicators relevant to their context. The SEEA tables form the middle layer, organising a variety of source data into formats that can be used to generate indicators.

Accounts make hidden data visible

The SEEA can be used to produce indicators that are derived from a clear set of accounting principles that relate logically to the base accounts and down to the primary data. The Australian Bureau of Statistics has focused on such economic measures because economic statistics is one of our primary domains — it is our core business. Many other indicators can be produced from ecosystem accounts, however the full realisation of this is beyond the ABS's expertise or remit.

A lot of relevant data fades from memory because it is collected in isolation rather than as part of a system. It becomes part of the hidden part of the data iceberg. Better return on investment can be achieved when data exercises are undertaken in ways that lend themselves to incorporation into a publicly accessible system of accounts that measures change over time across a range of dimensions. There will, however, be cases where these existing puddles can be incorporated into specific accounts right now, and that is fine as well. In this way the SEEA can help make visible important data that should be available to decision-makers right now.

We have only just scratched the surface in terms of the indicators that can be established using SEEA. For example, much work is being devoted to monitoring the UN Sustainable Development Goals (SDGs) — Mexico conducted some work earlier this year as part of a UNCEEA working group to map the goals to possible SEEA indicators, proving that a whole host of the SDGs can be monitored using SEEA accounts. For

example, in SDG6 — "Ensure availability and sustainable management of water and sanitation for all" — there are a number of indicators that can be supported by SEEA Water Accounts, including:

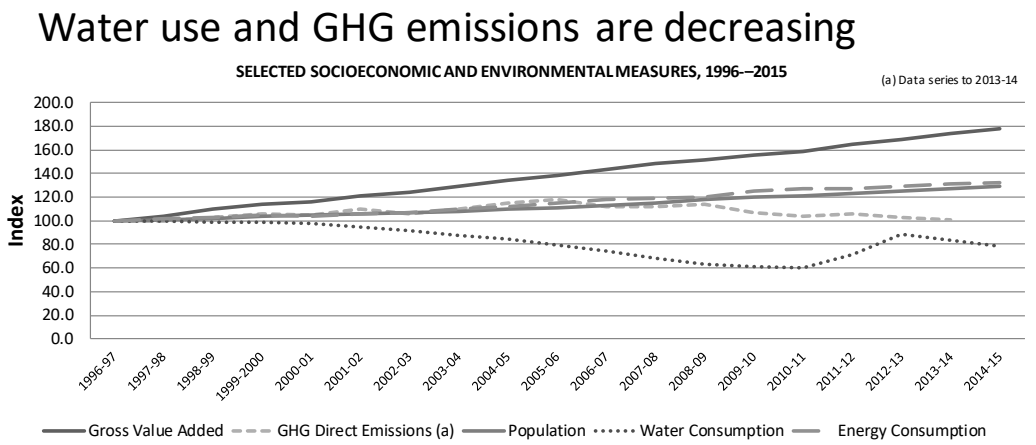
- 6.4.1 Percentage change in water use efficiency over time,
- 6.4.2 Percentage of total available water resources used, taking environmental water requirements into account (level of water stress), and
- 6.6.1 Percentage of change in the extent of water-related ecosystems over time.

Further, in SDG 7 — "Ensure access to affordable, reliable, sustainable and modern energy for all" —the energy accounts could measure:

- 7.2.1 Renewable energy share in the total final energy consumption,
- 7.3.1 Energy intensity measured in terms of primary energy and gross domestic product (GDP).

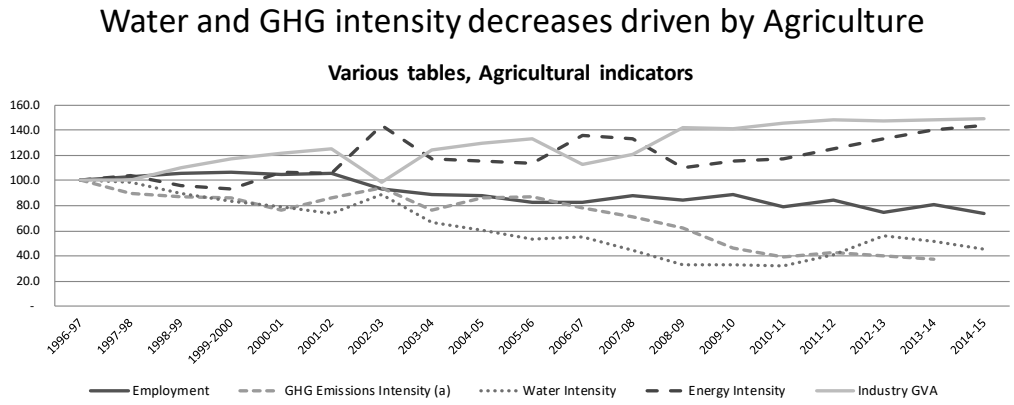
These are just a few of many examples.

The standard SEEA indicators that the ABS has traditionally published are resource intensity and decoupling measures. These show the economic value add per input of natural resource. The diagram below, from the ABS publication "Australia's Environmental-Economic Accounts", presents improvements in water efficiency and GHG emissions.



The top line shows that gross value added is growing while the use of water per unit of economic production is decreasing, as is the rate of GHG emissions.

When we want to know what we are doing right to achieve those results, we can drill down to see that these improvements are driven by improvements in the agricultural sector, where water and greenhouse emissions have become 'uncoupled' from the economic growth: that is they are going in the "other" direction.



Who are the end-users of the Accounts?

Currently there are more than 70 countries worldwide that produce SEEA accounts and there are a range of end users, primarily government.

An exciting development is the "Natural Capital Accounting and Valuation of Ecosystem Services" project, funded by the European Union and supported by implementing partners the United Nations Statistics Division (UNSD), the United Nations Environment Programme (UNEP) and the Secretariat of the Convention on Biological Diversity (SCBD). As a part of this project, China joins four other mega biodiverse countries — Brazil, India, Mexico, and South Africa — as a strategic partner in the creation of pilot ecosystem accounts under the SEEA Experimental Ecosystem Accounting (SEEA EEA) framework. The project is emphasizing links between the accounts and critical environmental challenges to ensure the information informs actual policy choices. As mentioned previously, emerging from this process is the development of a new measure of "Gross Ecosystem Product (GEP)", proposed by the Chinese Academy of Sciences, as an indicator for natural capital. China's president Xi Jingping has elevated the principle of "harmony between humankind and nature" to a central place in the nation's Global Vision.

The U.K. Office of National Statistics recently published a report on the monetary valuation of vegetation surrounding its urban and rural areas in removing harmful pollution and reducing healthcare related costs, based on SEEA-EEA accounts. These accounts showed a billion pounds of healthcare costs avoided due to ecosystem services provided by trees.

The ways in which SEEA indicators can be used are myriad, including:

- Fiscal policy settings (e.g. taxes, levies, subsidies, offsets);
- Regulatory levers (e.g. environmental protection, land clearing restrictions, catch limits);
- Assessing options for planning and economic development (urban development, land use, infrastructure, industry);
- Assessing policy options across the range of sectors (waste, pollution, trade, energy, water);
- Monitoring progress and evaluating the effectiveness of policies and programmes (SDGs, Green Growth, sectorial policies).

There is currently a significant focus on agricultural sustainability/natural capital accounting and the ways in which farmers can continue to demonstrate improvements to the land they work on to improve long term sustainability and levels of business risk. Users such as banks, insurance brokers, superannuation agencies and the like are playing a stronger role in this space.

Examples of accounts such as the ABS's Great Barrier Reef regional ecosystem accounts show that there are a multitude of possible users due to the broad lens indicators we have included to measure the surrounding lands, rivers and ocean. As an example, if the reef were to deteriorate further this could have a greater effect on tourism, which in turn would affect the businesses in the region, then the employment, then the agricultural production feeders into the region, that could in turn affect the way the land is used, and therefore quality of soils, etc. Across this chain of impacts are potential users — we need to look to service further collaboration around particular issues.

Big data possibilities

"What difference can big data make in expanding research and analytics possibilities? What are key risks and challenges?"

Turning these questions around — what can the accounts do for big data and expanding the use of derived information for research and analytics? One of the key risks with big data is lack of coherence with other statistics or accounts. While they are a great source of information and potential, they are invariably scattered, lack cohesion and in some respects are an inferior data set to data that are directly collected. Despite this, they are usually cheaper to obtain and can include other variables of interest which will tell a good story.

Potential big data sources include: Satellite, Sensor, Scanner, Web scraping, GPS and Telco data. The accounts can assist by aligning broad concepts that can be applied to big data; they can help to refine information being derived from the dataset and then have some coherence with other information sets that have ownership (industry/sector) and an environment product in mind. Once this coherence is settled then you can move on to other things. For example, if the data set is supposed to be a comprehensive data set, then aligning information into the accounts can quickly show up gaps, inconsistencies and enable some editing (e.g. do people really pay $10 per litre for diesel?).

Another example: if there is research interest in determining the reasons for change, then pushing the dataset into an account can highlight the changes and where further characteristics can be applied more broadly for testing hypotheses, examining longitudinal effects or looking for correlation in panels or in similar data clouds analysis.

The potential for using big data in SEEA accounts is still exploratory. It was the main focus of a workshop on "Earth observation for environmental-economic accounting" held in May 2018. The workshop was jointly organised by the ANU Centre of Water and Landscape Dynamics, Australian Bureau of Statistics, Commonwealth Department of the Environment and Energy, and Geoscience Australia. The event brought together a transdisciplinary group of 40 experts in environmental policy, environmental accounting and Earth observation to discuss issues and opportunities in the use of Earth observations (EO) for Environmental-Economic Accounting (EEA). It was one in a series of Environment & Society Synthesis workshops supported by the Australian National

University's Fenner School for Environment & Society.

The workshop responded to challenges such as the requirement for spatial data on different aspects of environmental composition and condition (e.g. land cover type, vegetation health) and the natural resources and other ecosystem services it provides (e.g. biomass, soil protection). The scientific literature shows that Earth observation should be able to provide at least some of these data in a cost-efficient manner, however it currently does not. The workshop was an opportunity to further this potential but there is still much progress to be made in this space.

Can accountants really save the planet?

"I found I had stumbled into what I soon realised was a revolution … taking place in the least likely realm of all: our accounting systems" (Jane Gleeson-White).

The above is taken from Jane Gleeson-White's *Six Capitals*. The subtitle of this book "The revolution capitalism has to have — or can accountants save the planet?" is a very catchy one. In many ways the SEEA is the statistical community's gift to the universe. The SEEA does present a possible solution to the problems of overconsumption of national assets inherent in the dominant economic paradigm. Importantly, it does so from within that same paradigm. However, the truth is that accountants alone cannot save the planet, nor can statisticians, economists or ecologists or hydrologists or spatial scientists. But if we come together through our various disciplines to build a working system of integrated accounting so that decision-makers have the information they need to make evidence-informed decisions, well we might just do it — together.

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Australia's AI future

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Abstract

How can Artificial Intelligence (AI) improve the economic, societal and environmental well-being of Australia? I explore why AI is now able to take on a range of cognitive tasks. I discuss the technological challenges remaining to build intelligent machines. In addition, I identify some of the ethical and societal obstacles that this is, and will be, creating.

Introduction

It is nearly impossible to open a newspaper today without reading a story about Artificial Intelligence (AI), and how AI is taking on some new cognitive task: an AI that can play the ancient Chinese game of Go better than any human player; an AI that can read X-rays faster, cheaper and more accurately than a human doctor; or an AI that can translate English into Mandarin. Where will this end? And how might it impact on life in Australia?

Why now?

You might wonder why AI is starting to gain traction today. Why was it not in 1956 at the end of the famous Dartmouth Summer Project which launched the field of Artificial Intelligence? The proposal for that project promised "*a significant advance can be made in one or more of these problems (of getting computers to solve cognitive tasks) if a carefully selected group of scientists work on it together for a summer.*" (McCarthy et al. 1955). But at the end of that summer, little progress had been made by the illustrious group of scientists who had met in Dartmouth to launch the field.

And why was it not 30 or so years later when AI had its first boom — the Expert Systems revolution — during which money and people first flooded into the field? Unfortunately for AI, that boom didn't last. An AI Winter followed in the late 1980s and early 1990s as funding was cut back in the face of disappointing progress.

It is clear now that early researchers in AI severally under-estimated the scale of the scientific challenge in emulating the cognitive abilities of humans. Seymour Papert famously gave Gerald Sussman the task of coordinating a group of 10 undergraduate students over the summer of 1966 with the goal of constructing "*a significant part of a (human) visual system*" (Papert 1966). Susan and his fellow students failed. But fifty years later we have made significant progress towards Papert's goal. Indeed, on the ImageNet benchmark, deep learning systems can now outperform humans in identifying objects in images.

The reason for this recent progress can be traced to four exponentials. Strangely enough, each of these exponentials has approximately the same doubling time: every two years or so. There's no technical or other reason why these four exponentials should double at the same rate. It is just an empirical observation that they have been doing so.

The first exponential has a well known name: it's called Moore's Law. Every eighteen months to two years, transistor counts on chips have been doubling. This roughly equates to a doubling in compute power. For example, our smartphones today have more compute power than took us to the moon and back in the time of the Apollo space race. As a result, some tasks that AI researchers dreamed about even 10 years ago are now technically possible. And if we don't have enough compute power on our devices, we have almost unlimited compute power to call upon in the cloud.

It is worth noting that Moore's Law is officially dead. Chip companies like Intel are no longer aiming to double transistor count every two year. Indeed, it doesn't just become financial difficult to double transistor counts, it becomes physically impossible as you run into quantum limits. Intel and the other chip manufacturers do not have plans any more to build the billion dollar fabrication plants to continue Moore's Law. As a result, there's absolutely no chance at all that we will continue to have a regular doubling in transistor count.

I am, however, not worried that we're going to run out of compute power. We're now designing more interesting architectures like GPUs and TPUs specialised to AI tasks like machine learning. These new architectures will provide improved performance that will continue to drive improvements in AI. Interestingly, chip manufacturers like Intel are looking instead to reduce power consumption, enabling more to be down on our devices.

The second exponential that has been driving improvements in AI is the amount of data we are collecting. Many corporations and governments are waking up to the idea that one of the most valuable things to enable better decisions is data A lot of progress in AI today is driven by the subfield of AI called machine learning. We write programs that learn to do cognitive tasks. We don't know how to write a program to recognise a stop sign. But we can give a program lots of examples, and it can learn, much like humans do, to recognise such a sign. This requires lots of data — thousands if not millions of examples of stop and other traffic signs. Increasingly, we have that data as enterprises collect lots of data about their operations, and individuals collect data via their smartphones and other devices.

The third exponential driving improvements in AI is a doubling in performance of many AI algorithms. This exponential trend has not been running for as many years as the last two exponentials. However, in the last decade or so, we've been making good improvements in the performance of many AI algorithms. One example of this is deep learning, a machine learning algorithm that has powered many recent advances in tasks like perception.

The fourth and final exponential driving progress in AI is nothing technological. It is an exponential increase in the amount of money being invested in the field. This has also been doubling every two years. If you put those four factors in a pot together, you have a recipe for making significant progress towards the challenging problem of building machines to do cognitive tasks.

How much longer?

So, how much longer before we can build machines that match humans in their cognitive abilities? The AIs we can write today only do narrow tasks. For instance, one of the most recent breakthroughs, AlphaZero taught itself to play Go, chess and shogi (Jap-

anese chess) at grand master level (Silver et al. 2018). But it can still only play two player, complete information board games. It cannot play a game of incomplete information like poker. And it certainly cannot translate English into Mandarin, or read an X-ray.

The median estimate of experts in AI and Robotics is that it will take at least 40 more years to match human cognitive abilities (Walsh 2018). When and if we build machines to match the cognitive abilities of humans, we likely have little to fear despite what Hollywood would have us believe. Computers do only what we tell them to do. They have no desires of their own. They are not conscious. And it is not at all clear that they ever will have anything resembling consciousness or free will of their own.

Putting aside such issues, we still have a long way to go to match the full breadth of abilities of humans. For example, it is trivial for most us to fold a towel. But the best towel-folding robot from University of California in Berkeley takes 5 minutes to fold a single towel. That is down from 25 minutes at the start of the project but still nothing like human level at this task.

Towel-folding is an example of Moravec's Paradox: the easy things for humans are often hard for machines to do, whilst the hard things for humans to do are often easy for machine. So it's easy to get a machine to do a hard thing like play Go or Chess, but it's hard to get it to do an easy thing like fold a towel. We have had millions of years of evolution to develop the motor and perception skills to fold a towel. It will take us a while before it is as easy for machines to replicate these.

Whilst human level AI is still some way off, we should be worried about stupid AI. We are already giving algorithms that aren't capable and smart enough the right to make decisions that impact on people's live. Algorithms are already deciding who gets a loan, welfare and even prison sentences. We should be very careful in handing over such decisions to computer.

What can AI do today?

Even if we have some time before AI can match all our cognitive capabilities, there is much that AI can do today that can improve our lives. One of the problems is that AI is already entering our lives but in a hidden way. Every time Google translates some German into English for you, Siri answers one of your questions, or Amazon recommends a book, that is AI at work.

Let me give some Australian examples. If you filed your tax return recently you might have noticed that the Australian Tax Office has a little chatbot called Alex to help you complete the form. Alex is a chatbot, a little AI program. It requires a little bit of intelligence to be able to understand your written questions and that's where Alex comes in.

As a second example, the Sydney Harbour Bridge has been instrumented with thousands of sensors to listen to its vibrations. Machine learning is then used to make predictions as to where and when it needs to be repaired. The goal is to extend the life of this asset indefinitely. This is probably a good idea because we likely can not afford to build a second bridge.

Another example in New South Wales is that a machine-learning algorithm is being used to predict which individuals are most likely to commit crime. This raises serious questions about ethics. One problem here is that we don't have ground truth. We don't know where crime takes place. We have lots of historical data of where we found crime taking place. But that isn't where all crime

took place, just where we happened to be looking. The machine-learning algorithm will learn those patterns, but those patterns may reflect biases that exist within our society. It may be that we sent more police patrols into particular, perhaps poorer neighbourhoods. That doesn't mean more crime actually took place there. We have to be very careful then when we hand over these sorts of decisions to machines as they may perpetuate historical biases.

As a final example in my own work, we have been optimising supply chains for some big multi-national corporations. We have a rule of thumb that we can shave around 10 percent from a company's transport costs. That saves the company a lot of money, but also it saves the planet. The company's trucks will be producing 10 percent less carbon dioxide which is a significant benefit for all of us.

AI in Australia

It is likely that AI will have a large impact on Australia's economy. In 2017, Price Waterhouse Coopers estimated that AI will about 15 per cent to the world's GDP in inflation-adjusted terms by 2030. Some countries will, however, receive greater returns. Top of the list is China where AI may grow the economy by 26 per cent, whereas in Africa, AI might only be growing the economy by five per cent or less. AI may therefore widen inequalities between countries, which is a matter for grave concern.

Many countries around the world have decided to make significant investments in AI to ensure that they get more of the benefits. Most recently, Germany announced that they will be investing 3 billion euros in AI by 2025. This comes after other announcements such as the UK investing 1 billion pounds, and France investing 1.5 billion euros.

Australia has so far made an announcement of just $22 million towards AI. However, the Australian Council of Learned Academies (ACOLA) is writing a report at the request of Government identifying the opportunities and challenges that AI pose. The report focuses on how AI can improve Australia's well-being: economic, societal and environmental. I should declare that I chair the Expert Working Group preparing this report. At the same time as this report, Data61 is writing an AI road map and ethics framework. A similar horizon scanning exercise for precision medicine last year was met by a significant response in the 2018 budget. I am optimistic that the Australian Government will seize the opportunities and challenges that AI now offer to improve our well being.

Acknowledgements

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The Artificial Intelligence race: will Australia lead or lose?

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Abstract

Artificial intelligence (AI) is poised to disrupt humanity, society, industries, local, national and global economies and politics by fundamentally transforming how people perceive, feel, reason and interact with the physical and digital worlds, shaping human experiences, beliefs and choices. The extraordinary potential of AI has created a fiercely competitive race to lead. The prize of leadership, as Vladimir Putin put it, is to shape and control the future for huge benefits and rewards. Some nations are playing hard, jostling for leadership positions. Others, like Australia, are relegated to the sideline, or, worse, have become the playing field where they have little choice but to acquire innovations and technology from AI leaders.

As a nation, Australia simply cannot afford to continue to be an AI adopter and follower, because our economy, our workforce, our national security and our future opportunity is increasingly vulnerable to the influence of AI and the power of those who wield it. Australia's major trading partners have already declared their ambitions to be AI leaders: they are developing strategies, roadmaps and making substantial investments in AI. Australia must urgently set a bold course, develop policies, and take critical strategic action. It must make AI a national priority, identify and mitigate the risks associated with AI, and address the challenges we face in becoming a leader in AI. This paper presents a case and strategies for Australia to aggressively pursue a leadership position in the new AI world order that will unleash significant productivity gains and inclusive economic growth, rather than let other nations and corporations reap the extraordinary rewards at the expense of Australia's national security and future prosperity.

Introduction

Artificial Intelligence (AI) that can enhance, improve and scale human expertise is profoundly changing everything. It is transforming how we perceive and interact with the physical and digital worlds, shaping our human experiences, beliefs and choices. AI technology is increasingly essential for business to compete and prosper in a global economy, as well as for attaining increased productivity and income generation.

Nations that can lead in AI will have the opportunity to shape the future and reap substantial rewards. Recognition of the strategic benefits of AI has led to the so-called AI Race (Lynch, 2019; AI Race 2017). For this paper, it is a race to lead: a multifaceted competition for talent, technology, control, opportunity, productivity, power, profit and prosperity.

The incentives for Australia to seek a leadership position are compelling, as the rewards are exceptionally high, and the and opportunity costs even greater.

The path to leadership in AI, however, is challenging for Australia because as a nation we are a long way behind: our AI capability and capacity is low relative to the current leaders in all areas: universities, industry,

government and civil society. Australia lacks both significant IT manufacturing capability and distinctive AI software offerings. Australians like to believe that Australia *punches above its weight* in a wide range of areas, but there is little independent evidence to suggest that Australia punches above its weight in AI (Australia 2030 Report, 2018). It is critically important for Australia to take a hard look at where the evidence places Australia as a nation in the scientific, engineering and societal aspects of AI. If we are to develop successful strategies that will ensure Australia can develop a leadership position, we must start with a realistic appraisal.

Recently, Infosys determined that Australia was low on AI-maturity (Barbaschow, 2019). However, there is evidence that Australia's aggressive approach to technology adoption (not research, innovation and development) has led to significant investments in digital transformation by individuals, business and government, and as a consequence Australia ranks high on AI preparedness. It stands ready for widespread adoption of AI. This could prove to be advantageous, if Australia can act to fill the gap quickly. However, there is also a significant risk that, without an effective national AI strategy, the opportunity to exploit Australia's preparedness will be seized by AI leaders in other countries with effective national strategies.

This paper presents a case for Australia to urgently make AI a strategic priority and pursue a global leadership position. Not by trying to produce more AI engineers than other countries, but by leveraging our robust political economy, strong legal and policy frameworks, high-quality education and training system, and relatively inclusive society, to avoid the major risks associated with AI, such as safety, security, civil liberty and privacy, and to address the key challenges to achieving AI leadership and productivity.

We first explore AI itself, the advantage it can bring, and the need to lead. We then identify the challenges and Australia's position relative to other key nations. Finally, we describe the risks and provide.

Artificial Intelligence

Artificial intelligence (AI) is a scientific field, a practice, and a capability of human-designed systems and engineered technologies. AI provides a set of methods for reasoning, discovering and recognising patterns, making decisions and taking action.

AI has been described as the new electricity, having the potential to disrupt industries and redefine the nature of business, markets, and government just as electricity began doing more than a century ago (Ng, 2017).

Some of the most successful businesses today are AI companies: Google, Apple, Amazon, Facebook, Microsoft, Alibaba, Tencent, Baidu and WeChat, the, so-called, *Big Nine* companies (Web, 2019), have rapidly scaled their services, and continue to have tremendous impact reshaping business and society in unprecedented ways.

AI technologies can outperform humans in a growing range of tasks. Deep Learning algorithms continue to improve with the volume of training data available, while human performance tends to plateau after a certain level of expertise is attained.

Al offers a wide range of advantages over human intelligence. It can make real-time evidence-based decisions using massive amounts of data; it can scale rapidly and be replicated effortlessly; it is non-judgmental; it can reduce subjectivity in decision making; it can solve complex analytical problems and optimise large scale solutions; it can deliver

services faster, cheaper, and better; it can use behavioural insights to manipulate people at scale; provide mass personalisation services; and recognise patterns in data that humans cannot detect.

The Challenges

Australia cannot produce more computer scientists and engineers than the current AI leaders, the United States and China, but leading in AI requires considerably more than scaling technical expertise.

To lead, Australia must first declare its strategic intent by making AI a national priority. It needs to create the necessary governance focus, economic incentives, and laws and regulations to attract strategic investment and amass AI talent across industry, academia, and the professions.

We cannot ignore the AI race because Australian society, business and our national security are increasingly vulnerable to the power and influence of AI.

Our major trading partners have already declared their ambitions to be AI leaders, taking critical strategic action, and making substantial investments.

Leadership in AI is increasingly important because AI will continue to have unprecedented influence and impact on the Australian and global economies, labour markets, and security. However, AI poses inherent risks and presents significant challenges. Taking a position at the forefront of AI is the best way to mitigate those risks and open up new and exciting opportunities.

Aside from the need to mitigate the risks of AI to attain leadership, there are additional challenges. The challenges have been categorised into four key areas for the purpose of developing actionable strategies.

Governance and Policy: Government influence is weakening, and the profit motive is driving AI developments with little oversight. Self-regulation is non-existent, and reputational risk mitigation is proving to be ineffective even in extreme situations such as live-streamed mass shootings of innocent people. AI impacts both equality and equity. Policy and governance settings determine the level of positive or negative impact.

Power and Access: AI companies are dominating the innovation and technology race. They are accumulating significant market and societal power and controlling access to a wide variety of services without much regard for privacy, diversity or inclusion. There has been a major power shift away from government authority to AI corporations. For example, AI corporations decide what is hate speech and develop specific mechanisms to identify and deal with it, but only in response to crises such as mass shootings. Access to AI services by users, customers, citizens, business, and researchers is not always open, available or accessible. This leads to a wide range of equity and equality.

Responsible AI: Australia needs to develop robust design and engineering practices and standards that ensure the development and deployment of responsible AI technologies that are safe, secure, transparent, accountable, fair, explainable, that respect human rights and generate benefits for society.

Education and Training: There is a significant global shortage of AI scientists, engineers, and professionals with AI skills in specific domains, ethics, policy, governance, law, business, finance and economics. Australia has not produced or attracted sufficient people skilled in AI to take a leadership position, or even a modestly advantageous

position. Lack of AI capability and capacity has created a major growing bottleneck in the development of AI in Australia. Significant work also needs to be done in the areas of educating for more diversity, inclusion, and access.

Addressing these four challenges is the key to becoming an AI leader. It is critical to note that all four are interrelated and need to be addressed in concert to achieve leadership and reap the productivity rewards. For example, governance and power are two sides of the same coin: mechanisms for oversight create the framework for containing market power. Similarly, AI education should not under-produce or over-produce AI engineers, computer scientists, statisticians, and domain experts required by business and industry as they seek to develop, test and deploy responsible AI systems.

How can we design and deploy Digital ID systems based on principles of data minimization, decentralization, consent, and limited access that reinforce our fundamental rights? How can we govern the surveillance economy where companies track, analyse and capitalize on our clicks and exploit our data without consent?

The Risks

AI is a general purpose technology that comes with major risks as it has the potential to exact significant negative impact on humanity, business, politics, society and the global economy. These risks can be organised into five major categories: economic, privacy, safety, security, and social — see Figure 1.

Economic Risk arises from the automation of work, the impact on labour markets and the economic opportunities that AI generates that affect productivity and wealth creation, and future prosperity. The widespread adoption of AI has strong parallels with the

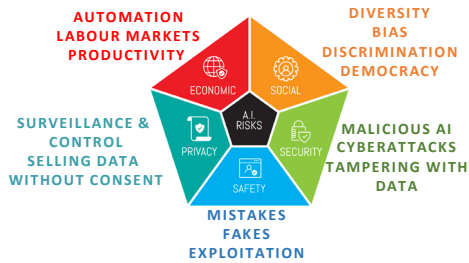


Figure 1: Risk categories associated with AI

British industrial revolution, in which there was an explosion of technology but wages were stagnant for an 80-year period. Other economic risks can arise from the misuse of AI, and poorly designed AI can lead to business failure and major reputational damage.

Privacy Risk: AI companies including Google, Facebook, Twitter and Yahoo! have experienced epic privacy failures revealing billions of consumers' data without consent for profit, by accident and malicious attack.

Authoritarian governments use AI to impose regimes of surveillance and control by collecting and using data for specific purposes without permission. The social credit system implemented in China exploits citizen data to award privileges and impose punishments, enabling and disabling participation in society.

Digital identification systems can lead to rampant exploitation and abuse, to the significant disadvantage and detriment of individual freedoms and rights.

AI companies like Uber use AI to allocate work to humans. AI fuels the power shift to companies away from government oversight, and from consumers' and citizens' control. Many consumers know that AI companies track and analyse their activities and behaviour. However, they do not have meaningful choices, access to information about how

their private data are exploited, or the ability to control access to data that impact them.

Safety Risk occurs when AI systems are poorly designed, not reliable, unpredictable or not robust. Risk can arise from vulnerabilities in AI algorithms and systems. AI is still more of an art than science, and few engineering standards have been developed to ensure safety. Today, AI can process vast amounts of data and outperform human experts in a growing array of tasks. However, it is far from perfect. The dominant AI algorithms today based on Deep Learning are greedy for data requiring huge volumes, sensitive and brittle to changes in parameters and data sources, and are not transparent. Researchers have shown how deep learning algorithms can confuse the image of a dog with a muffin, and how easy it is to fool and hijack them.

The development of AI is challenging as the field lacks robust engineering practices to ensure its safe application. As AI becomes more pervasive in business and society, leaders inside and outside the field have raised concerns, calling for more accountable, transparent, fair and explainable AI.

Security Risk involves the intentional interference by unauthorised parties. It can give rise to bullying, hacking, scams, fraud, loss of identity, mobility, property damage, and in extreme cases, life. AI can be used as an effective tool to perpetrate security breaches and to perform targeted scams using intelligent scareware, adware, spyware, and phishing.

The power and scale of AI are causing security threats to diversify and new types of attacks to emerge. A recent report on the malicious uses of AI identifies three main categories of security risk:

1. *Digital security risks* that arise from an increase in AI-enabled cyberattacks. Some examples include: (i) the use of AI to undertake large scale autonomous attacks that previously required significant human effort, such as spear phishing; (ii) exploitation of human vulnerabilities, such as speech synthesis for impersonation; (iii) exploitation of existing software vulnerabilities through automated hacking; and (iv) exploitation of AI system vulnerabilities using adversarial AI and data poisoning.

2. *Physical security risks* arise from the hacking of AI systems that are used to automate tasks in physical systems, such as nuclear power plants and energy grids. The malfunction of these cyber-physical systems controlled by AI systems poses serious dangers to physical security.

3. *Political security risks* arise from AI-enabled surveillance, persuasive propaganda through targeted misinformation, and deception. For example, "deep fakes," where digital content is manipulated by AI technologies to intentionally deceive, will enhance privacy invasion and social manipulation. AI will continue to improve its ability to manipulate and take advantage of individuals, citizens, groups and organisations.

Social Risk is associated with biased data used in AI algorithm training including lack of diversity and inclusion; laws including discrimination; threats to democracy; the right to freedom of thought, opinion and expression; the freedom of peaceful assembly and association; the right to liberty and social and cultural rights; unequal consumer treatment, financial fraud and identity theft; manipulative marketing and social instability. Applying AI to manipulate human behaviour and proliferate disinformation are

risks that affect human rights, and global peace and security.

Quest for AI Leadership Supremacy

The US and China have identified AI as a critical capability. China has declared that it wants to be the global leader by 2030.

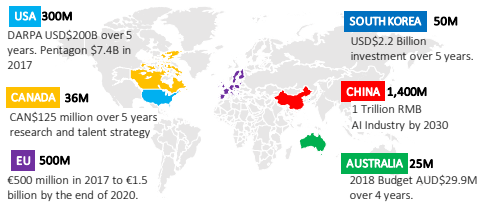
The US government is dramatically increasing its funding and also bringing future funding forward. It upscaled its strategic investments with the release of the National Artificial Intelligence Research and Development Strategic Plan in 2016.

The Big Five US companies (Google, Microsoft, Apple, Amazon and Facebook) make breathtaking undisclosed investments in AI directly and increasingly through acquisitions. According to Pitchbook data the global AI market is expected to expand at a compound annual rate of 36.6% from US$21.5bn to US$191bn between 2018 and 2025. In 2018 there were 146 AI mergers and acquisitions valued at US$213bn. Google made 8 acquisition deals, Apple 7, Intel 6, Microsoft 5, Amazon 4 and Facebook 3.

Many other companies across a wide range of industries such as Ford, Uber, Tesla and FedEx are also investing in AI, IoT, and robotics.

The US and China have emerged as the AI superpowers on almost every metric (Dutton, 2018). For example, according to *CB Insights*, in terms of the quantity of AI startup companies, US has 1394 in 2018: China 283, UK 245, India 84, and Australia less than 30. *CB Insights* also ranks AI startup companies. Australia does not have one in the top 100, the US has 67, China, UK, and Israel 6, Canada, Japan, India, Sweden, and Germany 1.

National governments including Canada, China, France, Japan, South Korea, and Singapore are prioritizing AI. They view AI as essential to growing their economies in the 21st century.



Country	Pop Millions	Source	Amount
USA	327		
		Defence Dept	US$2b in 2019 US$4b in 2020
		NSF, NIH, NIST and Dept Energy	US$850m
China	1420	Government	1 RMB
Canada	37	Government	CAN$125m over 5 years for National Strategy CAN$49M for AI-Health Data Platform
EU	512	EU Commission	€500m in 2017 to €1.5b in 2020
South Korea	51	Government	
Japan	127	Government	¥77.04m
Australia	25	Government	$30 AUD over 4 years

Figure 2: Population versus AI Investment

Canada is a long-time leader in AI research and working with industry including Google and Uber. The Canadian government developed a C$125 million plan to invest in AI research and talent development. The strategy has four goals: (i) increase the number of AI researchers and graduates, (ii) establish three clusters of scientific excellence, (iii) develop thought leadership on the economic, ethical, policy, and legal implications of AI, and (iv) support the national research community on AI.

China has a significant advantage in the areas that tend to determine AI success: people, financial investment, flexible or non-existent regulation, and access to data.

AI in Australia

AI research in Australia, relative to the AI leaders, could only be described as a boutique activity. Not surprisingly, the government has made modest investments in AI research, AI education, AI knowledge transfer and value creation. The Australian Research Council data – Figure 3 – shows major investment in quantum computing but not computer science or AI.

Despite the Australian economy's continuous growth for more than two decades, our innovation performance, innovation-related business collaboration, and industry engagement with universities and research organisations remains steady. Australia is one of the worse performers in the OECD in knowledge transfer. The reality is that Australia is punching well below its weight in areas that determine a nation's future safety, security, productivity and prosperity.

The private sector in Australia focuses on adoption of AI rather than breaking new ground in research, development and innovation with R&D investment dropping dramatically according to ABS data, particularly between 2014-2016, the critical years when AI developed and proliferated rapidly.

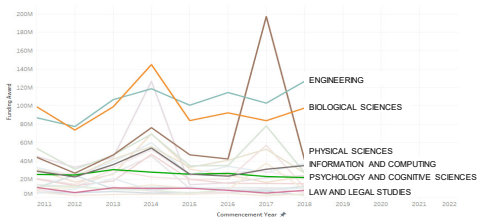


Figure 3: Australian Research Council Funding 2011–2018.

In 2015 Australia spent 0.4% of GDP on research and development, with higher education gaining 35% of the spend. By comparison South Korea spends 1.18%, the US 0.75%, and the UK 0.57%.

However, there are positive indicators that suggest that Australia ranks well on AI preparedness. But readiness for AI is a two-edged sword, as it not only creates opportunity for Australian firms to exploit, but provides more opportunity for firms based in other countries with AI products ready to deploy. Australia has become the playing field for companies in the US, China, and elsewhere that can readily provide high-quality AI software and suitable hardware e.g. phones, robots, drones, and IoT[1].

Australia does not yet have an artificial intelligence strategy or roadmap. However, in the 2018–2019 Australian budget, the government announced a four-year, AU$29.9 million investment to support the development of AI in Australia: the equivalent of *30c per Australian per year to invest in AI*. These funds will be used to create a Technology Roadmap, a Standards Framework, and a national AI Ethics Framework to support the responsible development of AI. The investment will also support Cooperative Research Centre projects, PhD scholarships, and other initiatives to increase the supply of AI talent in Australia.

A Leadership Roadmap for Australia

AI is not just impacting business and society today, it is shaping humanity and the future. Those who can deploy AI have tremendous power and influence. Increasingly, corporations are becoming the regulators, but they are not suited to the task because of their profit motive and conflict of interest e.g. as custodians of the customer data they exploit for economic and market advantage.

[1] The Internet of Things.

It is critical for Australia to develop a roadmap that ensures it can move into, and sustain, a leadership position as quickly as possible. We urgently need a game plan for a coordinated broad-based strategic response.

Australia is not a leader in AI today, but it is surprisingly well placed to take a leadership position. We have high levels of AI preparedness, a research, innovation and education ecosystem with scope for improvement, underpinned by a robust economic, legal and political framework, and a propensity for technology adoption. By simply reducing the risks associated with AI and addressing the challenges we can compete with larger stronger nations to attain dramatic increases in productivity and fuel future prosperity. We must act to stop foreign interests seizing a dominant position in Australia able to collect and control access to our data, and reap the rewards that AI can generate. The following four strategies that should include new funding and aggressive targets could be used to propel Australia into a leadership position in AI.

Strategy 1: *Develop and enforce effective policy and governance of AI for maximal benefit.* This will entail regulating and setting the objectives for AI. Government, policy makers, and regulators need to play a major role in determining how to incentivise the development of AI that can be trusted.

Strategy 2: *Ensure AI is used to provide equitable access to its benefits and that it is not used to build and abuse power*. AI can help create considerable market power as AI companies have historically been able to dominate markets and establish themselves as pseudo regulators. AI-driven dynamic pricing can be exploited to increase power effect abuse. AI should be beneficial to all: users, customers, citizens, developers and researchers need access to AI. Exclusions need to be removed. Government and business need to remove the significant barriers to entry in AI development, application and usage. Public value and access to AI need protection.

Strategy 3: *Design, develop and deploy responsible AI*. Responsible AI benefits humans. It is transparent, accountable, fair and explainable. Organisations need to set guidelines on AI development and its usage. When AI is solving economic or industry problems or optimising solutions, what are its settings and measures, how is success assessed, what constraints are needed — is it a decision support tool or does it actually make the decision? The foundation of ethics is values; what will the values we use to shape AI in Australia be? If we do not develop AI with the values we want, will we be able to safely import it?

Strategy 4: *Build internationally competitive education and training programs, and national capability and capacity for an AI future*. Lack of capability and capacity is one of the main bottlenecks to AI leadership in Australia. It is critically important to remove obstacles and develop incentives to dramatically increase the number of people taking up training in AI, its applications, its implications for business and society, AI policy, governance, and responsible development.

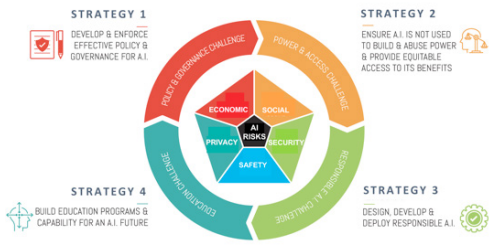


Figure 4: Strategies for Australia to achieve a leadership position in AI and boosting productivity.

Discussion

A critically important realisation is that in order to attain a leadership position in AI all four strategies need to be implemented in a coordinated fashion as they are all closely interrelated and must work together for maximal impact. For example, government needs to set policy and provide resources to ensure Australia produces the optimal quantity and quality of AI experts in engineering and the broader professions to fill the capability and capacity gaps. Responsible AI can and will only be developed in an environment where government has provided effective economic incentives and legal constraints.

There are no silver bullets, but what matters in the AI leadership race is having a clear understanding of where we are currently positioned, why it is critical to win, and how the risks will be mitigated and the challenges addressed to be a genuine AI leader.

The evidence that AI is worth investing in is overwhelming. Since the future of AI is uncertain, the most important strategy in uncertain times is to experiment, act, learn quickly, and reduce the uncertainty. Waiting for more certainty, and not acting with clear intent and relentless vigour, is Australia's highest risk.

Being a leader in an AI world is a challenging complex problem, requiring an integrated innovative solution. The usual methods of slicing and dicing to reduce complexity are probably not effective.

Australian governments, law and order policy makers, and regulators need to work together to help resolve the expected skill bottlenecks and tensions; to boost the adoption of AI technology to make it more human-centric, scalable and productive, using a combination of market and government incentives and constraints. These advances will not happen fast enough organically. They need to be accelerated. Now is the time to be proactive. AI leadership is within our grasp. It must be made a strategic objective and we must use the time available wisely to mitigate the risks and address the challenges to make Australia's leadership in AI a reality. The key is shared ambition to lead fuelled by need and coupled with strategic collaboration, cooperation and coordination across government and industry.

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Australia, the safe

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Abstract

In these turbulent times, Australia stands out as a safe option for foreign investors and migrants. The resulting capital and labour inflows are likely to be a boon for the economy. But they come with risks of fickle financial markets and political backlash over high levels of migration, no matter how skilled the migrants. I discuss the economic basis, consequences, and risks involved in being a safe harbour for the world.

Introduction[1]

Australia has experienced more than 27 years without a recession, the longest-ever period of uninterrupted economic expansion amongst advanced economies. But will the luck of the "Lucky Country" soon run out?

Predicting recessions is more difficult than often believed. Yes, if one *always* predicts the end (of expansion) is nigh, the doomsayer will eventually be right. But they would be wrong far more often than not. The trick is to do better than an "unconditional" forecast that effectively tosses a coin and chooses to predict a recession in any future quarter based only on their general historical frequency.

To do better than an unconditional forecast, one must try to take an objective stock of current economic conditions and consider how these might change in the near future. Despite some ominous storm clouds on the horizon, I argue that the prognosis for Australia in the near term is not so dire as it might at first appear. In particular, if we think of Australia's economic fortunes as at least partly reflecting global capital and labour flows, the news is actually pretty good.

Storm clouds on the horizon

Before explaining my optimistic prognosis for the Australian economy over the next few years, it is worth reviewing the major risks we currently face.

First, Australia, like many countries, has been suffering from relatively low productivity growth over the past decade or so, a particularly worrisome aspect of a phenomenon often referred to as "secular stagnation." This is clearly a risk to the continuation of the current expansion given that most theories of economic growth see productivity growth as *the* main driver of why economies prosper.

Second, house prices are declining in Sydney and Melbourne and the scale of the decline looks to be larger than it was in previous episodes. Given that housing represents a major source of wealth for Australian households, a dramatic fall in house prices could spill over into lower aggregate consumption and trigger a severe downturn in the economy, similar to what occurred in

[1] This article is based on a talk given at The Royal Society of New South Wales Forum on "Towards a prosperous yet sustainable Australia — What now for the Lucky Country?" on 29 November 2018. I thank participants at the forum for helpful questions and a stimulating discussion.

the United States with the Great Recession in the late 2000s.

Third, Australia has a very large current account deficit and has been continuously running one for decades.[2] If the capital inflows that sustain this deficit were to suddenly stop, there would be a serious economic crisis, as has happened in many other countries with similarly large current account deficits.

Fourth, inflation has remained stubbornly below the Reserve Bank of Australia's 2–3 per cent target for a number of years in a row. It has not been very far below, but it has notably failed to return to the target range despite fairly loose monetary policy over the same timeframe. Low inflation is, of course, not a major problem in and of itself. But it is a symptom of low wage growth, amongst other things. It is natural to expect that such low wage growth will spill over into weak aggregate consumption.

Fifth, there has been some political chatter in recent months about reducing immigration rates. Whether such policies will come into effect is unclear, regardless of the outcome of the next federal election. But if they do, it would directly reduce economic growth, although it would be unlikely to trigger a recession in and of itself.

[2] The current account measures the net flows of payments related to current income across countries. A current account deficit means that more such payments are going out of a country than coming in, such as would occur if there are more imports than exports, all else equal. Given a floating exchange rate, the direct counterpart of a current account deficit is a capital account surplus of the exact same amount, where the capital account measures net flows of payments for assets, broadly defined (i.e., claims on future income). Thus, it is natural to think of a current account deficit as reflecting net capital inflows.

Safe harbour

So, given these ominous storm clouds on the horizon, why do I argue that the near-term prognosis for the Australian economy is actually pretty good? My simple thesis is that the capital and labour flows that help prop up growth are based on *relative* risks and returns. On this basis, Australia stands out as a safe harbour in a world covered by tumultuous seas.

Where else should capital flow? Europe? The US? China? Japan? All of the large economies of the world face huge economic challenges. The rest of Asia? Latin America? Africa? Emerging economies always have risk.

In the following discussion, I take an investment-portfolio perspective to capital-flow determination.

Starting with Europe, most of its countries have demographic time bombs in the form of rapidly aging populations. As a consequence, Europe will soon have even lower economic growth, not just because of low productivity growth, but simply because working-age populations will start declining. At the same time, Europe is going through a period in which populist, nativist governments are elected and pursue policies that could be economically counterproductive (e.g., the anti-immigrant policies in Austria and Italy). Furthermore, while the sovereign-debt crisis that engulfed Greece and other countries in the early 2010s appears to be over for now, it could certainly flare up again at any moment. Meanwhile, if we choose to think of the UK as fundamentally separate from Europe, as many of its citizens did in voting for Brexit, the massive economic uncertainty that results from the Brexit vote doesn't exactly make it a safe choice by comparison. Whatever form it might take, Brexit

will almost certainly harm the UK more than Europe.

As in some of Europe, the US is also going through period in which populist, nativist policies are being implemented. Just how serious the long-run consequences of the protectionist trade policies will be is still unknown. Maybe it won't be so bad. After all, the renegotiation of NAFTA appears to have largely been a rebranding process rather than anything more fundamental in nature. But the trade war with China appears real and its consequences potentially far reaching. Basic economics tells us that those consequences are likely to be negative for all parties involved. Trade is not a zero-sum game. Furthermore, a high US dollar means that the US trade deficit is unlikely to actually improve despite the protectionist policies, while it mostly places a lot of downside risks on future growth and returns on US assets.

China has been the major engine of global economic growth for the past few decades. But a trade war with the US would introduces serious risks to the Chinese economy. Similarly, it would be prudent to think there are some risks for foreign investors in terms of the Chinese political and financial systems. For a risk-averse investor, it is better to look elsewhere first.

What about Japan? It is a large economy that, from some appearances, seems to be finally climbing out of three decades of relative stagnation. But the demographic time bomb that is ticking for Europe has already gone off in Japan, with more than a quarter of the population already over the age of 65 years. Thus, Japan is unlikely to be much of a powerhouse of growth, even if it crawls out of stagnation. Perhaps related, Japanese assets generate low returns and even very long-term government bonds are paying less than 1% interest rates. For an investor chasing yield, it is necessary to go elsewhere.

Turning to emerging economies in the rest of Asia, Latin America, and Africa, things actually look good in the sense that old political risks seem somewhat diminished (but not gone, as recent elections in Brazil and Venezuela have proven) and there has been some convergence in standards of living, as long predicted by neoclassical growth models. However, even if the expected returns are high, there is always more risk in emerging markets. The main point is that it would be prudent to diversify some of that risk by including major investments in safer countries such as Australia in any portfolio that also includes emerging markets.

"Countries like Australia" brings us to Canada, which would seem to be our main competitor as a potential "safe harbour." But it faces the same storm clouds and is certainly subject to huge risks if the US turns its protectionist focus north again.

Perhaps what is notable about this discussion is that there isn't anything particularly new about many aspects of it, although the rise of populist, nativist policies appears to be gaining momentum in the last few years. Many of the same forces have been contributing to net capital inflows into Australia for decades, with these inflows simply being the accounting counterpart to the persistent current account deficits mentioned above.

So is there a risk that the tap will be turned off and Australia forced to run current account surpluses? One big difference for Australia compared to many other countries that suffered "sudden stop" crises after years of current account deficits, such as many Asian economies in the 1990s or Argentina at many times, including recently, is that foreign-held liabilities are largely denomi-

nated in domestic currency.[3] Thus, we can still repay the debt even if the Australian dollar depreciates. And the dollar has actually depreciated in recent years, following the end of the mining boom. This has had the predictable effect of improving the trade balance. Indeed, Australia is currently running a trade surplus, even if payments on foreign-held debt mean that it still has an overall current account deficit. Were capital flows to suddenly stop, the Australian dollar would likely fall further and we would likely be able to pay back past debts by exporting more goods and services. Of course, the ability to pay back in this way helps prevent a crisis in the first place. That is, there is no reason to expect that capital flows will stop in anticipation of a failure to pay back foreign-held debts, the dynamic that can explain past crises in Asia and Argentina.

In terms of labour flows, the story is even simpler to tell. Australia is an unusually appealing destination for young, skilled migrants. Beyond the direct benefits to economic growth from skilled migration in terms of adding to the productive stock of labour, there is an indirect demographic benefit. In particular, Australia has a relatively low dependency ratio. It has more people of working age to support those of retirement age, in the range of more than 4 persons, compared to close to 3 for most of Europe or close to 2 for Japan. For Australia, a low dependency ratio is a clear consequence of sustained high levels of immigration, with one of the highest ratios of overseas-born citizens in the world keeping the population relatively young. This is not to say Australia is devoid of demographic challenges. It is just that they are less serious or pressing than for many other countries.

[3] See, for example, the discussion in a recent speech by Christopher Kent, Assistant Governor (Financial Markets) of the RBA at https://www.rba.gov.au/speeches/2018/sp-ag-2018-12-10.html

Silver linings

There are some silver linings that mitigate the risks associated with the storm clouds discussed above.

First, despite low productivity growth, it is notable how stable — at around 3% per annum — real GDP growth has been for Australia over the past few decades. As an accounting matter, this stability must reflect relatively strong growth of the labour force in order to offset the weaker productivity growth, so it doesn't translate into as strong an increase in income per capita. However, there is at least one economic setting where real GDP growth matters more than productivity growth. This is in terms the ability of a country to sustain or pay off its debts. Australia actually has a relatively low ratio of public debt to GDP, partly due to less runup of debt than in other countries with the global financial crisis, but also due to relatively strong GDP growth over the same period. Given that the ability to raise tax revenues goes up with GDP, this growth makes the level of public debt quite sustainable. Similarly, the ability to pay back foreign debt has been made more manageable due to strong GDP growth.

Second, even though house prices are falling a lot in Sydney and Melbourne, they are more stable in the other capital cities. This suggests a return to earth of high prices in particular markets, rather than a collapse due to oversupply or ill-advised loans, as arguably was the case in the US with the Great Recession. Furthermore, Australian banks, due in part to a lack of competition, are much better capitalized and able to cope with a significant fall in house prices than was the

case for the financial system in the US. If the migrant flows discussed above continue, the basics of supply and demand will mean house price growth should return to positive territory once a correction has occurred in markets with particularly high price-to-rent and price-to-income ratios.

Third, despite the ongoing current account deficits, Australia's net foreign holdings (net foreign-held debt plus net foreign-held equity) have stabilized over the past couple of years, albeit at a high level that is not far shy of 100% of GDP. This stabilization in the face of ongoing current account deficits reflects a better performance of Australian-owned assets abroad than foreign-owned assets in Australia. Combined with (and reflecting) the fact that most foreign holdings of Australian liabilities are denominated in Australian dollars, this stabilization suggests that no current account crisis is imminent.

Fourth, low inflation and wage growth reflect a number of one-off factors that suggest inflation and wage growth can be expected to pick up at least slightly in coming years. Inflation is low, but stable at close to the 2–3% target range for the RBA. This stability may have made inflation targeting a "victim of its own success", with market-based measures of inflation expectations (e.g., break-even 10-year inflation rate) at the low end of the RBA's target range. The manifestation of these low expectations is self-fulfillingly low levels of price growth for domestically produced goods and services for which producers have some ability to set prices. For example, price growth in the education sector showed a marked drop a couple of years ago that seems to have led to a similar drop in wage growth in the sector. What is notable is how price and wage growth in the education sector are more in line with overall inflation expectations, instead of running above in a way that would help offset lower price growth of import goods and services. It is this sense in which I suggest inflation targeting could be a victim of its own success.

At the same time, even with inflation expectations bringing down price and wage growth for some domestically produced goods and services on a one-off basis, there are countervailing forces that should lead to inflation returning back to the RBA's target range and higher wage growth in coming years. For example, despite the arrival of Amazon.com being widely touted as a reason for inflation to fall further, import price growth is currently higher than it has been for a more than a decade, in part due to the fall in the Australian dollar. Also, the unemployment rate is falling. The "Phillips curve" that links low unemployment to higher wage growth and inflation may go missing every so often. But, historically, it does eventually show up. And the recent increases in the participation rate are a reason why wage growth has not gone up as much in response to a low unemployment rate as would be historically expected given that new participants would be expected to earn lower wages than more established workers. However, there are limits to how much participation rates are likely to rise and when they stop doing so, the unemployment rate can be expected to fall faster and wages to start rising faster.

Furthermore, there is an important, but often overlooked silver lining to the slow wage growth in Australia. It has meant that, after a long period in the 1990s and 2000s of unit labour costs (i.e., how costly one unit of output is to produce in terms of hiring labour) growing at a much faster

rate than the G7 industrialized economies — which made Australian labour expensive and uncompetitive — these costs have been growing at a slower rate since 2012. This sustained lower growth of unit labour costs means that Australian labour is now finally becoming competitive again on the global scene, making Australia a more desirable place to invest. Any resulting growth from foreign investment in Australia should be expected to improve incomes over time.

Fifth, in terms of the political risks to migration flows, the silver lining is that there are frequent elections in Australia and it would be unusual to see a successful political movement that seeks to strongly restrict migration when the unemployment rate is low and the economy is growing at a reasonable rate. In particular, the rise of nativist policies in the US and Europe in recent years came out of economic crises from which Australia was relatively less affected.

Conclusion

It is, of course, always dangerous to make sanguine predictions. My prognosis for Australia would certainly look foolish if the Australian economy is in recession by the time someone reads this, as inevitably someday it will be.

But it would also be foolish to focus exclusively on downside risks and always predict the end is nigh. There are a number of reasons to expect economic growth to continue for the Australian economy for the next few years. One major reason is that the capital and labour flows that have helped sustain growth over the past few decades should continue in the absence of a major change in policy. In particular, the external forces that drive these flows are likely to continue. Australia is a relatively safe bet for both capital and labour when looking at the global landscape. Only a major change in domestic policies could disrupt these flows.

Furthermore, although there are various storm clouds on the economic horizon, there are silver linings to most of these that suggest economic growth should continue. Australia has a good public-debt situation, providing fiscal capacity to address future global economic shocks. It has low unemployment despite rising labour-force participation. Finally, after many years of increases in unit labour costs at a faster rate than most other industrialized economies, recent slow wage growth means that Australian labour is finally becoming relatively more competitive. Along with a low Australian dollar, this all suggests that capital inflows could actually increase and the resulting investment will produce somewhat faster, not slower growth over the next few years.

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The future of biosecurity in Australia

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I was assigned the task of talking about biosecurity, and biosecurity, it turns out, is an extremely broad term that can be used in a wide variety of ways so I'm just going to use it in the context of, as Brian notes, infectious diseases, particularly on what Australia may need to do to prevent and respond to future epidemics.

SARS and other 'flu-like respiratory viruses

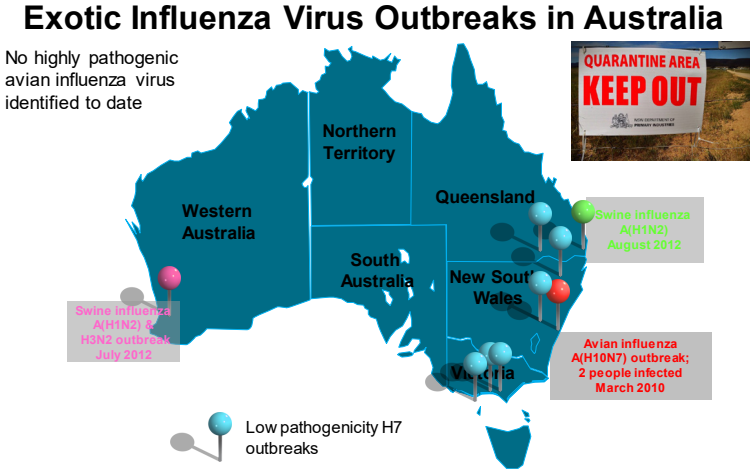
If you wind the clock back just a few years, you all remember the SARS outbreak of 2003. The numbers of people infected were not actually that great: overall globally about 8,000 people were infected. To put SARS in context, 'flu may infect millions every year, so 8,000 infected and about 800 died is not large, but even so it cost about $40 billion globally. Nonetheless, the consensus is that we dodged a bullet with SARS. SARS is extremely dangerous and if the world hadn't pulled together as well as it did, it could have been a very, very scary epidemic because the mortality rate is 10 per cent, which is high.

Australia in fact got very lucky. What happened in 2003 is that a businessman from Guangdong got ill. He went to Hong Kong, where he basically vomited all over his hotel floor. People on that floor went to the airport, they went to Singapore and from Singapore they flew to Canada and to Germany. No-one got on a flight to Sydney or Melbourne, but that could have happened. If it had come here, who knows what would have happened. SARS was a major warning shock.

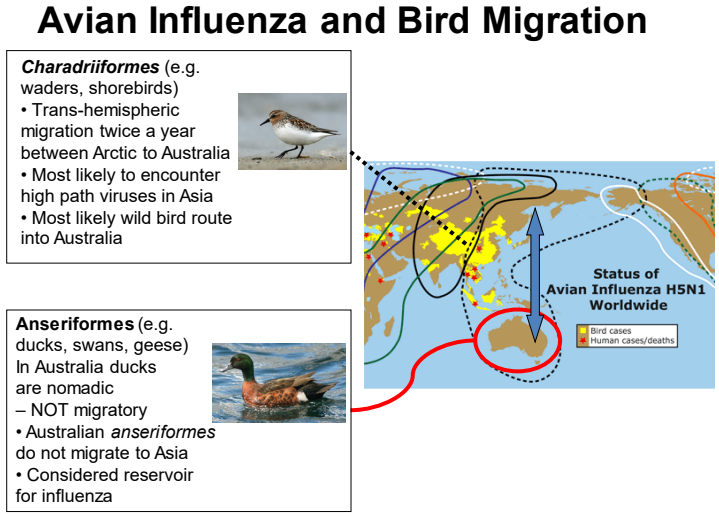
At the same time as these human outbreaks, our cultural systems face a very major threat too. Exactly at the same time as SARS, in the Netherlands there was an outbreak (which I'm sure you haven't heard about) of H7N7 influenza, a very nasty, highly virulent H7 strain of avian 'flu. This was completely concurrent with the SARS outbreak. The Dutch authorities were so scared about this that they basically went through a mass culling operation of chickens in Holland to eliminate the virus. They killed 30 million chickens: a third of the Dutch poultry industry was just wiped out in one go. They basically took these chicken barns, taped them up and gassed them, they were so worried about this virus. 89 people were infected by that virus, basically people involved in the control, and one person died.

These respiratory viruses circle the world and they will hit Australia. We will get them, we are at risk from 'flu — I'll keep coming back to 'flu. I sleep pretty well at night but if there's one thing that I do get worried about slightly it is still influenza. because it's a silent carrier. You don't know you're infected. By the time you've got off the train the bus, or the plane, you've infected somebody else. It is kind of a nerve-racking thing. So Australia is often exposed to 'flu. Every year or so our country experiences an exotic 'flu strain that

comes in that infects our poultry industry or our pig industry and of course the more centralised those industries are, the easier it is for a pathogen to spread quickly and cause a big outbreak. The figure shows some of the strains of 'flu that have hit Australia in the last decade or so. Luckily these are all low pantothenic strains, which means they're quite mild, there's no real mass culling.



To date, no very, very virulent strain of 'flu has hit Australia. We have been very lucky, and the H7N7 strain hasn't got here yet, but it could happen. We have very good biosecurity, we have very strong quarantine laws, but they may not stop the incursion. One reason for this, of course, is that the 'flu virus is basically a bird virus, and Australia is remarkably ecologically diverse: about 10 per cent of the world's bird populations live in Australia. We are on a flight path that birds take every year and birds will fly north and south. The arrow in the figure is a flyway, the Australian east-Asian flyway, and birds will fly up and down that as they migrate every year.



Globally, two sets of birds carry 'flu viruses. One is Anseriformes (kind of duck-like things). They're not migratory, they're reservoirs for the virus. If you go and sample a duck in the wild, about 10 per cent of them carry 'flu naturally, so they're reservoirs. The other is Charadriiformes (waterbirds, shorebirds, waders) that take these long migrations from Asia into Australia, actually from Antarctica to Asia, and they can bring a virus with them. So we are continually exposed to these strains and they could cause an outbreak. So that's 'flu.

Mosquito-borne diseases

But it's not just 'flu — you're getting scared now — that's a worry. We've also had an increase in the number of mosquito-borne diseases and, as climate change continues, as places get hotter and warmer, there will be more mosquitoes and there will be more mosquito-borne disease. It will happen. It's inevitable. For example, in Australia we have two or three native mosquito viruses that cause human illness: Ross River and Barmah Forest, and there are a few thousand cases every year. Occasionally people get a very serious thing called Murray Valley encephalitis, that can be fatal. Northern Queensland has had historic outbreaks of dengue, which again occasionally can be fixed. Not so much, it's controlled there now but it can happen.

There are also outbreaks of mosquito-borne diseases in cattle and livestock that are important to farmers and on our doorstep, in the region, we have viruses like Chikungunya and Zika, which are just off the coast of northern Australia, which could easily cause incursions. That's a threat to us.

Plant pathogens

It's not just animals and humans, plants and our agricultural systems are also under threat from exotic pathogens. The figure from Robert Park shows work on stem rust, which are fungi. Robert Park is the global expert on this but these fungi come in every so often and they can cause very nasty outbreaks on cereal crops. Every few years there's an exotic incursion of these stem rusts into Australia that can cause really profound economic damage to our agriculture industries. There's also myrtle rust, you may have heard of, that's come in and that's now spreading on eucalyptus plants and other Myrtaceous plants across the eastern seaboard too — another fungal pathogen.

Australia's biodiversity crisis

These pathogens are going to arrive, it is inevitable. So that's going to impact on many aspects of the way we live in Australia, including the biodiversity in this country. Australia has an absolutely miserable record in dealing with biodiversity. Australia's classified as a megadiverse country: we have more species of plants and animals than any other developed country. Most of what we have here is also endemic. Some numbers you see in the figure: 87 per cent of the mammals in Australia are endemic and 90 per cent of the reptiles are endemic. As I mentioned earlier, 10 per cent of bird species globally are found in Australia, yet our extinction rate for those animals is terrible. It's actually the highest of any country. So, 30 native mammals have gone extinct since Europeans arrived. That's one in three extinctions of mammals globally have occurred in this country in the last 400 years. That's partly human activity and it's also in part because pathogens come in and we bring them in on exotic systems.

Australia's Biodiversity Crisis

- Australia is "megadiverse" and home to more species than any other developed country.
- Most of Australia's wildlife is found nowhere else: 87% of mammal species and 93% of reptiles are found only in Australia.
- Australia has the worst mammal extinction rate in the world: 30 native mammals have become extinct since European settlement: 1 out of 3 mammal extinctions in the last 400 years have occurred in Australia.
- More than 1,700 species of animals and plants are at risk of extinction.
- Feral cats kill an estimated 75 million native animals every night across Australia.

Detection and Circulation of a Novel Rabbit Hemorrhagic Disease Virus in Australia

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European Rabbits

- *Continent-wide spread began in 1859 by the introduction of 18-24 wild rabbits for hunting near Geelong.*
- *Probably >1 billion rabbits by 1950.*
- *Enormous economic and ecological consequences.*

The Australian government estimates that something like 700 species of plants and animals are at risk of extinction and it's one staggering statistic of what has happened that feral cats kill an estimated 75 million native animals every single day. The number sounds unbelievable but I can tell you where it comes from. There are 4 million feral cats in Australia and every day they kill between five and 30 native animals. So 75 million is a kind of ballpark estimate. It's a staggering thing. Although Australia may have been lucky for some of the humans living here, for the animals it's definitely not been that lucky at all.

I'll just give you one little example of this miserable state of biodiversity and it's one that I've worked on myself for many years now: European rabbits. This is an extraordinary story. Rabbits were first brought into Australia successfully in 1859, when 24 were imported in Bowen Park near Geelong. By 1950 there were probably more than a billion. They literally bred like rabbits and it's the single biggest vertebrate population expansion in history. Just extraordinary. Virgin soil, no predators, explosion. You can imagine the kind of enormous economic and ecological consequences it's had. So these kinds of feral invasions are terrible and they're going on. Sadly, science has one view and governments have different views: now there's very, very strong evidence that we should cull the brumbies to a certain level because they are destroying the natural environment[1] but policy won't have it and it's a nonsense.

Global problem, local threat

You reply that we have great quarantine and we're safe, but actually it's not true. New things are coming in all the time. I work on viruses and just in the last couple of years a novel rabbit virus has entered Australia, which means either a rabbit has got in somehow or someone's been to a rabbitry, somewhere else in the world, and brought that in, which is quite extraordinary, and that's now

[1] Including Canberra's water catchment — Ed.

spreading through Australia. That's not a bad thing because it's actually killing rabbits, but there it is anyway.

The way I like to think about this is that we have a global problem and the global problem is that we have lots of these emerging diseases, but there's a local threat to Australia in that we're not very good at managing them. I'll try and put some meat on that statement. Emerging diseases like 'flu, like SARS, are everywhere. You can go on the web, you can find lots of pictures just showing you lists of these, maps of the world showing what's emerging. In our area we have Hendra, we have Nipah, we have Ebola, Zika, all these sorts of things are there and they mainly come — this is a very important point — from a pathogen that's jumped from an animal to humans. Animals are the reservoir and they jump to us and cause disease and it could also go the other way. Humans also give their diseases to animals too, it's a two-way kind of traffic.

Of course that process is exemplified in the modern world by the extreme rapidity and intensity of human travel. Global flight paths show the amazing kind of carbon footprint on the world and how we move so quickly. Australia is very well connected now, so we know it's one stop from many, many countries. Of course, that's going to bring people and it's going to bring pathogens too. The global problem is we don't really understand exactly how these pathogens jump boundaries in emerging new species, that's a kind of global research question that I work on as my day job. How do these epidemics actually start?

An Australian Centre for Disease Control

For the rest of my talk I'm going to focus on the local: Australia has no national organisation that's designed to combat emerging diseases. We have state levels, but there's no Federal system and we really need a national entity, a national body, that's going to help, like other countries do, that's going to try and prevent the threat of emerging disease. Also we can't just separate humans and animals, veterinary and medics, because they're one, unified — it's called One Health, the one unified framework because diseases pass in a very fluid manner.

A good example of how I think we can proceed can be found in China. China, in the last 15 years or so, has formed what's called a Centre for Disease Control, a CDC. It was set up directly after SARS because China got a kind of global hammering after SARS. They were accused of being slow in their response and not sharing data and, again, I think we dodged a bullet. So they set up this national disease framework across the whole country to respond to future outbreaks. I'll give you an example of how it works. In 2013 I was working in Xinjiang province in south-east China. I was out in the country and I was collecting samples from bats and other animals in this population. It's a very rural area and there were lots of chickens around; chickens and pigs are part of daily life in rural China.

While I was there, a very nasty virus called H7N9 emerged: it's in chickens and it spread to humans and it killed birds and it killed humans. The mortality rate in humans (when they're affected) is almost 50 per cent. It's a very, very nasty thing and it emerged in this province in China. Each town, each province, each city has a local CDC centre.

As the virus emerged in that village where I was, the local CDC officer wrote on the board in the village square, "We're closing the live bird markets. They may have virus. Avoid chickens." That response of the local CDC and others in China really dramatically dampened down that outbreak and it didn't get going. It really didn't become a national or a global threat. The CDC did a great job.

We haven't got that structure in Australia but we need it. It's not just me who thinks there's a pressing need for an Australian CDC, a national centre or focus that's going to allow us to respond to control infectious diseases. The House of Representatives in 2013 published a document called Diseases Have No Borders, and they realised that there is this threat of emerging disease. I'll just give you a few quotes now but they said in this report from 2013, "This committee is concerned that the lack of uniformity in infectious disease control and inadequate coordination between portfolio agencies and across all layers of government could potentially compromise Australia's preparedness to respond to a nation-wide outbreak of infectious disease in the future," and that kind of sums it up. We're not quite prepared. We have State level, we don't have a Federal system.

Another important body, the Australian Medical Association, in 2017 published a paper and their point number one was: "We call for an immediate establishment an Australian National Centre for Disease Control (CDC)," and they quote, "A CDC is urgently needed to provide national leadership and to coordinate rapid and effective public health responses to manage communicable disease and outbreaks. The current approach to disease threats and control of infectious diseases relies on disjointed State and [Commonwealth] informal structures, informal networks, collaborations and the goodwill of public health and infectious disease physicians." Quite correct. It's informal, it's ad hoc and I wouldn't say it's a shambles but it's an accident waiting to happen. We have to get better. Despite these kinds of calls, the inertia against it appears to be people in Sydney don't want it to be there; people in Melbourne want it to be in Sydney. No-one wants it in Canberra and no-one talks about the rest of the country and it appears to be a very weird realism, which I think we have to stop.

I just want to give you an example, going back to 'flu, which I work a lot on, why I think it's really important. These are some data we got from looking at the instances of 'flu in Australia over a 10-year period. All these little graphs in the figure are when 'flu peaks every year in Australia. You see the peak is about week 32, that's the second week of August, right, that's when 'flu maximises its intensity in Australia. Now, the data we got to do that were lab-confirmed cases of 'flu. So people have been to a doctor, the doctor's taken a sample and he's tested it and it's shown it's 'flu and there's almost half a million of those, but it took us almost a year to get those data. Each State and Territory has to sign off to give us that. We had to have an ethics approval for every single one. It's an absolute madness. In the US you can download those data online.

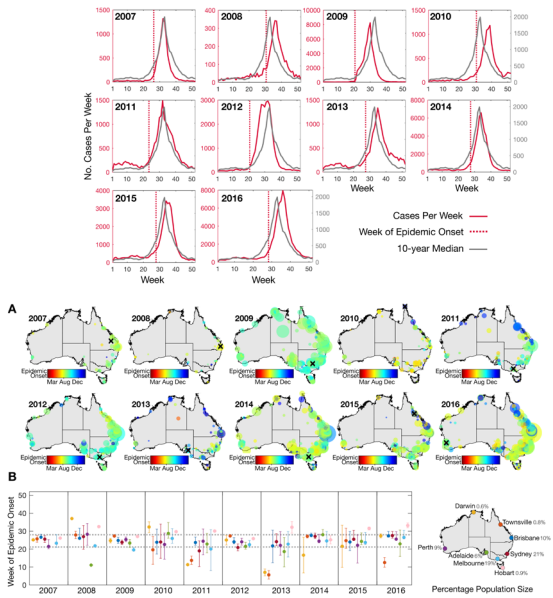
I'll just give you an idea of why we need this. The thing that came out from these data is that 'flu is extremely synchronised in Australia. Here we took samples of 'flu from these data from around the country, from Darwin, Townsville, Perth, Hobart, Sydney, and I've got that little plot in the bottom there, that's when you see the onset

Epidemiology of Influenza in Australia

- Lab-confirmed incidence data of >450,000 influenza cases from 2007-2016 (from the Australian National Notifiable Disease Surveillance System) – very slow to access these data

- Seasonal influenza in Australia is highly synchronized

Epidemic onset = timing of the break-point in influenza incidence



of 'flu happening in each of those places. You can see how similar they are in time. If you look at 2009, that's swine 'flu, it's basically simultaneous. When you get a case of 'flu in Sydney, you've got one in Perth at the same time, more or less. So there's no lag time. It's not that a doctor in Sydney rings up Perth and says, "Oh, I've got a 'flu case. Be careful." It's already in Perth. It's already there. This kind of wait and watch approach dependent on the goodwill of people contacting each other is not going to work for something like 'flu that's so fluid. Instead we need to be very, very quick.

The good news is that although we haven't got a national focus, the tools we have now to respond and analyse these are remarkably good and remarkably powerful. Almost in real time we can sample species, that could be humans, we can sequence the disease, the pathogens, and do lots of clever evolutionary analysis to show where the things have come from, how they're spread and we can model it in real time, in a matter of days. So that can be done. If we had a national focus we really could put this into action.

Just two quick examples of the technology now. It's so good you can now pretty much determine the cause of any new infection within 24 hours or so. A new novel disease, don't know what it is, the technology is so good with genome sequencing that the diagnosis we can do extremely rapidly. For example, there's lots of debate about whether tick-borne Lyme disease exists in Australia, particularly here in New South Wales. We can take people's tick bites and we can sample their tick bite and we can sequence and find out what bacteria or fungi Eukaryotes or viruses they have. We've done that across animals and people in New South Wales very, very quickly and it turns out there is no Lyme disease. You can go back and tell your friends it does not exist in Australia. These people are ill but they haven't got Lyme disease. We're now doing the same approach, we're going to work with Border Force and the Federal Police and the depart-

ments of agriculture to look at quarantined animals coming into Australia.

One other quick example: we've been looking at tularemia in Australia: this is a very nasty bacterial disease, and it's in animals. Again, it's an example of where you have animals and humans together, this is glandular tularemia, it's caused by something being bitten by a cat. We had a mass die off of possums in northern Sydney. We did lots of molecular work and it turns out the possums had tularemia too. In Australia, in suburban backyards the possums carry this very nasty bacterium that could spread to humans. That's kind of bad. The good news is the technology is there and we can detect that very quickly.

Conclusion

Animals carry an enormous number of pathogens. The pathogens will jump boundaries. We will get new outbreaks, it's inevitable, particularly because of the way we live today. We have change in land use, we have deforestation. We live in megacities, such as Shanghai. International travel obviously and wars as well, wars and refugees. I worked in West Africa a few years ago, and the Ebola outbreak was fuelled by the war in Guinea, Sierra Leone and Liberia, that really made lots of displaced people who got ill. What we need to do to get better, we need that One Health framework, we need to think about humans and animal health in one context and, most of all, we need to build that national centre, that national CDC-like centre that's going to allow us to respond to human and animal disease very efficiently in the near future.

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Getting climate policy back on track

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Uncontrolled climate change is among the biggest challenges to the achievement of a prosperous yet sustainable Australia. It is already evident that climate change is present and is having significant effects. There is now an extensive literature on the "attribution problem," that is the determination of the extent to which particular extreme climatic events can be attributed to climate change. In the last few years the scientific community has concluded that it is reasonable to attribute the severity and increased frequency of extreme high temperature events, to climate change. The current (November 2018) heatwave we are experiencing in Queensland at the moment is an example.

Heat waves have been experienced throughout Australian history but the frequency has increased as the global climate has warmed. In the event of, say, a 4-degree warming those things would be drastically worse. Peter Christoff's (2014) *Four Degrees of Global Warming: Australia in a Hot World* is an excellent, if depressing description of the consequences.

The target agreed at the Conference of Parties in Paris was to hold global warming definitely below 2 degrees and ideally as low as 1.5 degrees. That in turn implies a carbon budget, that is an allowance of the total amount of carbon dioxide and other greenhouse gases that we can collectively emit as a species, a limited amount, most of which has already been used.

The Paris Agreement was what embodied those goals. It's certainly an Australian discussion, not discussed very satisfactorily. It begins less ambitiously than, for example, Kyoto. Rather than with a globally agreed scheme, it has individual contributions by individual nations determined by them.

The starting point is what are called Intended Nationally Determined Contributions, (INDC). Those were the commitments that countries made at the conference of Parties in Paris which were understood to be first bids. That is that each country said, "We'll do this." Some of them had conditions attached, some of them were unconditional.

Everyone understood that this wasn't a solution to the problem. Some of the more negative rhetoric from environmental pessimists takes the view that that the INDCs were the commitments and there's nothing else to the Paris Agreement, a point on which they agree with some of the deniers. In reality, the whole point was that these commitments should be scaled up over time with a ratcheting up of ambition.

What are the implications of the INDCs alone? The first point to observe is that the INDCs are commitments to 2030. By design they don't say anything about what will happen beyond 2030. The INDCs alone imply emissions will level out by the late 2020s. That clearly is not going to limit warming to 2 degrees. Even assuming gradual decarbonization, the likely warming is least 3 degrees. So very clearly those commitments aren't adequate and weren't intended to be agreed as a solution to the problem.

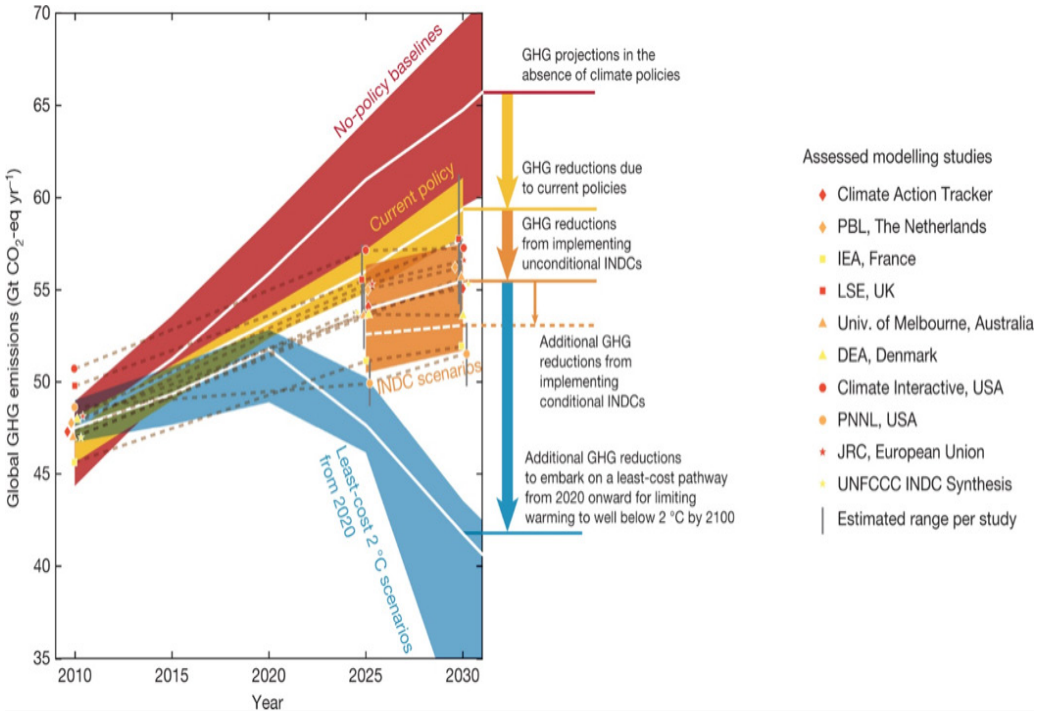

Figure 1: Emissions scenarios to 2030

Figure 1 shows a range of scenarios for emissions. The top ones are the no-policy based lines, that's what's estimated will just happen if we ignored carbon dioxide emissions entirely. That is, effectively, the policy of the current Australian government, which is to remove all the existing policies and replace them with nothing. The next set of red lines consists of current policy, doing nothing new but keeping existing policies in place. Then if we look at the orange section of the curve, that's where we get to essentially with the INDCs, looking first at the unconditional commitments that countries have made and then if there are various things which are conditional on other people doing things. All of those have essentially emissions increasing or, in the case of the most optimistic INDC (flattening out clearly getting nowhere near what we need.

The blue curves are the ones that are actually needed to get on to a low-cost pathway of limiting warming. Of course, because this only goes to 2030, there's always a higher-cost pathway. We could close down the economy as of 2030 and that would, at incredible cost, solve the problem but these are low-cost and least-cost policies. The longer we delay, the closer we come to the famous wrecking ball that would destroy the economy.

In retrospect, had the world acted in a coherent way in, say, 2010 we'd be well on the way to solving the problem and indeed well and truly on these low-cost pathways. As you can see if you extrapolate, if you just join an imaginary graph going back at 2010 and imagine a decline starting shortly after that, we would clearly be there. The longer we delay, the greater are those costs.

What was Australia's INDC? The Abbott government made this commitment in 2015. As with a number of other countries, Australia's INDC has a conditional and an unconditional component. The commitment was to achieve a 26 to 28 per cent reduction in emissions relative to 2005[1] by 2030.

We had, and may yet have again[2], something called the National Energy Guarantee, which at least in its initial incarnation was supposed to achieve this goal but only for electricity, which is the easiest and cheapest part of the system to decarbonise. Substantial progress has already been made through the Renewable Energy Target. That in turn means that we are indeed on track to achieve substantial reductions in emissions from electricity generation. We haven't opened a new coal-fired power station for a long time and they're gradually closing down.

Electricity generation is only about one-third of emissions, so a 26 per cent reduction in this sector wasn't going to achieve our INDC, which in turn wasn't remotely adequate. As noted above, it was only ever meant as a starting commitment to be negotiated upwards subsequently. Both the NEG and Renewable Energy Target were abandoned by Prime Minister Turnbull immediately before his replacement and haven't been replaced by anything much. Effectively therefore Australia has repudiated its INDC, although we have yet to follow the US in terms of actually withdrawing from the Paris Agreement.

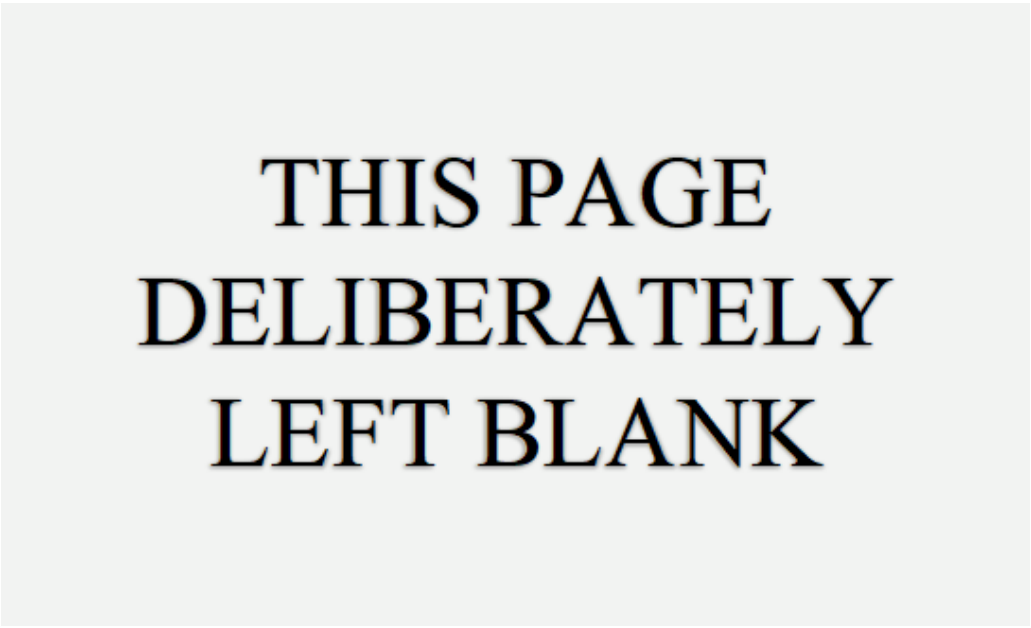

Figure 2: The Morrison government's climate policy

[1] 2005 always appears in the Australian targets, unsurprisingly because that was when our emissions peaked and so of course we always pick the highest date to make our numbers look good.

[2] It appears that the Labor Party is going to make one last try for bipartisanship (or possibly mischief making) and revive a version of the National Energy Guarantee if elected.

To understand this failure it is necessary to look at the political background, As stated by former Prime Minister Turnbull, the controlling faction of the government, has shown it's opposed to any action whatsoever on climate change[3]. Even policies that previous conservative governments introduced have been repudiated. Whatever policy is announced, they call it a carbon tax and reject it.

In economic terms, in a sense, the denialists are right. Any policy that attempts to stop something puts a price on that policy and is therefore a tax. It can be a regulation or whatever it is, effectively any policy can be expressed as a tax. It's just a question of whether you have an efficient and clear overt tax or an inefficient and half-baked one such as the Abbott government's "Direct Action" policy. Direct Action involved a bizarre kind of carbon pricing mechanism, based on auctions, although with a substantial subsidy involved. It was the last policy to be applied under the current government, and funding has now been exhausted.

To consider options for progress, we must assume a change of government and, in all probability, abandon the prospect of bipartisanship with the LNP. A policy must at least have sufficient community support to get through a new House of Representatives and through the Senate, and that implies support from the Labor Party, from Greens, the Centre Party, at least some Independents. We have to have a policy that at least can sustain itself from changes in the balance of power in the Senate, if not a bipartisan one.[4]

Interestingly, in attacking this, of course, the government has revived the phrase "wrecking ball through the economy" used to describe the carbon tax imposed or more precisely the fixed price Emissions Trading Scheme, imposed under the Gillard government[5]. The GDP did exactly nothing in response to that carbon tax but the phrase has been revived and the longer we go with no action, of course, the more costly the delay will be.

Looking at an economically feasible road map, this is a global road map so it's not specific to Australian circumstances but it works fairly well, based on Rockström et al, Meinshausen, one of the authors of this paper. So first point is no brainer policies for immediate adoption.

Carbon pricing makes sense essentially independently of climate change because it might internalise the health costs of burning coal. In places like Delhi and Beijing air pollution kills thousands of people every year and so imposing a tax price of some kind on carbon makes eminently good sense. A recent study suggested that, even in places like Sydney where the coal-fired power stations are a fair distance away, fine particle pollution kills hundreds of people every year

[3] Turnbull referred to climate change as the third rail of Australian politics. This (American) metaphor comes from the high-voltage third rail in some electric railway systems, and for any issue so controversial that it is "charged" and "untouchable" to the extent that any politician or public official who dares to broach the subject will invariably suffer politically. Given that Mr Turnbull has twice lost the leadership of the Liberal Party over this issue, the metaphor seems apposite. https://en.wikipedia.org/wiki/Third_rail_of_politics

[4] This paper was presented before the May 18, 2019, federal election, at which the conservative Morrison government was returned. (Ed.)

[5] The dramatic imagery conjures up visions of economic destruction and hordes of beggars in the streets. Of course, as with most apocalyptic prophecies, nothing of the sort happened when the carbon tax was introduced. Equally, as with other failed prophecies, this failure did not stop the prophecy being repeated.

(Ewald 2018). The same is true for the US (Muller et al 2011).

There's also a range of no-regrets options which we'll come to. Fuel efficiency and energy efficiency policies are essentially just a matter of reallocating people's attention a bit. Now, attention isn't free but considering the stuff which we do allocate attention to, putting a bit of that attention towards energy efficiency, I think, comes under the category of a no-regrets policy. The big efforts come between 2020 and 2030. In that period we need essentially to decarbonise electricity supply, at least getting coal out of the electricity mix, and we also need to be well on the way to a massive shift towards electric vehicles. So those are the two big discrete lumps of the decarbonisation process, electricity generation and transport. There's then a bunch of trickier and more case specific problems in industry, agriculture and so forth. We need by 2030 to have made very substantial progress on those goals, with the aim of completely decarbonising the industrial economy by 2050. Quite a few governments have committed to this in principle. What they haven't done is adopt the policies needed to achieve that goal.

We need negative net emissions after 2050. Some of that's just a matter of planting lots of trees. Some of it rests on exotic options like removing carbon dioxide from the atmosphere which may or may not work. Some of it though we can potentially get for free if we can reduce methane emissions. Because methane has a relatively short residence time, if we can reduce emissions from methane, which is basically paddy rice and ruminants belching, those are the two big sources, the methane will gradually dissipate from the atmosphere over the period from 2050.

What must a new government do? First, we need to set a more ambitious target and again we need to remember this isn't just electricity. The Climate Change Authority, of which I was a member for some time, recommended to governments of both parties a target of 40 to 60 per cent reductions in emissions relative to 2005 to be achieved by 2030. That requires a substantially higher rate of emissions reductions for electricity and we're nowhere near that. We need immediate acceleration of progress towards decarbonisation across the fields of electricity generation, transport, industrial and residential use and land use.

What kind of policies do we need? Economists fought globally a losing battle for prices. Prices are by far the best way of doing this. If we had a uniform carbon price which had been introduced when we saw the problem at a low rate, like $10 a tonne in 1997 and had ratcheted it up steadily, we would have the problem solved by now but as usual, the advice of economists was ignored. Carbon pricing faced political resistance almost everywhere it was proposed.

Nonetheless carbon pricing is finally happening. The EU, which has had many false starts, finally has an effective carbon price running at currently close to 20 Euros (around $A30) a tonne. The scheme started around 2007, so it's taken 10 years to iron out the concessions that were made to national governments, which led to an excessive issue of permits, but it's finally having an effect.

Following a change of government, Australia will, in effect be starting from scratch. In these circumstances we need to use all the tools at our disposal: prices but also regulation and direct action. Even when you're primarily using regulation heavily, you want

prices because if the prices are right, people don't have the incentive to find their ways around the regulation. If you have regulation that tells people to do something that isn't in their financial self-interest, they'll find a way around it, and so prices are a crucial backup in making sure that a regulation system works.

As regards land use, we need subsidies rather than taxes. We need to pay farmers to keep land forested and we need to pay them to adopt measures such as dietary supplements that will reduce methane emissions.

Energy efficiency is a topic close to my heart. When I was on the Climate Change Authority I pushed hard to get a study into motor vehicle fuel efficiency. We produced a report advocating this. It's been sitting on the government's desk for a number of years. That partly reflects the efforts of climate deniers in the government. In addition, car dealers like selling cars that perform well on the sales floor. They don't care about fuel efficiency which people pay for later, so they've resisted it. We need to push hard on this issue of particulate pollution and substantially raise standards on sulphur emissions from fuel, which is another of the obstacles to more fuel-efficient vehicles, on coal from coal-fired power stations and so forth.

In terms of direct intervention, the crucial step is public investment in renewable energy, I'm happy to say Queensland is leading the way in that respect. We actually have CleanCo, a public company which will invest in renewable energy. We need to move much faster on creation of infrastructure for renewables, for electric vehicles. Again, Queensland is taking the lead on that point.

We still have time but not much. A decade wasted. Some of that was due to the efforts of interest groups but most of it is sheer bloody mindedness. History will judge very harshly the people who have led this country for the last five or six years who have pursued, essentially, cultural vendettas at the expense of the environment. We need an unconditional commitment from both sides to return to reality. Unfortunately we've already foreclosed the low cost options. Thank you.

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Summing up the Forum: what future the Lucky Country?

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Abstract

Professor Emerita Ann Williamson summarised the presentations given at the Forum.

Thank you very much for having the faith in me to be the person to summarise the Forum. As I am also the person between you and a drink, I will try to be succinct. The day has left my mind buzzing with ideas and new knowledge, and I've been challenged to really stretch my limits in many ways. I'm not an economist and one or two of the talks really demonstrated that to me.

Interpretation of our rather challenging topic of "the future of the Lucky Country" has ranged broadly across speakers. Many of the presentations have been strong on the issues relating to whether a prosperous and sustainable Australia is possible. Several presentations pointed out many of the future problems we face in these areas. Fewer presentations talked about solutions to these problems. Perhaps that reflects the state of the art on these issues.

We have seen prosperity broadly defined. We have seen it defined in terms of wealth, as you'd expect, but also health, both of people and the environment. Sustainability was also broadly defined, not just in terms of sustainable climate, but also sustainable growth, and, interestingly, sustainable well-being.

Our speakers tackled some of the serious problems in achieving both prosperity and sustainability outcomes that we face now and into the future and which cross many aspects of society.

We have had a couple of salient, well-argued talks about the limits to growth from Graham Turner and Brian Czech, that focused on the issues arising from unfettered economic growth. One of Graham's books likens it to a runaway train — and from their presentations, we can see why both speakers would take that view. On the other hand, we have seen some tempering of the anxiety we might feel about the Australian economy in the presentation by James Morley. He advanced an argument that Australia may become a safe haven, and foreign investment and migration are not only justified but will actually help us maintain the prosperity and sustainability nexus.

The presentations also ranged into some of the specific difficult challenges to future prosperity and sustainability. Eddie Holmes talked about biosecurity, an issue that scares all of us. He pointed out the insidiousness of influenza and many other communicable diseases in a highly physically connected world and talked about their impact on our health and biodiversity. By so doing, he highlighted problems that just don't get enough discussion. In a Forum about the future, climate change of course was included, in a fascinating discussion by John Quiggin. Less often recognised, the issue of social fragmentation was raised by Hugh Mackay. He pointed to increasing social isolation, loneliness and

anxiety that threaten well-being and threaten our social harmony, cohesion and our way of life into the future.

So, we have identified a broad range of problems that are likely to jeopardise our future prosperity and sustainability. Identifying problems is an important first step to resolving them, but do the solutions to our prosperity and sustainability lie in just fixing these specific problems? Will we solve our problems of prosperity and sustainability if we stop economic growth, regulate migration and investment, stop travelling so much, only use renewables and be nice to each other? Well, probably not; in fact, it is highly unlikely. Having raised these issues, though, we need to think harder about what does create prosperity and sustainability; how do we bring these potentially competing aims together to achieve the kind of balance that we want in Australia's future?

At the Forum, we heard some talks that put forward some interesting ideas for how we might work toward solutions. Two speakers gave us some frameworks and tools that should help our thinking on how to achieve the prosperity and sustainability relationship we seek. On the premise that "if you don't measure it, you can't manage it," the U.N. sustainability goals that Sam Mostyn talked about and the Australian Environmental-Economic Accounts that Jacky Hodges introduced provide methods for evaluating our progress towards sustainability. Both speakers pointed to the challenges that we face in achieving goals in both cases. These types of benchmarks are really a vital part of the solution. We must have them in order to plan our course towards these goals, to know how well we're doing on the path and whether we are being successful and effective in achieving our prosperity and sustainability goals. We need these tools and we need to use them.

Some presentations made arguments for some solutions. To paraphrase and draw these together, we saw solutions that talked about the limits and the impact of our activities through interesting ideas such as the circular economy and recycling from Ashley Brinson, and managing greenhouse gases, which was our last wonderful talk from John Quiggin. As our speakers demonstrated, there are eminently possible ideas here, but they need political will to be achieved. Similarly, the ideas put forward about steady-state economies from Brian Czech could be achieved with enthusiastic and supportive leadership. Graham Turner described the concept of duelling loops of influence where he pointed out that achieving sustainability through greater use of renewables, stabilising population, reducing household consumption and reducing the working week will benefit the environment without reducing GDP or individual wealth. This has certainly made me, and I am sure others, pause to think because while there are some real challenges in achieving them, the question is whether we can be clever enough to make them happen.

Three speakers painted a picture of the benefits of technology. We heard from Hugh Durrant-Whyte, from Toby Walsh, and from Mary-Anne Williams, all of whom see that technology has a major place in solving our prosperity issues now and into the future. This is not a place for my particular soap box, but I think we do need to pause to think here. These presentations place a real emphasis on the positive aspects of technology, arguing that it is the future. Mary-Anne Williams, however, provided a comprehensive description of the risks of Artificial Intelligence (AI),

but then we moved on and the problems these risks present were not discussed further.

I think we glossed over a major concern about the introduction of technology and the use of AI in our world. For AI and new technologies to achieve the benefits predicted, they must be convincing and satisfying for people to use. They must fulfil a human need or purpose and be designed to make tasks easier rather than more complex or difficult. Consider technology failures like Google glass or the Segway, or technology interface complexities like the proliferation of passwords. These are all examples of clever technologies that fail or that people resist using because their interfaces with the user do not take into account how people work or prefer to operate in the world. People will not use technologies that they find difficult, confusing, or that they feel they cannot trust to work reliably. People are going to need to feel that AI is sufficiently trustworthy to use. Certainly, trust in AI and new technology will not be developed by the early introduction of imperfect technologies. Why should users trust technology that doesn't work the way they expect it to or requires them to learn many new skills to operate it, or doesn't work at all. Introduction of driver-assistive technology and automated vehicles is a clear case in point, where acceptance by drivers and purchasers will depend on the extent to which they trust its reliability and whether it really makes driving easier.

We need AI and new technologies that are not just designed to be clever but to be useful and useable by their target population. I think we have some way to go here. I know Toby Walsh has said this too, but I think we need to take this further than he did in the Forum. Talking about AI as a holistic concept is probably not the way to go. Not all applications of AI and new technology are good or of benefit to users. I think there's a very important debate to be had here. We are seeing the need to pause and consider the implications of particular AI applications before they are introduced to the community. The recent experiences of two major air crashes involving Boeing 737 Max 8 aircraft with consequent tragic losses of many lives is surely telling us this. In both cases, Boeing's automation software that operated without pilots being aware was a major cause of the crashes. Keeping pilots "out-of-the-loop" has been recognised as a threat to safety in aviation, yet Boeing allowed these aircraft onto the market. Similarly, we are seeing medical devices being beta-tested in patients without fully assessing their function and how they are used. There are many other examples of technologies being introduced too early before proper testing to ensure their safety. It is time to draw back a little and resist the temptation to be persuaded to introduce AI and new technologies before we can be convinced that they are of benefit for human users.

What does all this mean for achieving prosperity and sustainability? One question is whether it is possible to have these two dimensions come together. Some people are arguing, yes, it is possible for Australia to have sustainability and be prosperous, but others are saying maybe it isn't. Certainly, both Brian Czech's and Graham Turner's talks suggest that these are competing goals. Many of the talks alluded to the need to involve and motivate our decision makers. I think all the speakers mentioned policy, decision makers, government to a greater or lesser degree, the last talk by John Quiggin in particular in the context of needing people with decision-making power to act. Many

of the problems that were highlighted in the Forum require this sort of action. I was very pleased to see our first speaker, Hugh Durrant-Whyte, arguing in that direction. As the New South Wales Chief Scientist & Engineer, he is eminently well placed to do that. Many of the talks highlighted options that should become at least short-term targets for policy and decision-makers in government.

Many targets could be achieved right now. The establishment of an Australian Centre for Disease Control, as argued by Eddie Holmes, is a prime example. Having worked in public, workplace and transport safety-related fields for many years myself, I have often wondered why we don't have an equivalent of the U.S. Centers for Disease Control. The rise of communicable diseases, many with very serious consequences, certainly indicates a need. John Quiggin also pointed out the urgent need for action on managing greenhouse gases and showed us a way of achieving that right now. Similarly, it is possible to strengthen recycling policies and provide incentives to do so right now. We just need political will to do so. Other problems will probably take medium- or longer-term policy action such as controlling growth and managing new technology but, again, it's going to need the decision makers, and the people who actually can make things happen in our society to seize the problem and solve it.

I loved the concept of stewardship put forward by Sam Mostyn, which relates, in this context, to assuming responsibility to shepherd and safeguard shared valuables and resources. Sam's point was that Australia's progress on the U.N. Sustainable Development goals is lacking. While individuals can, and should, play a stewardship role, we need to lobby governments to assume stewardship for areas covered by the U.N. goals: poverty, inequality, climate, environmental degradation, prosperity, and peace and justice. I know many people in the room have spent a significant proportion of their lives lobbying government on many issues related to sustainability, prosperity and well-being, and the shared experience is often that it's not so easy. I also know that's true. But stewardship can also extend to our personal responsibilities to create sustainability and prosperity in our communities. Sam Mostyn pointed out that prosperity can be defined in terms of happiness as well as dollars. This point dovetails nicely with Hugh Mackay's reminding us that we are not just bystanders in building sustainability. He argued convincingly that it's our responsibility to act, to fill in some of the holes that are appearing in our social fabric, such as loneliness, isolation and general social disintegration, and that we need to work on these. We have a role, as stewards, to take action, to build a more prosperous social structure as well as the prosperous wealth-related structure and sustainability.

Overall, I think that the presentations raised issues and questions that must be answered if we are to achieve sustainability and wealth in Australia in the future and they gave us some directions for action. But what of the question raised by the theme for the Forum? If we do manage prosperity and sustainability, will this change Australia's luck? Will we continue to be The Lucky Country?

I think it's worth pausing here to remind ourselves of the origin of the concept of The Lucky Country. There are likely to be many people in the room who, like me, were around in 1964 and they might well remember Donald Horne's best-selling book *The Lucky Country*. It was a bestseller: I think a

hundred thousand copies or so sold out in nine days. It's been reprinted continuously, it's still in print, and I believe Hugh Mackay wrote the introduction to the sixth reprint.

The term "lucky country" is often interpreted as a favourable comment about Australia, but Horne wasn't being favourable. In fact, he was being ironic. The beginning of his last chapter sums up his argument this way:

> Australia is a lucky country run by second-rate people who share its luck. It lives on other people's ideas and although its ordinary people are adaptable, most of its leaders (in all fields) so lack curiosity about the events that surround them that they are often taken by surprise.

Horne's thesis is a bit tough to read. Certainly, when I first read it, I thought, "surely that's not true?" On reflection, I think Horne's argument was that Australia's prosperity relied too much on the luck of our history, our rich natural resources and our tradition of importing good, clever people rather than on "clever" innovation, technology and enterprise. Now, more than fifty years later, I think it is right to ask whether this argument is still apt; if it ever was.

The theme of the Forum was bold enough to pose the question of the future for the Lucky Country. From the presentations, I think there is evidence that challenges Horne's argument and suggests that Australia's current and future prosperity is not and will not just be based on luck. The ideas and the debate we've participated in are testament to the fact that Australia and Australians can and will challenge themselves to build a better future. How we build a sustainable and prosperous Australia and the stumbling blocks that are in our way have been the objective of the Forum, and the discussion has ranged widely about strategies and solutions. Nevertheless, just as Donald Horne in 1964 challenged Australia not simply to rely on luck but to take action and to do better, our Forum, I think, has been an attempt to actually do the same: to put forward our ideas towards achieving a prosperous and a sustainable Australia in the future.

I think much of what we have heard also tells us that we need to take up the challenge of action and we need to encourage our leaders to adopt the available strategies and solutions and to act to make them happen rather than just let luck run its course. We need to ensure that our leaders are aware of the issues raised in the Forum, and encourage them to be part of the action, the decision making, the policy making to overcome the problems identified to be limiting our quest for improved sustainability and prosperity. I think these really are the essential ingredients to taking the irony out of the concept of The Lucky Country.

Reference

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Thesis abstract

Responsibility for iatrogenic death in Australian criminal law

David J. Carter

Abstract of a thesis for a Doctorate of Philosophy submitted to University of Technology Sydney, Sydney, Australia

Iatrogenic harm is harm, including death, that arises in the course of medical or healthcare treatment and is caused by the application of treatment itself, rather than by the underlying disease or injury. Each year, some 27,000 deaths in Australian acute care hospitals are associated with iatrogenic harm. Such harm in its iatrogenic form raises for us, in an urgent contemporary setting, some of the perennial questions associated with moral and legal answerability and questions of the limits of medicine, the difficulty of healing and of the politics of care.

Criminal law, in the form of manslaughter by criminal negligence, has been heavily criticised whenever its deployment has been contemplated as a response to iatrogenic death. And yet, the doctrine both remains in place, and exerts a significant influence on the regulation and conduct of medicine and healthcare. To understand why criminal law, despite its rare use, has been subject to such strident critique, this thesis engages with the assemblage of ways of knowing (epistemology), of deciding (ethics) and of acting (praxis) known as the 'healthcare quality and safety sciences', or more simply, the 'patient safety movement', that has been its chief interlocutor.

Scholars in this field of patient safety generally maintain that manslaughter by criminal negligence should not be prosecuted, with many claiming that criminal prosecution promotes the very harm it purports to address. The first cluster of arguments mounted against criminal prosecution of iatrogenic harm claim that it is unhelpful or ineffective. As the argument goes, the threat of prosecution reduces transparency and discourages the reporting of error, consequently choking off the 'error wisdom' that would otherwise be collected from such instances of harm or 'near- misses'. By stifling this valuable error wisdom – the 'gold standard' of data for quality improvement – the criminal law needlessly obstructs quality and safety science-led efforts to reduce harm. In so doing, the criminal law *itself* is said to produce, or at least worsen, the very iatrogenic harm it aims to prosecute.

The second cluster of arguments against criminal prosecution assert that it is unjust. Leading scholars argue criminal prosecution should be based upon conscious and willed contributions to harm, all of which must arise due to a positive choice, or reckless disregard, on the part of the defendant-practitioner. When healthcare is understood as a complex, adaptive and socio-technical system, as the best learning of quality and safety science has it, no individual agent can avoid or prevent iatrogenic harm in a morally or legally relevant way. When the literature holds that what we are respon-

sible for can only be based upon what we choose, criminal culpability is impossible to imagine within the context of health care as constructed by the patient safety movement, for practitioners cannot 'control' nor really 'choose' within a self- organising, complex and adaptive system. For this reason, manslaughter by criminal negligence is singled out for particular critique, given that it does not use 'choice' as the definitive marker of criminal culpability by its eschewal of subjective forms of mens rea as the prerequisite for criminal liability.

In response to the charge made by the patient safety movement that criminal prosecution is both unhelpful and unjust, I argue that these calls for rejection of manslaughter by criminal negligence have not been sufficiently attentive nor responsive to the actual practices of criminal law in this field; not to the history of its use, to its particular understanding of human action in health care, or to its mobilisation in the courtroom. As this thesis shows, when these foundational aspects of law's actual practice in the field are more fully and critically engaged, they seriously destabilise the validity of claims that manslaughter by criminal negligence is unhelpful or unjust when applied to iatrogenic harm in the Australian setting. The thesis builds its argument in three sections, each providing a new account of the actual practices of criminal law in this field: firstly, as to the history of its use in Australia; secondly, as to its fundamental and animating 'logic'; and finally, as to its mobilisation in the Australian courtroom.

First, the thesis greatly extends previous work on the topic by developing new historical material. Drawing on new archival work, a newly expanded account of prosecution challenges claims of prosecutorial overreach, speaking instead to criminal law's judicious and consistent capacity to distinguish between culpable and non-culpable instances of harm. Then by offering an historical analysis of the emergence of iatrogenic harm in Australia during the 1990's, I show that, contrary to the dominant perspective of the literature, criminal negligence and the patient safety movement are in fact neither incompatible nor autonomous: rather, their histories demonstrate that they exist in a highly dynamic, mutually constitutive relationship, one that is productive for both the formation of the field of quality and safety practice, and of its 'object', iatrogenic harm. In the contemporary moment, 'law', far from being simply opposed to advancing healthcare safety, has been productive of it.

Second, the thesis offers a highly original theoretical analysis of what might be at the core of the ongoing conflict surrounding criminal law and its application to iatrogenic harm: the reliance upon choice by the patient safety movement to understand agency, action, causation and responsibility. Criminal negligence, which stridently opposes the use of 'choice' as the definitive marker of criminal culpability, is rejected on this basis. Yet, I argue, this mobilisation of choice is quite curious – and particularly so for proponents or supporters of the quality and safety sciences; for, taken as a whole, the discipline's major contribution has been to theorise the emergent properties of iatrogenic harm, human agency and action in a manner that denies the health practitioner's ability to choose as an autonomous subject, subject as they are to control by external forces, and existing in a state of severely attenuated freedom. In short, choice is simply not part of the discipline's way of seeing the world, however, that same litera-

ture uses criminal negligence's own rejection of choice (as the definitive marker of culpability) as reason to reject it. Using choice in this way, to deny the legitimacy of criminal law, represents a worrying slippage or dissonance internal to this literature, one that I argue represents a deep betrayal of its more fundamental commitments. I argue that this dissonance offers the opportunity to recognise that both the doctrine of manslaughter by criminal negligence and the discipline of quality and safety sciences itself – aside from its argumentation against criminal prosecution – have a great deal in common. Both eschew the centrality of choice, and instead theorise human agency, action and healthcare-related harm in a manner deeply suspicious, if not in outright denial, of the relevance or availability of personal, subjective control or choice.

Third, and finally, the thesis develops a novel reading of the deep workings of the doctrinal material itself. The doctrinal material or structure of the offence of manslaughter by criminal negligence has been charged with being problematically devoid of content, and circular in logic. I accept these descriptions of the doctrinal material as accurate. However, I present a theory of criminal negligence and of negligent culpability that emerges from these very 'inadequacies' of the doctrine. Closely reading the workings of the doctrine in recent case law, I argue that the doctrine of criminal negligence develops its very form and content through a process of drawing into itself the practices and standards of the area of human activity with which it engages; borrowing, reflecting and thus reinforcing what is particular to the field of practice, rather than imposing standards alien to it. At the same time, the doctrine maintains normative solidity and coherence by drawing upon its own 'internal normativity', all the while continuing to actively re-affirm the underlying values of the area of human activity with which it is engaged: in this case, medicine and healthcare practice.

In light of the new research, it can be no longer said that the offence of manslaughter by criminal negligence is overused in Australia in response to iatrogenic harm. Nor can it be said that law, and specifically criminal law, has been wholly unhelpful for progressing the agenda of the healthcare quality and safety sciences, or that manslaughter by criminal negligence operates with an understanding of human action and agency that is incompatible with the quality and safety disciplinary project. Finally, it can no longer be said that manslaughter by criminal negligence represents an unjust imposition of liability by imposition of standards alien to those of medicine and healthcare.

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Thesis abstract

Functional magnetic interface phenomena in nano-architectures

Grace L. Causer

Abstract of a thesis for a Doctorate of Philosophy submitted to University of Wollongong

The work embodied in this thesis aims to investigate the occurrence of magnetic interface phenomena in low-dimensional thin-film systems which have conceivable utility in future condensed-matter technologies. Namely, the magnetic interface quality of an $FePt_3$ nano-magnet formed via ion-induced chemical disorder will be critically analysed, in addition to a Co/Pd bilayer which features modifiable magnetic surface anisotropy upon exposure to hydrogen gas. The studies are enabled chiefly through advanced X-ray and neutron scattering techniques specifically chosen to probe interface structure as well as chemical and magnetic orders, and supplemented by traditional lab-based characterisation tools.

To begin, a much-anticipated experimental confirmation of the intrinsic sharpness of magnetic interfaces formed by locally driving magnetic phase transitions in materials using ion beams is presented. This is achieved through a unique experimental design whereby a room-temperature ferromagnetic nano-layer is encoded with depth-control onto a paramagnetic $FePt_3$ film by inducing chemical disorder using energy-specific He^+ ions. The magnetic transition is investigated through theoretical modelling, whereby the first density functional theory results for the entire suite of potential long-range magnetically ordered states of $FePt_3$ are presented. In doing so, the energetically favourable ground-state spin structure is identified. By analysing several localised defect structures which may form in $FePt_3$ under ion irradiation, the fundamental mechanism of the disorder-driven magnetic transition is revealed and shown to be caused by an intermixing of Fe and Pt atoms in anti-site defects above a threshold density.

In a second study, hydrogen-induced modifications to the layer-averaged static magnetisation and macroscopic magneto-dynamic behaviours of a Co/Pd heterostructure are investigated. The modifications are observed and examined in detail through simultaneously probing the magnetic anisotropy energy and studying the changing chemical and magnetic depth-profiles across the entire bilayer during primary hydrogen gas absorption. It is revealed that the in-plane interfacial magnetisation of the Co/Pd bilayer irreversibly increases after primary hydrogen-gas absorption, indicating a weakening of the perpendicular magnetic anisotropy energy. To aid in conducting this analysis, an original experimental method is first developed which innovatively combines neutron scattering and microwave spectroscopy; equipment is then commissioned, and feasibility studies are performed.

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Thesis abstract

Mycoplasma hyopneumoniae proteases: Investigating their role in pathogenesis and chronic infection

Veronica Jarocki

Abstract of a thesis for a Doctorate of Philosophy submitted to University of Technology Sydney, Sydney, Australia

Proteases are enzymes that cleave peptide bonds in polypeptides thus influencing protein shape, size, composition, function, cell localisation, turnover, and degradation. In bacteria, in addition to being responsible for a myriad of physiological processes, proteases are also secreted as toxins and other virulence factors. Hence proteases have been identified as potential therapeutic targets in a range of microbial pathogens and have successful applications in treating viral and fungal infections.

The genome-reduced, and economically significant, swine respiratory pathogen, *Mycoplasma hyopneumoniae*, is predicted to encode ten proteases. So far, a glutamyl aminopeptidase (GAP) has been characterised as a moonlighting protein with adhesive functions, and signal peptidase I was found to be cytotoxic to mammalian cells. In this thesis, four proteases (loci: MHJ_0522, MHJ_0659, MHJ_0461, MHJ_0169) were expressed as polyhistidine tagged recombinant proteins, and their activities, both canonical and moonlighting, were characterised. Further substrate characterisation of GAP was also achieved.

MHJ_0522, MHJ_0659, and MHJ_0461 were characterised as functional oligopeptidase F (PepF), xaa-pro aminopeptidase (PepP), and leucine aminopeptidase (LAP), respectively. All three proteases were predicted to be cytosolic, yet all three were identified on the surface of *M. hyopneumoniae* by both proteomic methodologies and immunofluorescence microscopy. All three proteases were found to possess moonlighting adhesive properties by binding heparin, and LAP was found to additionally bind exogenous DNA and plasminogen. Furthermore, LAP binding plasminogen enhanced its conversion to plasmin.

Collectively, PepF and PepP are described here as possessing the ability to deactivate four important mediators of inflammation. Using a matrix-assisted laser desorption/ionisation (MALDI) — time-of-flight (TOF) — mass spectrometry (MS) assay, PepF and PepP were shown to cleave bradykinin, substance P, neurokinin A, and neuropeptide Y in ways that would disable receptor binding. This discovery may help explain how *M. hyopneumoniae* is able to establish chronic infections and avoid host innate immune system clearance.

M. hyopneumoniae is known to proteolytically process, often extensively, proteins that reside on its cell surface. By mining N-terminiome data, this thesis also provides an *in silico* analysis of *M. hyopneumoniae* generated protein fragments, demonstrating an increase in disorder and availability of protein:protein interaction sites. This observation suggests that genome-reduced *M. hyo-*

pneumoniae uses proteolytical processing to increase its proteins functional repertoire. An observed N-terminal methionine excision (NME) peculiarity, that is, NME occurring when the P1' residue is large and charged, is explored by expressing and characterising recombinant methionine aminopeptidase (MAP; MHJ_0169). Ultimately, the activity is assigned to surface exposed GAP and LAP using peptides mimicking the N-termini of offending proteins and MALDI-TOF-MS.

Lastly, formylated bacterial peptides are known to be potent chemo-attractants for innate immune cells, particularly white blood cells. In bacteria, a formyl group is added to methionine to initiate protein synthesis. This thesis provides evidence that *M. hyopneumoniae,* and fourteen other mycoplasmas, lack the enzymes required to generate and attach formyl groups. It is proposed that these mycoplasmas have evolved an alternative NME process that may be a means to escape host recognition.

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Thesis abstract

The use of Matrix Assisted Laser Desorption Ionisation Time of Flight Mass Spectrometry (MALDI-TOF-MS) and associated technologies for the study of disease pathogenesis and advanced diagnostics

Matthew B. O'Rourke

Abstract of a thesis for a Doctorate of Philosophy submitted to University of Technology Sydney, Sydney, Australia

The use of Matrix Assisted Laser Desorption Ionisation Time Of Flight Mass Spectrometry (MALDI-TOF-MS) for the analysis of biomolecules is a technique that has existed since the late 1980s. Recent advances have meant that this technology is able to be applied to a range of biological samples that open up new pathways for diagnostics and research.

The utilising of MALDI for the spatial analysis of biomarkers is an established application that is currently being utilised primarily in cancer research and diagnosis and is termed imaging mass spectrometry (IMS). The work within this thesis describes and discusses a reapplication of this technology and the creation of new protocols for the investigation of disease pathogenesis at a protein level using IMS.

The development of these techniques, however, outlined a number of critical limitations inherent to the technology including the inability to perform IMS analysis at sub-cellular spatial resolutions. It is for this reason that development was shifted towards the direct analysis of pathogens utilising more traditional MALDI workflows. The result of this investigation was the development of a novel protocol for the analysis of microbiological samples using MALDI that provides rapid and accurate identifications for mammalian and agricultural pathogens at strain and sub strain levels.

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Thesis abstract

Difficult knowledge and uncomfortable pedagogies: student perceptions and experiences of teaching and learning in Critical Indigenous Australian Studies

Marcelle Townsend-Cross

Abstract of a thesis for a Doctorate of Philosophy submitted to University of Technology Sydney, Sydney, Australia

This research presents a grounded interrogation of students' perceptions and experiences of teaching and learning in two mandatory stand-alone Critical Indigenous Australian Studies subjects at an Australian university. The study proffers rare empirical insight into the student experience of teaching and learning about colonialism, racism, whiteness and privilege. It contributes to building a better understanding of the complexities, opportunities, challenges and risks of four specific pedagogical approaches: critical anticolonialism, critical race theory, critical whiteness and intersectional privilege studies. The research was conducted by way of a critical ethnographic process involving in-depth interviews with students and teachers, focus group discussions with students and classroom observations. The research design was built on critical social constructionist foundations informed by poststructural and critical hermeneutical theoretical perspectives.

The study produced two key findings. The first is that learning in Critical Indigenous Australian Studies is inherently affective. Affectivity plays a determinant role in the opportunities, challenges and risks of teaching about colonialism, racism, whiteness and privilege. This finding signposts the need to take into serious consideration the emotionally onerous task of teaching and learning in Critical Indigenous Australian Studies and the need for compassionate pedagogical approaches and strategies that can productively navigate and manage affectivity. The second key finding is that if Critical Indigenous Australian Studies is to inspire and motivate students to act for social justice and social change, teaching and learning must focus equally on both the 'know-what' and the 'know-how'. Knowing what the urgent matters are without the cultivation of practical skills to engage in social change action falls short of meeting teaching and learning objectives. A dedicated and substantive focus on cultivating practical social change skills such as discursive counter-narrative skills is a pedagogical pathway toward empowering, inspiring and motivating students to act for social change.

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Thesis abstract

Quantum emission from hexagonal boron nitride

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Abstract of a thesis for a Doctorate of Philosophy submitted to University of Technology Sydney, Sydney, Australia

Realization of quantum technologies demands successful assembly of crucial building blocks. Quantum light sources, lying at the heart of this architecture, have attracted a great deal of research focus during the last several decades. Optically active defect-based centres in wide bandgap materials such as diamond and silicon carbide have been proven to be excellent candidates due to their high brightness and photostability. Integration of quantum emitters on an on-chip integrated circuit, however, favours low dimensionality of the host materials. In this thesis, we introduce a class of novel quantum systems hosted in hexagonal boron nitride (hBN) — a wide bandgap semiconductor in the two-dimensional limit. We demonstrate that the quantum systems possess a record high single photon count rate, exceeding 4 megahertz at room temperature, extremely high stability under high excitation at ambient conditions, and fully linear polarized emission. Spin-resolved density functional theory calculation suggests that the defect centre is an antisite nitrogen vacancy. Furthermore, we demonstrate engineering of quantum emitters from hBN by a range of nanofabrication techniques and that resonant excitation of the emitters is achievable. Coupling of quantum emitters in hBN to plasmonic particle arrays is also demonstrated, showing several times the Purcell enhancement factor.

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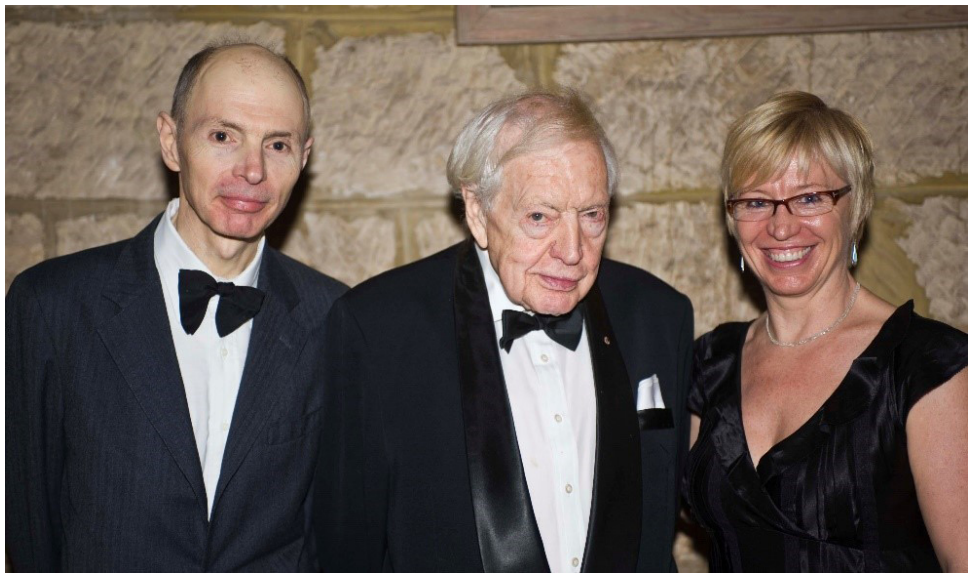
Obituary

Noel Sydney Hush
AO, Dist FRSN, FAA, FRS, FNAS, FRACI

15 December 1924–20 March 2019



Noel Hush with his children, David and Julia, both of whom are Fellows of the Society. The occasion was the presentation of his Fellowship (later Distinguished Fellowship) testamur in 2012.

Noel Hush, a Distinguished Fellow of the Society and one of Australia's finest scientists, has died at the age of 94. He was one of the key figures in establishing the field of electron-transfer theory, a phenomenon at the heart of oxidation-reduction processes, a class of chemical reactions that are ubiquitous in nature.

At school, Noel was an outstanding student, achieving near-perfect marks in eight subjects at the Intermediate Certificate. In 1942, at the age of 17, he matriculated and commenced his tertiary studies at the University of Sydney. He was a voracious reader and ultimately decided that chemistry was where his passion lay. The emerging field of quantum mechanics was his area of particular interest and Noel was keen to investigate the mechanisms that occur between electrons when a chemical reaction takes place.

While at university, Noel was actively engaged in student politics, in particular on the editorial board of the student newspaper, *Honi Soit*. In 1945, when he was approaching the end of his formal studies, *Honi Soit* became embroiled in a public controversy. In July that year, an edition was published that carried articles attacking religious and sexual views. There had been a rowdy symposium on birth control at the Women's Union,

Manning House. A Catholic viewpoint was put by a member of the Newman Society and an Andersonian philosopher presented an opposing position. The *Sydney Morning Herald* published a report on the meeting and the controversial articles and Noel, representing the staff of *Honi Soit*, was quoted as saying, "The objections resolve themselves into the question whether *Honi Soit* is to be permitted to publish material that may arouse controversy — that is, whether it is to give principal attention to the truth or to people's feelings. We cannot have controversy without paining people who have prejudices. I am sure that the anti-liberal forces will not meet with success." Noel had a strong belief in the importance of dealing with the social issues of the time, such as birth control and the transmission of sexual diseases with servicemen returning home from World War II. His deep-seated interest in philosophy and important social matters stayed with him his whole life.

In 1949, Noel completed his Master of Science degree and published an important paper in *Nature*. He was offered a lectureship by M. G. Evans at Manchester University in the theoretical chemistry department established by Michael Polanyi, a chemist of great distinction but also well known for his political and philosophical writings. At the time the department was the leading theoretical chemistry research group in Europe and Noel collaborated with H. C. Longuet-Higgins. Here, Evans arranged for Noel to meet the brilliant mathematician, Alan Turing. Noel was interested in the process by which an ion or molecule would diffuse to the surface of an electrode to transfer an electron to the metal. Turing was solving diffusion problems in two dimensions, so the field was rich with collaboration opportunities. When Turing committed suicide, Noel was appalled at the tragic outcome of the prejudice that Turing had suffered.

Noel moved to the University of Bristol in 1955 and worked with M. H. L. Pryce. Based on his prolific publications and his work with Longuet-Higgins and Pryce, he was awarded a Doctor of Science in 1959 and was promoted to Reader in Inorganic Chemistry. In 1971, he returned to Australia as the founding professor of the Department of Theoretical Chemistry at the University of Sydney.

Under his leadership, the Theoretical Chemistry Department at Sydney became internationally recognised both for teaching and research. Staff members whom Noel appointed (for example, Robert Gilbert, Sture Nordholm and George Bacskay) became internationally renowned leaders in their fields, as did a number of his students. From about 1980, Noel was one of the leaders in developing the field of Molecular Electronics, in which techniques were developed to have molecules act as electronic devices. Noel formally retired in 1989 but as Emeritus Professor, he continued full-time research until recently.

Over the last decade or more, Noel worked closely with Jeffrey Riemers, whose award-winning work has given new and important insights into the electronic and vibrational structure of many complex phenomena, such as catalysis, spectroscopy, single-molecule electronic circuits and photosynthesis. Noel's work on electron-transfer theory was an important foundation of this work. Throughout this time, Noel was a contributing author of many papers, with the last of these being submitted for publication on the day he died.

Noel received much recognition during his long career, including Fellowship of the Australian Academy of Science, the Royal Society of London, the National Academy of Sciences, USA, and Distinguished Fellowship of the Royal Society of NSW. He was appointed an Officer of the Order of Australia in 1993 and received many other prestigious awards. Noel's outstanding lifelong contribution was recognised by the University of Sydney in 2009 when he was awarded an honorary Doctor of Science.

Noel was closely involved in the activities of the Royal Society of NSW and rarely missed a meeting. If I might conclude on a personal note — over the last few years, through our shared interest in the Society, Noel and I became friends. He was a great supporter of the renaissance of the Society, particularly the broadening of its activities to its original purpose of advancing knowledge in science, art, literature and philosophy. At monthly meetings of the Society and on numerous other occasions, we had stimulating discussions on a wide range of subjects but particularly on philosophy, an area of mutual interest. I shall miss him.

Acknowledgements: I would like to thank Thomas Maschmeyer, Max Crossley, Richard Christopherson and Jeffrey Reimers for their contributions to this obituary.

— Donald Hector FRSN

Donald Hector FRSN is a former President of the Royal Society of NSW.

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Royal Society of NSW Awards 2019

James Cook Medal

The James Cook Medal is awarded from time to time for outstanding contributions to both science and human welfare in and for the Southern Hemisphere. Nominations for the 2019 award will close on 30 September 2019. A letter of nomination and the nominee's full curriculum vitæ should be sent to the Awards Committee at royalsoc@royalsoc.org.au. The medal will be presented at the Society's Annual Dinner, probably in May 2020.

The Clarke Medal and Lecture

The Clarke Medal is awarded each year for distinguished research in the natural sciences conducted in Australia and its territories. The fields of botany, geology, and zoology are considered in rotation. For 2019, the medal will be awarded in Geology. The recipient may be resident in Australia or elsewhere. Nominations for the 2019 award will close on 30 September 2019. A letter of nomination and the nominee's full curriculum vitæ should be sent to the Awards Committee at royalsoc@royalsoc.org.au. The medal will be presented at the Society's Annual Dinner, probably in May 2020. The date and location of the Clarke Memorial Lectureship will be arranged as mutually convenient with the Medal's recipient, usually at the recipient's institution.

Edgeworth David Medal

The Edgeworth David Medal is awarded each year for distinguished research by a young scientist under the age of thirty-five (35) years on 1 January 2019 for work done mainly in Australia or its territories, or for contributing to the advancement of Australian science. A letter of nomination and the nominee's full curriculum vitæ should be sent to the Awards Committee at royalsoc@royalsoc.org.au by 30 September 2019. The medal will be presented at the Society's Annual Dinner, probably in May 2020.

History and Philosophy of Science Medal

The Society's History and Philosophy of Science Medal is awarded each year to recognise outstanding achievement in the History and Philosophy of Science. A letter of nomination, the nominee's full curriculum vitæ, and a letter from the nominee agreeing to the nomination should be sent to the Awards Committee at royalsoc@royalsoc.org.au by 30 September 2019. The conditions of this award allow for self-nomination. The medal will be presented at the Society's Annual Dinner, probably in May 2020.

The winner will be asked to submit an unpublished article, drawing on recent work, which will be considered for publication in the *Journal & Proceedings of the Royal Society of New South Wales.* Manuscripts will be peer reviewed.

Warren Prize (Lecture & Medal)

The Warren Prize, which includes $500, is awarded from time to time to an early- or mid-career researcher in engineering or technology whose work has achieved national or international

significance. The research must have originated or been conducted principally in New South Wales. Entries may be submitted by researchers from any public or private organisation. Application must include submission of an original paper to the *Journal & Proceedings of the Royal Society of New South Wales* by 30 September 2019. The paper should review the body of research conducted by the applicant and demonstrate its relevance across the spectrum of knowledge — science, art, literature, and philosophy — that the Society promotes. A judging panel appointed by the Royal Society of NSW will determine the winner. The Medal will be presented at the Society's Annual Dinner, probably in May 2020. The time and location of the lecture will be arranged as mutually convenient with the Award's recipient.

Walter Burfitt Prize

The Walter Burfitt Prize consists of a bronze medal and $150, awarded every three years for research in pure or applied science, deemed to be of the highest scientific merit. The winner must be resident in Australia or New Zealand. The papers and other contributions must have been published during the past six years for research conducted mainly in these countries. There will be an award for 2019.

Archibald Ollé Prize

The Archibald Ollé Prize of $500 is given from time to time to the member of the Society who has submitted the best paper to the *Journal & Proceedings of the Royal Society of New South Wales* in any year.

Liversidge Lecture

The Liversidge lectureship is awarded biennially for research in chemistry. The lecture is presented in conjunction with the Royal Australian Chemical Institute. The lecture will be published in the *Journal & Proceedings of the Royal Society of New South Wales*.

The Jak Kelly Award

The Jak Kelly Award was created in honour of Professor Jak Kelly (1928–2012), who was Head of Physics at University of NSW from 1985 to 1989, was made an Honorary Professor of University of Sydney in 2004, and was President of the Royal Society of NSW in 2005 and 2006. Its purpose is to encourage excellence in postgraduate research in physics. It is supported by the Royal Society of NSW and the Australian Institute of Physics, NSW branch. The winner is selected from a short list of candidates who made presentations at the most recent Australian Institute of Physics, NSW branch, postgraduate awards.

Royal Society of New South Wales Scholarships

Three scholarships of $500 plus and a complimentary year of membership of the Society are awarded each year in order to acknowledge outstanding achievements by young researchers in any field of science. Applicants must be enrolled as research students in a university in either NSW or the ACT, and must be Australian citizens or Permanent Residents. The winners will be expected submit a paper to the *Journal & Proceedings of the Royal Society of New*

South Wales (which will be peer reviewed) and to deliver a short presentation of their work at the general meeting of the Society in February 2020 (following their nomination).

Nominations for the 2019 awards will close on 30 September 2019. Self-nominations are allowed for this award. The following documents should be sent as a single package to the Awards Committee at royalsoc@royalsoc.org.au:

- The letter of nomination should clearly state the significance of the student's project.
- The student's curriculum vitæ, containing a list of publications, details of the student's undergraduate study, and any professional experience.
- An abstract of 500 words describing the project
- A statement of support from the student's supervisor, confirming details of the student's candidature.

The applications will be considered by a selection committee appointed by the Council of the Society and the decision will be made before the end of November. The scholarships will be awarded on merit.

The Poggendorff Lectureship

The Poggendorff Lectureship is awarded periodically for research in plant biology and more broadly agriculture.

Nominations are sought every year, but the lectureship may not be awarded in any particular year. Nominations for 2019 will close on 30 September 2019. A letter of nomination and the nominee's full curriculum vitæ should be sent to the Awards Committee at royalsoc@royalsoc.org.au.

The medal will be presented at the Society's Annual Dinner.

The time and location of the lecture will be arranged as mutually convenient with the award's recipient.

The Pollock Memorial Lectureship

The Pollock Memorial Lectureship has been awarded about every four years since 1949 and is sponsored by the University of Sydney and the Society in memory of Professor J. A. Pollock, Professor of Physics at the University of Sydney (1899–1922) and a member of the Society for 35 years.

Nominations are sought every year, but the lectureship may not be awarded in any particular year. Nominations for 2019 will close on 30 September 2019. A letter of nomination and the nominee's full curriculum vitæ should be sent to the Awards Committee at royalsoc@royalsoc.org.au.

The medal will be presented at the Society's Annual Dinner.

The time and location of the lecture will be arranged as mutually convenient with the award's recipient.

Archibald Liversidge:
Imperial Science under the Southern Cross

Roy MacLeod
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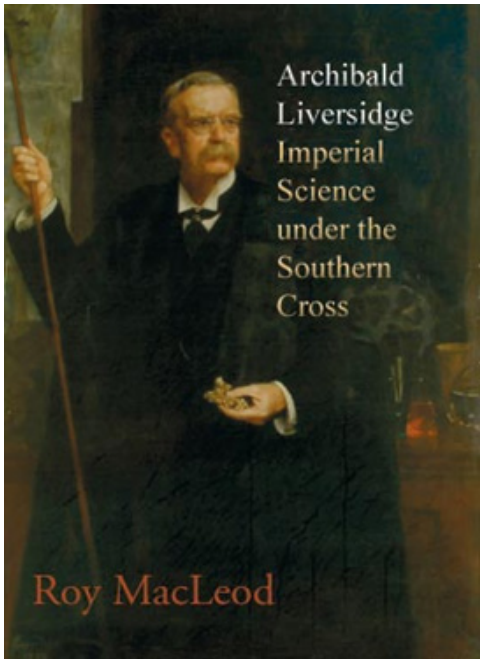

When Archibald Liversidge first arrived at the University of Sydney in 1872 as Reader in Geology and Assistant in the Laboratory, he had about ten students and two rooms in the main building. In 1874, he became Professor of Geology and Mineralogy and by 1879 he had persuaded the University Senate to open a Faculty of Science. He became its first Dean in 1882.

In 1880, he visited Europe as a trustee of the Australian Museum and his report helped to establish the Industrial, Technological and Sanitary Museum which formed the basis of the present Powerhouse Museum's collection. Liversidge also played a major role in establishing the A*ustralasian Association for the Advancement of Science* which held its first congress in 1888.

This book is essential reading for those interested in the development of science in colonial Australia, particularly the fields of crystallography, mineral chemistry, chemical geology and strategic minerals policy.

To order your copy, please complete the Liversidge Book Order Form available at:
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The Royal Society of New South Wales

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