FATAL CALCULATIONS

HOW ECONOMICS HAS UNDERESTIMATED CLIMATE DAMAGE AND ENCOURAGED INACTION

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FOREWORD BY IAN DUNLOP

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IMPRINT
Published by
Breakthrough - National Centre for Climate Restoration
Melbourne, Australia
Breakthroughonline.org.au
info@breakthroughonline.org.au
April 2020
Note: All $ figures are US dollars unless otherwise stated.

FOREWORD

A rational response from Australia's leaders to the unprecedented and disastrous 2019-20 megafires would have recognised, first, that they are another warning— and the strongest yet — that the catastrophic impacts of human-induced climate change are here now as lives are lost and livelihoods destroyed. Second, it would accept the need for emergency action.

But no. The moment the rains came and extinguished the fires, rationality sank back into the political swamp. The government's commitment to massive fossil fuel expansion immediately resurfaced. Apparently nothing could be contemplated which might interfere with maximising short-term economic growth, or achieving a budget surplus — until the coronavirus hit hard. And disinformation exploded, as denialists attempted to fob off bushfires as just another example of Dorothea Mckellar's "Land of drought and flooding rains". Nothing unusual here, they said, move on.

Even those more inclined to now accept the reality of climate change do not, or prefer not to, understand the real risks. The Australian Labour Party, the Business Council of Australia and others commit to a net-zero emission reduction target by 2050, and simultaneously support the expansion of the coal and gas industries.

This is a pathway with two fatal flaws. First, a net zero emission by 2050 target is wholly inadequate to prevent extremely dangerous climate change; it would probably result in irreversible runaway warming as tipping points are triggered. Far faster implementation is essential, ideally by 2030, but as soon as possible. Second, any further fossil fuel expansion is incompatible with net zero by 2050, let alone 2030, as there is no further carbon budget today for a realistic chance of staying below 2°C, let alone 1.5°C.

The scientific rationale for these views is set out in Breakthrough reports, including *Disaster Alley*, *What Lies Beneath* and *Climate Reality Check*. Why is it so hard for leaders to accept scientific reality?

In part, it has been due to the scientific reticence, highlighted in these reports, to articulate the full risks of climate change. Of particular concern are the major tipping-point threats to the climate system, uncertainties which so far cannot be quantified but which we know are increasingly likely to occur as atmospheric carbon concentrations and warming both rise.

This has allowed political and corporate leaders to insist on waiting for further information before acting. Whilst such predatory delay allows the opportunistic maximisation of returns from fossil fuels, it increases the risks even further.

Equally important, and little understood, is that the economic analysis on which most policy is based — supposedly derived from the science — has quite deliberately ignored these major climate uncertainties, and even downplayed the risks the science has been able to quantify. Hence the irresponsible, and extremely dangerous, political obsession with minimising "the costs of action", whilst at the same time ignoring the far greater damage of inaction.

The most egregious example is the 2018 award of the Nobel Prize for Economics to Professor William Nordhaus, whose Integrated Assessment Model tells us that the optimal level of warming, using cost–benefit analysis, would be 4°C. This is a world which national security experts consider would see the collapse of civilisation as we know it.

What cost should be put on civilisation? Apparently very little from the economist's perspective, for despite the escalating climate disasters globally, not least our bushfires, this preoccupation with the cost of action — and a blind eye turned to overwhelming future damage — remains the dominant thinking within politics, business and finance.

This report explains why such thinking must change, fast, if we are to have a realistic chance of avoiding escalating climate catastrophes. The economics profession must reassess its approach to existential threats of this kind, giving far greater weight to precautionary policies to prevent such outcomes, whatever the cost. Our survival should be paramount, not economic numbers.

The coronavirus pandemic is a major threat to human security, but human-induced climate change is even more so, with the potential to destroy civilisation as we know it. The global response to coronavirus demonstrates the importance of immediate precautionary action in the face of major uncertainties.

Sensible economic analysis would urge exactly the same emergency-action principles be applied to climate disruption without delay.

Ian Dunlop

SUMMARY

Economic analysis applied to climate change has systematically underestimated the cost of future damage, which in turn has been used as a reason to delay action.

At the heart of global policymaking is a concern that actions to limit the magnitude of climate warming (mitigation) should not be economically disruptive or curtail future growth in production.

Yet, at the projected levels of warming, consistent with the current Paris commitments, the economic damages by not acting may be so large as to be unquantifiable.

This report outlines how and why economists, in their fatal economic miscalculations, have ignored the real risks of climate change. In particular, they have not accounted for non-linear changes, reinforcing feedbacks and system thresholds.

Some economic consequences of a hotter world are beyond valuation, including how the socio-economic impacts of climate disruption are translated into national and human security consequences: the breakdown of society, forced migration and conflict.

Economic research has focused on cost–benefit analysis, which attempts to compare the cost of mitigation with the benefit of damages avoided. However the failure to account for some likely changes in the climate system — the inherent incapacity to deal with damages beyond quantification, and inadequately weighting the benefits of mitigation policies — makes cost–benefit analysis a deeply flawed tool for policymaking.

This is especially the case with the economy–energy–climate system models, known as Integrated Assessment Models (IAMs), which reflect the social views of their architects, contain arbitrary input values and assumptions, underestimate damages and often rely on unproven technologies.

These models are now at the centre of the UN climate-science and policy processes, but contain so many levels of inherent and irreducible uncertainties that their projections should not be used more than 20 years into the future, and even then with strict caveats as to their relevance.

Because climate change is now an existential threat to human society, risk management and the calculation of potential future damages must pay disproportionate attention to the high-end, extreme possibilities, rather than focus on middle-of-the-spectrum probabilities.

In contrast to the results from conventional IAM analysis, recognition of potential unquantifiably-large future damage leads to the conclusion that all possible effort should be put immediately into an emergency-level economic transformation to minimise the existential risks of climate change.

ALL COST & NO BENEFIT

At the heart of global policymaking is a concern that climate change/mitigation should not be economically disruptive or curtail future growth in production. Perhaps as a consequence, and in order to mesh with this policy paradigm, the economic methods of analysis applied to climate change have underestimated the risks and provided reasons to delay action.

The evidence is all around us. Listen to most government and business leaders, and especially those nations with a large carbon footprint, and the climate conversation for decades has been about taking it slowly; of incremental policy change that does not rock the economic boat, cost jobs, disturb growth or disadvantage significant national industries. With minimal discussion about the jobs and growth that will be destroyed in a hotter world.

Business largely holds sway over government, and many companies have preferred to live with the risk of global warming than face the consequences of government action to decarbonise at the speed required. As well, business fears government leadership on climate mitigation may open the door to increased government spending and investment in other areas neglected by the private sector (Frankel 2019).

This primary concern for the non-disruption of the economic system was displayed in the reports to the UK and Australian governments by two of the best known economists in this field: Sir Nicholas Stern and Prof. Ross Garnaut (see *The prophet of postponement*, page 7).

UK researchers have provided a penetrating analysis of reports, including those by Stern and the UK's Committee for Climate Change (CCC) in 2008, that constrain the maximum emissions reduction each year to levels thought to be compatible with economic growth and are considered politically feasible: normally 3% to 4% per year. The CCC report said that "rich developed economies need to start demonstrating that a low-carbon economy is possible and compatible with economic prosperity", but acknowledged that "it is not now possible to ensure with high likelihood that a temperature rise of more than 2°C is avoided" (Anderson & Bows 2011).

In other words, if there is a trade-off between economic growth and keeping warming below what at the time was conceived to be a dangerous threshold, growth wins.

It's all about the costs of transition, not about future economic damage as the climate gets hotter. A case in point occurred in Australia in February 2020, when federal parliamentary opposition leader Anthony Albanese announced a recycled Labor Party climate policy "to make Australia a net-zero-carbon emitter by 2050", but with no interim (2030) target.

In the aftermath of a devastating drought and record-breaking season of megafires, the National Farmers Federation said Albanese was unable to point to any economic case for the target; the agriculture minister said Labor had to "take the target off agriculture's back"; and *The Australian* newspaper warned that "the policy could put the growth of the key sectors at risk" (Lewis & Visontay 2020). Prime Minister Morrison said Albanese "can't tell you what it would cost… can't tell you how many jobs will go" (ABC 2020).

Journalists piled on too, and it wasn't just the Murdoch media. The ABC reported that Labor's lack of costings means "the prime minister is zeroing in on the same weakness that haunted (former Labor leader) Bill Shorten during last year's election campaign" (ABC 2020).

These responses illustrate the policy paradigm where mitigation action is framed as "all cost and no benefit", even though Labor's 2050 policy was mirrored by states and territories across Australia and in 73 countries.

Analysis of the economic damage caused by the failure to act barely saw the light of day. This portrayal of the issue would put a smile on the face of fossil fuel executives: lots of talk about the burden of Labor's policy, none about the existential risk to humanity of their own industry's business model.

When the Prime Minister was asked in parliament, just days after Labor's announcement, about the economic damage of 3°C of warming, he replied that "we do understand there are costs associated with climate change", but did not say what they were (Murphy 2020). Three years earlier, Morrison had gleefully brandished a lump of black coal in parliament to goad his political opponents.

Morrison's glib response was similar to that of former Prime Minister John Howard on 5 February 2007, who told the ABC's *Lateline* that it would be "less comfortable for some than it is now" if average global temperatures rose 4-6°C by the end of the century (Hansard 2007). In fact, 4°C is likely incompatible with the maintenance of an organized global community (see *Beyond calculation*, page 6).

Too often, the real economics of climate damage is the missing element in Australia's climate debate because attention swings to the costs of action, for example the cost of a zero-carbon energy system. What is overlooked is that ageing coal-fired generators need to be replaced one way or another, and doing so with renewables will be cheaper than rebuilding with coal or gas as the solar/wind/battery option slips under the fossil-fuel-energy cost curve.

More importantly, understanding of the real economic damage that will be done by failing to act fast is poor across politics, business and most of the media in Australia.

BEYOND CALCULATION

The world is currently on a path of 3–5°C of warming, according to the World Meteorological Organisation (Reuters 2018). The damages may be so large as to be unquantifiable.

In 2019, Johan Rockström, the head of one of Europe's leading research institutes, warned that in a 4°C-warmer world it would be "difficult to see how we could accommodate a billion people or even half of that… There will be a rich minority of people who survive with modern lifestyles, no doubt, but it will be a turbulent, conflict-ridden world" (Gaia 2019).

In fact, 4°C is "incompatible with an organized global community, is likely to be beyond 'adaptation', is devastating to the majority of ecosystems, and has a high probability of not being stable" according to Prof. Kevin Anderson (Roberts 2011). Eight years ago, the World Bank reported that "there is no certainty that adaptation to a 4°C world is possible" (World Bank 2012).

Social breakdown… countries disappearing… global conflict… billions dead. At 4°C of warming the damages, for all practical purposes, are beyond quantification. They are infinite.

At this point, traditional cost–benefit analysis goes out the window because if the damages are infinite in mathematical terms, then the models simply do not compute. All you need to conclude is that any level of economic expenditure is justifiable to avoid a 4°C outcome, and understanding that does not require thousands of lines of economic modelling equations and code.

In 2017, one of the first research papers to focus explicitly on existential climate risks proposed that "mitigation goals be set in terms of climate risk category instead of a temperature threshold", and established a "dangerous" risk category of warming greater than 1.5°C, and a "catastrophic" category for warming of 3°C or more (Xu and Ramanathan 2017).

Even at 3°C the impacts may be so great that it is not possible to put a figure on the global economic damage.

At these levels of warming, the desire by economists to put a number on everything is a curse, not a help. It is meaningless to attempt to quantify the impacts in monetary terms. Precautionary action must be taken to ensure such outcomes are avoided at all costs.

Shortly after the Prime Minister's non-answer to the question about damage at 3°C, evidence emerged that the Australian Treasury had not modelled the damage cost of global warming for more than a decade (Stayner 2020). This is an appalling omission given that climate change is the greatest economic threat facing Australia.

In fact, a cursory survey of the scientific literature on the likely impacts of 3°C paints a frightening picture of a world in which it is likely that the structures of societies will be severely tested, and some will crash (see *Three degrees of warming*, page 10).

Australia's intelligence community is well aware of this analysis, and has a duty of care to brief the Prime Minister on its risk assessment. So when the Prime Minister refuses to detail the impacts of a 3°C-warmer world, and his Treasury fails to make such assessments, ignorance is not an excuse.

Nevertheless, the Australian government's predatory delay on climate action has played a significant role in ensuring that a 3°C or more warmer future has become accepted in global policymaking circles, where urgent action is "all cost and no benefit" and catastrophic levels of warming are normalised.

This report is the story of the underestimated future damages and missing risks that have blighted economic analysis of climate disruption. Bad economics has contributed to a policy-making failure on a global scale, and continues to drive the world to the edge of civilisational collapse.

THE PROPHET OF POSTPONEMENT

A look at the peer-reviewed literature on the economics of climate change soon reveals gross deficiencies that result in severe underestimation of the economic damage caused by climate disruption.

This is most obvious with Integrated Assessment Models — the principal modelling tool for analysing economic, energy and physical climate system interactions — which have become the most important source of information for climate policymaking.

Nowhere is this deficiency more obvious than in the IAMs developed by the foundational figure in the field, Prof. William Nordhaus, who was rewarded with the Nobel Prize for Economics in 2018 for "for integrating climate change into long-run macroeconomic analysis". Nordhaus's model is known as DICE and it calculates that at 4°C of warming the impact on global production may only be relatively minor, a conclusion that, in George Orwell's words, can only be described as "a flagrant violation of reality".

In his 2018 Economics Nobel Prize acceptance speech, Nordhaus described a 4°C rise as "optimal", saying it would lead to only a 3.6% cut in global economic output (Nordhaus 2018). In a recent publication, Nordhaus says that "damages are estimated to be 2% of output at a 3°C global warming and 8% of output with 6°C warming" (Nordhaus 2019). He says that: "'optimal policy' would result in global warming of about 3°C by 2070 and 4°C by 2150" (Khadem 2020).

Climate change economist Martin Weitzman has shown that using the damage function in Nordhaus's DICE model produces a drop in GDP of 19% at 10°C of warming and 26% at 12°C (Weitzman 2011). In reality, at such levels of warming it is debatable if, and how many, humans would actually be left on the planet.

This absurdity is possible because Nordhaus's damage function is not based on work by physical scientists, but instead is derived from a number of methodology-poor statistical estimates made by a small, close-knit group of economists (Keen 2019).

Incredibly, this approach is evident in the 2014 Intergovernmental Panel on Climate Change (IPCC) report: "For most economic sectors, the impact of climate change will be small relative to the impacts of other drivers… (such as) changes in population, age, income, technology, relative prices, lifestyle, regulation, governance (which) will have an impact... that is large relative to the impact of climate change" (Arent at al. 2014).

The IPCC report noted that economic impacts are difficult to estimate, in part due to the failure to account for "catastrophic changes, tipping points, and many other factors", but still concluded that "with these recognized limitations, the incomplete estimates of global annual economic losses for additional temperature increases of ~2°C are between 0.2 and 2% of income" (Keen 2019). Back in the real world, scientists were describing 2°C as the boundary between dangerous and very dangerous climate warming.

Since 2014, significant work has been published, including a landmark study (Burke at al. 2015), to provide a more evidence-based, country-by-country assessment of economic damage in a warming world.

In Nordhaus's "optimal" scenario, global greenhouse emissions at mid-century are higher than they are today. This is an astounding message to policymakers.

By way of comparison, an Oxford Economics paper says that a 4°C rise by 2100 could cut output by as much as 30% (Takeo 2019). Other recent research finds that a high-emissions scenario could cut global production by more than 40% by 2100 (Ueckerdt et al. 2019). And one study found that "If future adaptation mimics past adaptation, unmitigated warming is expected to reshape the global economy by reducing average global incomes roughly 23% by 2100 and widening global income inequality, relative to scenarios without climate change" and that "average income in the poorest 40% of countries declines 75% by 2100 relative to a world without climate change" (Burke et al. 2015).

While different in magnitude from Nordhaus's fictional estimate, these studies too are likely to understate the damage. Prof. Hans Joachim Schellnhuber, Director Emeritus of the Potsdam Institute, says that "If we go into a runaway climate effect, the damage may be between €100 trillion and the loss of civilisation… If we don't solve the climate crisis, we can forget about the rest" (Roberts 2019). And that runaway effect could be triggered at just 2°C of warming (Steffen et al. 2018).

Contrary to Nordhaus's world of "optimum" warming of 3°C by 2070 and 4°C by 2150, such a level of warming would be catastrophic and may be incompatible with an ordered global community (see *Beyond calculation* on page 6 and *Three degrees of warming* on page 10).

Anthropologist Jason Hickel describes Nordhaus as the "Prophet of postponement" because the failure of international policymaking to pursue aggressive mitigation over the last few decades is in large part due to arguments that Nordhaus and fellow thinkers have advanced (Hickel 2018).

IAMs have become favoured as a policymaking tool for IPCC reports and in United Nations Framework Convention on Climate Change (UNFCCC) documents such as the 2015 Paris Agreement (Part 6). Nordhaus's "4°C-optimal" advocacy may be a key reason why governments have procrastinated for so long.

Australian Prime Minister Morrison, like several of his conservative predecessors, appears to suffer the delusion common amongst global political and business leaders that the world can adapt to such circumstances. Australia joins the chorus of ritual public recitation of the Paris mantra of keeping warming to the 1.5–2°C band, but there is a different back-room story.

For a decade, Todd Stern, the chief US climate negotiator, told anyone who would listen that 2°C was just a pipedream (Johnson 2012), The politics of delay became a diplomatic art form for Stern and fellow ambassadors to the UN talks from Russia, Saudi Arabia, the Gulf and other states. After the diplomatic sabotage of the crucial 2009 Copenhagen climate talks, the failure to agree to ambitious action reached its nadir in Paris in 2015, when voluntary, non-binding, national commitments consistent with 3-5°C of warming were heralded as a political triumph.

Procrastination was also a feature of the recommendations to their governments by Sir Nicholas Stern and Prof. Ross Garnaut.

In 2006 and 2008, both Stern and Garnaut, in their initial reports to the UK and Australian governments respectively, canvassed the targets of 450 parts per million atmospheric carbon dioxide (ppm CO_2) — which is roughly equivalent to 2°C of warming before carbon cycle feedbacks are considered — and 550ppm CO_2 (around 3°C of warming).

While both economists said that an upper limit of 450ppm would inflict significantly less damage, they advocated that governments start with the 550ppm figure because the lower goal would be too economically disruptive. Stern said that keeping levels to 450ppm is "already nearly out of reach" because "450ppm means peaking in the next five years or so and dropping fast" (Stern 2006) . In other words, it would require immediate and radical action that Stern judged to be neither politically likely nor economically desirable.

Likewise, Garnaut's policy review did not heed strong calls from climate action advocates to model and consider a safer 350ppm scenario, and stuck to modelling the 450 and 550ppm targets. While describing the action necessary for Australia to play a reasonable part in holding to 450ppm, Garnaut suggested that as an interim measure, pending global agreement, Australia should act only for the 550ppm target.

Both Stern and Garnaut have since acknowledged that evidence of accelerating climate impacts has rendered their approach dangerously complacent. In 2013 Stern reflected: "Looking back, I underestimated the risks… Some of the effects are coming through more quickly than we thought then" (Stewart and Elliott 2013).

But the point remains that, at a crucial time, the advocacy of economists Stern and Garnaut was one of postponing the strong action that the evidence indicated was urgently required.

In 2011, UK researchers described the schism between word and deed: "Put bluntly, while the rhetoric of policy is to reduce emissions in line with avoiding dangerous climate change, most policy advice is to accept a high probability of extremely dangerous climate change rather than propose radical and immediate emission reductions" (Anderson & Bows 2011).

Anderson and Bows concluded that given the view that reductions in emissions in excess of 3–4% per year are not compatible with economic growth, then proponents of such rates of mitigation are, in effect:

> conceding that avoiding dangerous (and even extremely dangerous) climate change is no longer compatible with economic prosperity... In prioritizing such economic prosperity over avoiding extremely dangerous climate change, the CCC, Stern... and similar analyses suggest they are guided by what is feasible. However, while in terms of emission reduction rates their analyses favour the "challenging though still feasible" end of orthodox assessments, the approach they adopt in relation to peaking dates is very different... the logic of such studies suggests (extremely) dangerous climate change can only be avoided if economic growth is exchanged, at least temporarily, for a period of planned austerity within Annex 1 (developed) nations and a rapid transition away from fossil-fuelled development within non-Annex 1 (developing) nations. (Anderson & Bows 2011)

The *realpolitik* of procrastination in the policymaking process remains unabated, motivated by a desire of the fossil-fuel economies to slow the energy transition so that they can continue to extract and sell coal, oil and gas. There are also more-widely-shared goals to ensure that any transition is incremental and does not impinge on global growth or national interests, and a desire to avoid the stranding of assets or upset to the financial system.

“THE ECONOMICS OF CLIMATE CHANGE WILL BE SEEN AS ONE OF THE WORST MISTAKES HUMANS HAVE MADE, MUCH WORSE THAN ANY OF THE DENIALISTS.”

— SPENCER GLENDON, SENIOR FELLOW,
WOODS HOLE RESEARCH CENTER, AND
FORMER DIRECTOR OF INVESTMENT
RESEARCH AT WELLINGTON MANAGEMENT
(KORMANN 2020)

THREE DEGREES OF WARMING

Cost–benefit analysis, the mainstay of climate change economics, requires dollar numbers to be put on the costs of acting to reduce the level of future warming as compared to the damage caused by not acting, for various emissions scenarios. The first requirement is that these numbers can be reasonably estimated.

Recent work from the University of Melbourne has shown that on current global emission patterns, a conservative estimate of costs of inaction for Australia would be $A584.5 billion by 2030, $A762 billion by 2050, and more than $A5 trillion in cumulative damages from now until 2100. On the other hand, the cost of effective emissions reduction is estimated to be $A35.5 billion up to 2030, or 0.14% of cumulative GDP (Kompas et al. 2019).

The estimated costs in the report and the majority of economic analyses to date focus on infrastructure damage, agricultural and labour productivity losses, human health impacts and ecosystem losses, but this is just the tip of the iceberg. The costs of extreme weather events, pollution and ecosystem and biodiversity loss are not included.

More importantly, neither are the economic damages that Australia will incur as 3°C of warming sweeps through Asia and the Pacific, devastating nations, disrupting major trading partners and supply chains, and likely turning the region — the "disaster alley" of global climate disruption — into one of social chaos and breakdown (Dunlop & Spratt 2017).

Thirteen years ago, senior US national security analysts looked at the consequences of 3°C of warming and concluded that it would "give rise to massive nonlinear societal events. In this scenario, nations around the world will be overwhelmed by the scale of change and pernicious challenges… Armed conflict between nations over resources… is likely and nuclear war is possible. The social consequences range from increased religious fervor to outright chaos" (Campbell et al. 2007).

A survey of the scientific literature on the likely impacts of 3°C paints a frightening picture (Spratt and Dunlop 2019). In such a world, it is likely that the structures of societies will be severely tested, and some will crash. The poorest nations will suffer first and most deeply from climate change, but no region will escape.

Water availability will decrease sharply in the lower-latitude dry tropics and subtropics, and affect almost two billion people worldwide. Agriculture will become nonviable in the dry subtropics. The Sahara will jump the Mediterranean as Europeans begin a long trek north. Water flows into the great rivers of Asia will be reduced by the loss of more than one-half, and perhaps much more, of the Himalayan ice sheet.

Aridification will emerge over more than 30% of the world's land surface, most severely in southern Africa, the southern Mediterranean, west Asia, the Middle East, rural Australia and across the south-western United States.

Most regions in the world will experience a significant drop in food production and increasing numbers of extreme weather events, including heat waves, floods and storms. Food production will be inadequate to feed the global population and food prices will skyrocket, as a consequence of a one-fifth decline in crop yields, a decline in the nutritional content of food crops, a catastrophic decline in insect populations, aridification, monsoon failure and chronic water shortages, and conditions too hot for human summer habitation in significant food-growing regions.

The lower reaches of the agriculturally-important river deltas such as the Mekong, Ganges and Nile will be inundated, and significant sectors of some of the world's most populous cities — including Kolkata, Mumbai, Jakarta, Guangzhou, Tianjin, Hong Kong, Ho Chi Minh City, Shanghai, Lagos, Bangkok and Miami — abandoned.

Deadly heat conditions will persist for more than 100 days per year in West Africa, Central America, the Middle East and South-East Asia, which together with land degradation, aridification, conflicts over land and water, and rising sea levels will contribute up to a billion people being displaced. Refugee conventions may give way to walls and blockades.

One of the most recent and detailed cost-benefit analyses to be published uses detailed country-specific damage calculations. It finds that losses from climate damages for the higher emission scenarios will be up to 42% of global GDP by 2100. This is ten times the figure suggested by Nordhaus in his Nobel oration. Even so, the authors acknowledge that they do not account for "possible amplifications, for example, due to a potential destabilization of societies" (Ueckerdt et al. 2019).

UNDERESTIMATING DAMAGE

Economic analysis of climate change has systematically underestimated the impacts of future damage, and in particular failed to account for non-linear changes in the climate system.

A recent report (see page 12), describes the problem of missing risks in economic assessments of climate change impacts.

Do we have a realistic measure of the economic costs from future climate damages? "In a word, no," is the answer from Prof. Tom Kompas, who says projections for economic damages under different global warming scenarios "are difficult to come by, save for simple, highly aggregated measures drawn from basic computational models… which can often be very misleading given their extreme and implicit tendency to average effects" (Kompas 2020).

This deficiency in analysis is not restricted to IAMs. It is a broader methodological problem. Stated most bluntly, in the sphere of economics, there is no robust methodology for understanding the full range of economic consequences of climate disruption. Such a methodology may not be possible because it would require a systems-level analysis of global interactions in the physical, economic and socio-political spheres.

There are also profound challenges in understanding how physical impacts translate into economic and social consequences.

Economic analysis of climate change impacts falls into two broad categories: estimates of climate-warming-related economic damage; and cost–benefit analysis of various mitigation and technological paths, using IAMs. In both cases, there are big grey areas because such work requires understanding of:

- Cumulative greenhouse gas emissions for the period under consideration;
- How that affects atmospheric greenhouse gas levels;
- The direct physical climate consequences for temperature and precipitation patterns, the range of extreme events, and impacts on major climate system elements such as the cryosphere, sea levels, carbon stores, ocean and atmospheric circulations;
- How these physical changes impact the biosphere, agricultural land and water resources, and hence the impact on human societies and their ability to fulfil their basic needs for food, water and shelter;
- How this impacts social and political relationships, and hence stability at local, regional and global levels; and
- How climate-induced disruptions in one human system, for example the financial system, interact and feedback on other human system elements to act as climate and economic disruption impact multipliers.

There are significant uncertainties in moving through these steps. What is the climate sensitivity value — the relationship between changes in greenhouse gas levels and temperature? How do changes in the basic physical system affect agriculture, tourism, labour productivity and human health, let alone more complex issues such as where we live and social organisation? How can accounting be made for non-linear climate system changes given the basic unpredictability of such events? How do the more immediate socio-economic impacts become translated into national and human security consequences: the breakdown of society, forced migration and conflict? How can disruptions in one or several systems affect other systems?

Australia's 2019-2020 megafires are a good case study, in which impacts spread across various systems: housing, infrastructure and communications, local economies, banking services, water and food security, agriculture and tourism, as well as the losses of biodiversity and ecosystems. The problem of analysis can also be seen in the very wide range of estimates of the damage caused by the mega fires, from $A4 billion up to $A100 billion.

All these difficult-to-analyse and quantify possibilities mean that, particularly at the higher end of the range of projected warming, the uncertainties are such that no credible estimates in dollar terms can be made. And it is foolish to try and reduce devastating social and human security consequences to a monetary figure. What is the value of a human life? What is the value of the lives lost in the Syrian war, where climate impacts (drought and desertification) became an accelerant to instability?

There are big issues concerning the underestimation of physical impacts, and the failure to account for non-linear changes, system thresholds and mutually reinforcing processes. Risk analysis has been poor, and there is scant recognition within the academic literature that "high-end" outcomes may eventuate and produce economic damage beyond quantification. The reports of the IPCC have exhibited a preference for conservative projections and scholarly reticence (Spratt & Dunlop 2018).

MISSING RISKS

- Economic assessments of the potential future risks of climate change have been omitting or grossly underestimating many of the most serious consequences for lives and livelihoods because these risks are difficult to quantify precisely and lie outside of human experience.
- Scientists are growing in confidence about the evidence for the largest potential impacts of climate change and the rising probability that major thresholds in the Earth's climate system will be breached as global mean surface temperature rises, particularly if warming exceeds 2°C above the pre-industrial level.
- Many of these impacts will grow and occur concurrently across the world as global temperature climbs.
- Some of these impacts involve thresholds in the climate system beyond which major impacts accelerate, or become irreversible and unstoppable.
- When a threshold is breached, it might cause one or more other thresholds to be exceeded as well, leading to a cascade of impacts.
- Many of these impacts could exceed the capacity of human populations to adapt, and would significantly affect and disrupt the lives and livelihoods of hundreds of millions, if not billions, of people worldwide.
- These impacts would also undermine economic growth and development, exacerbate poverty and destabilise communities.
- Economic assessments fail to take account of the potential for large concurrent impacts across the world that would cause mass migration, displacement and conflict, with huge loss of life.
- Economic assessments that are expressed solely in terms of effects on output (e.g. gross domestic product), or that only extrapolate from past experience, or that use inappropriate discounting, do not provide a clear indication of the potential risks to lives and livelihoods.
- It is likely that there are additional risks that we are not yet anticipating simply because scientists have not yet detected their possibility, as we have entered a period of climate change that is unprecedented in human history.
- The lack of firm quantifications is not a reason to ignore these risks, and when the missing risks are taken into account, the case for strong and urgent action to reduce greenhouse gas emissions becomes even more compelling.

From: "The missing economic risks in assessments of climate change impacts" (DeFries et al. 2019).

This scientific reticence is one basis for economic reticence. Naomi Oreskes and Nicholas Stern say that since climate scientists have been underestimating the rate of climate change and the severity of its effects, "then economists will necessarily underestimate their costs" (Oreskes & Stern 2019). When the climate conditions change sufficiently for experience to no longer be a reliable guide to the future, then economic estimates become more and more uncertain. In many cases, modellers:

> simply omit it from the model, assessment or discussion. In economic assessments of climate change, some of the largest factors, like thresholds in the climate system, when a tiny change could tip the system catastrophically, and possible limits to the human capacity to adapt, are omitted for this reason. In effect, economists have assigned them a value of zero, when the risks are decidedly not (Oreskes & Stern 2019).

The consequence of ignoring the "missing risks" is that a stark reality is overlooked: the damage caused by climate change may be infinite, beyond all equations, models and cost-benefit analysis (see *Beyond quantification*, page 6). An IMF Working Paper notes a growing agreement between economists and scientists "that risk of catastrophic and irreversible disaster is rising, implying potentially infinite costs of unmitigated climate change, including, in the extreme, human extinction" (Krogstrup & Oman 2019).

Martin Weitzman proposed a Dismal Theorem that society should expect an unquantifiably large loss from high-impact, low-probability events. On the economic analysis of climate impacts and cost-benefit analysis Weizman said:

> It is painfully apparent that the dismal theorem makes economic analysis trickier and more open-ended in the presence of deep structural uncertainty. The economics of fat-tailed catastrophes raises difficult conceptual issues that cause the analysis to appear less scientifically conclusive and more contentiously subjective than what comes out of an empirical cost–benefit analysis of more usual thin-tailed situations… Perhaps in the end the climate-change economist can help most by not presenting a cost-benefit estimate for what is inherently a fat-tailed situation with potentially unlimited downside exposure as if it is accurate and objective — and perhaps not even presenting the analysis as if it is an approximation to something that is accurate and objective — but instead by stressing somewhat more openly the fact that such an estimate might conceivably be arbitrarily inaccurate depending upon what is subjectively assumed about the high-temperature damages function along with assumptions about the fatness of the tails and/or where they have been cut off (Weitzman 2009).

So should publications of IAMs and their cost–benefit analysis stress more openly the fact that their estimate(s) might conceivably be "arbitrarily inaccurate"? The answer is yes, but that leaves another black hole: in the middle of the UN science and policy processes that have become too dependent on IAMs.

INTEGRATED ASSESSMENT MODELS

IAMs attempt to combine the key elements of the physical, economic and energy systems, and are a key input to policymaking. They measure the costs and benefits of climate policy options, with the default goal of maximising growth by finding an optimum pathway that maximises the benefits of limiting climate change impacts, while also minimizing the costs of emissions mitigation.

However, a number of factors make cost–benefit analysis and IAMs a deeply flawed tool for climate policymaking.

Neo-classical framing

IAMs are based on neoclassical economic assumptions that a self-regulating economy will achieve a state of stability (general equilibrium) in which the economy's resources are fully employed and efficiently allocated, resulting in the optimization of utility. This framing assumes competitive markets characterised by rational choice by producers and consumers, perfect competition (no market dominance or oligopolistic behaviour) and a number of other ideals disconnected from modern reality. All IAMs assume "some sort of idealized equilibrium for the economy", but the real-world economy is never in a perfect equilibrium, or even close to it (Rosen & Guenther 2015).

Social construction

Models reflect modellers' view of society. Depending on how modellers perceive the roots of the problem to be solved, they will "design the model structure, including possible instruments and relationships within the model accordingly… Hence, the very structure of a model depends on the modeller's beliefs about the functioning of society" (Ellenbeck & Lilliestam 2019). Consequently, IAM results have the capacity to privilege particular pathways and fool policymakers into thinking that the forecasts the models generate have some kind of scientific legitimacy:

> Such models work as meaning-making machines, having the power to define and delimit the solution space in which to search for possible solutions, and this space is determined by the discursive structure. Although modellers often make explicit that their results are not predictions but explorations of possible futures, model results are powerful tools to legitimate specific arguments or policies and to reproduce and strengthen a specific political goal without explicitly referring to the social context of the numbers… To describe it illustratively, models can be used for policy-based evidence making, instead of the evidence-based policy-making that scientists and policy makers alike claim to strive for (Ellenbeck & Lilliestam 2019).

The recent evolution in the use of IAMs from descriptive to prescriptive analysis has subsequently legitimised near-term political inaction and narrowed policymaking attention to a particular set of mitigation and carbon dioxide removal pathways, such as bio-energy with carbon capture and storage (BECCS), at the expense of other strategies. The drawbacks and tradeoffs associated with the pathways that are given the most attention in the IAMs have been obscured by the model results (Workman et al. 2020).

Assumptions and input values

Key model inputs include the discount rate for future costs and benefits, climate sensitivity, the damage function, future economic growth, the speed and type of technology uptake, and various social and ecological assumptions. These inputs are arbitrary and reflect and reproduce wider social or scientific discourses. The huge disparity in outcomes between models is due in part to the modellers' freedom to choose inputs and parameter values that will produce a desired result, thereby legitimizing "what might be little more than a subjective opinion about climate policy" (Pindyck 2017).

This freedom allows modellers to make unproven technologies such as carbon capture and storage (CCS) and BECCS a centre point of a model, to choose a carbon price as the optimal policy tool, or select an arbitrary discount rate to compare current costs to future damages. This freedom to choose inputs includes assumptions about new technology learning rates, what is the "best" time to phase out fossil fuel subsidies, whether distributive effects are important, or whether a scenario of "overshooting" a temperature target is legitimate. And it extends to questions of whether ecosystem destruction or human life have monetary value, and whether the main goal should be cost-efficiency and economic optimisation, or instead be the avoidance of high-end existential risks.

Discount rate

A discount rate is used in cost–benefit analysis on the assumption that a dollar today has greater buying power than a dollar in the future. The discounting of future climate damage means the monetary value right now of future impacts (cost of inaction) is lower than the actual value when the damage occurs.

One important question is whether to put resources into mitigating today or whether to leave that to a future generation. Discounting assumes that future generations will be richer than today, and so more capable of paying the cost, whether it be through mitigation or adaptation strategies.

Cost–benefit analysis will provide different answers according to the discount rate applied, which is a major determinant as to whether the benefit to society of reducing emissions is larger or smaller, worth doing or not. The higher the discount rate, the lower the present-day value of future damage, and hence less reason to act now.

Using high discount rates inflates the cost of acting now, and trivialises the long-term benefits of mitigating climate change, breaking the intergenerational link (Stanton et al. 2009).

There is significant disagreement between economists and modellers on the discount rate that should be used. The Stern Review models used a lower discount rate (1.5%) than that of Nordhaus's DICE model (5.5%), producing very different outcomes (Frisch 2013). Stern's results supported more action now, compared to Nordhaus' procrastination outcomes.

Stern used a lower discount rate because he employed a moral argument that future generations are reasonably equal to our own in terms of capacity to respond to climate impacts, whereas Nordhaus's discourse is based on traditional economic theory (Ellenback & Lilliestam 2019).

Because the discount rate is so important in determining whether future climate damage is considered costly or not, many economists argue that a discount rate that declines over time should be used, to give a higher present value to long-term climate change impacts. The result is a higher social cost of carbon, or "optimal" carbon price (Revesz et al. 2014).

A practical example illustrates the power of the discount rate. US government agencies often use benchmark discount rates of 3% (low) and 7% (high). A benefit of $1 million 200 years from now has a present value of about $2700 at a 3% discount rate, but just $1.33 at a 7% discount rate. So unless the discount rate is very low, the benefits of climate change mitigation in future centuries are almost worthless in present day terms, and any significant short-term expenditures are then computed to be too expensive in relation to their future benefits in present-value terms (Ackerman & Finlayson 2006).

Under-estimation of damages

The damage function in IAMs determines the expected economic costs of various levels of climate warming. If the damage function chosen as the model input is relatively low, as is the case in Nordhaus's DICE model, then there is less incentive to implement strong mitigation policies, particularly where the costs of mitigation are estimated to be high.

Sometimes the benefits of mitigation in terms of avoided impacts are not included in the analysis. One case in point is the IPCC's 2014 Working Group III report. By intentionally omitting the benefits of action from the numerical cost results, the report glossed over the biggest possible effect of mitigating climate change; avoiding massive damage to the world, its ecosystems, its people and its economies. Incredibly, most models relied on by the 2014 Working Group III report do not even calculate these avoided global damages (Rosen & Guenther 2016).

In the case of Nordhaus, cited above, damages are estimated to be 2% of output at a 3°C global warming and 8% with 6°C warming at current-day values, estimates which are unworldly. This is due to damages simply being parameterised in the models, such that an arbitrarily-defined equation is assigned to the damages function without serious regard to the real physical and social consequences.

Stern notes that because the IAMs omit so many of the big risks, the social cost of carbon estimates are often way too low. So, as a first step, "the consequences being assessed should include the damages to human well-being and loss of life beyond simply reduced economic output… And the very large uncertainty, usually involving downward bias, in the social cost of carbon estimates should always be made explicit" (Stern 2016).

The benefits of climate mitigation are "intrinsically unpredictable and unpriceable" (Ackerman et al. 2009), and so are frequently under-estimated in economic modelling. Additionally, IAMs assume that the value people attach to ecosystems will remain constant, yet "as a commodity becomes more scarce, its value increases. In the desert, water is extremely valuable. During a flood, dry land is highly prized" (Revesz et al. 2014).

Positive economic mitigation outcomes such as increased economic growth from investments in decarbonisation are generally not considered, while the reality of technology development and uptake, including the associated costs and benefits, is difficult to forecast (Stanton et al. 2009).

Uncertainty

Most IAMs struggle to incorporate the scale of the scientific risks, such as the thawing of permafrost, release of methane, and other potential tipping points. And many of the largest impacts are omitted, such as "widespread conflict as a result of large-scale human migration to escape the worst-affected areas" (Stern 2016).

Tipping points, thresholds beyond which large change will be initiated, and non-linear responses, where there are sudden changes rather than smooth progress from one stage to the next, are characteristics of the climate system. So are system feedbacks, the self-reinforcing loops that drive further change. But such processes are rarely, if ever, factored into IAMs. Most economic models assumed a relatively linear relationship between temperature rise and damage.

Economists are uncertain about the growth rate next year, let alone in ten years. Or what the energy mix will be. Or whether the financial system may crash, or whether Tesla shares will fall or boom. So how can complex equations taking in scores of hundreds of variables and parameters be expected to give an accurate view of the economy in 80 years time, depending on various mitigation strategies? The answer is, they cannot. It is difficult to construct even a reference case with any degree of certainty.

THERE IS “GROWING AGREEMENT BETWEEN ECONOMISTS AND SCIENTISTS THAT RISK OF CATASTROPHIC AND IRREVERSIBLE DISASTER IS RISING, IMPLYING POTENTIALLY INFINITE COSTS OF UNMITIGATED CLIMATE CHANGE, INCLUDING, IN THE EXTREME, HUMAN EXTINCTION”.

— IMF WORKING PAPER

(KROGSTRUP & OMAN 2019)

Trying to reduce the uncertainty in key inputs to IAMs "is not helpful in the face of catastrophic risks and deeply uncertain probabilities of worst-case scenarios.… Economies are highly complex non-linear systems and it is impossible to accurately predict their future evolution" (Scrieciu et al. 2013). IAMs in general have poor treatment of uncertainty and non-linear outcomes. They can be "highly misleading by providing a veneer of scientific credibility to their results despite irreducible uncertainties in underlying assumptions" (Workman et al. 2020).

Gernot Wagner describes:

> ...an inherent asymmetry in how benefits and costs are tallied. With large uncertainties on both sides, the problem calls for heroic extrapolations and outright guesswork. In calculating benefits, however, only "known knowns" have traditionally made it into the headline figure, whereas the bias goes the other way in the case of costs: the rapid progress made in clean-energy technologies is largely ignored, despite its likely cost-abatement effects (Wagner 2020).

But he says these biases "haven't stopped economists from offering confident benefit–cost analyses".

Reliance on unproven technologies

The social construction of IAMs means that untested technologies, little more than techno-imaginaries, can be placed at the centre of the models. This was the case for the work that became incorporated into the 2015 *Paris Agreement*, with its underlying framework of overshoot and a large role for a currently non-viable technology — BECCS — in the second half of this century.

The scale of BECCS envisioned in the Paris emissions scenarios is monumental, "requiring up to 1100 Mha of land dedicated to energy crops, with severe negative implications for food security, land rights and conversion of natural ecosystems, impacting multiple sustainable development goals and potentially surpassing planetary boundaries" (Workman et al. 2020).

Because neither BECCS nor any other carbon drawdown approaches have been developed at scale, there is deep concern that "a dependence on carbon drawdown is being baked into emissions targets without a public debate about their use", and that legitimises political inaction in the short term (Workman et al. 2020).

PANDEMIC ECONOMICS

The world is spending very large amounts of money and running large government deficits in order to respond effectively to the COVID-19 pandemic, but has not done so for the even greater threat of climate disruption.

Pandemics and climate change, along with threats such as weapons of mass destruction (nuclear, biological and chemical), ecological collapse, asteroid impact and artificial intelligence, are recognised as global catastrophic or existential risks. The pandemic's impact will be profound and long-lasting, but in the medium term they will not be nearly as large or long-lasting as self-reinforcing climate disruption of 3-4°C or even higher.

In response to the pandemic and the forced curtailment of economic activity, government stimulus spending around the world has amounted to 8-20% of GDP (as of mid-April 2020). Australia, for example, has promised to spend more than $A200 billion so far and there will be more spent in subsequent financial years. This is around 10% of GDP in 2019-2020.

And this is done because there is a clear understanding in the community and across politics that it is necessary to prevent a health and economic disaster, to protect people. The COVID-19 pandemic, like climate disruption, is an emergency requiring an emergency response in which: there is a brutally honest assessment of immediate, or looming, threat to life, health, property or environment, which has a high probability of becoming overwhelming if immediate action is not taken; the crisis becomes the highest priority for the duration because the speed of response is crucial; bipartisanship and public leadership are exhibited; and non-essential functions and consumption may be curtailed or rationed so all available resources are devoted to the emergency.

As discussed above (see *Three degrees of warming* on page 10), there are estimates that the cumulative damages to Australia caused by climate disruption will be in the trillions of dollars this century, but the cost of effective emissions reduction is estimated to be around $A35 billion up to 2030. This is only one sixth of the amount Australia has already allocated in pandemic response funding.

The COVID-19 pandemic provides an opportunity to understand the world's preparedness for such a risk, and how and why the world's response, by and large, was grossly inadequate. This failure has important lessons for the preparedness of human society to respond to the much greater threat posed by human-induced climate disruption. There are also important, positive lessons in the pandemic response about the capacity of society to move quickly into emergency mode.

The biggest question is why can governments show some leadership and spend what is necessary to avoid a catastrophic threat — pandemic — but be so incapable of applying the same approach to climate disruption? It doesn't add up.

AUSTRALIAN ECONOMIC ASSESSMENTS

In Australia, there is a striking absence of broad analysis of social and economic impacts for the levels of warming that current policies commit the world to, in the range of 3-5°C.

Whilst some of the basic physical science of warming in this range has been published, and a conference on the topic was held in Australia in 2011, little detailed, peer-reviewed work is available on the socio-economic consequences. Yet such levels of warming would constitute an existential risk to Australian society and its neighbours.

Economic analysis of climate-change impacts in Australia differs widely across sectors. It is concentrated where impacts are more tangible and quantifiable, for example, the replacement value of damaged infrastructure or revenue losses from lower agricultural yields.

However, there is little to no analysis of the interactions between sectoral impacts and how, particularly in the case of extreme climate warming, the consequences will likely reverberate through the economy as happened with the 2019-2020 bushfires. As a consequence, damage estimates are unlikely to be close to the true cost.

There is some acknowledgement of the interconnectedness of systems, with infrastructure described as a "critical enabler"of the wider society and economy.

But estimates of damage are also limited because in most cases they represent only the loss for the current value of production or infrastructure, whereas impacts in the future in a growing economy will be larger than today. As well, many damage costings are represented in dollar value for years past and not at today's prices.

Analysis of climate impacts for other sectors, such as health and emergency services, are largely limited to qualitative descriptions of the risks, for example which regions will experience heightened vulnerability and which specific populations — such as lower socio-economic groups, elderly, children and remote communities — have a more limited capacity to respond.

Understanding of the risks that climate change poses to the financial sector and to economic system stability is also largely qualitative. Some studies use future loss of GDP to represent climate risks to the financial system, but these estimates vary widely.

The available academic studies are predominantly studies about adaptation and vulnerability assessments. They consider what future climate impacts might look like on the world of today, not in the future, and without consideration for new technologies, changed patterns of development and settlement or climate mitigation policies.

The studies are scientifically conservative and often out of date. Modelled impacts and costings are based largely on a maximum sea-level rise of 1.1 metres and temperature scenarios of 1.5°C–2°C based arbitrarily on *Paris Agreement* targets, not where projected warming is currently heading in the range of 3-5°C of warming. And sea-level projections to 2100 now run to more than 2 metres in the literature.

Most studies acknowledge that they do not take into account a range of factors, including climate tipping-points, new technology uptake rates and policy changes. And they include arbitrary assumptions about input parameters such as the future rate of economic growth and the discount rate.

For example, a recent report from the Australian Climate Council, *Compound Costs: How climate change is damaging Australia's economy*, which focused on economic damage from climate impacts on agriculture, labour productivity and property, acknowledged that the following factors were not considered: losses from bushfires, cyclones, floods; some impacts on infrastructure; some impacts on health; and losses of biodiversity and ecosystems (Steffen et al. 2019).

As well, many of the economic-impact reports use outdated baseline climate data, such as the IPCC 2001 assessment report or CSIRO reports more than a decade old, and much of the adaptation-focussed literature was conducted some time ago.

The following impacts, amongst others, appear not to have been generally subject to economic analysis and/or quantification:

- Climate impacts on major trading partners and economic consequences for Australia;
- National security impacts, social breakdown, climate-driven forced migration and the implications for Australia, both from a narrow disaster response and humanitarian aid viewpoint, and more broadly for the state of the global economy;
- The possibility of global collapse of key political, financial and/or economic systems;
- Economic consequences of extreme climate events and disasters which, if assessed at all, appear to be significantly underestimated.

In summary, there is no literature that synthesises the large-scale impacts that climate change could have on Australia's economy, and no reliable snapshot of Australia's economic vulnerability to future climate warming in a regional and global context.

Despite the highly conservative baselines that the literature uses, and its limited range, the expected consequences of warming are dramatic. The literature shows that researchers expect even moderate levels of warming to have large negative consequences on health outcomes, agricultural output, tourism and water availability, and pose significant challenges for an array of infrastructure and emergency services, and with significant damage to the Australian economy.

SNAPSHOT: AUSTRALIAN INFRASTRUCTURE

Residential and commercial buildings are highly vulnerable to climate change impacts, particularly in coastal areas, where development is concentrated. Future losses in residential property values may total $A571 billion by 2030, $A611 billion by 2050 and $A770 billion by 2100, concentrated on 5-6% of properties (Steffen et al. 2019). The costs of extreme weather is projected to rise to $A91 billion per year annually by 2050 and $A117 billion per year by 2100 (Steffen et al. 2019).

Climate change will accelerate the ageing of energy infrastructure through increased ground movement due to increased intensity of droughts and rain, sea-level rise affecting coastal infrastructure and severe weather increasing network fault frequency (Foster et al. 2013; Holper et al. 2007).

Damage to water infrastructure and water quality can be expected from a range of climate impacts, including increased bushfires, dry soil conditions exacerbating collapse and failure of water pipe infrastructure, and flood impacts on water quality, quantity, drainage and storage (Commonwealth of Australia – Senate 2018). Water treatment facilities located near coasts will be increasingly impacted by cyclones and storm surges and experience overflows from heavy rainfall. More hot days will likely increase demand for water and compound existing climate pressure on water infrastructure (Commonwealth of Australia – Senate 2018). Sydney Water has identified $A39 billion worth of water assets that may be at risk from future climate change impacts (Sydney Water, n.d.).

Significant economic costs can be expected from climate impacts on transport infrastructure: the Victorian 2009 heatwave resulted in losses of $A800 million from electricity outages and transport network disruption alone (Commonwealth of Australia – Senate 2018). Researchers note that "Roads (urban, arterial and freeways) link and facilitate movement within cities and regions, [so] their disruption due to climate change impacts will affect businesses, trade and the lifeline of communities by impeding and/or damaging evacuation routes as well as hindering service provision, such as food and critical supplies" (Serrao-Neumann et al. 2011).

A sea level rise of 1.1 metre could place $A266 billion of emergency services infrastructure at risk, including 258 police, fire and ambulance stations as well as 75 hospitals and health services (Commonwealth of Australia – Senate 2018). An increased burden on health services is expected due to extensive health challenges that are forecast with various climate impacts, compounded by existing public health issues and an ageing population.

SNAPSHOT: AUSTRALIAN AGRICULTURE

Australia's agricultural sector is at significant risk from climate change impacts. The loss of wealth from climate change impacts on agriculture and labour productivity may reach $A4.2 trillion by 2100 under a business-as-usual scenario (Steffen et al. 2019).

The Millennium Drought reduced the gross value of Australian agriculture by 28.5% (Hughes et al. 2015). Over coming decades, agriculture production is expected to decline, with major export commodities including wheat, beef, dairy and sugar projected to fall 9-10% by 2030 and 13-19% by 2050. Overall declines of agriculture exports of 11-63% by 2030 and 15-79% by 2050 depend on the level of adaptation and warming (Gunasekera et al. 2007).

The Murray-Darling Basin (MDB) accounts for approximately half of Australia's irrigated agricultural production and is projected by 2050 to lose half of its irrigated agricultural output, which is currently worth $A7.2 billion annually. The MDB experienced reduced agricultural yields of 20% during the Millennium Drought (Steffen et al. 2019).

By 2090 wheat yields on 4,200 family farms that produce 50% of Australia's wheat in WA are projected to fall by 41-49% in the absence of reduced emissions, with shifts in rainfall patterns the strongest influence (Steffen et al. 2019).

Demand for water could grow by one-third to one-half by 2030 due to rapid economic and population growth, exacerbating hotter and drier climate conditions for agriculture in the south-west (McFarlane et al. 2012). Hydro-economic modelling for the MDB shows that a dry extreme 2030 scenario, based on rainfall 13% below historical average, would result in 81% less water use and a 51% reduction in agricultural profits (Jiang & Grafton 2012).

There is also strong evidence to suggest that climate change will impact the quality as well as quantity of food produced. The nutritional content of major food crops such as potatoes, wheat, corn, soybean and rice are likely to lower with increased atmospheric CO2, potentially leading to deficiencies in iron, zinc and protein (Fanzo et al. 2018).

Climate impacts on agriculture have the potential to significantly threaten food security in Australia, particularly through the consequences of reduced yields. Globalisation exposes food supply systems in Australia to rising resource prices and increases in global demand, compounding challenges associated with economic and population growth, biodiversity and climate change impacts and increasing resource competition for land and water (Farmar-Bowers et al. 2013).

“IF DAMAGING TIPPING CASCADES CAN OCCUR AND A GLOBAL TIPPING POINT CANNOT BE RULED OUT, THEN THIS IS AN EXISTENTIAL THREAT TO CIVILIZATION. NO AMOUNT OF ECONOMIC COST–BENEFIT ANALYSIS IS GOING TO HELP US.”

— PROF TIM LENTON AND CO-AUTHORS

(LENTON ET AL. 2019)

EXISTENTIAL RISK-MANAGEMENT

Human-induced climate change is an existential risk to human civilisation — where existential risk is understood as an adverse outcome that will either annihilate intelligent life or permanently and drastically curtail its potential — unless carbon emissions are rapidly reduced. Special precautions that go well beyond conventional risk-management practice are required if the increased likelihood of very large climate impacts — known as "fat-tail risks" — are to be adequately dealt with.

The bulk of climate research and the reports of the IPCC have tended to underplay these risks, and exhibited a preference for conservative projections and scholarly reticence (Spratt & Dunlop 2018).

This is a particular concern with potential climate tipping points where the impacts of global warming are non-linear and difficult to model with current scientific knowledge.

A prudent risk-management approach means a tough and objective look at the real risks to which we are exposed. The potential consequences of the fat-tail risks — which may be damaging beyond quantification — would be devastating for human society.

It is important to understand the potential of, and plan for, the worst that can happen, and be pleasantly surprised if it doesn't. Focusing on middle-of-the-road economic outcomes may result in an unexpected catastrophic event that we should have seen coming.

This means that economic analysis of climate damage should focus on those possibilities where the risk is highest, but so far this has not been done. Too often the opposite has occurred, with large amounts of research applied to understanding the difference in economic damage between 1.5°C and 2°C, for example, but little on the difference between 1°C and 4°C of warming.

Existential risks are not amenable to the reactive (learn from failure) approach of conventional risk management, and we cannot necessarily rely on the institutions, moral norms, or social attitudes developed from our experience with managing other sorts of risks. Because the consequences are so severe — perhaps the end of global human civilisation as we know it — "even for an honest, truth-seeking, and well-intentioned investigator it is difficult to think and act rationally in regard to… existential risks" (Bostrom & Cirkovic 2008).

This is a challenge for economists as much as scientists, policymakers and advocates.

CONCLUSION

The UN's climate science body, the IPCC, produces reports synthesising science for the primary purpose of informing its policymaking body, the UNFCCC. Policymaking processes have norms: rules and practices, assumptions and boundaries, that constrain and shape them.

The IPCC's output may be termed "regulatory science" (as opposed to pure "research science"), which Prof. Sheila Jasanoff describes as straddling the dividing line between science and policy as scientists and regulators try to provide answers to policy-relevant questions (Jasanoff 1998). In this engagement between science and politics, science is seen "neither as an objective truth, nor as only driven by social interests, but as being co-produced through the interaction of natural and social orders" (Dooley et al. 2018).

Models, as characterisations of the world, are highly subjective and are not necessarily accurate and truthful description. They also describe "the ways in which we wish to live in the worlds that our science discovers and describes", and this is perhaps most obvious in the case of the environmental sciences, says Jasanoff (Hajer 2019).

The same blurring of purpose may be ascribed to economics — the purpose, the assumptions, the methods — as it weaves a tangled dance with physical climate science, always with policymakers and "policy relevant" outputs front of mind.

As noted previously, the structure and input parameters of a climate–economy model depend on the modeller's beliefs about the functioning of society. All economics has a social framing, and it is disingenuous to think that it does not.

Prof. Hans Joachim Schellnhuber, in writing the foreword to Breakthrough's *What Lies Beneath* report on scientific reticence, identifies a current trend towards "erring on the side of least drama", and says that when "the survival of civilization is at stake, conventional means of analysis may become useless" (Spratt & Dunlop 2018).

While he was referring to the physical sciences, Schellnhuber's question as to the usefulness of orthodox methods should also be applied to the economic analysis of climate disruption.

And that includes cost–benefit analysis. Schellnhuber was one of seven scientists to co-author a research paper published in November 2019 which said that: "If damaging tipping cascades can occur and a global tipping point cannot be ruled out, then this is an existential threat to civilization. No amount of economic cost–benefit analysis is going to help us" (Lenton et al. 2019).

The IMF Working paper, discussed above, points to a growing agreement that risk of a catastrophic disaster is rising, and with it potentially infinite costs if climate change remains unmitigated. At the same time, overemphasis on the costs of mitigation has resulted in grossly under-emphasising the benefits of action.

Recent analysis has drawn attention to the huge economic benefits associated with climate mitigation, outweighing mitigation costs 5.5-to-one (Kompas et al. 2019). That study makes this conclusion with a 7% discount rate, but also shows that a lower (and arguably more suitable) discount rate of 3% takes the benefit-to-costs ratio to an extraordinary 15.9-to-one ratio (Kompas et al. 2019). Other studies have shown the benefit to cost ratio to be as high as 20-to-one.

The Kompas report also highlights the many co-benefits associated with mitigation, including enhanced agricultural productivity, reduced energy costs and improved environmental qualities such as less pollution and more biodiversity. Yet only some of these are included in the benefits analysis "where possible", meaning climate mitigation benefits are likely even greater than concluded in the report's final cost-benefit ratio.

In this work, the case for action is so overwhelming that there is no need to use IAMs to produce fictional accounts of various policy consequences eighty years from now. The case for action now is already watertight.

"If damaging tipping cascades can occur and a global tipping point cannot be ruled out, then this is an existential threat to civilization. No amount of economic cost–benefit analysis is going to help us" (Lenton et al. 2019).

So, some conclusions to be drawn from our look at the "fatal calculations" of conventional climate economics are:

- If climate policymaking is to be soundly based, a reframing of economic analysis within an existential risk-management framework is now urgently required. The higher-impact possibilities may have less research available for consideration, but there are good risk-management reasons for giving such possibilities much more prominence in economic assessments, even if the event probability is relatively low, and because the damage may be unquantifiably large.
- On the use of IAMs, no projection or forecast in the area of costs and benefits of mitigating climate change out as far as 2100 is credible, and IAMs should not be used to formulate policy. There are too many levels of inherent and irreducible uncertainties in the equations and input assumptions, which grow and accumulate as the time-frame extends. IAMs should be run only for the short to medium term, for example 10–20 years at most (Rosen & Genther 2016).
- Rather than complex IAM modelling, an approach to damage analysis that combines sectoral damage assessments with expert elicitations from a diverse range of relevant disciplines is more appropriate for warming of 3–5°C, in part because the damages may be beyond quantification and this needs to be made explicit in impact assessments.
- Such an approach would quickly lead to an understanding that all possible effort, regardless of the short-term costs or disruption, should immediately be put into an emergency-level economic transformation to minimise the existential risks.

As it's turned out, says economist John Quiggin, the costs of climate change inaction have arrived much sooner than we expected: "While a full economic analysis must still evaluate the stream of future costs and benefits of mitigation, it's now possible to justify a large cut in emissions in terms of benefits that will be realised within a much shorter time frame" (Quiggin 2020).

In a nutshell, don't make the economic argument any more complex than is necessary.

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