From: Emily Platt

**To:** OIC Public Comments **Subject:** 25 Oct 2023 OIC meeting

**Date:** Sunday, October 15, 2023 1:27:46 PM

### This email is from a party external to Treasury. Use care with links and attachments.

Dear Treasurer Read and Oregon Investment Council Members,

I am a retired PERS member who strongly supports divestment of Oregon Public Employees Retirement Fund and all of the Oregon Treasury from risky fossil fuels. We have a vanishingly slim chance of holding global warming to 1.5C

(https://www.scientificamerican.com/article/the-world-will-likely-miss-1-5-degrees-c-why-isnt-anyone-saying-so/), due more to lack of political will than to technical issues. The world has already warmed ~1.3C and we see the effects – lethal floods, incineration of entire towns, droughts and catastrophic storms. This summer was the hottest on record and yet will likely be the coolest we experience for the rest of our lives. Despite the climate emergency, the sluggish response of those in power indicates that they think this emergency will somehow fix itself. Those in power who have the ability to affect systemic change have an imperative duty to do all in their power to address this crisis.

So, what does taking action to mitigate climate chaos look like for the OST? Since they are a financial institution, they can start by divesting from fossil fuels. "Money is the oxygen on which the fire of global warming burns" (https://www.newyorker.com/news/daily-comment/money-is-the-oxygen-on-which-the-fire-of-global-warming-burns). Divestment is completely consistent with the fiduciary responsibility of the OST/OIC to provide for long-term returns, since fossil fuels are inherently risky investments impacted by geopolitical events, decarbonization, and illiquidity. I note that at least 50% of OPERF is invested in illiquid untransparent private equity that is heavily leveraged in fossil fuels. Investments in opaque private equity are deeply inconsistent with a public entity whose principal tenet is transparency. Comparison to other state retirement funds shows that OPERF performs no better and often times worse than those that have little or no private equity investments (https://www.divestoregon.org/treasurys-private-investment-problem-report)

The recent OPERF decarbonization plan released by Treasurer Read lacks ambition, urgency, and a real-world understanding of the duplicity of fossil fuel companies. In order not to blow past the 1.5C benchmark, the global community must enact a profound and immediate decrease in GHG emissions, brought about by a just transition to renewable energy alongside the non-implementation of new fossil fuel projects. Since we can't rely on fossil fuels companies to do the right thing, we must withdraw all funding for their misguided, polluting and often, human rights violating projects. False solutions such as "offsets" and engagement with fossil fuel companies must also be avoided. To quote Bill McKibben "But we're all going to have to change - that's the point. Farmers around the world are leaving their land because the sea is rising; droughts are already creating refugees by the millions. On the spectrum of shifts that the climate crisis will require, bankers and investors and insurers have

it easy. A manageably small portion of their business needs to disappear, to be replaced by
what comes next." Please enact a bold decarbonization plan – and don't even consider new
fossil fuel investments.

Sincerely,

Emily Platt

From: <a href="mailto:thomassonct@gmail.com">thomassonct@gmail.com</a>
To: <a href="mailto:OIC Public Comments">OIC Public Comments</a>

Subject: Add more specificity to Framework-Testimony
Date: Sunday, October 15, 2023 8:22:23 PM

### This email is from a party external to Treasury. Use care with links and attachments.

Dear Oregon Investment Council members:

I am gravely concerned about climate change. Serious consequences that I began to warn about as a physician 20 years ago are now happening here in Oregon and around the globe. I engaged a financial planner and investment company over 10 years ago to divest my personal retirement savings from fossil fuels and subsidiary support companies. It wasn't hard by focusing on eliminating fossil fuels. My investments earned as much or more than the average. Not everyone can afford to do that if one wishes to settle for average funds, but an entire department of treasury with paid staff certainly can.

Fossil fuel investments have been boom or bust. We know now that fracking for oil or gas plays out sooner than expected so long-term investments make no sense, certainly for investments of retirement accounts. Exxon looks very exciting to invest in today, but as electric vehicles ramp up, we don't want to be holding their stock in our portfolio.

The framework is not nearly advanced enough. There is a goal to reduce investments in GHG emitting businesses by 2050 and 50% reduction by 2035. Nowhere is there a call or goal to stop investments in all fossil fuel companies now. Sure, we support investments in the building sector which uses cement, wood and steel (potentially high emissions) but these are not the immediate targets because there are regulations in the state of Oregon to build more sustainably over time, so the investments are less risky and will naturally reduce their GHG overtime. We certainly hope that these regulations become the norm for the entire country.

The most important point action to take is to stop any new investments in fossil fuels and no new investments in private equity sector fossil fuel infrastructure development. This is the highest risk and Oregon has over 27.8% of its investment in private equity-double the average. We have <u>seen this year's losses as a disaster for the state of Oregon</u>. These will take longer to divest from, but certainly doable by 2035. This needs to be part of the framework and doesn't take vast analysis and quantification.

Thank you for starting down this road. It will help our PERS and other investments and will help our future on this planet.

Sincerely,

Catherine Thomasson, MD Portland, OR

thomassonct@gmail.co

From: Robin McLeod

To: OIC Public Comments

Subject: fossil fuel investments

**Date:** Tuesday, October 17, 2023 1:15:49 PM

This email is from a party external to Treasury. Use care with links and attachments.

I strongly urge the OIC to closely monitor fossil fuel investments. These are high risk products and often in private holdings that do not allow inspection by us the investors. My pension funds are being put at risk and are at risk for long periods of time while damage to our environment continues. Dell Goldsmith and Robin McLeod

From: Richard Pope
To: OIC Public Comments

Subject: Fwd: OIC meeting 9/6/23 - Testimony of Rick Pope Date: Wednesday, September 6, 2023 10:42:56 AM

Attachments: Testimony of Rick Pope re unaddressed issues in climate risk assessment.pdf

This email is from a party external to Treasury. Use care with links and attachments.

Rick Pope

rspope@icloud.com

Sent from my iPad

Begin forwarded message:

From: rspope@icloud.com

**Date:** August 28, 2023 at 2:08:00 PM PDT **To:** OIC.PublicComments@ost.state.or.us

Subject: OIC meeting 9/6/23 - Testimony of Rick Pope

Please see the attached testimony of Rick Pope for the OIC meeting of September 6, 2023.

**Rick Pope** 

### Testimony of Rick Pope re unaddressed issues in climate risk assessment

September 6, 2023, Oregon Investment Council meeting

How is Treasury rolling the climate-risk dice?

In 2021, Treasury's consultant Ortec predicted a 63% lower US GDP by the year 2100, and a 20% to 33% negative impact on OPERF's assets by the year 2060, if fossil fuel use continues unabated (Exhibit 1).

It is now two years closer to those predicted losses, and Treasury still has no documented climate risk policy. Nor will it say how it assesses climate risk to OPERF investments (Exhibit 2).

Treasury is acting like serious climate risk is far away. That's not what a new report says from Carbon Tracker, the organization that brought the world the now-standard concept of fossil fuel stranded assets.

The report title is "Loading the DICE against pension funds – Flawed economic thinking on climate has put your pension at risk" (Getting the report and its support requires opening an account, so I've attached them as Exhibits 3 and 4). The author is Professor Steve Keen, distinguished research fellow at University College London.

Professor Keen's fundamental point is simple. Today's standard climate risk analysis is based on climate assumptions approved only by economists. Missing from their equations are climate assumptions approved by climate scientists. Because of that flaw, economic damage predictions, and the time they could occur, are seriously understated.

The omission, when you stop to think about it, is astounding.

In a worst case of average warming over 200 years to **7° C, or 12.6° F,** standard economists predict a mere bump in the road—a growth slowdown of only 20% over the next two centuries.

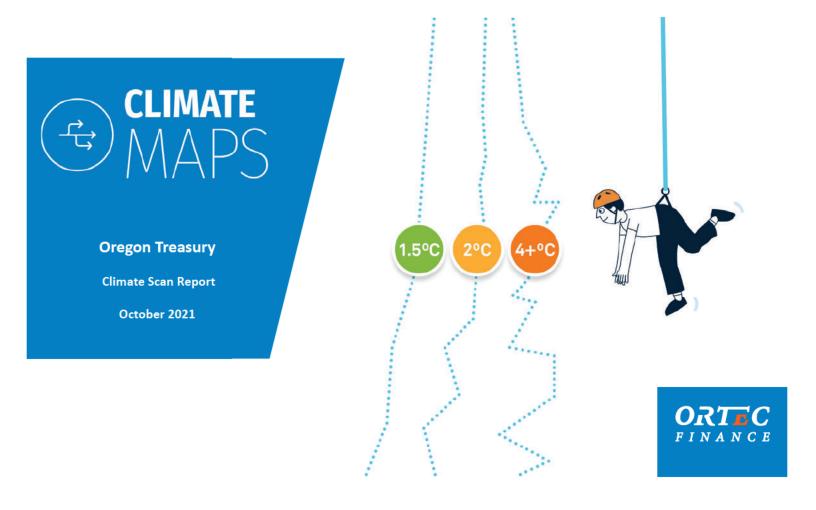
The climate scientists, however, in that case foresee environmental catastrophes and existential threats. That is no bump in the road. Many of their concerns are described in the 2023 Climate Change Report policymaker summary of the <u>Intergovernmetal Panel on Climate Change</u>.

Shouldn't careful trustees require climate scientists' risk knowledge to be refereed into economists' climate risk damage assumptions?

The grandparent damage model, if Treasury is even using one, is called the Dynamic Integrated Climate Economy model, or DICE. It is the direct ancestor of most all climate-related damage models today. But DICE has shortcomings.

- DICE puts most climate impacts into the distant future by assuming, with no support, that a non-accelerating quadratic equation would calculate them accurately. Substituting accelerating exponential or logistic growth equations, however, captures the risk of tipping points, and puts the vast majority of climate damage into this century.
- Tipping points excluded from DICE's equations are ocean current collapse and its effects on food supply, deforestation of the Amazon carbon sink, South Asian monsoon changes, sea ice and permafrost melts, and polar ice sheet disintegration. Their foreseeable risks are totally missing from DICE.
- DICE originally ignored drought and floods as an economic factor, and many models continue to omit precipitation changes as a risk. DICE and its progeny did not take into account the devastating floods, droughts and wildfires across the globe we are increasingly seeing today.
- DICE assumed only industries out in the weather, such as agriculture and forestry, would be severely affected by climate change. DICE downgraded risk, among other lapses, for the energy, real estate, tourism, recreation, finance and insurance sectors.
- DICE found relatively weak relationships today between temperature and income, and assumed that would carry forward with global warming. DICE ignored that today, warm countries prosper by trading with available cooler countries. What will happen as cooler countries become less and less available? DICE doesn't compute.

We need an explanation, now, for how Treasury is or isn't assessing climate risks to PERS investments. Those risks exist now. How is Treasury rolling OPERF's climate-risk dice in the face of them? Don't PERS beneficiaries deserve to know?





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Annex

### Climate risk exposure | OPERF investment portfolio



The view from 10,000 feet

### 1. Lower return expectations across all assets due to negative climate impact over time.

Over he nex 20 years, all three climate scenarios see lower growth expectations compared o a base ne. h s poses a ma er a r sk o bo h scheme ba ance shee s and fu ure con r bu on/fund ng needs.

#### 2. Worst outcomes come in a Failed Transition due to physical risks.

G oba y, he physical risks experienced when transition to a greener economy fails, have the most significant impacts (63% ower US GDP by 2 00). Notably, by 2037 OPERF's portfolio value in the Failed Transition scenario is significantly down compared to an orderly low-carbon transition, n a a ed rans on by 2060 your asset por folio value is expected of c.20% ower han base ne.

### 3. Transition risk impacts may occur sooner than most expect.

On he o her hand, a transition scenario – even a d sorder y one – enables global economies to stabilize once he rans on has been comp e ed. here s hope, and h s demons ra es he need for nives ors o engage w h companies and sovereigns on he rans on whis a so position on night er por foliosiste.

n he near fu ure, rans on mpac s are genera y pos ve n urope. n con ras, he US s more nega ve y mpac ed han many o her coun r es due o foss fue s expor s and o her h gh-em ng ac v y curren y be ng a s gn f can con r bu or o GDP. Re a ve o he base ne, n a disorderly transition scenar o, h gh exposure o he US economy con r bu es o OP R 's por fo o reduc ng n va ue by rough y 8% over he nex 5 years.

### 4. Climate risk changes the Strategic Asset Allocation (SAA) landscape as climate impacts affect long-term expectations.

R sk-ad us ed re urns vary across asse s, pa hways and me hor zons. n genera, cash & corporate bonds are more resilient whereas the least resilient asset classes are listed/private equities and properties due o her sens v y o prc ng-n shocks and marke over-reac on.

Compared o a yp ca g oba y-exposed pens on scheme, your portfolio's current climate risk exposure is relatively more vulnerable due o a exposure o sens ve reg ons, sec ors, and asse c asses.

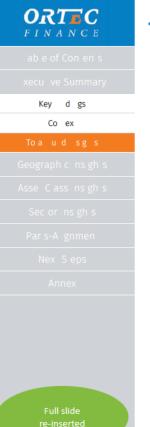
C ma e change s ke y o see s rong y d fferen a ed r sk/re urn a a sec or eve . As such, fu ure SAA/A M dec s ons may benef from sec or- eve d fferences be ng cap ured n he ana ys s.

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### **OPERF** investment portfolio performance

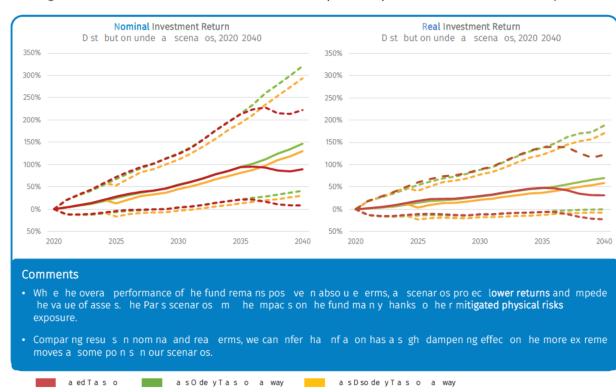
The figure below shows the ratio of cumulative impacts relative to baseline over the next 40 years





## The impact of climate risk on OPERF's portfolio

The two figures below show the ratio of cumulative climate impacts compared to baseline in the next 20 years



### ORTEC FINANCE

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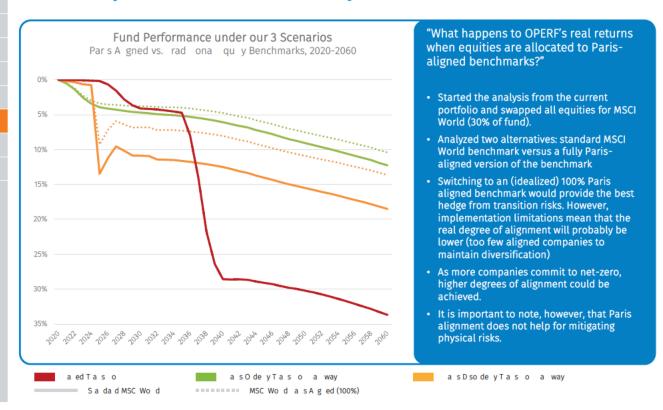
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# Switching to Paris-aligned benchmarks potentially mitigates downside performance if a disorderly transition scenario unfolds





### **Request for Public Records**

**REQUESTER** Rick Pope

**DATE** February 10, 2023

**REFERENCE NO.** R000304-013123

You submitted the following request for public records:

"I am requesting any climate-specific policy document Treasury has for how to address climate risk in OPERF's portfolio. There is no climate-specific document in OIC investment policies provided to me."

Hi,

We have no further records responsive to this request to provide. Treasury has integrated environmental-related risks as one of its core factors within the investment decision-making framework. Consistent with fiduciary standards and state laws, Treasury considers all material risks and benefits when making an investment decision with the primary objective of delivering sustainable returns for our beneficiaries.

I'd like to point you to the Oregon Investment Council's <u>webpage</u> where resources are available, such as the Council's 'Investment and Management Beliefs' and a 'Statement of Investment Objectives and Policy Framework', and can provide more information about what guides our investment staff's work in performing their fiduciary responsibilities.

If you have any questions or need additional information, please reply to this email.

Sincerely,

### **Treasury Public Records Team**

867 Hawthorne Ave. SE | Salem, OR 97301-5241

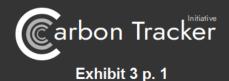
P: 503-373-7609

July 2023

# Loading the DICE against pension funds

Flawed economic thinking on climate has put your pension at risk





### **About Carbon Tracker**

The Carbon Tracker Initiative is a team of financial specialists making climate risk real in today's capital markets. Our research to date on unburnable carbon and stranded assets has started a new debate on how to align the financial system in the transition to a low carbon economy.

www.carbontracker.org | hello@carbontracker.org

### About the Author

### Professor Steve Keen

Steve Keen is a Distinguished Research Fellow at UCL (see https://www.isrs.org.uk/people), and is supported by crowdfunding on Patreon (https://www.patreon.com/ProfSteveKeen) and Substack (https://profstevekeen.substack.com/).

He is the author of *The New Economics: A Manifesto* (Keen 2021), *Can We Avoid Another Financial Crisis?* (Keen 2017), *Debunking Economics* (Keen 2011), and about 80 refereed papers, on topics including flaws in the economic analysis of climate change (Keen et al. 2022; Keen 2020a), the role of energy in production (Garrett, Grasselli, and Keen 2020; Keen, Ayres, and Standish 2019), the causes of financial instability (Keen 2016, 2015, 1995), and flaws in Neoclassical (Keen and Standish 2010; Keen 2005, 2004a, 2004b) and Marxian economics (Keen 1993b, 1993a). He is the designer of the Open-Source system dynamics program Minsky (https://sourceforge.net/projects/minsky/).

### Acknowledgements

Carbon Tracker wishes to thank Professor Tim Lenton - Chair in Climate Change & Earth Systems - University of Exeter for his role as an external academic referee on this paper.

We are also grateful for the assistance of external reviewers & expert contributors - some of whom wished to remain anonymous.

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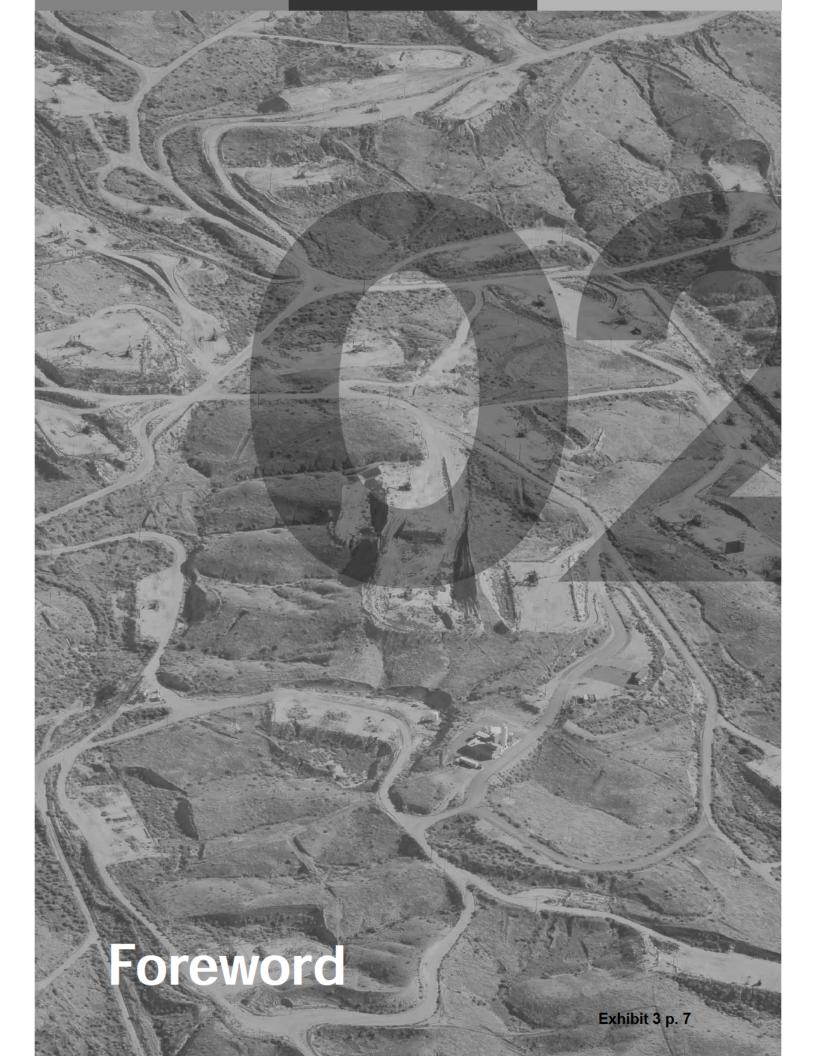
# **Table of Contents**

UΙ	Key Findings	5
02	Foreword	7
03	Introduction	9
04	Executive Summary	11
05	Pension funds, consultants, and climate change	14
06	A Bright Future of Global Warming?	17
07	The gulf between science and economics	20
08	A divided discipline 8.1 Dry Economics 8.2 Ignoring internal critics Flawed methodologies and damage functions	24 26 28 31
10	A better, though still flawed, method	35
11	Tipping Points and "the smell test"	40
12	Managing risk on unsound foundations  12.1 How climate damage functions impact investment advice and analysis  12.2 Advisors—the representative example of Mercer  12.3 Other Consulting Firms  12.4 The UK Local Government Pension Scheme (LGPS)  12.5 LGPS funds' reliance upon advisors  12.6 Financial Regulators  12.6.1 The Financial Stability Board (FSB)  12.6.2 The Network for Greening the Financial System (NGFS)	46 47 47 54 55 56 58 58 59
	12.6.3 The Federal Reserve  12.7 The Economist Intelligence Unit	60 60
	12.8 Misinformation begets financial instability	61

13	A Climate Minsky Moment?	62
14	Taking Stock	64
	14.1 Informing members	65
	14.2 End commercial confidentiality on climate change advice	65
	14.3 Ask questions	66
	14.4 Reform academic practices on climate change	66
15	Conclusion	67
16	References	69
<b>17</b>	Appendix	79



- Investment consultants to pension funds have relied upon peer-reviewed economic research to provide advice to pension funds on the damages to pensions that will be caused by global warming.
- ▼ Following the advice of investment consultants, pension funds have informed their members that global warming of 2-4.3°C will have only a minimal impact upon their portfolios.
- The economics papers informing the models used by investment consultants are at odds with the scientific literature on the impact of these levels of warming.
- The economics of climate change is an interdisciplinary subject, but papers on the economics of climate damages were refereed by economists alone. Properly refereeing these papers required knowledge of the science of global warming that economists typically did not have. Consequently, economic referees approved the publication of papers that made claims about global warming that are seriously at odds with the scientific literature.
- These claims have been fundamental to the predictions by economists of minimal impacts on the economy from global warming.
- ✓ Economists have claimed, in refereed economics papers, that 6°C of global warming will reduce future global GDP by less than 10%, compared to what GDP would have been in the complete absence of climate change.
- ✓ In contrast, scientists have claimed, in refereed science papers, that 5°C of global warming implies damages that are "beyond catastrophic, including existential threats," while even 1°C of warming—which we have already passed—could trigger dangerous climate tipping points.
- This results in a huge disconnect between what scientists expect from global warming, and what pensioners/investors/financial systems are prepared for.
- Consequently, a wealth-damaging correction or "Minsky Moment" cannot be ruled out, and is virtually inevitable.
- Pension funds have a fiduciary duty to correct the erroneous predictions they have given their members.
- Similarly, financial regulators, who have used the same erroneous and misleading economic damage predictions to stress test the exposure of financial institutions to climate change, must drastically revise their stress test studies.
- ▼ This report calls on all stakeholders, from governments, regulators, investment professionals, all the way to civil society groups and individuals, to ensure that climate change policy is based upon the work of scientists.
- Climate change must be treated as a potentially existential threat to the economy, rather than an issue which is suitably addressed by economic cost-benefit analysis.



Since 2011, when Carbon Tracker published its first report "<u>Unburnable Carbon: Are the World's Financial Markets Carrying a Carbon Bubble?</u>," Carbon Tracker's mission has been to translate climate science into financial risk in order to align our financial system within a sustainable global temperature outcome.

However, the relationship between climate science and financial risk is not a comfortable one: as this report shows, the scientific and the economic literature are conflicted on the topics of how much damage climate change will do to the economy, and when. These conflicts, and more crucially, the effects of them when assessing the risk of climate change on both people's financial futures, and the wider financial system, are the focus of this report.

Within the financial ecosystem, one of the primary areas the conflict between climate science and financial risk plays out is in pension funds.

To ensure that the world moves into a new climate secure energy system, it's crucial that pension schemes send the market the right investment signals. The signal has to be that a swift, orderly transition is in everyone's financial interests, particularly for scheme beneficiaries. Also, in the case of local government pension schemes featured in this report, early action to reduce climate risk is in the best interests of tax payers, who would likely bear the brunt of any short fall in pension fund assets.

However, if the climate risk models used to guide investment decisions trivialise the extent of the financial impacts of climate change, then it is unlikely that finance officers and trustees will have the incentives to act now. This is the worrying finding of this report.

This report is a call to action for investment professionals to look at the compelling evidence we see in the climate science literature, and to implement investment strategies, particularly a rapid wind down of the fossil fuel system, based on a 'no regrets' precautionary approach. Behaving cautiously now and acting to avoid a 1.5°C increase (let alone the 4°C outcome featured in this report) will enable future generations to secure the prosperity and quality of life that comes from a healthy planet.

Mark Campanale

Founder and Director of Carbon Tracker





Introduction

Exhibit 3 p. 9

Mainstream economics last failed society badly prior to the Global Financial Crisis in 2008. Rather than anticipating the crisis, Dynamic Stochastic General Equilibrium (DSGE) models that dominated macroeconomic analysis predicted the immediate economic future was bright.

This led to the OECD<sup>1</sup> claiming in June of 2007 that:

"The current economic situation is in many ways better than what we have experienced in years... Our central forecast remains indeed quite benign... In line with recent trends, sustained growth in OECD economies would be underpinned by strong job creation and falling unemployment." (Cotis 2007, p. 7)

The worst economic crisis since the Great Depression began just two months later. Only after this crisis occurred were critics of the dominant approach to macroeconomics listened to (Bezemer 2009).

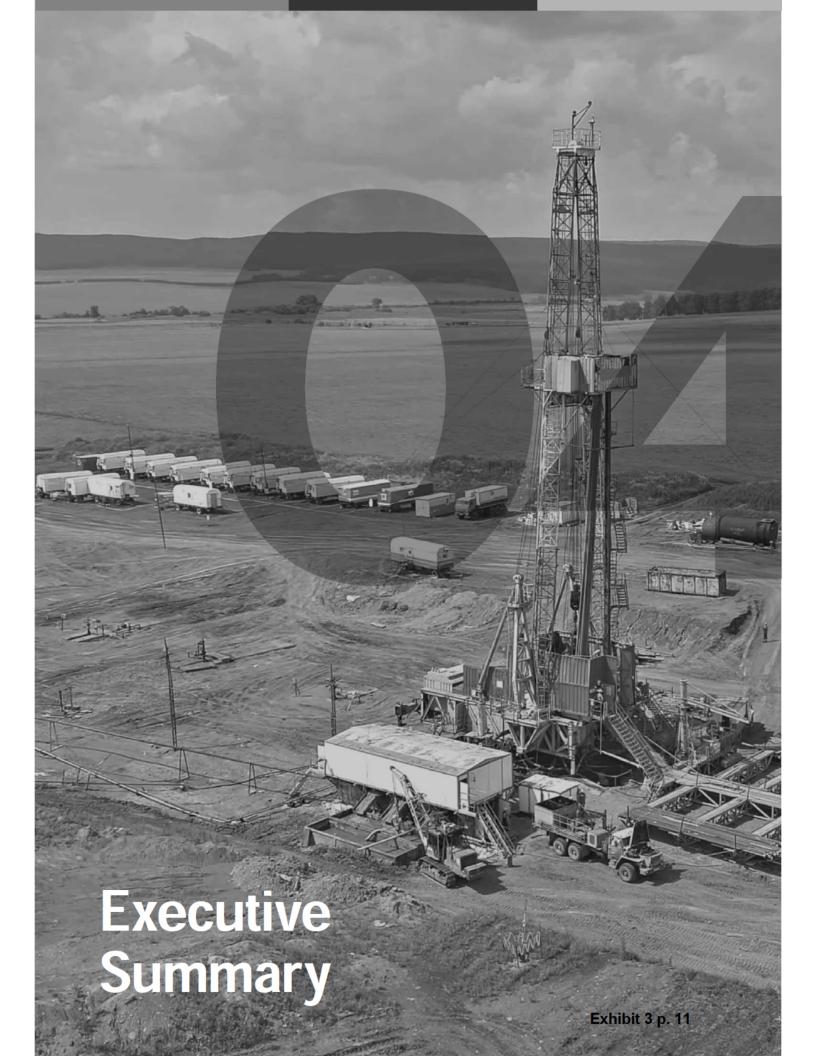
Robert Solow, who was awarded the Nobel Prize for Economics for his work on growth theory, had been criticising this approach for years (Solow 2001, 2003, 2007, 2008). After the crisis began, he spoke at a United States Congressional Hearing on the topic of "Building a Science of Economics for the Real World." Solow suggested that a simple test— "the smell test"—should be applied to any macroeconomic proposition, while cautioning that economists who had developed the dominant approach to macroeconomics were incapable of carrying it out themselves:

"Especially when it comes to matters as important as macroeconomics, ... every proposition must pass the smell test: does this really make sense? I do not think that the currently popular DSGE models pass the smell test... The advocates no doubt believe what they say, but they seem to have stopped sniffing or to have lost their sense of smell altogether." (Solow 2010, p. 2.)

Solow's insight is very relevant to the issue tackled in this report: the way mainstream climate change economists have assessed the dangers that global warming poses for the economy. None of the assumptions that this relatively small group of economists have made about global warming "pass the smell test." Nonetheless, they continue to produce similar studies, which reach similar conclusions about relatively trivial economic damages from relatively large increases in the global average temperature, because "they seem to have stopped sniffing or to have lost their sense of smell altogether."

This report demonstrates how work on climate change by a relatively small number of economists—work which has been heavily criticised by other economists, as well as by climate scientists—has woven its way into the global population's financial lives, with unnerving consequences for our wellbeing, both physical and economic.

<sup>1</sup> The "Organization for Economic Cooperation and Development" is a policy analysis and advisory body with members from 38 of the world's largest economies.



It is now 50 years since economists first disputed the warnings of ecologists and engineers about the potential dangers of climate change (Nordhaus 1973, 1974; Solow 1974; Stiglitz 1974; Forrester 1971; Meadows, Randers, and Meadows 1972; Forrester, Gilbert, and Nathaniel 1974). Just as with the OECD's assurance that the economic future was bright in June 2007, nothing could be further from the truth.

It ain't what you don't know that gets you into trouble. It's what you know for sure that just ain't so.<sup>2</sup>

Many peer-reviewed economic studies assert that economic damages from global warming will be slight. Summarizing this literature, the 2022 IPCC Report concluded that:

"warming of ~4°C may cause a 10-23% decline in annual global GDP by 2100 relative to global GDP without warming." (IPCC 2022, p. 2459)

These estimates imply that a trajectory towards 4°C of warming by 2100 would cause global GDP in 2100 to be between 13 and 15 times larger than today, whereas without global warming, it would be about 17 times larger than today.<sup>3</sup> These are substantial differences in GDP in 2100, but they imply that significant global warming will cause a relatively small fall in the annual rate of economic growth until 2100.

These economic studies have been relied upon by the consulting firms which pension funds commission to calculate the impact of global warming on their members' portfolios, by central banks undertaking stress tests of the resilience of financial systems to the changes in climate, and by governments developing climate change attenuation policies. For example, the investment consultant Mercer advised Australian super fund HESTA that a warming trajectory of 4°C in 2100 would result in a -17% portfolio impact.<sup>4</sup>

In contrast, research by climate scientists implies that the impact of a 3°C increase (or even lower) could be "catastrophic" (Kemp et al. 2022), that climate tipping points could be triggered even at 1°C of warming (Armstrong McKay et al. 2022),<sup>5</sup> and that changes to our climate which could trigger tipping points are "too risky to bet against." (Lenton et al. 2019)

While this paper does not attempt to corroborate the views of the science on the scale and timing of catastrophic climate change, we can confirm that assertions by advisors to pension funds that

<sup>2</sup> Attributed to Mark Twain, but unverified: see <a href="https://quoteinvestigator.com/2018/11/18/know-trouble">https://quoteinvestigator.com/2018/11/18/know-trouble</a> and <a href="https://marktwainstudies.com/the-apocryphal-twain-things-we-know-that-just-aint-so/">https://marktwainstudies.com/the-apocryphal-twain-things-we-know-that-just-aint-so/</a>.

The average growth rate of global GDP between 1960 and 2016 was 3.7% p.a. (see <a href="https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG">https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG</a>). Assuming, for simplicity, that this growth rate would continue in the absence of global warming, these IPCC estimates imply that a trajectory towards 4°C of warming by 2100 will cause a fall in the annual growth rate of global GDP from 3.7% p.a. to between 3.35% and 3.55% p.a. This is a trivial decline in the rate of economic growth, and lies within the error range for the measurement of economic growth today.

<sup>4</sup> HESTA, 2021, 'Our Path to Net Zero' p 17

<sup>5 &</sup>quot;Setting aside achievability ... this suggests that ~1°C is a level of global warming that minimizes the likelihood of crossing CTPs." (Armstrong McKay et al. 2022, p. 7)

the economic impact of climate change will be relatively minor are at best, inconsistent with climate science, and at worst, entirely wrong.

This inconsistency between climate science and climate economics has arisen largely because climate change economics papers have been refereed by economists only.

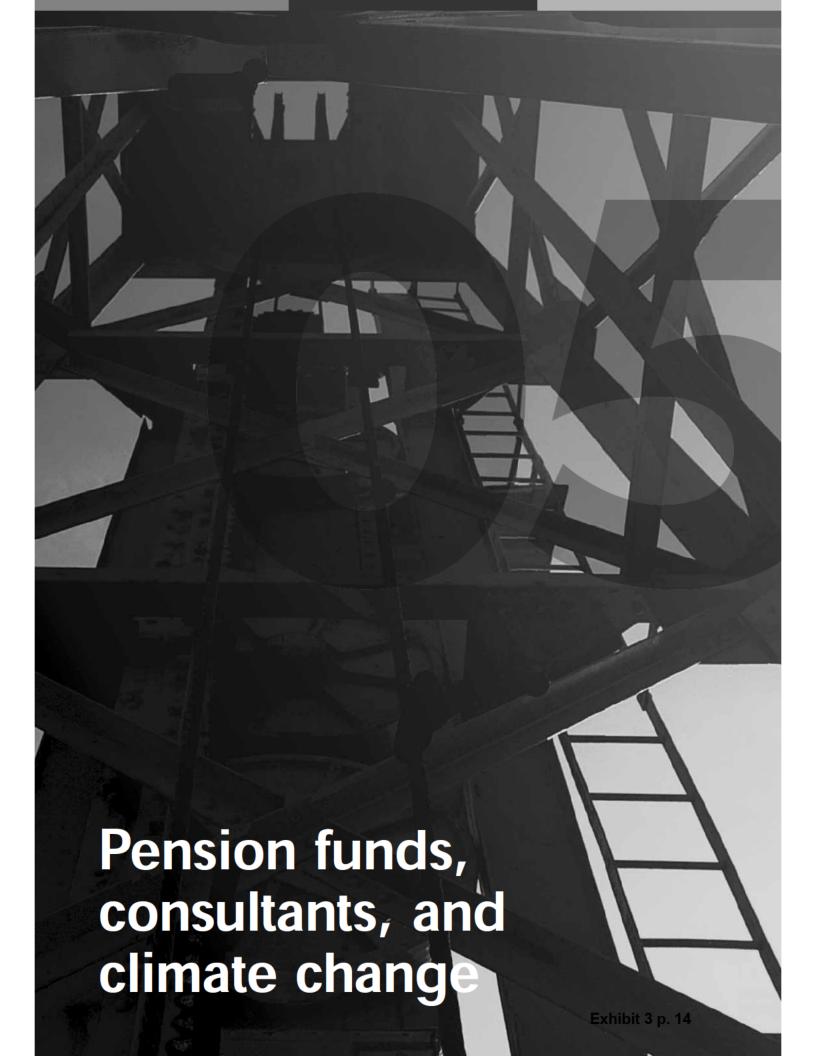
There is no problem with economists being the sole peer-reviewers for topics on which economists are the domain experts. However, the economic impact of climate change necessarily covers issues on which climate scientists, and not economists, are the domain experts. It therefore would have been prudent for scientists to peer-review the climate change assumptions made in economic papers. Instead, referees with domain knowledge of economics only approved the publication of opinions on global warming that climate scientists would almost certainly have disputed.

As a result, the empirical components of the vast majority of climate change economic papers are based on scientifically false assumptions. These assumptions drastically underestimate the damages that climate change could do to the economy.

Once these erroneous assumptions entered the economic literature, other weaknesses of the refereeing process that we discuss in the supporting document How Did We Get Here? meant that they were preserved and embellished, rather than being challenged and rejected.

The inconsistency between scientific research on climate change and the conclusions of financial trustees and their advisers is not the fault of the trustees or advisors themselves. It is entirely reasonable for them to rely on refereed economic literature. They are entitled to take the fact that a paper has been approved by academic referees at face value, rather than looking critically "behind the curtain" at the papers themselves.

This report does look "behind the curtain" at the economic and scientific literature on climate change, to show that global warming is not a relatively minor cost-benefit problem that will mainly affect future generations, as the economics literature asserts, but a major challenge to the sustainability of human civilisation, as the scientific literature asserts, and on a timescale that could occur within the lifespan of pensioners alive today.



### Pension fund trustees face an ever more challenging remit

The primary duty of any pension fund is to ensure that pension scheme members are paid their rightful benefits. In our increasingly complex financial world, funds often rely on external expert help and advice. These services are primarily provided by investment consultants.

### What is the role of an investment consultant within the Pension Fund system?

Investment consultants are engaged by Pension Fund Trustees or committees to support them in developing investment strategies that deliver the long-term objectives of the scheme. Within this umbrella they sometimes assist in selecting investment managers and evaluating/monitoring the performance of the scheme's investments. Consultants also advise on compliance with the Pension Regulator's integrated risk management structure, most of which are regulated activities under the remit of the UK regulator, the Financial Conduct Authority.

Investment consultants also provide pension funds and other institutional investors information, staff training and advice on net-zero target implementation<sup>6</sup> and managing climate risks, which are new and rapidly evolving fields, and are often unregulated.

### Why are they needed?

It is essential that trustees of pension schemes formulate an appropriate investment strategy, within acceptable risk parameters, which matches the scheme's liabilities: in plain language, the payment of the expected benefits to the fund's beneficiaries. It is reasonable to assume that pension fund trustees cannot be experts in everything, and it is also realistic to expect that they will seek advice in areas where they are not expert.

However, it must be noted that wholly delegating management of climate risk to external investment managers and advisory consultants does not discharge the legal duties of an administering authority to appropriately consider and manage that risk themselves.

### Who are the external investment managers and consultants?

In the UK, Hymans Robertson, Mercer, Aon Hewitt, ISIO, Deloitte, Barnett Waddingham, Minerva, MJ Hudson and Willis Tower Watson are significant players. The big three pension fund consultants—Aon Hewett, Willis Towers Watson, and Mercer—advise approximately 80% of the funds.

### The representative example of UK Local Government Pension Schemes (LGPS)

Within this report, due to the availability of information within the public realm, we focus our attention on how climate risk advice is being provided to LGPS public pension funds in England, Scotland and Wales — a list of which can be found in the FOIA Table in the Appendix, pages 80-82.

The Department for Levelling Up, Housing and Communities (DLUHC) which oversees the LGPS, consulted in September 2022 on the governance and reporting of climate risks,<sup>7</sup> and made recommendations requiring each fund obtain "proper advice." Questions about what constitutes proper advice are thus a live topic, for LGPS funds, and government regulators.

<sup>6</sup> https://www.mercer.com/content/dam/mercer/attachments/global/investments/gl-2022-net-zero-report.pdf

<sup>7</sup> https://www.gov.uk/government/consultations/local-government-pension-scheme-england-and-wales-governance-and-reporting-of-climate-change-risks/local-government-pension-scheme-england-and-wales-governance-and-reporting-of-climate-change-risks/local-government-pension-scheme-england-and-wales-governance-and-reporting-of-climate-change-risks/local-government-pension-scheme-england-and-wales-governance-and-reporting-of-climate-change-risks/local-government-pension-scheme-england-and-wales-governance-and-reporting-of-climate-change-risks/local-government-pension-scheme-england-and-wales-governance-and-reporting-of-climate-change-risks/local-government-pension-scheme-england-and-wales-governance-and-reporting-of-climate-change-risks/local-government-pension-scheme-england-and-wales-governance-and-reporting-of-climate-change-risks/local-government-pension-scheme-england-and-wales-governance-and-reporting-of-climate-change-risks/local-government-pension-scheme-england-and-wales-governance-and-reporting-of-climate-change-risks/local-government-pension-scheme-england-and-wales-governance-and-reporting-of-climate-change-risks/local-government-pension-scheme-england-and-wales-governance-and-reporting-of-climate-change-risks/local-government-pension-scheme-england-and-wales-government-pension-scheme-england-and-wales-government-pension-scheme-england-and-wales-government-pension-scheme-england-and-wales-government-pension-scheme-england-and-wales-government-pension-scheme-england-and-wales-government-pension-scheme-england-and-wales-government-pension-scheme-england-and-wales-government-pension-scheme-england-and-wales-government-pension-scheme-england-and-wales-government-pension-scheme-england-and-wales-government-pension-scheme-england-and-wales-government-pension-scheme-england-and-wales-government-pension-scheme-england-and-wales-government-pension-scheme-england-and-wales-government-pension-government-pension-government-pension-government-pension-government-pension-government-pension-government-pension-government

### LGPS funds reliance on external consultants and investment managers

While in theory, pension trustees or committees are required by law to make their own decisions, as finance becomes more complex, in practice, as non-experts, they have outsourced the implementation of policy to investment consultants and asset managers.

In 2017, Share Action and Client Earth referred multiple LGPS funds to the Pensions Regulator over failures to manage climate risk.<sup>8,9</sup> The response to this referral to the Pensions Regulator<sup>10</sup> confirmed that many pension funds have been relying upon consultants and asset managers for their risk analysis of climate change, as these quotes indicate:

South Tyneside Council Pension Fund: "The investment decision making is with the external managers, who take account of all risks, including climate change, in the decision-making process."

London Borough of Bexley Pension Fund: "The London Borough of Bexley Pension Fund investments are all managed externally and the ESG decisions are delegated to Fund Managers who have been provided with a copy of the Fund's SRI policy."

Derbyshire Council Fund: "The Fund has no climate risk policy in place and believes that climate risk is inexorably bound-up within the decision-making processes of the appointed investment managers. There are currently no intentions of introducing a policy in this area and, given the move towards the pooling of assets within the LGPS that will commence within the next two years, policies such as this will soon become the responsibility of the asset pool rather than individual Funds (although individual Funds will be able to influence the pool)."

We now turn to the current state of the assessment of climate risk by pension funds and other financial institutions and compare this to the economic literature—with which these assessments are consistent—and the scientific literature, with which they most decidedly are not consistent.

<sup>8 &</sup>lt;a href="https://www.room151.co.uk/local-government-pension-scheme-investment/regulator-declines-to-offer-guidance-on-lgps-and-climate-change/">https://www.room151.co.uk/local-government-pension-scheme-investment/regulator-declines-to-offer-guidance-on-lgps-and-climate-change/</a>

<sup>9 &</sup>lt;a href="https://www.clientearth.org/latest/documents/referral-to-the-pensions-regulator-lgps-funds/">https://www.clientearth.org/latest/documents/referral-to-the-pensions-regulator-lgps-funds/</a>

<sup>10</sup> https://www.clientearth.org/latest/documents/referral-to-the-pensions-regulator-lgps-funds/



Based on investment consultants' advice, many pension funds claim that substantial warming will only have a minimal impact on portfolio returns.

"Investing in a bright future" is the subtitle to the Australian superannuation firm Unisuper's report Climate Risk and Our Investments. It used a "worst case scenario" which implied a "4.3°C increase in global temperatures by 2100," and concluded that "the overall risk to our portfolio is acceptable." (Unisuper 2022, p. 36) The UK-based Shropshire County Pension Fund (Fund 2020) estimated a trajectory that led to 2°C warming by 2100 would actually boost returns till 2030 by 0.05% p.a.<sup>11</sup> (see Figure 1), while a trajectory leading to a 4°C increase by 2100 would only reduce annual returns to 2030 by 0.06% p.a:

"Over the coming decade, a 2°C outcome is, according to the model used, the best climate scenario from a returns perspective (adding 0.05% in annual returns to the asset allocation on a timeline to 2030) while a 4°C outcome is the worst of the three considered (detracting by 0.06% annually over the same period)." (Fund 2020, p. 11)

Figure 1: Shropshire County Pension Fund Climate-Related Disclosures Table 2 (Fund 2020, p. 11). The Table, produced by Mercer shows impacts on portfolio growth rates, till 2030 and 2050 respectively, of temperature trajectories to 2,3 and 4°C of warming by 2100:



Table 2: Annualised climate change impact on portfolio returns - to 2030 and 20503

Scenario	Timeline	Estimated climate impact on returns
2°C	2030	+0.05%
Ä	2050	-0.06%
ပ္	2030	-0.01%
ň	2050	-0.05%
ۍ 2	2030	-0.06%
, <del>4</del>	2050	-0.10%

These predictions of the minimal economic impact of global warming of 2-4.3°C are representative of the advice being given by pension funds worldwide to their members.

However, this advice is completely at odds with research by climate scientists, who are increasingly asserting that global warming is an existential threat to human civilisation, and at temperatures well below those contemplated by pension funds. Numerous scientists have expressed alarm at the damages society will face from warming of 2°C or less (Lenton et al. 2008b; Cai, Lenton, and Lontzek 2016; Steffen et al. 2018; Lenton et al. 2019; Xu et al. 2020; Brovkin et al. 2021; Armstrong McKay et al. 2022; Kemp et al. 2022; Xu and Ramanathan 2017).

A recent paper entitled "Climate Endgame: Exploring catastrophic climate change scenarios" (Kemp et al. 2022) "set global warming of 3°C or more by the end of the century as a marker for extreme climate change," and also noted that "There is ample evidence that climate change could become catastrophic ... at even modest levels of warming." (Kemp et al. 2022, pp. 4, 8)<sup>12</sup>

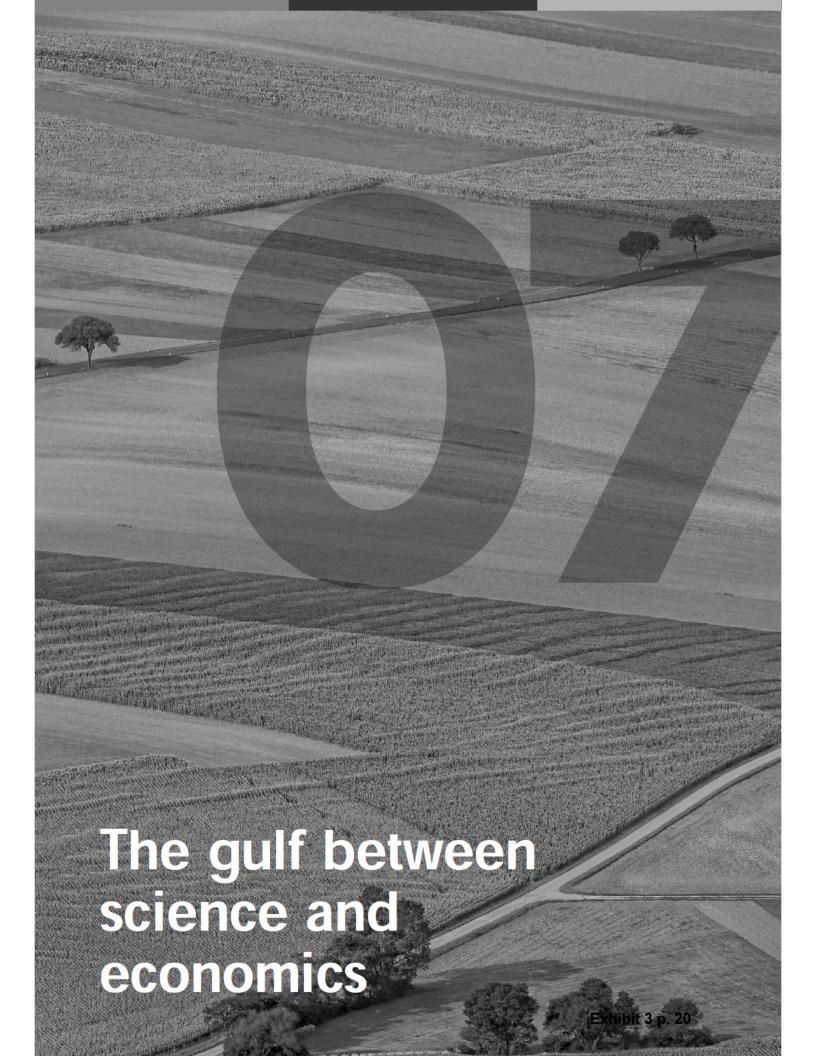
Steffen et al. suggested 2°C as a critical marker, because of:

"the risk that a 2°C warming could activate important tipping elements, raising the temperature further to activate other tipping elements in a domino-like cascade that could take the Earth System to even higher temperatures (Tipping Cascades) ... conditions that would be inhospitable to current human societies" (Steffen et al. 2018, pp 8253-4.)

### Another paper defined:

">1.5°C as dangerous; >3°C as catastrophic; and >5°C as unknown, implying beyond catastrophic, including existential threats" (Xu and Ramanathan 2017, p. 10315.)

Assertions by advisors to pension funds that the economic impact of climate change will be relatively minor are clearly inconsistent with this scientific literature.



Howard and Sylvan surveyed "all economists who have published climate-related research in the field's highest-ranked academic journals" (Howard and Sylvan 2021a, p. i). 13 Question 11 asked respondents to "Provide your best estimates for how the following climate scenario would affect global GDP over time." (Howard and Sylvan 2021b, p. 36) The survey question provided estimates of global GDP in the absence of climate change, which were generated using Nordhaus's *Dynamic Integrated Climate-Economy* (DICE) model. Nordhaus's projection was that, in the absence of global warming, global GDP in 2220 would be 21 times higher than in 2025. 14

Figure 2: Q11 in the survey: "Please provide your best estimates for how the following climate scenario would affect global GDP over time" (Howard and Sylvan 2021b, p. 36)

Scenario	Scenario 1 - 2025	Scenario 1 - 2075	Scenario 1 - 2130	Scenario 1 - 2220	
Year	2025	2075	2130	2220	
Temperature increase (relative to pre-industrial era)	1.2°C	3°C	5°C	7°C	
Average annual temperature increase over previous 30 years	0.03°C	0.04℃	0.03℃	0.01°C	
Estimated global GDP without climate change (trillions in 2019 USD)	173.3	595.1	1430.4	3654.5	

Figure 3 summarises the economic damage estimates provided by the survey respondents. The median predictions were that 3°C of warming would reduce global GDP by 5%, 5°C of warming by 10%, and 7°C of warming by 20%. 15

Howard and Sylvan sent their questionnaire to 2169 economists and received 738 responses. While this is a large number of survey recipients and respondents, it is still a small fraction of the total population of academic economists. There are, for example, over 65,000 economists registered with the online archive RePEc (Research Papers in Economics). Oswald and Stern also note that global warming is a minority issue in economics, with the leading 9 journals having published only 57 papers on climate change, out of a total of over 77,000 papers (Oswald and Stern 2019). See Section 2 of the supporting document: How Did We Get Here? for more information.

<sup>14</sup> The two drivers of growth in DICE are population and "total factor productivity" (TFP). Nordhaus assumes that population stabilises at 10.5 billion, while TFP initially grows at 15% per decade, and declines by 1.2% per decade thereafter (Nordhaus and Sztorc 2013, p. 96). This explains the apparent discrepancy between the growth multiples noted in the Executive Summary and the multiples derived from this survey.

<sup>15</sup> The temperature changes considered, as summarized by Tol (Tol 2022, Table 1), ranged from minus 0.6°C (i.e., a fall in global average temperature) to plus 16.7°C, while the changes to GDP at the end date ranged from plus 5.1% to minus 78.9%. For temperature increases of between 4.6°C, the estimates of effect on future GDP, compared to GDP in the absence of climate change, ranged from plus 5.6% to minus 16.1%. These figures were generated by Tol, and often cannot be found explicitly in the source papers. Tol's numerical summaries of the literature are relied upon by other researchers, despite frequent criticism of his work, and past corrections of his errors by journals (Gelman 2014, 2015, 2019; Editors 2015)

Figure 3: "Climate Damage Estimates" f	from (Howard and Sylvan 2021a, p. 23)
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Year	2025	2075	2130	2220
Temperature increase (relative to pre-industrial era)	1.2°C	3°C	5°C	7°C
Economic damages (% of global GDP) - Median estimate	-1%	-5%	-10%	-20%
Economic damages (trillions of 2019 USD) - Median estimate	-\$1.7	-\$29.8	-\$143.0	-\$730.9
Economic damages (% of global GDP) - Mean estimate	-2.2%	-8.50%	-16.10%	-25.20%
Economic damages (trillions of 2019 USD) - Mean estimate	-\$3.8	-\$50.6	-\$230.3	-\$920.9
Standard deviation	2.9	7.6	13.3	20.7

The median prediction, that 7°C of warming by 2220 implied a global GDP two centuries hence of \$2,924 trillion, is 17 times Nordhaus's estimate for global GDP in 2025, versus the 21 times ratio he expected in the absence of global warming.

In other words, these economists expected global GDP to continue growing on a trajectory towards 7°C of warming by 2220, but just more slowly than in the absence of warming. The expected difference in the annual rate of growth of GDP between no-warming and 7°C warming by 2220 is a mere 0.02% per year, which is well below the accuracy with which GDP growth is measured today. Though the accumulated effect of this slower rate of growth over two centuries is large—equivalent to four times global GDP in 2025—the effect on the annual rate of economic growth would be, according to mainstream economists who specialize in climate change, imperceptible.

This highlights the huge gulf between science and economics on global warming. 7°C is well above the 5°C level that scientists have described as "unknown, implying beyond catastrophic, including existential threats." (Xu and Ramanathan 2017, p. 10315) A level of warming that, to scientists, implies existential threats, is seen by economists as a minor impediment to continued economic growth.

The enormous disparity between the expectations of scientists and economists has not gone entirely unnoticed by scientists. In 2013, Lenton and Ciscar observed that:

"There is currently a huge gulf between natural scientists' understanding of climate tipping points and economists' representations of climate catastrophes in integrated assessment models (IAMs)." (Lenton and Ciscar 2013, p. 585)

In a joint report by the Institute and Faculty of Actuaries and the University of Exeter (Trust et al. 2023), co-author Tim Lenton touched on the topic of this report, the extent to which dubious predictions of minimal damages from climate change have affected the formation of policy on climate change:

"some economists have predicted that damages from global warming will be as low as 2% of global economic production for a 3°C rise in global average surface temperature. Such low estimates of economic damages — combined with assumptions that human economic productivity will be an order of magnitude higher than today — contrast strongly with predictions made by scientists of significantly reduced human habitability from climate change.

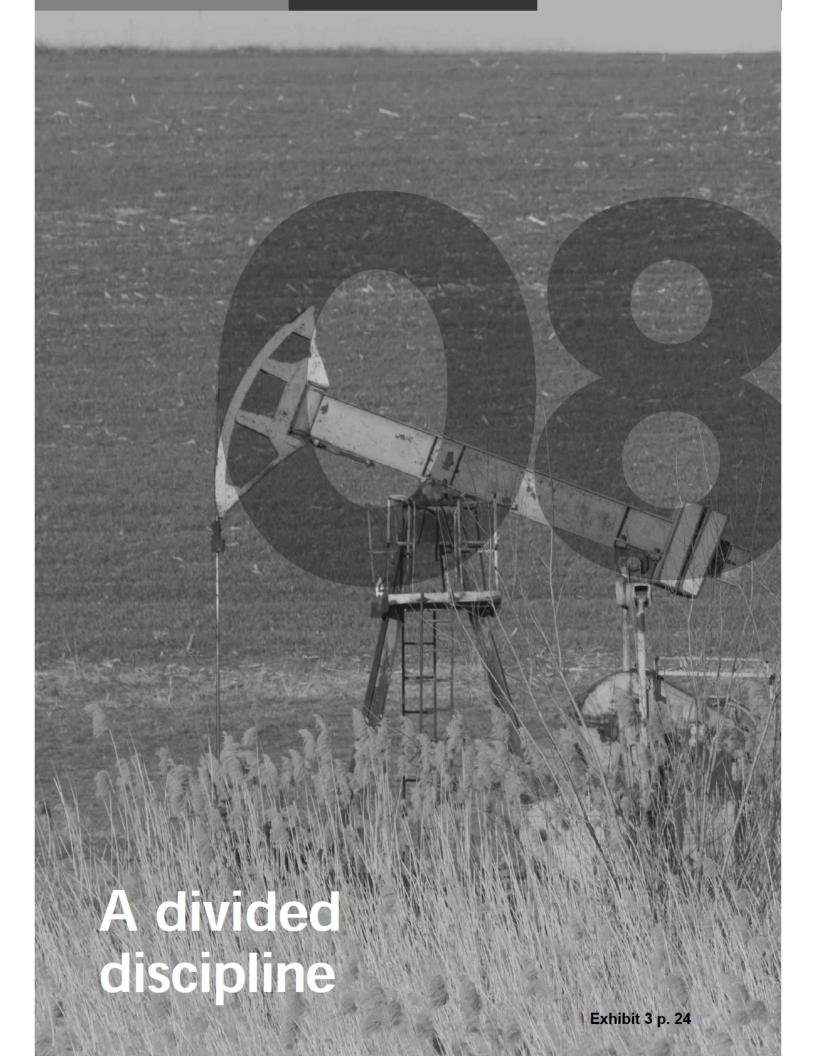
It is concerning to see these same economic models being used to underpin climate-change scenario analysis in financial services, leading to the publication of implausible results in the Task Force on Climate-related Financial Disclosures (TCFD) reporting that show benign, or even positive, economic outcomes in a hot-house world. This jars with climate science, which shows our economy may not exist at all if we do not mitigate climate change." (Trust et al. 2023, p. 4.)

Some scientists have also strongly criticised the "cost-benefit" approach that economists have taken to climate change:

"Society may be lulled into a false sense of security by smooth projections of global change. Our synthesis of present knowledge suggests that a variety of tipping elements could reach their critical point within this century under anthropogenic climate change." (Lenton et al. 2008b, p. 1792.)

"With these trends likely to continue for the next several decades at least, the contemporary way of guiding development founded on theories, tools, and beliefs of gradual or incremental change, with a focus on economy efficiency, will likely not be adequate to cope with this trajectory." (Steffen et al. 2018, p. 8257.)

Unfortunately, this conflict between the economic and scientific analysis of climate change transcends academia and has serious consequences for everyday life. By following the advice of consultants who have relied on the damages estimates from the small group of mainstream economists who work on climate change, pension funds have unwittingly and unintentionally misled their members about the threat that global warming poses for the size and security of their pensions.



This economic literature on climate change can be partitioned into four strands: 16

- 1. Estimates of the total economic costs of global warming (the "Total Cost of Carbon", or TCC), in terms of a decline in future GDP (normally global GDP in 2100), due to a change in global average temperature (relative to pre-industrial levels) by the same date;
- Development of "Integrated Assessment Models," (IAMs) primarily by the same economists who develop estimates of the total costs of climate change. IAMs combine a temperature-based climate model with an economic growth model to convert predictions of temperature increase from anthropogenic CO2 increase into a prediction of damages to GDP;
- 3. Estimates of the Social Cost of Carbon (SCC), and the development of the "Shared Socioeconomic Pathways" (SSPs), undertaken by a much larger—but still relatively small—group of economists, who use the estimates of the total cost of carbon and the IAMs developed by the first group; and
- Criticism of all three of these research strands, sometimes by economists who had previously contributed to those research strands.

Consultants to pension funds have relied upon the first two strands of the literature, and in particular, the first: estimates of the impact of global warming upon future GDP.

Both the number of estimates of the total economic costs of global warming, and the number of economists producing these estimates, are extremely small. Tol's 2009 literature survey (Tol 2009) documented three USA-based and 13 global studies (Tol 2009): see Table 1, which lists the 13 global studies, and their 13 authors.<sup>17</sup>

lable 1: The numbers in	Tol 2009) to which Nordhaus	fitted his DICE-2013 damage function

Authors	Year	Warming °C	Change in future GDP, relative to a world without global warming
Nordhaus	1994	3	-1.3%
Nordhaus	1994	3	-4.8%
Fankhauser	1995	2.5	-1.4%
Tol	1995	2.5	-1.9%
Nordhaus and Yang	1996	2.5	-1.7%
Plambeck and Hope	1996	2.5	+2.5%
Mendelsohn Schlesinger and Williams	2000	2.5	0.0%
Nordhaus and Boyer	2000	2.5	1.5%
Tol	2002	1	+2.3%
Maddison	2003	2.5	0.1%
Rehdanz and Maddison	2005	1	0.4%
Норе	2006	2.5	0.9%
Nordhaus	2006	2.5	0.9%

There is also a fifth strand of research by economists who reject mainstream "Neoclassical" economics completely, and who analyse global warming using very different methodologies (Bovari, Giraud, and McIsaac 2018; Gourdel et al. 2021; Dunz, Naqvi, and Monasterolo 2021; Dunz et al. 2021; Howarth and Monasterolo 2017; Keen et al. 2022; Keen 2020a; Keen, Ayres, and Standish 2019; Garrett, Grasselli, and Keen 2020). However, the work of this group of scholars has not affected policy, and their work is often ignored by the mainstream economists.

<sup>17</sup> Nine of these TCC estimates were used by the second group of economists to produce 232 estimates of the SCC (Tol 2009, Table 1 & Table 2, pp. 30 & 39). Tol notes that 9 TCC estimates can generate more than 200 SCC estimates, because the SCC estimates apply different assumptions about discount rates to the same input data, use "different projections of CO2 emissions, different representations of the carbon cycle, different estimates of the rate of warming, and so on" (Tol 2009, p. 40).

This group is also closely interrelated. As Tol noted, "The studies can be roughly divided into two groups: Nordhaus and Mendelsohn are colleagues and collaborators at Yale University; at University College of London, Fankhauser, Maddison, and I all worked with David Pearce and one another, while Rehdanz was a student of Maddison and mine." (Tol 2009, p. 30) The number of researchers and studies have increased since 2009—Tol's 2022 literature survey paper noted 61 estimates of the Total Cost of Carbon (TCC), from 33 studies (Tol 2022, p. 2; Table 1, pp. 19-20)<sup>18</sup>— but it still remains a close-knit community, with just 27 lead authors, 45 primary authors, and fewer than 80 authors in total.<sup>19</sup>

Such small and interrelated groups can potentially fall prey to groupthink, as Tol acknowledged:

"...[A]Ithough the number of researchers who published marginal damage cost estimates is larger than the number of researchers who published total impact estimates, it is still a reasonably small and close-knit community who may be subject to group-think, peer pressure, and self-censoring." (Tol 2009, pp. 42-43)

## 8.1 Dry economics

One key instance of groupthink is the fact that the first IAM—Nordhaus's DICE model—used temperature change as the sole marker of climate change, ignoring the impact of global warming on precipitation as well. Thirty years later, the practice of ignoring precipitation changes in economic IAMs continues, as acknowledged by a recent survey of economic studies of tipping points:

"effects on precipitation... have yet to be incorporated in economic studies. (Dietz et al. 2021b, p. 25.)

Models developed by climate scientists—known as Global Circulation Models (GCMs)—do include precipitation effects as well as temperature. This difference alone is sufficient to explain some of the, to the lay reader, perplexing difference between the projections of scientists and economists on the impacts of climate change.

Two recent studies of the same phenomenon—the potential shutdown of the Atlantic Meridional Overturning Circulation (AMOC)—provide a striking example. The AMOC is part of an enormous circulation of seawater known as the "Thermohaline Circulation"(THC). This process links all the planet's oceans and is driven by differences in temperature and salinity.<sup>20</sup> The AMOC, which keeps northern Europe substantially warmer than it would otherwise be, is susceptible to being "turned off" as increased melting of Northern Hemisphere ice reduces the salinity of the North Atlantic.

<sup>18</sup> In fact, Tol's Table 1 lists 39 studies with 70 estimates.

<sup>19</sup> We define either the first three co-authors, or subsequently listed authors who have contributed to other studies, as primary authors. The sum of less than 80 authors in total is despite the fact that two papers had 18 (Takakura et al. 2019) and 21 (McCallum et al. 2013) co-authors respectively.

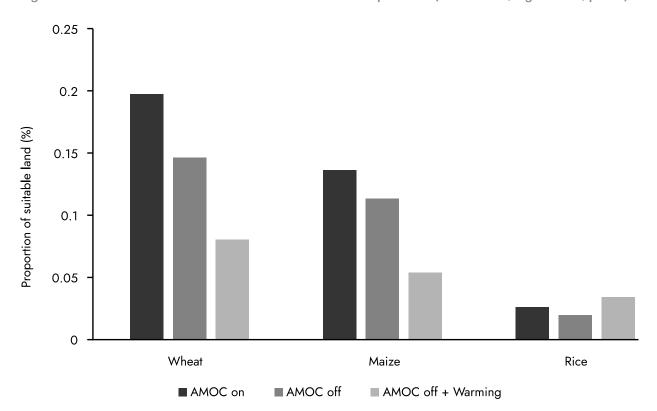
<sup>20</sup> See https://oceanservice.noaa.gov/education/tutorial\_currents/05conveyor1.html; the Wikipedia entry https://en.wikipedia.org/wiki/ Thermohaline\_circulation provides more detail.

A scientific study of the shutdown of the AMOC, commissioned by the OECD, concluded that:

"an AMOC collapse would clearly pose a critical challenge to food security. Such a collapse combined with climate change would have a catastrophic impact." (OECD 2021, p. 151)

Its prediction was that an AMOC slowdown, combined with a 2.5°C rise in global average temperatures, would reduce the amount of the planet's land area that is suitable for growing wheat from 20% to 7%—see Figure 4.

Figure 4: The Fraction of Total Land Grid Boxes Suitable for Crop Growth (OECD 2021, Figure 3.20, p. 153)<sup>21</sup>



An economic study of the impact of weakening the Thermohaline Circulation (THC), on the other hand, predicted that global GDP would rise substantially if this tipping point were triggered:

"If the THC slows down a little, the global impact is a positive 0.2-0.3 percent of income. This goes up to 1.3 percent for a more pronounced slowdown." (Anthoff, Estrada, and Tol 2016, p. 604)

<sup>21</sup> The labelling of the Y-axis is in fractions, rather than percentages as stated in the OECD document itself.

The study's authors simply assumed that if temperature moved closer to some hypothetical optimum, then so too would precipitation:

"As is common, we use the change in the average annual temperature as an indicator of the severity of climate change... Integrated assessment models often assume that other climate variables scale with temperature, but the relationship may be different for greenhouse warming and THC cooling." (Anthoff, Estrada, and Tol 2016, pp. 603, 605.)

This is a climatologically absurd assumption. However, despite this obvious failing, this study was used as the estimate of the economic impact of losing the AMOC in Dietz et al.'s study of the economic impact of tipping points. Its incorporation lessened the damages that Dietz et al. predicted (Dietz et al. 2021a, p. 7. See section 11 of this report for further details).

### 8.2 Ignoring internal critics

The work of climate change economists has been strongly criticised in the 4<sup>th</sup> strand in the economic literature. Eminent and well-respected economists such as Stern, Stiglitz, de Canio, Ackerman, Stanton, Weitzman and Pindyck have been strident and persistent critics of the dominant approach within economics to modelling global warming.<sup>22</sup> However, their criticisms appear to have had little to no impact on the way in which mainstream climate change economists do their research. Their criticisms have been noted, but they have not affected the research practices of the first three groups of economists.

Cited below are two key examples of the criticisms levelled. The first targets the use of today's temperature and economic output data as a proxy for the effects of global warming over time, while the second rejects the way that the dominant models assume that economic damages occur.

The earliest criticisms (Cline 1996; Darwin 1999; Quiggin and Horowitz 1999) relate to the use of current data on agricultural output and temperature to predict the impact of global warming on GDP (see, e.g., (Mendelsohn, Nordhaus, and Shaw 1994). Tol describes this practice as "the statistical approach", and explains that:

"It is based on direct estimates of the welfare impacts, using observed variations (across space within a single country) in prices and expenditures to discern the effect of climate. Mendelsohn assumes that the observed variation of economic activity with climate over space holds over time as well; and uses climate models to estimate the future effect of climate change." (Tol 2009, p. 32.)

<sup>22</sup> Critical works by economists include (Cline 1996; Darwin 1999; Quiggin and Horowitz 1999; DeCanio 2003; Spash 2007; Ackerman and Stanton 2008; Oreskes, Conway, and Shindell 2008; Stanton, Ackerman, and Kartha 2009; Ackerman, Stanton, and Bueno 2010; Ng and Zhao 2011; Weitzman 2011b, 2011a; Ackerman and Munitz 2012; Aldred 2012; Auffhammer et al. 2013; Pindyck 2013; Stern 2013; Howard and Sterner 2017; Pindyck 2017; Auffhammer 2018; Stern and Stiglitz 2021; Stern 2022; Stern, Stiglitz, and Taylor 2022). See Section 8.1 on pages 52-53 of the supporting document: How Did We Get Here? for details on these papers.
Exhibit 3 p. 28

In other words, these economists assumed that the relatively weak relationship that exists today between the temperature of different regions of a country and the income of those regions could be used as a proxy for the impact that higher global temperatures will have on future global economic income. Tweets by the economist who authored the above quote elaborate upon the thinking behind this assumption:

"10K [10°C] is less than the temperature distance between Alaska and Maryland (about equally rich), or between lowa and Florida (about equally rich). Climate is not a primary driver of income. (Tweet posted 17 June 2019)<sup>23</sup>

"Argument is this: As there are very different living standards in almost identical climates (e.g., the two halves of Hispaniola and Korea) and almost identical living standards in very different climates (e.g., Singapore and Iceland), climate is not a dominant economic factor. (Tweet posted 9 July 2019)<sup>24</sup>

Other economists rejected this assumption from the outset. Cline noted that "there are basic conceptual questions about the validity of applying cross-section analysis of present-day land values to predict future global-warming impacts." (Cline 1996, p. 1309) Quiggin and Horowitz observed that "There are strong reasons to expect that a comparative static approach will yield small estimates of global warming's impact on agriculture." (Quiggin and Horowitz 1999, p. 1045)<sup>25</sup>

Section 5.3 of the supporting document How Did We Get Here? elaborates on one key weakness of this approach, that cold, temperate, and hot regions of the planet today generate much of their incomes from sales to regions with different temperatures. Incomes of different regions of the planet today are therefore not independent from one another. The studies by these economists failed to correct for this fact, which invalidates their results, even as studies of the impact of temperature on income today.

Despite these early criticisms, this method was used in several subsequent empirical studies (Mendelsohn, Schlesinger, and Williams 2000; Mendelsohn and Neumann 1999; Nordhaus and Boyer 2000; Tol 2002b, 2002a; Hope 2006; Nordhaus 2006; Nordhaus 2008, 2013; Hope 2011). The numbers generated by these studies are still used to calibrate IAMs today (Tol 2022, Table 1). The dominant empirical estimation technique today, which uses change in temperature and GDP data to estimate the future impact of global warming (Kahn et al. 2021; Burke, Hsiang, and Miguel 2015; Kalkuhl and Wenz 2020), is simply an embellishment of this same, flawed method.

Secondly, ever since (Nordhaus 1991), economists in this research tradition have normally assumed that damages from global warming will be equal to the temperature increase squared, multiplied by a small constant, so that 2°C of warming does four times as much damage as 1°C, 3°C does nine times, and so on. This assumption has been strongly criticized by Pindyck, Stanton, and Weitzman (Pindyck 2017; Stanton, Ackerman, and Kartha 2009; Weitzman 2012).

<sup>23</sup> https://twitter.com/RichardTol/status/1140591420144869381?s=20

<sup>24</sup> https://twitter.com/RichardTol/status/1678040832312483840?s=20

<sup>25</sup> We cover these issues in detail in Section 4 of the supporting document: How Did We Get Here?.

In 2009, Stanton, Ackerman, and Kartha observed that:

"Our review of the literature uncovered no rationale, whether empirical or theoretical, for adopting a quadratic form for the damage function—although the practice is endemic in IAMs." (Stanton, Ackerman, and Kartha 2009, p. 172)

#### Weitzman noted that:

"we might be underestimating considerably the welfare losses from uncertainty by using a quadratic damages function." (Weitzman 2012, p. 221)

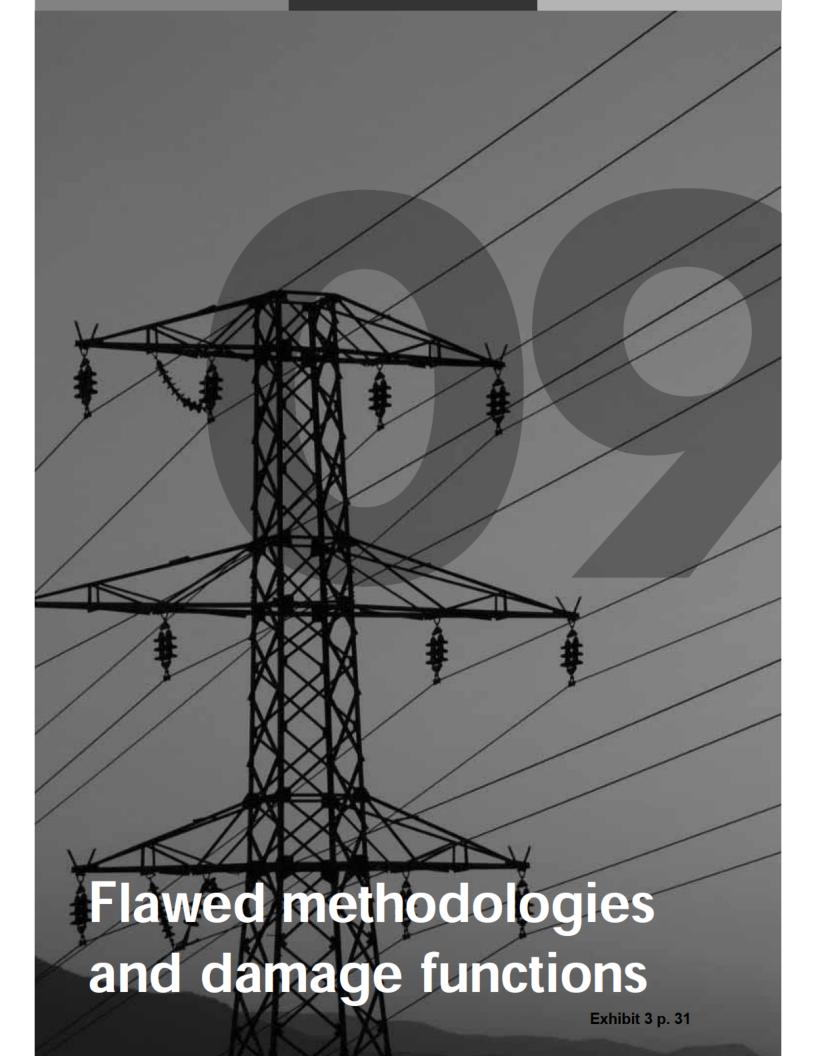
### Pindyck cuttingly remarked that:

"The damage function used in the Nordhaus DICE model, for example, is a simple inverse quadratic relationship ... this damage function is made up out of thin air. It isn't based on any economic (or other) theory or any data. Furthermore, even if this inverse quadratic function were somehow the true damage function, there is no theory or data that can tell us the values for the parameters or the correct probability distributions for those parameters, or even the correct means and variances." (Pindyck 2017, pp. 103-104.)

Despite this criticism from within the economic fraternity itself, mainstream climate change economists have continued to use quadratic or very similar damage functions, right up to the current day: three more papers using quadratic damage functions were published in 2021 (Dietz et al. 2021a; Kahn et al. 2021; Warren et al. 2021)—including one purporting to predict the economic damages from tipping points (Dietz et al. 2021a).

The critical literature within economics has therefore had no significant effect on how estimates of the total damages from global warming are calculated by the climate economists who develop and calibrate IAMs. Nor has it altered the way in which climate risk models are translated into everything from investment advice to pension schemes, to economic policy on climate change and stress testing global financial systems.

Consequently, the approach that has dominated the economic analysis of global warming has led to governments, central banks, regulators, and financial stakeholders, all the way down to pension/savings advisors, operating under a false sense of security in the face of what, according to climate scientists, could be an existential threat (Lenton et al. 2019).



This paper proposes practical remedial actions by the finance sector later. For now, we will elaborate upon the significant and irreparable inaccuracies in the work of these economists on climate change, which completely invalidate their sanguine conclusions about the economic and financial dangers. Only an overview is provided here: with more detail provided in the supporting document How Did We Get Here?.

These economists have used a set of strikingly invalid assumptions to develop predictions of relatively minor economic damages from global warming. These include, but are not limited to:

- 1. That industries not exposed to the weather will be unaffected by global warming.
- That today's data on temperature and GDP across regions and countries can be used to predict the future impact of global warming on GDP, by using the geographical relationship between temperature today and income today as a proxy for the economic impact of global warming over time.
- 3. That data on change in temperature and GDP can be used to predict the future impact of global warming on GDP, by extrapolating the relationship between the change in global temperature between 1960 and 2014 and GDP to predict the impact of further temperature increases on GDP between now and 2100.

Nordhaus used the first assumption, that "activities ... which are undertaken in carefully controlled environments ... will not be directly affected by climate change," to assert that 87% of the USA's economy would be "negligibly affected by climate change." (Nordhaus 1991, p. 930) The industries that he assumed would be "negligibly affected" are those that are not exposed to the weather: 26 manufacturing, retail and wholesale trade and services, finance and insurance, most transport and communication, and government—see Figure 5. Nordhaus also commented that:

"for the bulk of the economy - manufacturing, mining, utilities, finance, trade, and most service industries - it is difficult to find major direct impacts of the projected climate changes over the next 50 to 75 years." (Nordhaus 1991, p. 932)

Figure 5: Nordhaus's Breakdown of US Industries into Severely, Moderately, and Negligibly Affected Sectors (Nordhaus 1991, p. 531)

	National income	
Sector	Value (billions)	Percentage of total
Total national income	2415.1	100.0
Potentially severely impacted		
Farms	67.1	2.8
Forestry, fisheries, other Moderate potential impact	7.7	0.3
Construction	109.1	4.5
Water transportation Energy and utilities	6.3	0.3
Energy (electric, gas, oil)	45.9	1.9
Water and sanitary Real estate	5.7	0.2
Land-rent component	51.2	2.1
Hotels, lodging, recreation Negligible effect	25.4	1.1
Manufacturing and mining	627.4	26.0
Other transportation and communication	132.6	5.5
Finance, insurance, and balance real estate	274.8	11.4
Trade and other services	674.6	27.9
Government services	337.0	14.0
Rest of world	50.3	2.1

Breakdown of economic activity by vulnerability to climatic change, U.S. 1981

<sup>26</sup> Mining is the only exception, but later papers showed that Nordhaus was thinking of underground mining only when he wrote this paper (Nordhaus 1993, p. 15).

Section 3 of the supporting document How Did We Get Here? explains in detail why exposure to climate change cannot be reduced to exposure to the weather. Global warming is also caused in large measure by how we generate and use energy, so of course these industries will be affected by global warming, since they need energy in order to operate.

The second assumption, that "the observed variation of economic activity with climate over space holds over time as well," (Tol 2009, p. 32) was used to justify using regional data on temperature and income today as a proxy for the impact of global warming on global GDP. In addition to the obvious issue that space is not a proxy for time, the empirical studies done using this assumption ignored the fact that incomes across regions today are not independent: cold regions can achieve high incomes today because they can trade with temperate and hot regions. However, a hotter future global economy cannot trade with today's colder global economy.

The third assumption, that GDP and change in temperature data between 1960 and 2014 can be extrapolated to predict the impact of global warming on future GDP, ignores the likelihood that further temperature rises will trigger tipping elements (Lenton et al. 2008b). These are large-scale components of the Earth's climate whose existence and states depend upon temperature, in such a way that a substantial increase could "flip" them from one stable state to another. Examples include:

Summer sea ice in the Arctic (and Antarctic), which reflects up to 90% of the solar radiation falling on it, whereas the dark ocean it covers absorbs up to 90% of solar radiation. (Vihma 2014)

Permafrost, soil near the Poles which contains frozen organic matter with twice as much carbon as is currently in the atmosphere. This carbon could be released into the atmosphere as methane or CO2 by more warming. (MacDougall, Avis, and Weaver 2012)

Using these three assumptions, mainstream climate change economists generated a set of numbers purporting to link global warming to its impact on GDP, at global warming temperatures ranging from 1–6°C. Economists then treated these numbers as data, to which they fitted "damage functions," which purport to show the relationship between global warming and a fall in future GDP, relative to what GDP would have been in the absence of global warming. Table 1 shows the numbers published in (Tol 2009, Table 1, p. 31) to which Nordhaus fitted his damage function in the 2013 incarnation of his Integrated Assessment Model DICE.<sup>27</sup> Figure 6 shows Nordhaus's plot of these numbers, together with his damage function (the green curve), from his 2013 manual for DICE (Nordhaus and Sztorc 2013 Figure 2, p. 12).

<sup>27</sup> DICE stands for "Dynamic Integrated Model of Climate and the Economy". Nordhaus adjusted his statistical fit with an arbitrary "adjustment of 25 percent of the monetized damages to reflect these non-monetized impacts" such as "(the economic value of losses from biodiversity, ocean acidification, and political reactions), extreme events (sea-level rise, changes in ocean circulation, and accelerated climate change), impacts that are inherently difficult to model (catastrophic events and very long term warming), and uncertainty (of virtually all components from economic growth to damages)." (Nordhaus and Sztorc 2013, p. 11)

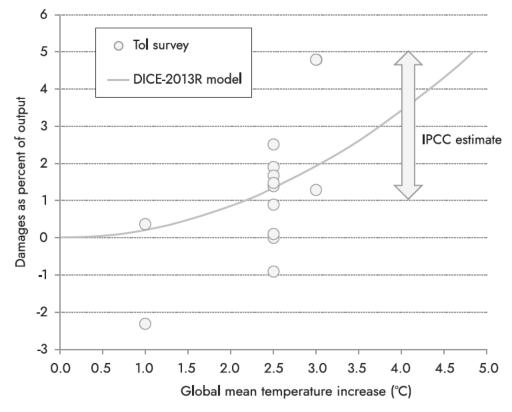


Figure 6: from the DICE manual (Nordhaus and Sztorc 2013, p. 12)

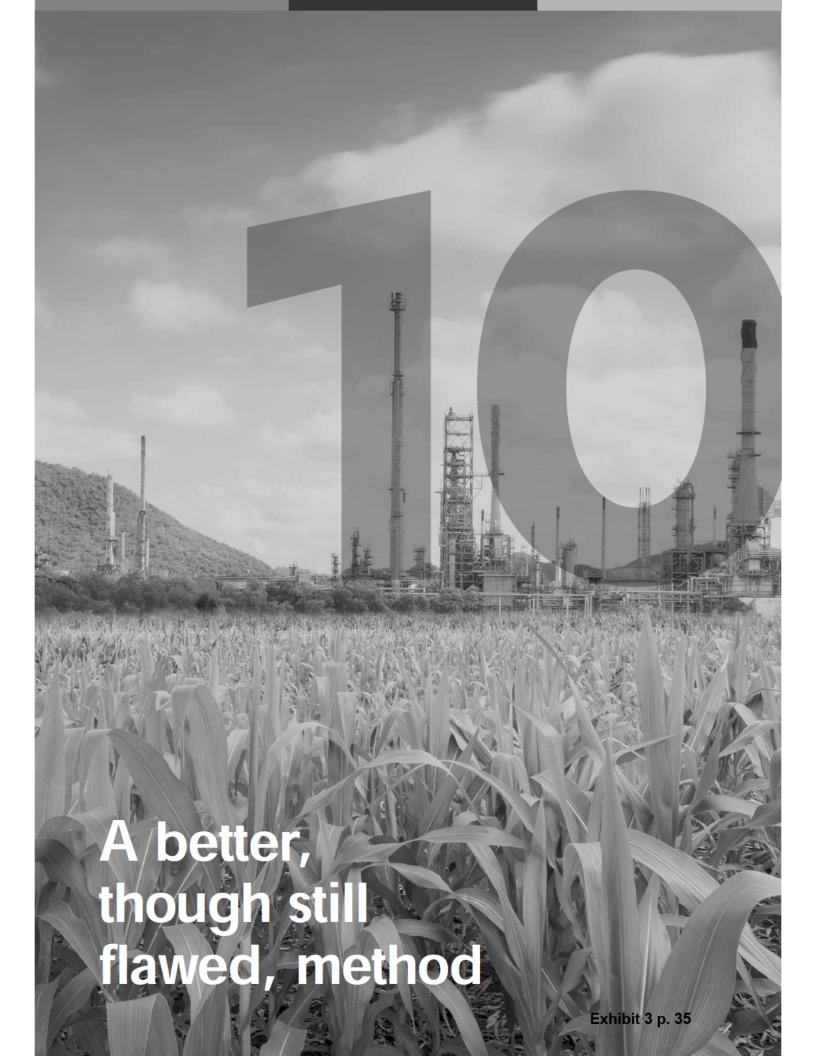
The damage function in DICE-2013 is:

$$Damages(Temperature_{Change}) = 0.267\% \times (Temperature_{Change})^2$$

This yields the prediction that economic damages from global warming will be "2.0 percent of income at 3°C, and 7.9 percent of global income at a global temperature rise of 6°C" (Nordhaus 2018, p. 345).

Given the temperature and damage to GDP numbers generated by these economists, a quadratic is as good a function as any to fit them. However, these numbers are not data: they are instead "hunches" (to use Nordhaus's own word from Nordhaus 1991, p. 933) based on spurious assumptions about global warming, which have been used to generate equally spurious estimates of damages to future GDP.

In the next section, we demonstrate why a quadratic is, as many critics have argued, a singularly inappropriate function to use to model the economic damages from global warming (Ackerman and Munitz 2012; Ackerman, Stanton, and Bueno 2010; Diaz and Moore 2017; Pindyck 2017).



The assumptions that (a) the impact of global warming on the economy can be discerned from current data, and (b) that the impact of global warming on the economy can be captured by smooth functions, are tenuous at best. However, these assumptions have been made by climate change economists, and they have been applied badly: the numbers they have used are not data, but hypothetical numbers generated by economists themselves; while the functions that have been fitted to these numbers cannot capture the phenomenon of non-linear step changes in the climate, normally referred to as "tipping points."

In this section,<sup>28</sup> we illustrate how these assumptions are the key factors that have generated the predictions by economists<sup>29</sup> that damages to GDP from global warming will be very modest, by:

- 1. Using as data a publicly maintained database of weather and climate damages, rather than the numbers generated by economists;
- 2. Fitting this data using three functions: a quadratic, an exponential, and a logistic, rather than a quadratic only; and
- Judging which equations are more compatible with the scientific literature on global warming and tipping points.

The USA's National Oceanic and Atmospheric Administration (NOAA) maintains the Billion-Dollar Weather and Climate Disasters database, which records the cause and scale of every weather or climate event since 1980 that generated \$1 billion or more of damages in 2015 US dollars.<sup>30</sup> The data spans the period 1980 till 2022, over which period global average temperature rose from 0.2°C to 1°C, compared to the average in 1900.<sup>31</sup>

The three functions used are a quadratic—the function habitually used by climate change economists—an exponential, and a logistic. A quadratic cannot capture the phenomenon of tipping points, while the exponential and logistic can. This is because, though a quadratic implies accelerating damages from rising temperatures, the rate of acceleration never changes.

Tipping points, however, imply an acceleration in damages after they are crossed, as factors like reduced reflection of sunlight (from the replacement of Arctic summer sea-ice, which reflects solar radiation, with ocean water, which absorbs it) or increased greenhouse gas emissions (from the release of CO2 and methane from permafrost or ocean methane hydrates) add to global warming caused by humanity's burning of fossil fuels. Both the exponential and the logistic can capture this phenomenon.<sup>32</sup>

Figure 7 plots this data, and fits three functions to it: a quadratic, which is the function used by most IAMs; an exponential; and a logistic.

<sup>28</sup> See the supporting document How Did We Get Here? to this Report for a detailed exposition of the points summarised here

<sup>29</sup> Whenever we say "economists" without qualification, we are referring to the mainstream economists who have specialised on the economics of global warming, and in particular, the much smaller group of mainstream economists who have developed estimates of the total economic cost of global warming

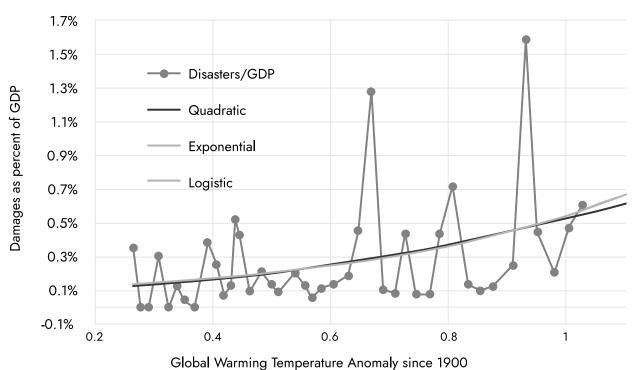
<sup>30</sup> https://www.ncei.noaa.gov/access/billions/.

<sup>31 &</sup>lt;a href="https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/global/time-series/globe/land\_ocean/ytd/12/1880-2021">https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/global/time-series/globe/land\_ocean/ytd/12/1880-2021</a>.

<sup>32</sup> A quadratic has the form  $y(x) = e \cdot x^2$ , where in this case x represents the increase in global average temperature and y represents the economic damages caused by that increase The acceleration of a quadratic is 2a, which is a constant, regardless of the level of x. An exponential has the form  $y(x) = e^{ex}$ . Its acceleration is  $a^2 \cdot e^{ex}$ , which keeps changing as x increases. A logistic has the form  $y(x) = \frac{1}{1 - e^{-ex}}$ . Its acceleration term is too complicated to show here, but it too keeps changing as x increases.

Figure 7: Temperature anomaly-->Damages data and functional regressions

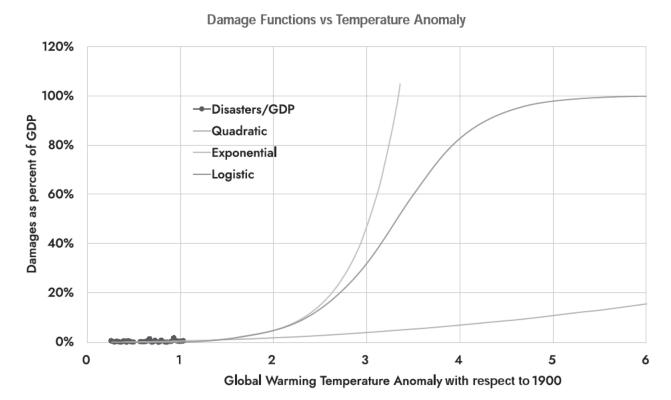
# Damage Functions vs Temperature Anomaly



It is obvious that the fit of these three functions to the current data *cannot be distinguished from one another*. In fact, they are so similar that, between 0.2 and 0.95°C of warming, the three functions have the same values to two decimal places—hence their plots overwrite each other in Figure 7.

However, the functions diverge dramatically once we move beyond existing data. The quadratic fit predicts about twice the damages from 6°C of warming as Nordhaus's function, but this is still within the ballpark of IAMs. On the other hand, the exponential function predicts the total destruction of the economy at 3.3°C, while the logistic predicts total destruction by 5°C—see Figure 8.

Figure 8: Extrapolating historic damages forward against the predicted temperature anomaly



When these functions are mapped against time, the quadratic returns the usual predictions of economists, that most damages will occur in the 22nd and subsequent centuries. The exponential and the logistic, on the other hand, imply that the vast majority of economic damages from climate change will occur this century—see Figure 9.

Projected Damages by Damage Function 120% 100% Projected damages as percent of GDP Disasters/GDP 80% Quadratic Exponentia 60% Logistic 40% 20% 0% 1960 1980 2020 2040 2080 2000 2060 2100 Year

Figure 9: Extrapolating historic damages against time, given the temperature anomaly

Since these functions cannot be distinguished from each other based on their fit to current data, then, given the huge differences in their implications about both the threat from global warming and its immediacy, it is vitally important to decide which functional form is more plausible.

The quadratic can be ruled out because its mathematical characteristics contradict the concept of tipping points (Lenton et al. 2008b, 2008a). In particular, a quadratic cannot show a change in the acceleration of damages from global warming, and the economic damages resulting from it. Yet damage will accelerate as tipping points add to the increase in temperature caused by the increase in anthropogenic greenhouse gas emissions alone.

Both the exponential function and the logistic can show such an acceleration, and their numerical implications are closer to the expectations of scientists than any paper in the mainstream economics literature.

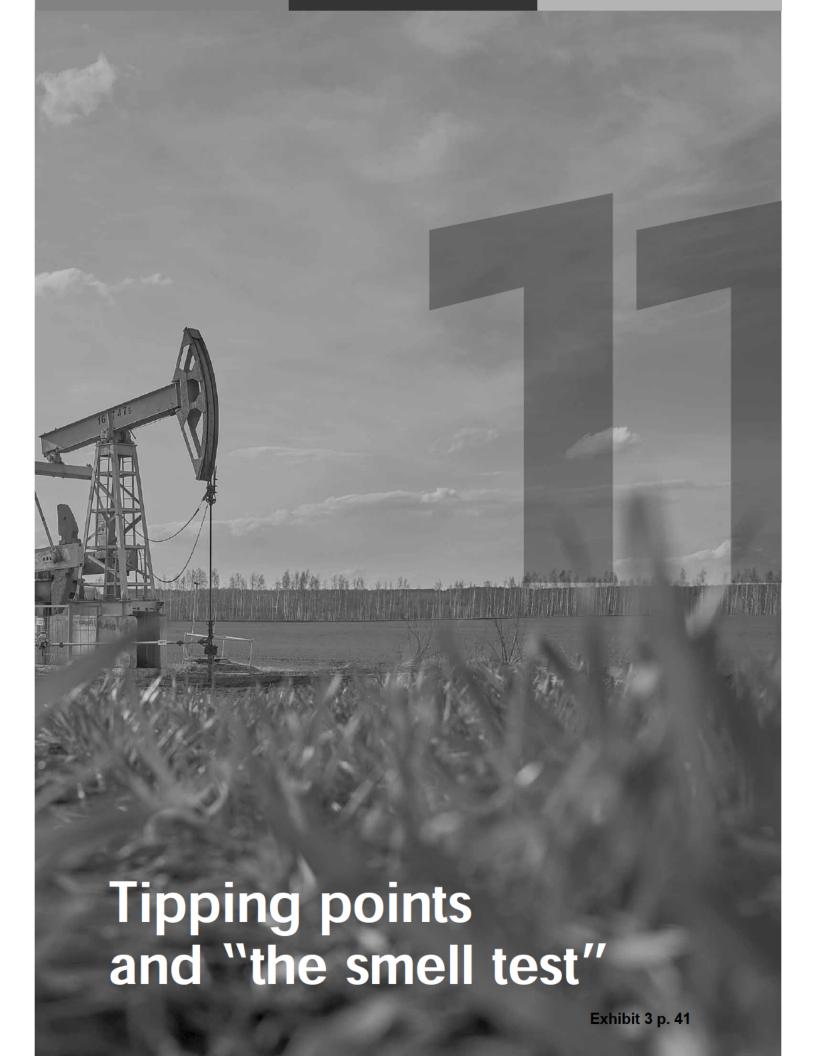
We emphasise that the assumption on which all work by mainstream climate change economists has been based—that current data contains a footprint of global warming from which its future economic impact can be predicted—is tenuous at best. Nevertheless, simply by replicating their empirical methods using an independently developed database, and by fitting several damage functions rather than just a quadratic, we have reached results that are not inconsistent with the scientific literature. This shows that assurances by these economists that damages from global warming are minor and distant, cannot be trusted. We emphasise that the assumption on which all work by mainstream climate change economists has been based—that current data contains a footprint of global warming from which its future economic impact can be predicted—is tenuous at best. Nevertheless, simply by replicating their empirical methods using an independently developed database, and by fitting several damage functions rather

than just a quadratic, we have both reached results that are not only consistent with the scientific literature. This shows that assurances by these climate economists that damages from global warming are minor and distant, cannot be trusted.

We also emphasise that the gradual onset of economic breakdown implied by these functions is not at all how the process of climate-change-induced economic collapse is likely to occur, should we trip planetary tipping points. Nor is the timing implied by the relatively more realistic functions—the exponential and the logistic—an accurate guide to when significant economic damage could occur.

Nor are we proposing that economists should in future use an exponential or logistic damage function, rather than a quadratic.<sup>33</sup> Instead, the point of this section is to illustrate that the sanguine predictions made by economists about limited economic damages from global warming are the product of two false assumptions—that the numbers they have generated are relevant to global warming, and that damages from climate change can be modelled using a quadratic.

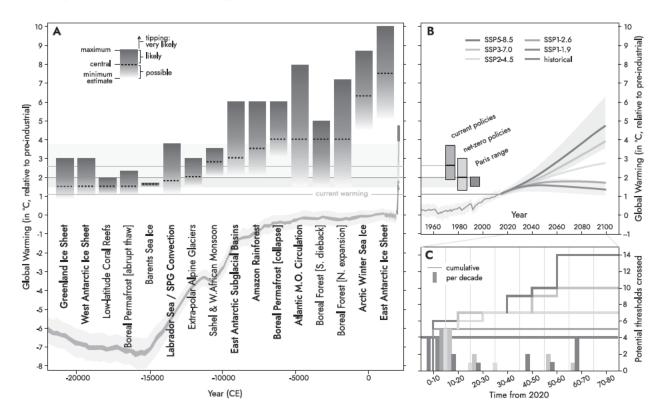
<sup>33</sup> However, one of the referees to this report the climate scientist Tim Lenton has adapted the logistic function we proposed here, as a means to "start with what we want to avoid, then work backwards from there "He proposed that "A relatively simple log damage function could be used that assumes 100% GDP loss at a certain level of warming, say 6°C, 5°C, or 4°C, although some may argue that even 3°C would be extremely challenging to adapt to "(Trust et al. 2023, pp. 2425)



Given the nature of tipping points, change in the economic impact from global warming is far more likely to be discontinuous and abrupt, rather than continuous and relatively gradual, and could occur far earlier than implied by Figure 9. Armstrong McKay et al. postulate that several tipping points could be triggered in the next decade (Armstrong McKay et al. 2022).<sup>34</sup>

Key candidates for sudden and near-term tipping include the loss of the Barents Sea winter ice, and the collapse of deep convection in the Labrador Sea—which would cause a more extreme seasonal climate in Europe (akin to the Little Ice Age), and significant sea level rise on northeast seaboard of USA—see Figure 10.

Figure 10: from (Armstrong Mckay et al. 2022, p. 8) global warming threshold estimates for global core and regional impact climate tipping elements.



Since global warming has already reached 1.25°C, which exceeds the minimum estimated threshold for tipping Arctic summer sea ice, and the Greenland and West Antarctic ice sheets (Armstrong McKay et al. 2022, pp. 1 & 3), the topic of tipping points and their potential impact upon both the global economy and pensions cannot be ignored by pension funds and their advisors:

"Setting aside achievability (and recognizing internal climate variability of ~±0.1°C), this suggests that ~1°C is a level of global warming that minimizes the likelihood of crossing CTPs." (Armstrong McKay et al. 2022, p. 7)

Given how critical tipping points are to the dangers of global warming, a recent paper by Dietz, Rising, Stoerk and Wagner, entitled "Economic Impacts of Tipping Points in the Climate System" (Dietz et al. 2021a), deserves special mention for its underestimation of these dangers. The tipping points considered in this paper were:

- 1. Loss of summer sea ice in the Arctic;
- 2. Slowdown of the Atlantic Meridional Overturning Circulation (AMOC);
- 3. Increased variability of the Indian summer monsoon;
- 4. Release of carbon from permafrost;
- 5. Release of carbon from ocean methane hydrates;
- 6. Dieback of the Amazon rainforest;
- 7. Disintegration of the Greenland Ice Sheet; and
- 8. Disintegration of the West Antarctic Ice Sheet. (Dietz et al. 2021a, p. 8)

The paper concluded that the sum effect of triggering these eight tipping points would be to add an additional 1% of damages to those caused by temperature rise alone at 3°C, and an additional 1.4% to temperature-induced damages at 6°C:

"Tipping points reduce global consumption per capita by around 1% upon 3°C warming and by around 1.4% upon 6°C warming, based on a second-order polynomial fit of the data." (Dietz et al. 2021a, p. 5)

This paper was criticised by a group of climate scientists and non-mainstream economists, who noted that:

"Asserting consumption would be just 1.4% lower with all tipping points breached, i.e., critical elements of the current climate destroyed—while also being much larger than today—is inconceivable, and impossible to reconcile with scientific literature." (Keen et al. 2022, p. 1)

Dietz et al.'s response challenged the assertion that damages would be significantly larger than their estimates:

"Keen et al. argue the conclusions and procedures ... do not make sense, seemingly taking it as given that the economic impacts of climate tipping points will be larger than our estimates." (Dietz et al. 2022, p. 1.)

Of course, the critics took it as given that damages from triggering these eight tipping points would be larger than a mere 1% to 1.4% of future GDP!

The climatic changes envisaged by Dietz et al. would be visible from space: the Arctic during summer would be deep blue rather than white; the Amazon would go from green jungle to brown savannah or desert; Greenland and the West Antarctic would ultimately go from white ice to brown rock. The energy content of ocean methane hydrates exceeds that of all other fossil fuel deposits (Stephenson 2018, p. 18); the carbon held in permafrost is roughly twice the current carbon content of the atmosphere (Zimov, Edward, and Chapin 2006, p. 1612). The weakening or collapse of the AMOC could plunge Europe into conditions akin to the Little Ice Age (Lehner et al. 2013) and drastically reduce the land area suitable for wheat and corn farming (OECD 2021, p. 153), while increased variability of the Indian monsoon would jeopardise the lives of over a billion people.

The claim that these changes would have effectively zero impact upon the human economy is extraordinary, <sup>35</sup> and it should be supported by extraordinary analysis or evidence. Instead, the paper is representative of the many weaknesses of this literature, right down to the use of quadratics to extrapolate hypothetical data.

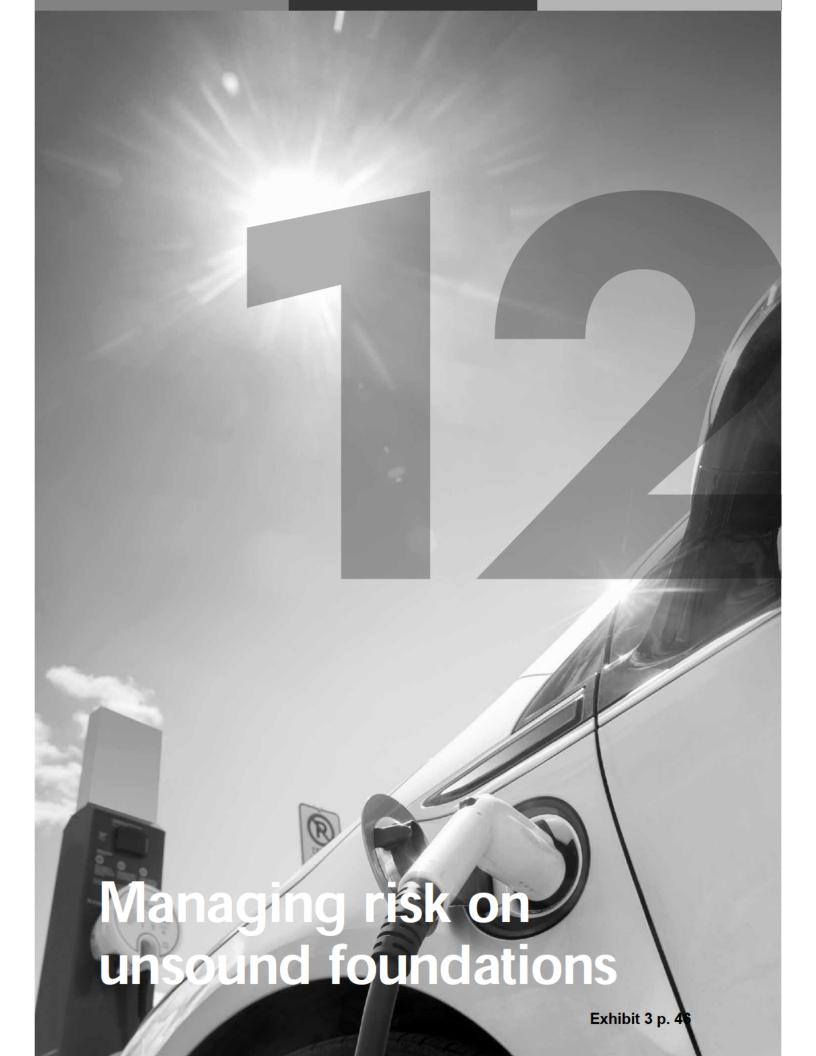
Within the range of temperature increases contemplated by most mainstream climate change economics papers (up to 6°C), Dietz et al. assert that the impact of tipping points can be emulated by increasing damages from temperature alone by roughly 15%. Past 7°C of warming, they even claim that tipping points will attenuate damages from temperature rises alone. This is a consequence of their use of a quadratic to extrapolate their results:

"Using a second-order polynomial to fit the data, 2°C warming in the absence of tipping points corresponds to 2.3°C warming in the presence of tipping points, for instance... Beyond 7°C warming in the absence of tipping points, the combined effect of tipping points is to reduce the temperature response to GHG emissions." (Dietz et al. 2021a, p. 5, & bottom chart in Fig. 5., p. 6.)

To repeat Robert Solow's observation on macroeconomic models, the conclusions of Dietz et al. do not "pass the smell test", while the reactions of Dietz et al. to criticism shows that "The advocates no doubt believe what they say, but they seem to have stopped sniffing or to have lost their sense of smell altogether." (Solow 2010, p. 2)

This paper is now being used by other economists to claim that tipping points can be included in the estimates of the economic damages from climate change, via a small increase in the parameters for their damage functions. In his most recent revision to DICE, Nordhaus notes that:

"we have added the results of a comprehensive study of tipping points (Dietz et al. 2021), which estimates an additional 1% loss of global output due to 3 °C warming." (Nordhaus and Barrage 2023, p. 9)



"On two occasions I have been asked,—"Pray, Mr. Babbage, if you put into the machine wrong figures, will the right answers come out?" ... I am not able rightly to apprehend the kind of confusion of ideas that could provoke such a question." (the inventor of the first mechanical computer, Charles Babbage 1864)

The main issue for pension funds, central banks and governments, is how this flawed analysis has effectively compromised their risk management and investment decisions with respect to climate change, and what to do about it.

Any analysis or stress testing which attempts to apply the work of these economists on climate change to real-world issues, such as portfolio choice and prudential regulation, will inherit its underlying problems, and will therefore substantially underestimate the dangers and damages.

Unfortunately, though understandably, since non-academic entities are entitled to regard peerreviewed literature as having met scientific standards, commercial and government third parties have used the results of this unreliable economic analysis of climate change as the foundation of their risk assessment of climate change. The result is an applied form of the trivialisation of the dangers of climate change that has been the norm in academic economic publications.

## 12.1 How climate damage functions impact investment advice and analysis.

To gain a better appreciation of how investment consultants use these economic models to inform advice offered to institutional investors, we surveyed UK local government pension scheme (LGPS) members. Using replies from FOIA requests (refer to appendix pages 80-82) and published annual report data, one can estimate that the market share of consulting firms in the UK local government pension sector is roughly as follows:

- Mercer advise approximately ~38 clients in LGPS, LGPSS and various pooled funds;
- Hymans Robertson advise ~33 clients in LGPS, LGPSS and various pooled funds;
- Aon advise ~16 clients in LGPS, LGPSS and various pooled funds;
- MJ Hudson advise ~7 clients in LGPS, LGPSS and various pooled funds;
- Barnett Waddingham advise ~5 clients, and ISIO advise 4 clients in LGPS, LGPSS and various pooled funds; and
- 18 LGPS funds have either not disclosed their investment consultant, or don't use one.

As an example of the application of mainstream economic analysis of climate change to pension funds, we consider the advice given to LGPS pension funds by the investment consultant firm Mercer, which claims to work with 50% of the LGPS sector.<sup>36</sup>

#### 12.2 Advisors—the representative example of Mercer

We would like to stress that while Mercer is used as an example, this is due to their transparency and widespread work with UK Local Government Pension Schemes (meaning some information is available under the Freedom of Information Act). In contrast to several other advisory firms, Mercer have also intentionally shared significant details on their models in public forums, as evidenced by the publication of the 2015 report *Investing in a Time of Climate Change* and its sequel.

Mercer have (with the help of Ortec Finance and Cambridge Econometrics)<sup>37</sup> recently updated their model to bring it closer to damages of the order that the rapidly evolving science might suggest.

Mercer are also by no means alone in relying upon this flawed economic analysis. The evidence indicates that their advice is typical of the advice offered to pension schemes by a wide range of consultants working in the investment consultant community globally.

Mercer's written advice is that "Climate change poses a systemic risk, and investors should consider the potential financial impacts of both the associated transition to a low-carbon economy and the physical impacts of different climate outcomes." However, Mercer also states that it advocates "decarbonization at the right price," which implies a cost-benefit approach to this existential issue. This is indeed how they have approached the numerical estimates of the impact of climate change on pensions.

Mercer commenced its climate change consulting work in 2011, with the report Climate Change Scenarios—Implications for Strategic Asset Allocation (Mercer 2011a). The influence of climate change economists was very direct in this report, with two prominent authors of this literature acting as consultants to the Mercer team and performing the IAM simulations.<sup>40</sup>

The report used two IAMs, WITCH (World Induced Technical Change Hybrid) and PAGE (Policy Analysis of Greenhouse Effect), and worked with four different scenarios, rather than a simple mapping of temperature change to GDP. It manifests all the pivotal weaknesses in the economic literature, including damages being modelled by a quadratic, <sup>41</sup> and set to trivial values, even at 3°C warming by 2050 (see Figure 11) under its "Climate Breakdown" scenario.

<sup>37 &</sup>lt;a href="https://www.camecon.com/news/mercer-collaborates-with-ortec-finance-and-cambridge-econometrics-on-climate-crisis-portfolio-modelling/">https://www.camecon.com/news/mercer-collaborates-with-ortec-finance-and-cambridge-econometrics-on-climate-crisis-portfolio-modelling/</a>

<sup>38</sup> https://www.mercer.com/content/dam/mercer/attachments/global/investments/gl-2022-net-zero-report.pdf

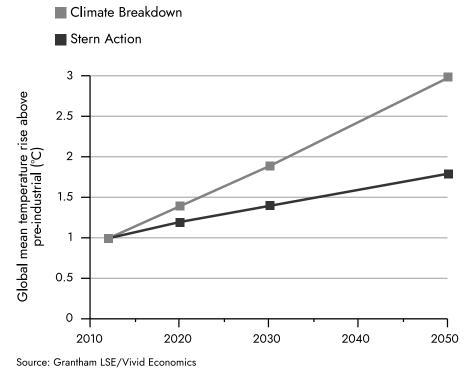
<sup>39</sup> https://www.mercer.com/content/dam/mercer/attachments/global/investments/gl-2022-net-zero-report.pdf. This report emphasises the importance of taking into consideration short-term movements in price caused by a disrupted energy sector, and recommends that where possible, divestment should be avoided.

<sup>40</sup> Simon Dietz, principal author of the tipping points paper (Dietz et al. 2021a) criticised in section 10 of this Report, and the supporting document How Did We Get Here?, and Sam Fankhauser, who developed one of the early "enumeration" estimates of the damages from global warming (Fankhauser 1995), that 2 5 of warming would reduce GWP by just 1 4%

<sup>41</sup> In fact, the polynomial power used was 1.8 (Mercer 2011b, p. 112), which is slightly less than the power of 2 that applies in a quadratic.

Figure 11: Assumed Temperature trajectories in two of the report's 4 scenarios (Mercer 2011b, p. 105)

Figure 20
Rapid warming under Climate Breakdown, lower under Stern Action

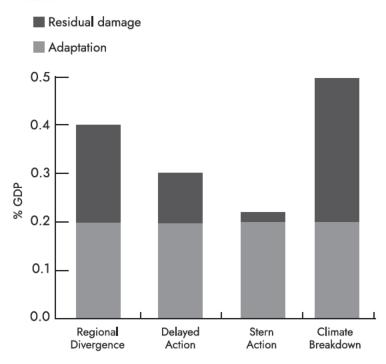


Source: Grantnam LSE/ VIVID Economics

Global economic damages from 3°C of warming by 2050, under the report's worst-case scenario, "Climate Breakdown," were just 0.5% of GWP. These were made up of fixed adaptation costs of 0.2% of GWP by 2050 across all scenarios, and up to 0.3% of GDP in "residual damages"—see Figure 12.

Figure 12: The report's aggregate damages by 2050 across 4 scenarios (Mercer 2011b, p. 107)

**Figure 21**Residual damage costs + Adaptation costs as a percentage GDP to 2030



Source: Grantham LSE/Vivid Economics

These residual damages—damages that were not eliminated by the adaptation costs—were concentrated in the developing world, with the worst damages (3.1% of GDP) occurring in Africa and the Middle East. In contrast, the USA was shown as incurring such trivial damages (US\$5.9 billion) that they rounded down to 0.0% of GDP. Europe's damages were 0.1% of GDP, as were China's and East Asia's: see Figure 13.

Figure 13: The report's damage estimates under its most severe scenario (Mercer 2011b, p. 104)

Table 26
Residual climate damages are steeply rising under Climate Breakdown and are highest in the developing world

	Residual damage costs in US\$ billion and % GDP (in parentheses)							
	2012	2020	2030	2050				
Climate Breakdown								
Europe	0.0 (0.0)	0.0 (0.0)	1.3 (0.0)	10.3 (0.1)				
USA and Canada	0.0 (0.0)	0.0 (0.0)	0.7 (0.0)	5.9 (0.0)				
OECD Pacific	0.1 (0.0)	0.0 (0.0)	1.9 (0.0)	4.8 (0.0)				
China and East Asia	0.0 (0.0)	0.1 (0.0)	4.4 (0.0)	44.0 (0.1)				
Russia and the former Soviet Union	0.0 (0.0)	0.0 (0.0)	0.1 (0.0)	1.2 (0.0)				
Latin America and the Caribbean	6.1 (0.2)	20.3 (0.5)	70.1 (1.2)	285.4 (2.8)				
Middle East and North Africa	6.3 (0.3)	20.9 (0.6)	45.8 (1.3)	154.2 (3.1)				
India and South Asia	4.0 (0.2)	12.5 (0.3)	57.4 (0.7)	288.2 (1.5)				
Sub-Saharan Africa	4.8 (0.3)	16.1 (0.3)	35.3 (1.3)	16.4 (3.1)				

A key reason for the presumption that economic damages from climate change will be focused in developing countries, which are largely based in the tropical and sub-tropical regions of the planet, is the fact noted in section 8.1, that economic IAMs consider only temperature changes, and ignore changes in precipitation. Since developed countries are concentrated in the temperate regions of the planet, IAM's conclude that some global warming will be beneficial to these regions, by raising their average temperatures, whereas tropical areas will suffer from having their temperatures pushed even further above the optimum:

"The results indicate that there will be large benefits from warming in the Former Communist Bloc (the former Soviet Union and Eastern Bloc countries). The benefits in this region almost offset losses throughout the tropics in the Experimental results. The Soviet benefits account for two-thirds of the net global benefits in the cross-sectional results. The results also suggest that there will be large benefits in North America and small benefits in Western Europe. The critical factor that these benefiting countries have in common is that they are currently cool so that warming is helpful." (Mendelsohn, Schlesinger, and Williams 2000, p. 42.)

The climatological and political assumptions implicit in this analysis are contradicted by current climatic and geopolitical events.

The Canadian wildfires of 2023, which have been amplified dramatically by declining precipitation levels in Canada's boreal forests, emphasise the folly of economic IAMs being based only upon temperature changes, and ignoring precipitation effects from global warming. Research such as the OECD's on the impact of losing the AMOC (OECD 2021) implies that developed economies will

be substantially affected by global warming, since warming is much stronger at higher latitudes than lower ones, and the rainfall altering effects of higher global temperatures could severely reduce crop yields in high latitude countries.

The Ukraine War shows that it extremely unwise to offset hypothetical losses in Africa by hypothetical gains in food output in Siberia.

These weaknesses in economic analysis are only apparent if one does not take the reported results of refereed economic papers at face value. Unfortunately, consultants relying upon only the conclusions of these papers did not notice the flimsy foundations from which these conclusions were derived.

Mercer's next report in 2015, *Investing in a Time of Climate Change* (Mercer 2015), diversified its output to include the impact on various investment portfolios, but stood on similar foundations: economic IAMs calibrated to trivial damage estimates, and using quadratics to extrapolate damages at higher temperatures.

In that report, 2°C of warming was portrayed as a possible source of portfolio gains:

"For example, a 2°C scenario could see return benefits for emerging market equities, infrastructure, real estate, timber and agriculture... 2°C scenario does not have negative return implications for long-term diversified investors at a total portfolio level over the period modelled (to 2050), and is expected to better protect long term returns beyond this timeframe." (Mercer 2015, p. 7.)

Also, 4°C was seen as a negative, but only for weather-exposed industries:

"Under a 4°C, or Fragmentation (Higher Damages) scenario, chronic weather patterns (long-term changes in temperature and precipitation) pose risks to the performance of asset classes such as agriculture, timberland, real estate, and emerging market equities." (Mercer 2015, p. 7.)

One positive development, compared to the 2011 report, was some criticism of IAMs in its appendix—though in the end, these IAMs still generated the numbers the report used. Mercer noted, but did not detail, that IAMs have been criticised in the economic literature.

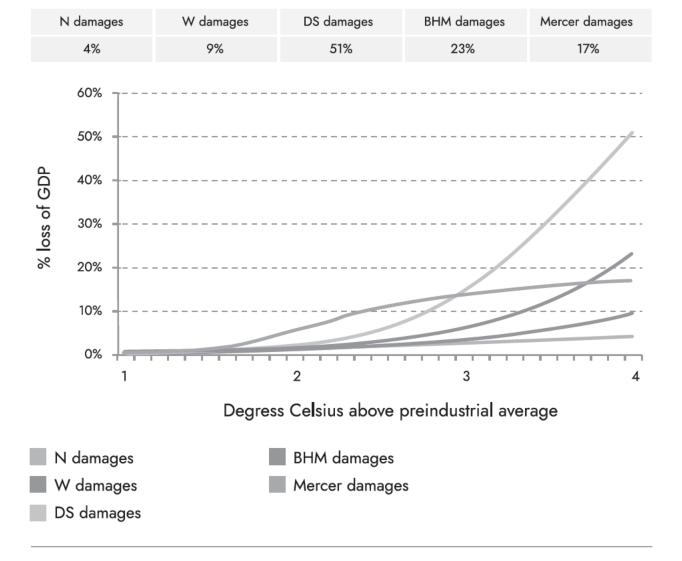
Mercer's level of scepticism about IAMs rose further in its 2019 report Investing in a *Time of Climate Change: The Sequel 2019 (Mercer 2019)*.

Unfortunately, Mercer also took a step backwards by producing its own damage function, in response to the weaknesses it saw in economic IAMs—see Figure 14. This damage function is, if anything, even more problematic than those generated by academic economists. As Mercer documented, it is dominated by one factor—coastal flooding—and it does not include the impact of tipping points, which lead Mercer to describe its shape as linear:<sup>42</sup>

"The Mercer damage function produces the highest damage ratio at 2°C of warming. It is linear in shape, primarily reflecting the coastal flood damage study used, which accounts for the majority of the Mercer damages... The Mercer damage function also does not take account of climate tipping points, which could drive nonlinearity in terms of the severity of coastal flooding or wildfire and/or the incidence and intensity of extreme events." (Mercer 2019, p. 79.)

Figure 14: Mercer's damage function compared to others, with a table showing forecast damages at 4°C (Mercer 2019, p. 79). the codes N, W, DS, and BHM stand for damages functions in (Nordhaus 2013; Weitzman 2012; Dietz and Stern 2014; Burke, Hsiang, and Miguel 2015) respectively.

Figure 34. Comparison of Various Climate Change Physical Damage Functions



Source: Mercer

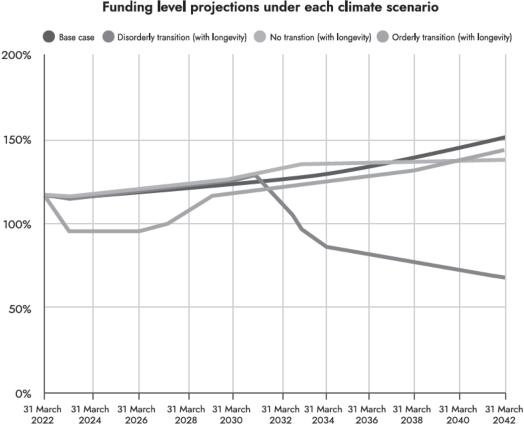
This dependence upon just one effect from global warming, and the absence of any increasing nonlinearity to its damages, let alone the cascading damages expected by climate scientists, makes Mercer's damage function unfit for portfolio management as we enter significant levels of warming—by which we mean the 1-2°C levels that concern scientists, much less the 4-6+°C levels that are contemplated by economists.

In the supporting document How Did We Get Here?, we detail further examples of correspondence between pension funds and members of the public on how funds have accounted for the risks of climate change. The correspondence copied below demonstrates the reliance of pension funds upon the advice of consultants like Mercer, who in turn have relied on the unsound work of mainstream economists on climate change.

## 12.3 Other consulting firms

The conclusions that have been reached about damage to pension portfolios from global warming are misled, not just by the work of economists, but also the specific portfolio questions posed to consultants by pension funds. For example, both Cardiff Council and Hampshire employ AON as an investment consultant, and both modelled the impacts of 4°C warming on their portfolios by 2042, yet their scenarios produced very different results. The Hampshire TCFD report scenario analysis by Aon predicted a -35% decline in funding level values by 2042, based on a "disorderly transition" 43 at 3-4°C warming —see Figure 15.5.

Figure 15: Hampshire Council's Projections



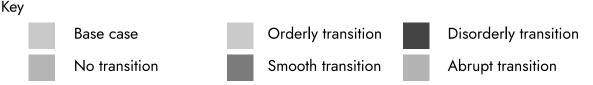
<sup>43</sup> A "disorderly transition" is one of the hypothetical scenarios developed by consultants, in which coordination between countries is weak Though "disorderly" implies serious policy failures, these scenarios rely upon economic estimates of damages from climate change, and therefore still postulate positive growth in a "disorderly transition"

Cardiff also employed scenario analysis by Aon and modelled a disorderly transition scenario at 3-4°C, to model a much steeper -55% hit to funding levels by 2042—see Figure 16.

150%
100%
31 Mar 2022 31 Mar 2027 31 Mar 2032 31 Mar 2037 31 Mar 2042

Figure 16: Cardiff Council's Projections

Run by Aon with an effective date of 31 March 2022, using a liability basis of RPI Curve +2.05% to enable us to carry out future projections. This basis gives us the same liability value as the valuation basis as at 31 March 2022. However, the liability value excludes the short-term inflation allowance, which is included in the valuation results. Since we have excluded the short-term inflation allowance, at time 0, the funding level is higher than the valuation results. This doesn't affect the future projections as we have allowed for expected inflation.



Given the shared reliance upon the unsound analysis of global warming by mainstream economists, both estimates are likely to seriously underestimate damages from global warming. However, LGPS fund members, taxpayers and regulators should press both the councils and consultants to understand what combination of factors explains the 20% gulf in values these funds might expect in 20 years time, under a disorderly transition scenario.

#### 12.4 The UK Local Government Pension Scheme

The LGPS is one of the largest pension schemes in the UK with 6.2 million members and a significant UK and global investor with £342 billion of assets as of 2022. It is locally managed and funded by 86 administering authorities (AAs) in England and Wales.<sup>44</sup> In addition, there are a further 11 LGPSS funds in Scotland<sup>45</sup>, with £46 billion of assets.<sup>46</sup>

<sup>44</sup> https://www.gov.uk/government/consultations/local-government-pension-scheme-england-and-wales-governance-and-reporting-of-climate-change-risks/local-government-pension-scheme-england-and-wales-governance-and-reporting-of-climate-change-risks

<sup>45</sup> https://pensions.gov.scot/local-government

<sup>46</sup> https://commonslibrary.parliament.uk/research-briefings/cbp-7309/

Not all local authorities manage their own pension fund, but those which do are known as 'administering authorities' (AAs). AAs are already required to consider factors (including climate) that are financially material to the performance of their investments, including environmental, social, and corporate governance (ESG) matters. They also must have a policy stating how such considerations will be considered in setting their investment strategy — known as an *Investment Strategy Statement* (ISS) — (previously a 'SIP').

In addition to the administering authorities, a further layer of LGPS fund management was created by 2016 pension regulations within England and Wales, forcing individual funds to merge their assets into one of eight larger 'pools' to achieve efficiencies of scale, and in theory, reduce fund management fees.

As background research for this report, Freedom of Information Act (FOIA) requests were sent to LGPS and LGPSS (Scotland) administering authorities, requesting internal email correspondence with their investment consultants on climate risk, and examples of consultants' advice, including climate scenario analysis outputs. Links to the FOI requests and summaries of the councils' responses can be found in pages 80-82 of the appendix.

## 12.5 LGPS funds' reliance upon advisors

LGPS correspondence obtained by Carbon Tracker regarding climate change advice from investment consultants and related correspondence with scheme members underscores how the advice has been taken up by pension schemes.<sup>47</sup>

For example, the Derbyshire Pensions and Investments Committee was asked about its 2020 and 2021 Climate Related Disclosures reports at its 18 January 2023 meeting by the Derbyshire Pensioners Action Group. 48 They challenged the assertions in the related Disclosures report suggesting that a trajectory towards 3°C warming by 2100 would have a "relatively muted" effect on returns:

"The world will have large areas that are uninhabitable by humans if we reach 3 degrees. ... The analysis that 3C warming will have a muted impact on the funds returns seems to lack recognition of the reality of what will happen and seems incredibly complacent. Can you explain where this analysis has come from and whether you think it represents a realistic analysis of the future?" 49

The committee's response made clear that the source of the numerical forecasts was "climate scenario analysis conducted by Mercer LLC (Mercer)" for "LGPS Central Limited's 2020 Climate Risk Report." 50

However, it ignored the substantive challenge that its assessment of 3°C lacked "recognition of the reality of what will happen and seems incredibly complacent." Instead, the committee turned immediately to the reputation of Mercer's as a "leading consultancy firm in terms of developing, and reporting on, climate change scenario analysis, which is grounded in the latest scientific and economic research."<sup>51</sup>

<sup>47</sup> See Section 8 of the supporting document: How Did We Get Here? for the full correspondence and public queries.

<sup>48</sup> https://democracy.derbyshire.gov.uk/documents/s19199/2023-01-18.pdf

<sup>49</sup> https://democracy.derbyshire.gov.uk/documents/s19199/2023-01-18.pdf

<sup>50</sup> https://democracy.derbyshire.gov.uk/documents/s19199/2023-01-18.pdf

<sup>51</sup> https://democracy.derbyshire.gov.uk/documents/s19199/2023-01-18.pdf

The committee's answer unwittingly exposed the core problem that this report has identified. Each layer in the process of assessing the risks of climate change has assumed that the previous layer has done its job adequately, and has relied upon the previous layer's reputation, rather than scrutiny of the work undertaken. Pension funds relied upon consultants, because of their reputation in the field; consultants relied upon academic economists, because their papers had passed refereeing.

As this report shows, the foundational layer in this inverted pyramid of trust—the refereed mainstream economic literature on climate change—did its job extremely badly. Therefore, the work of the layers above—the consultants, the funds, the financial regulators and governments—is also unsound, and fails Solow's "sniff test."

The Shropshire County Pension Fund (SCPF) Pensions Committee meeting of 17 September 2021,<sup>52</sup> included a response to a trade union representative's email of February 2021, at which the Fund's Climate-Related Disclosures report was discussed. That report concluded that a 4°C rise by 2100 would reduce annual returns to 2030 by 0.06%. The SCPF was asked to explain how the figure of 0.06% drop in returns could possibly be correct, given a 4-degree rise, as the science says this will cause catastrophic climate events.<sup>53</sup>

The committee's answer was that the impact on investment portfolios at 2°C largely reflected the cost of mitigation, while those at 4°C largely reflected the physical impacts of global warming, since SCPF's portfolio was mainly allocated to financial fixed-income assets, which the committee claimed are "relatively less sensitive to the different climate scenarios".<sup>54</sup> It also acknowledged that it relied upon LGPS Central, which "uses an external service provider"—Mercer, as detailed in Derbyshire's response.

Further evidence of the use of the critiqued economic models comes from Cheshire Pension Fund Joint Committee, at a public meeting on November 20<sup>th</sup>, 2020, at which a member of the public requested they:

'Please provide references to climate science studies that support LGPS Central's core assumption that the world will be so unaffected by 3°C and 4°C of warming that financial processes will be able to function and continue with only minimal loss of revenue... likely to present a "slight drag" 55 on the fund.'

The committee's response<sup>56</sup> referred once more to Mercer's study, rather than scientific studies, and claimed that Mercer's modelling "captures developments in the collective understanding of environmental science." In fact, as this report shows, Mercer's models, and those of all consultants engaged in predicting the financial consequences of climate change, rely upon the economic literature, which is incompatible with the findings of climate science.

The influence of the trivialisation of the dangers of climate change, by the majority of mainstream economists specialising on climate change, does not stop with pension funds. This research has also been taken at face value by regulators.

<sup>52</sup> https://shropshire.gov.uk/committee-services/documents/s29248/Draft%20Minutes%20Pensions%2017%20Sept%202021.pdf (refer to item 23 - public questions

<sup>53</sup> https://shropshire.gov.uk/committee-services/documents/s28658/Pensions%20Committee%20Public%20Questions%20and%20Responses%20 17th%20September%202021.pdf

<sup>54 &</sup>lt;a href="https://shropshire.gov.uk/committee-services/documents/s28658/Pensions%20Committee%20Public%20Questions%20and%20Responses%2017th%20September%202021.pdf">https://shropshire.gov.uk/committee-services/documents/s28658/Pensions%20Committee%20Public%20Questions%20and%20Responses%2017th%20September%202021.pdf</a>

<sup>55</sup> https://www.cheshirepensionfund.org/members/wp-content/uploads/sites/2/2020/11/Joint-committee-20.11.20-public-Qs.pdf

<sup>56</sup> https://www.cheshirepensionfund.org/members/wp-content/uploads/sites/2/2020/11/Joint-committee-20.11.20-public-Qs.pdf (refer pg 11)

## 12.6 Financial regulators

lust as advisors have taken refereed economic estimates of damages from climate change at face value, so too have financial regulators.

A number of regulatory initiatives on climate change have developed over the last decade. Central banks have formed subdivisions devoted to studying the economics of climate change, such as the Bank of England's CBES ("Climate Biennial Exploratory Scenario") to apply climate change stress tests to the financial companies that fall under its regulatory umbrella. Simultaneously, central banks have formed an overarching body NGFS ("Network for Greening the Financial System") to coordinate their studies: as of October 2022, 121 central banks had become members of NGFS.

At both the national and supranational level, these bodies have accepted the refereed economic literature as providing realistic estimates of the economic damages from climate change.

12.6.1 International: The Financial Stability Board (FSB)

The FSB brings together senior policy makers from ministries of finance, central banks, and supervisory and regulatory authorities, for the G20 countries, plus four other key financial centres — Hong Kong, Singapore, Spain and Switzerland.

The FSB report The Implications of Climate Change for Financial Stability (FSB 2020) is based on the work of climate change economists, with key citations including (Hsiang and Kopp 2018; Dietz et al. 2016; Nordhaus 2017). Though literature critical of the work of economists is also cited (Stern 2013; Lenton et al. 2019), the estimates of economic damages are clearly within the parameters set by economic IAMs, rather than by scientists. The predictable result is that levels of global warming that scientists warn pose serious risks to human civilisation are predicted to cause relatively trivial declines in asset values.

Its key publication, *The Implications of Climate Change for Financial Stability* (FSB 2020), predicted that a 4°C increase in global temperatures would reduce asset prices by between 3% and 10%:

"Under a scenario where the increase in global mean temperature above pre-industrial levels is likely to remain within 2°C, estimates of the mean reduction in global financial asset values are between 0.7 and 4.2% (US\$ 1–6tr), depending on the study and discount rate. Under a 'baseline' scenario in which policies to mitigate climate change that were in place in 2010 are extended indefinitely but there is no additional action to reduce emissions, the expected temperature increase is around 4°C and the estimated mean reduction in asset prices is between 2.9% and 9.7% (US\$4-14tr), depending on the chosen discount rate." (FSB 2020, pp. 7-8.)

The report Climate Scenario Analysis by Jurisdictions (FSB 2022) notes that, "Regarding financial vulnerability, it stands out that economic modelling is central in all exercises to translate climate-specific information into financial impacts," (FSB 2022, p. 20) and confirms the use of economic IAMs and damage functions in its approach to assessing financial risk:

"In the NGFS modelling framework, three integrated assessment models (IAMs) and a damage function are used to translate climate variables into a core set of macroeconomic variables, such as GDP, energy prices or carbon prices." (FSB) 2022, p. 10)

## 12.6.2 The Network for Greening the Financial System (NGFS)

The NGFS is a consortium of Central Banks and financial supervisors working to share best practices on addressing climate change. Over 130 Central Banks are members of the NGFS.

This lack of preparedness is a global phenomenon—again, because of the reliance on refereed economic studies. The NGFS's key publication NGFS Scenarios for central banks and supervisors (NGFS 2022), for example, relies on the damage function methodology set out in Kalkuhl & Wenz (2020). (NGFS 2022, p. 17)

Kalkuhl & Wenz's paper "The impact of climate conditions on economic production. Evidence from a global panel of regions" (Kalkuhl and Wenz 2020) is based on the third method outlined in section 3 above (which is covered in detail in section 4.4 of the supporting document How Did We Get Here?), of treating an extrapolation from change in temperature and GDP data as the basis for predicting the damages from climate change. The paper uses "climate and economic data at the subnational level for the years 1900–2014," (Kalkuhl and Wenz 2020, p. 6) from which it derives a damage function that, while more complicated than in Nordhaus's DICE model, still treats damages as a function of the change in temperature squared:

"Importantly, damages here are a quadratic function of the warming level." (Kalkuhl and Wenz 2020, p. 14)

This is despite the fact that the paper refers to criticisms of the use of quadratic damage functions (Kalkuhl and Wenz 2020, p. 2). The paper also makes no acknowledgement of the fact that its data sample period does not include any impact from tipping points, and yet its extrapolation to 3.5°C of global warming covers temperature increases that scientists have predicted will trigger several tipping points (Armstrong McKay et al. 2022; Brovkin et al. 2021; Cai, Lenton, and Lontzek 2016; Lenton et al. 2019; Lenton et al. 2008b), quite possibly in a cascading fashion (Steffen et al. 2018). Consequently, though they describe their predictions of future damages as "considerable," they are slight, since they are in relation to a hypothetical future global GDP in which global warming does not occur:

"Applying the panel and cross-sectional results to projected warming levels for a high-warming scenario, we project considerable production losses, around 7–14% in the year 2099 compared to a scenario of no further warming." (Kalkuhl and Wenz 2020, p. 18)

#### 12.6.3 The Federal Reserve

Federal Reserve Board Governor Christopher Waller's speech "Climate Change and Financial Stability" summarised the consensus on climate change within the Federal Reserve with the opening statement that:

"Climate change is real, but I do not believe it poses a serious risk to the safety and soundness of large banks or the financial stability of the United States. Risks are risks. There is no need for us to focus on one set of risks in a way that crowds out our focus on others. My job is to make sure that the financial system is resilient to a range of risks. And I believe risks posed by climate change are not sufficiently unique or material to merit special treatment relative to others." <sup>57</sup> (Waller 2023, p. 1)

This ranking of climate change as no more significant than a wide range of other risks is consistent with the economics chapter of the 2014 IPCC Report. 58 Waller observed that "There seems to be a consensus that orderly transitions will not pose a risk to financial stability," and reference the Financial Stability Board report *The Implications of Climate Change for Financial Stability* ((FSB) 2020). That report relied upon (Dietz et al. 2016) and ((EIU) 2015), both of which used Nordhaus's DICE model to estimate changes from climate change.

Waller was confident that "economic agents are already adjusting behaviour to account for risks associated with climate change," and stated that this "should mitigate the risk of these potential 'Minsky moments'." (Waller 2023, p. 7) Unfortunately, because of the fatally flawed work by economists on climate change, the Federal Reserve may be far less prepared for a "Climate Minsky Moment" than it expects.

# 12.7 The Economist Intelligence Unit

The Economist Intelligence Unit (EIU) is the research and analysis division of the publisher of *The Economist* magazine, which is one of the world's most influential non-academic economic publications. Its report *The Cost of Inaction: Recognising the Value At Risk from Climate Change* ((EIU) 2015) was squarely based on the research of William Nordhaus:

"To estimate the effect of climate change to 2100 on the changing stock of manageable financial assets, The Economist Intelligence Unit (The EIU) and Vivid Economics have used a leading, peer-reviewed forecasting model of the impact of climate change on the economy, the DICE (Dynamic Integrated Climate-Economy) model." ((EIU) 2015, p. 8)

<sup>57</sup> https://www.reuters.com/markets/us/feds-waller-says-climate-change-not-serious-risk-financial-stability-2023-05-11/

<sup>58 &</sup>quot;For most economic sectors, the impact of climate change will be small relative to the impacts of other drivers (medium evidence, high agreement). Changes in population, age, income, technology, relative prices, lifestyle, regulation, governance, and many other aspects of socioeconomic development will have an impact on the supply and demand of economic goods and services that is large relative to the impact of climate change." (IPCC et al. 2014, p. 662)

Needless to say, the EIU reached results that echoed Nordhaus's trivialisation of global warming:

"Warming of 5°C could result in US\$7trn in losses ... while 6°C of warming could lead to a present value loss of US\$13.8trn of manageable financial assets, roughly 10% of the global total." ((EIU) 2015, p. 2)

The EIU observes that, at least according to conventional finance theory, the value of stocks depends on dividends, and these in turn depend upon GDP:

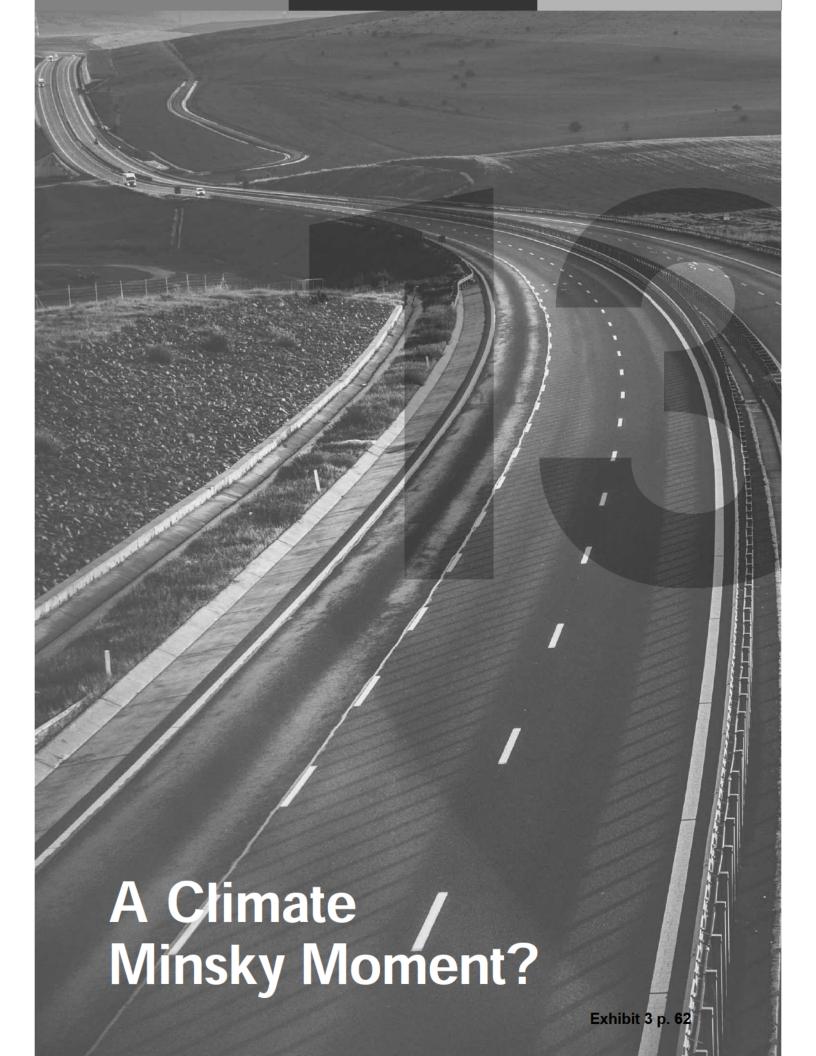
"This modelling recognises that, since the present value of a portfolio of equities is just the discounted cash flow of future dividends, then in the long run—i.e., over the course of a century—dividends in a diversified portfolio should grow at the same rate as GDP, because ultimately dividends are paid for from the output of the economy." ((EIU) 2015, p. 9)

Assuming, with reason, that the majority of financial market participants accept the figures provided by The Economist Intelligence Unit—and consulting firms like Mercer, the FSB, the Bank of England, and the Network for Greening the Financial System—as accurate estimates of the impact of climate change on the financial sector, it is highly likely that stock market valuations are wildly out of step with the future course of stock prices, dividends, and GDP in a climate-changed world.

## 12.8 Misinformation begets financial instability

The influence of the trivialization of climate change-induced damage generated by this small band of economists is thus pervasive: it affects financial institutions, advisors, regulators, and the media alike. Since this misinformation drastically underestimates the dangers of climate change, and is shared across the financial sector, there is likely a huge disconnect between current asset prices—and the false expectations of future damages they encapsulate—and the real-world effect of global warming.

As some point, reality will drown out this misinformation—figuratively, if not literally. Asset markets will then dramatically reset in what has come to be known as a "Minsky Moment," in honour of the distinctly non-mainstream economist Hyman Minsky (Minsky 1982), the originator of the "Financial Instability Hypothesis." (Keen 1995)



A Minsky Moment is a sudden major collapse of asset values (financial asset: equities, bonds and real estate) caused by the end to an unsustainable period of overly bullish activity, due to a sudden realisation of the gap between market aspirations and economic reality. The huge disconnect between what scientists expect from global warming, and what economists have claimed, means that a "Climate Change Minsky Moment" could occur at a time within the investment horizon of existing firms.

This would cause a plunge in asset market valuations, not as the result of a collapse in credit-based demand as in previous financial crises (Keen 1995, 2020b), but as the result of divergence between the optimistic predictions of economists on the one hand, and the reality of global warming on the other.

It may sound unwise to see this convergence as inevitable, since "markets can remain irrational for longer than you can remain solvent." However, given the erroneous assumptions applied, the use of non-independent data, the lack of scenario analysis (including the widespread failure to use nonlinear damage functions other than a quadratic), and the faith invested in this work by pension funds, consultants, financial regulators, and financial markets, we believe that an unpleasant, abrupt and wealth-destroying Minsky Moment is virtually inevitable.

There are at least three possible, and non-exclusive, routes to a Climate Minsky Moment:

- The large-scale destruction of physical assets themselves could occur because of climatic events.
   This would cause a write-off of their financial value as well;
- Significant government policy actions could limit fossil fuel usage, as a policy response to growing awareness of the actual, versus the expected, severity of global warming. The financial valuation of physical assets would fall; and
- Financial valuations of the key parts of the fossil fuel system, particularly coal mines, coal or gas
  fired power stations, oil and gas facilities particularly wells, refineries, pipelines and tankers could
  be written down by auditors. The costs of decommissioning and remediation could be imposed
  upon their owners, which would severely impair their balance sheets.

Investors, and pension funds in particular, would be wise to prepare for all eventualities. So too would governments, since—while the FOIA response received from the Hammersmith and Fulham pension fund stressed that contributions to the LGPS do not in themselves constitute "public money"— defined benefit (DB) schemes effectively guarantee retirees a certain level of income in retirement.

Should climate change overwhelm financial markets and fund returns to the point LGPS liabilities exceed fund income, any shortfall would likely be made up by the UK government. It is therefore in all our interests to ensure both climate risk advice and investment practices in the LGPS are aligned with climate science, and not operating in isolation from it.



The economic analysis that has led funds to have a sanguine perspective on 2-4°C or more of global warming is not fit for purpose. Climate dangers that this research implied were minor and distant are more likely to be major and relatively immediate. The prospect cannot be ruled out that significant damages might occur in the next one to two decades.

The question then is, how to navigate from a position based on misconceptions, to one at least grounded to some extent in the reality we face?

Some economists have called for new and better studies of the economic costs of global warming (Stern, Stiglitz, and Taylor 2022; Stern 2022; Mattauch et al. 2022; Stern and Stiglitz 2021). In addition, economists should consider how economic policy could help avoid further temperature rises, and help prepare for economic disruption that current warming has already locked in.

Pension funds face many dilemmas. There is little point in solely revising portfolio allocations, when the consequences of global warming are systemic, rather than restricted to the few industry sectors that are not undertaken in "carefully controlled environments." (Nordhaus 1991, p. 930) Answers to these questions are beyond the remit of this paper, since its purpose is not financial advice. However, we would recommend at least the following actions.

# 14.1 Informing members

One ethical responsibility is unavoidable: pension funds must let their members know that the past guidance they have given on the impact of global warming on pensions is unsound. They must be told that their pensions are much more vulnerable to climate change than they have been led to believe.

This of itself may do substantial good, since it would counter the global warming denialism and trivialisation that is still highly influential today, which is due in no small measure to the same economic research that has misled pension funds themselves. If members could realise that their personal futures will be dramatically and deleteriously impacted by future climate change, this could help shift public sentiment in favour of drastic government and private sector action in the near term to prevent further climate change.

# 14.2 End commercial confidentiality on climate change advice

Section 9 of the supporting document How Did We Get Here?, together with the FOIA Table in the Appendix to this report details the responses that Carbon Tracker has received from pension funds, councils, and consultants to questions about their climate change preparedness. Frequently, funds and consultants have refused to provide details on the basis of client commercial confidentiality.

While client confidentiality is an important safeguard of client and consultant rights in standard commercial evaluations, it should not be applied in the case of estimating the impact of climate change. Climate change is the quintessential instance of John Donne's poetic declaration that "no man is an island": what one consultant or client claims will be the impact of climate change on that client affects how the whole of the body politic interprets the dangers of climate change. This is especially so in local government, where councillors are responsible for the delivery of public services and maintaining the built environment. Especially given the poor quality of the economic research on which consultants have relied to date, both the advice given by consultants and the models that have been used to generate that advice should be publicly available.

# 14.3 Ask questions

Beneficiaries of pension schemes should raise these issues with their own scheme administrators and the scrutiny committees which oversee council financial decision making to ensure that their plans are getting sound and appropriate advice.

Pension fund trustees and committees should challenge their advisors and the regulators. Trustees should be able to seek and rely on expert advice, but also be able to deeply query that advice without fear of reproach.

In particular, pension fund trustees and committees should ask consultants and investment managers to produce scenarios showing the impact upon fund valuations of a rapid wind down of the fossil fuel system in line with the 1.5C warming outcome that many net zero pledges are based upon. These assume a drop in emissions of 50% in a decade and a similar 50% drop in fossil fuel use. Scenarios like this best indicate which sectors and companies might be impacted and which components of the new energy system might benefit.

# 14.4 Reform academic practices on climate change

Investment advisers, regulators, central banks, and governments should be able to rely on verified and robust academic research. Given the critical importance of this issue to humanity, the issue of why academic refereeing failed so badly deserves serious investigation by academic institutions such as the UK's Economic and Social Research Council (ESRC).

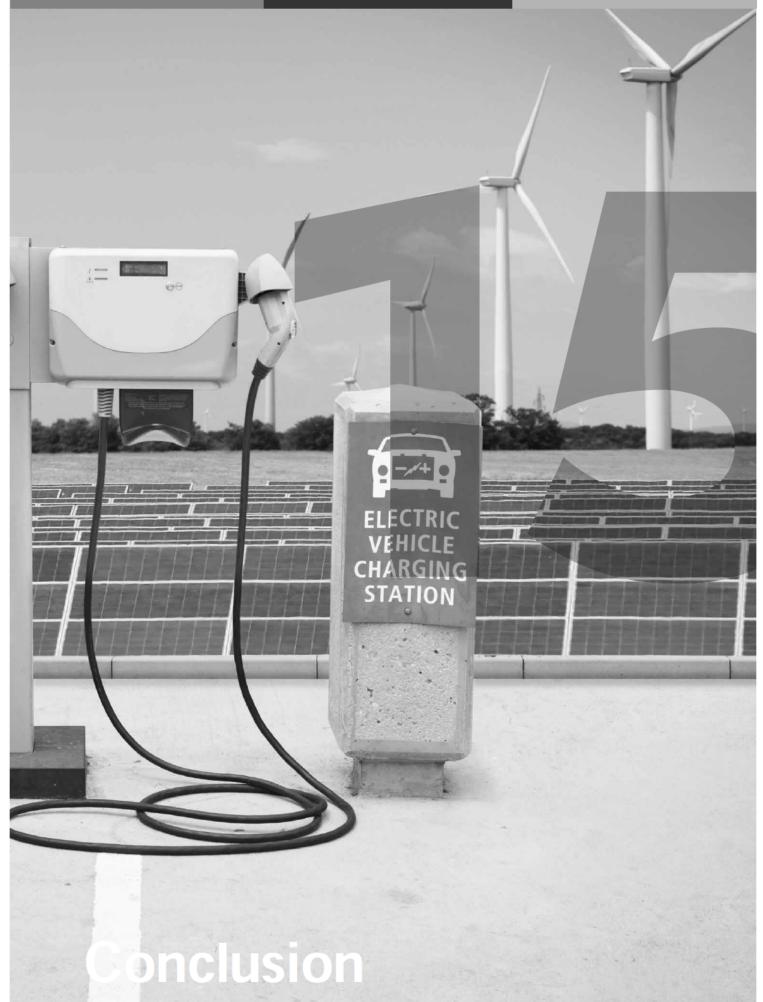


Exhibit 3 p. 67

The objective of this report is to alert all stakeholders to the economic dangers of climate change that, to date, have been seriously underestimated.

Pension funds have been poorly advised, inadvertently or not, on the dangers that climate change poses for their portfolios. The challenges that climate change poses to the retirement incomes of their members are not distant and small, but immediate and potentially wealth-destroying.

Given the scale of the dangers of global warming, and the penetration into our financial and political systems that this unsafe analysis has achieved, the changes needed necessarily go well beyond modifying portfolio allocations.

As well as showing that a drastic change in policy is needed, from cost-benefit analysis to the precautionary principle, this report shows that significant change is needed in academic review processes. The refereeing process, which is supposed to prevent low quality research from being published, instead resulted in low quality work being treated as valid by the non-academic individuals and institutions who relied upon it. In future, the empirical claims in economics of climate change papers should be refereed by scientists, rather than by other economists alone.

This report is a call to all stakeholders, from governments, regulators, investment professionals, all the way to civil society groups and individuals, to ensure that the critical error of taking this unsound research seriously is reversed, before it is too late.

Given the extent to which the beliefs of economists have overruled the analysis of scientists in the development of policies to combat climate change, we give the last word to scientists who have specialised in the analysis of climate tipping points. This is the conclusion to the 2019 paper "Climate tipping points - too risky to bet against" (Lenton et al. 2019):

"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. We need to change our approach to the climate problem...

In our view, the evidence from tipping points alone suggests that we are in a state of planetary emergency: both the risk and urgency of the situation are acute...

We argue that the intervention time left to prevent tipping could already have shrunk towards zero, whereas the reaction time to achieve net zero emissions is 30 years at best. Hence, we might already have lost control of whether tipping happens. A saving grace is that the rate at which damage accumulates from tipping — and hence the risk posed —could still be under our control to some extent.

The stability and resilience of our planet is in peril. International action — not just words—must reflect this." (Lenton et al. 2019, p. 595.)



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80			Loading the DICE against pens	JOH TUHU
		STS SENT TO LGPS ADMINISTERING A		
Administering Authority	External Investment Consultant	FOIA Reply Status	Summary of information received	FOIA Lin
Barking and Dagenham	Hymans Robertson	Denied/ S 43 (2) commercial secrecy + S 41 confidential info	Council argues information should be withheld to maintain "a confidential, private space (away from public scrutiny) for policy making	link
Barnet	Hymans Robertson	Some info received. Emails denied - s41 info in confidence & s42 legal privilege	Provided some information on climate risk modelling. Consultant emails refused citing s43(2) commercial secrecy	link
Bath & NE Somerset	Mercer	Some info provided. Emails denied - s12 cost	Provided Mercer Analytics for Climate Transition (ACT) equity portfolio review & climate policy update	link
Bedfordshire Pension Fund	Hymans Robertson	Delayed reply	No information provided - awaiting delayed response	link
Bexley	Aon	Denied/ S 43 (2) commercial secrecy + s12 cost	Disclosure likely to prejudice commercial interests of any person, incl public authority holding it. Info commercially sensitive to investment advisors	link
Bradford D.C (West Yorkshire)	Aon	Most Info Provided	Provided consultant emails ("FCA regulated) & Aon Scenario Analysis - full document	link
Brent	Hymans Robertson	Some info. Emails denied - S 43 (2) commercial secrecy + S 12 cost	Some info provided on climate change risk analysis - consultant emails were refused	link
Bromley	MJ Hudsons	Denied/ S 43 (2) commercial secrecy	Information withheld - "Council believes disclosure will prejudice commercial interests of Fund Managers, Pension Fund & Council itself."	link
Buckinghamshire	Mercer	Denied, S12 - cost, S41 trade secrets, & S 43 (2) commercial secrecy	"disclosing details of consultant reviews would likely prejudice Council's commercial interests & ability to negotiate best investments for pension fund"	link
Camarthenshire	Mercer	Denied- s12 cost	"We've only been able to provide info in the public domain as info provided by advisors is commercially sensitive & contains their intellectual property which would prejudice their commercial interests, causing them significant harm."	link
Cambridgeshire	Mercer	Some info provided. Emails denied/ S 43 (2) commercial secrecy + s12 cost	"Investment consultants' research is proprietary info which yields a prime revenue stream. Info in question is presented to Committee as private papers. We're aware competing investment consultants, & financial press, scour Committee minutes for competitor intelligence that can be found at minimum effort & cost to their own businesses." Provided TCFD report & Climate Action Plan	link
Camden	ISIO + Karen Shackleton	Denied/ S 43 (2) commercial secrecy + s 12 cost	Conflates climate risk mgmt with London CIV carbon footprinting. Council gamed key word search results to cost bar the request.	link
Cardiff	Aon	Some info provided. Emails denied citing - s12 cost	Provided useful AON scenario analysis showing -40-50% valuation impact at 3-4 deg warming by 2042	link
Cheshire West & Chester	Not disclosed	Delayed reply	No response received	link
City of London	Mercer	Denied- s12 cost, s17	Provides clmate action strategy & TCFD report	link
Cornwall	Mercer	Denied - s12 cost, s43(2) commercial secrecy	Rejected on cost & commercial secrecy grounds. Refers to TCFD report and ISS	link
Croydon	Mercer (Hymans = actuary)	Some info. Emails denied s12 (cost)	Fund included TCFD climate scenario stress testing in the contribution modelling exercise for the 2022 valuation	link
Cumbria County Council	Mercer	Some info provided. Reports exempted uder s22 - Info soon to be published	Emails provided with Mercer re: TCFD consultation.	<u>link</u>
Derbyshire County Council	MJ Hudson Allenbridge/ Mercer	Denied/ S 43 (2) commercial secrecy	See 2022 Climate Risk Report via LGPS Central	link
Devon	Mercer	Some info provided. Scenario analysis witheld as commercially sensitive	Emails provided inc survey of Peninisula Pensions member views on climate change & divestment matters.	link
Oorset	Mercer	Info Not Held	Claim no climate risk consultancy work/ scenario analysis done	<u>link</u>
urham	Aon	Denied/ S 43 (2) commercial secrecy	Emails were refused. For Aon climate scenario analysis - see slide 23 /	link
aling	Hymans Robertson	Denied/ S 43 (2) commercial secrecy + S 12 cost	No information provided - awaiting delayed response to internal review	link
ast Riding of Yorkshire	MJ Hudson Allenbridge	Denied/ S 43 (2) commercial secrecy + S 12 cost	Council search applied overly broad term "climate" instead of climate scenario analysis as specified	link
ast Sussex	Hymans Robertson/ ISIO	Denied/ S 43 (2) commercial secrecy	Emails were refused. Provided actuarial valuation & other publicly available reports	link
infield	Aon	Some info provided re: TCFD & scenario analysis. Contract info denied s43(2)	Some info provided re: London CIV and Enfield TCFD reporting	link
Invironment Agency	Mercer	Denied s43(1)trade secret & 43(2) commercial secrecy	"we consider the materials contains trade secrets used in Mercer's business &, if disclosed, would be liable to cause real or significant harm"	link
ssex County Council	Minerva/ Hymans Robertson	Denied s 12 Cost	Emails were refused. No climate risk analysis (ACCESS). Provided climate action report	t <u>link</u>
lintshire C.C (Clywdd)	Mercer	Denied S 12 Cost. Internal review response delayed	Provided Mercer (climate risk) Analysis for Climate Transition (ACT) tool & TCFD report	link
Gloucestershire	Mercer	Denied S 12 Cost	Claim to have not engaged a climate risk advisor/ done scenario analysis	link
Greenwich	Hymans Robertson	Denied/ S 43 (2) commercial secrecy	Consultant emails were refused. Provided links to public Net Zero Road Map	link
Gwynedd Council	Hymans Robertson	Denied/ S 43 (2) commercial secrecy	Consultant emails were refused. "No extenal climate scenario analysis undertaken"	link
Hackney	Redington, prev Hymans	Denied/ S 43 (2) commercial secrecy	Consultant emails were refused. Provides links to pension investment strategy & climate targets	link

Exhibit 3 p. 80

Loading the DICE against	pension funds			81
Administering Authority	External Investment Consultant	FOIA Reply Status	Summary of Information received	FOIA Link
Hammersmith and Fulham	John Raisin ex LBWF s151	Denied / S12 cost, & S43 (2) commercial secrecy	Consultant emails were refused. Climate risk advice/analysis refused. Clarification provided on extent to which LGPS = public money	link
Hampshire County Council	MJ Hudson + AON climate risk advisor	Denied / S21 + s43(2) commercial secrecy	Provided links to public <u>TCFD report</u>	link
Haringey	Not disclosed	No response	No response received. Case referred to the ICO - reference: IC-231842-P2B1	link
Harrow	Aon	Info Not Heid	Claim no climate risk advice sought. Hymans provide Acturial valuation	link
Havering	Hymans Robertson	Some info provided. Emails denied/S 43 (2) commercial secrecy	Refers to 2021/22 TCFD report	link
Hertfordshire	Mercer	Denied s12 Cost	No information received	link
Hillingdon	Not disclosed	Info Not Held	Info Not Held	link
Hounslow	MI Hudson (CO2 footprinting)	Denled s12 Cost, s43(2) commercial secrecy	No climate scenario analysis done to date, but planning on doing so in line with TCFD reporting	link
Isle of Wight	Hymans Robertson	Denied/ S 43 (2) commercial secrecy + S 12 cost	No climate risk scenario modelling undertaken. Some info provided re: ESG & Govt TCFD consultation	link
Islington	Mercer, MJ Hudson Allenbridge	Denied - s12 cost	Referred to pension sub-committee minutes on climate related issues impacting the pension fund	link
Kensington and Cheisea	Mercer	Denied/ S 43 (2) commercial secrecy	No Information received	link
Kent County Council	Mercer	Denied/ S 43 (2) commercial secrecy + S 12 cost	No information received	Unk
Kingston upon Thames	Aon	Denied EIR 12(4)(b) cost, + 12(5)(f) information provided in confidence	Consultant emails refused. Do not hold climate scenario anlysis info	link
Lambeth	Mercer	Denied/ S 43 (2) commercial secrecy + S 12 cost	Provided Internal emails re: climate risk workstream. Scenario analysis info was refused	link
Lancashire	Mercer - IFAs A Devitt E Lambert	Denied/ S 43 (2) commercial secrecy	Emails provided re scenario analysis. Claim to not hold information on scenario analysis.	link
Leicestershire	Mercer	Some Info Provided	Scenario analysis (2050) of 1.5, 1.6, & 4degC scenarios -1% annual hit to fund value only under 4degC warming?	link
Lewisham	Hymans Robertson	Denied/ S 43 (2) commercial secrecy	No information received	link
Lincoinshire	Hymans Robertson	Info Not Held	Info Not Held	link
London Pension Fund Authority	Barnet Waddingham	All Info Provided	BW emails + Scenario analysis (part redacted) *all info 2023 only	link
Merton	Hymans Robertson	Denied/ S 43 (2) commercial secrecy	Consultant emails refused. No climate scenario anlysis undertaken	link
Middlesbrough (Teeside)	Hymans Robertson	Denied/ S 43 (2) commercial secrecy	Emails refused. See "Sensitivity & risk analysis: climate change" pg 18 of Valuation Report	link
Newham	Barnet Waddingham	Denied - s12 cost	No emails provided. No scenario modelling done yet. Provided committee meeting links	link
Norfolk Pension Fund	Hymans Robertson	Denied, S12 cost, S41 info provided in confidence, S43 (2) commercial secrecy	Emails with consultants refused. No scenario analysis provided	link
North Yorkshire	Aon	Denied- s12 cost	No information received	link
Nottinghamshire	Mercer	Denied - s12 cost, & s43(2) commercial secrecy	Refers to Notts 2020 TCFD report climate scenario analysis, table 2 pg 60 of 2021 Annual Report	link
Oxfordshire County Council	Not disclosed	Claim no info heid	"Specific advice on climate risk has not been sought"	link
Powys County Council	Aon	Denled- s12 cost	Consultant emails refused. Refers to public investment strategy statement	link
Redbridge	Mercer	Info Not Heid	Consultant emails not provided. Response refers to pension fund annual report	link
Rhonda Cynon Taff County BC	Not disclosed	Denied/ S 43 (2) commercial secrecy	Does not state what info the council holds within the scope of the request	Link
Shropshire County Council	Aon - (Mercer - Actuary)	Denied s36	Response Implies council pension fund members only care about returns	link
Somerset County Council	None used	Info Not Held	Claim to not use investment consultants, nor seek advice on climate risk	Jink
South Tyneside (Tyne & Wear)	Hymans Robertson	Denied s41 - Info provided in confidence, & s43 (2) commercial secrecy	Email correspondence refused. Climate scenario analysis in Nov 2022 pension committee pack.	link
South Yorkshire Pensions Authority	Hymans Robertson	Denied S 43 (2) commercial secrecy + S12 cost	"We've not engaged external investment consultants on climate risk & not commissioned scenario analyses on our portfolios."	<u>Ilnk</u>
Southwark	Mercer	Denied/ S 43 (2) commercial secrecy	Repty links to investment strategy statement (ISS) & Net zero carbon investment strategy	link
Staffordshire County Council	Hymans/ Mercer, CO2 Footprinting - MSCI	Info Not Held	Claim Info is now held centrally by LGPS Central	link
Suffolk	Hymans Robertson	Denied S 43 (2) commercial secrecy + S12 cost	Email correspondence was refused. No scenario analysis undertaken	link
Surrey County Council	Mercer	Denied / S12 (cost) & 43 (2) commercial secrecy	Email correspondence was refused. Response directs to <u>public TCFD report</u>	link
Sutton	Hymans Robertson	Denied EIR 12(4)(b) cost unreasonable, + EIR 12(5)(f) adverse effect on provider	Email correspondence was withheld. Council does not hold climate scenario analysis info	link
			F - 1 - 1 - 1 - 0	

Exhibit 3 p. 81

Administering Authority	External Investment Consultant	FOIA Reply Status	Summary of Information received	FOIA Link
Swansea	Hymans Robertson	Denied S 43 (2) commercial secrecy + S12 cost	Email correspondence was withheld.	link
Tameside (Greater Manchester)	Hymans Robertson	Denied s41 info provided in confidence & 43(2) commercial secrecy	Hymans undertook climate analysis as part of the Asset Liability Modelling exercise following the 2019 valuation exercise. Info exempt	link
Torfaen	Not disclosed	Denied - s12 cost, s41 info in confidence & s43(2) commercial secrecy	Email correspondence withheld. Refers to annual report under the 'Strategy' section at p47	link
Tower Hamlets	Mercer	Denied - s12 cost, & s43(2) commercial secrecy	Mercer have produced reports on climate change, & TCFD	IInk
Waltham Forest	Mercer	Denied/ S 43 (2) commercial secrecy. Awaiting internal review reply	Email correspondence & scenario analysis withheld	link
Wandsworth	Mercer	Denied/ S 43 (2) commercial secrecy	Email correspondence withheld. Some Info on climate sensitivity from Actuary in Annual Report	link
Warwickshire	Hymans Robertson	Denied s41 info provided in confidence & 43(2) commercial secrecy	Email correspondence & scenario analysis withheld. Provided out of scope CO2 footprint info	link
West Sussex County Council	Not disclosed	Denied S 43 (2) commercial secrecy + S12 cost	Claim no scenario analysis undertaken	link
Westminster	Deloitte	Some Info Received	Delottle TCFD report provided	link
Wiltshire	Mercer	Denied- s12 cost	Email correspondence & scenario analysis withheld - council gamed key word search results to cost bar the request.	link
Windsor and Maindenhead UA	Barnet Waddingham	Some Info received	Provided emails with BW re: climate scenario analysis. "No emails pre-2023 discussing pension fund climate risk."	link
Wirral	Redington · prev Aon. Mercer = actuary	Denied- s12 cost. Awaiting Internal review reply	Email correspondence withheld. Mercer currently working on climate sensitivity. Info not held	link
Wolverhampton	Redington (inv)/ Mercer (risk)	Denied/ s43(2) commercial secrecy, s36 "chilling effect" on public office + s12 cost	Email correspondence witheld. Claim fund returns, not climate risk of interest to members	link
Worcestershire County Council	MJ Hudson	Refused as "confidential information"	Emails were refused. Response linked to <u>TCFD report</u> and ISS	link

LGPS Pools				
Wales Pension Partnership	Hymans Robertson	Denied/ \$ 43 (2) commercial secrecy	Withheld emails. Linked to responsible investment & climate policies. No scenario analysis	<u>IInk</u>
London CIV	Not disclosed	Some Info Received	Claim to have not sought advice/ no scenario analysis. Linked to 2022 TCFD report	link
Brunel	Not disclosed	Info Not Heid	Claim no scenario modelling undertaken so info not held	link
Borders to Coast	Not disclosed	Info Not Held	We have not engaged any external consultants or undertaken external climate risk analyses on our customers portfolios.	link
LGPS Central	Mercer	Denied/ S 43 (2) commercial secrecy	Emails & scenario analysis withheld.	link
ACCESS	Minerva Consulting	Info Not Held	Claim no climate risk assessment undertaken (Essex C.C) - only responsible investment policy	link
Local Pensions Partership	Mercer	Some Info Received	Emails between LPP - Barnett Waddingham & Mercer on scenarios	link
Northern LGPS	Not disclosed	Info Not Held	Claim no investment consultant - info not held	link

LGPS Scotland						
Aberdeen - NE Scotland Pension	Not disclosed	Some info received. Climate risk & negotiation info withheld as commercially sensitive	Provided pension fund manager emails on ESG (engagement) & TCFD.	link		
Dumfries and Galloway	Not disclosed	Info Not Held	Claim no climate risk info is held/ was sought	link		
Dundee - Tayside	ISIO	Denied s12(1)- cost/ Info not held	Email correspondence withheld. Claim climate risk info not held	link		
Edinburgh - Lothian	Hymans Robinson	Info Not Held	Implausibly claim no email trail with advisors, despite relevant climate work on pro-bono basis.	IInk		
Falkirk	Hymans Robinson	Info Not Held	Ctaim no email trail with advisors, despite relevant climate work on pro-bono basis with Lothian PF acting as Falkirk advisors "on some matters"	link		
Fife	Not disclosed	Info Not Held	Provided SIP, investment strategy & actuarial valuation	link		
Glasgow - Strathclyde	Not disclosed	Denied s12(1)- cost	Email correspondence withheld. Claim climate risk info not held	Jink		
Highland Council	Hymans Robertson	Some Info Received	Asked our Actuary Hymans to complete stress-test modelling of climate change risk on our funding for Triennial Valuation 31 March 2023	link		
Orkney	Hymans Robertson	Denied s36(2) confidential information & s33 (1b) commercially sensitive	Hymans = actuary & investment consultant. Info withheld, copy/ pasted consult- ants arguments against public disclosure	<u>IInk</u>		
Scottish Borders	Not disclosed	s33 (1b) commercially sensitive/ info not held?	Emails & scenario analysis withheld. Provided a summary on non-requested public info. Claim consultant left & email cant be accessed	link		
Shetlands	ISIO	Some Info Received	Email trail with advisors ISIO & background docs - no scenario analysis	link		
Disclaimer: Information up to date for	sclaimer: Information up to date for data as requested as at March 2023, with a data cut off date of June 30					

Disclaimer: Information up to date for data as requested as at March 2023, with a data cut off date of June 30

## Disclaimer

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# Supporting Document to Loading the DICE Against Pension Funds: How did we get here?





# **About Carbon Tracker**

The Carbon Tracker Initiative is a team of financial specialists making climate risk real in today's capital markets. Our research to date on unburnable carbon and stranded assets has started a new debate on how to align the financial system in the transition to a low carbon economy.

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Steve Keen is a Distinguished Research Fellow at UCL (see <a href="https://www.isrs.org.uk/people">https://www.isrs.org.uk/people</a>), and is supported by crowdfunding on Patreon (<a href="https://www.patreon.com/ProfSteveKeen">https://www.patreon.com/ProfSteveKeen</a>) and Substack (<a href="https://profstevekeen.substack.com/">https://profstevekeen.substack.com/</a>).

He is the author of The New Economics: A Manifesto (Keen 2021), Can We Avoid Another Financial Crisis? (Keen 2017), Debunking Economics (Keen 2011), and about 80 refereed papers, on topics including flaws in the economic analysis of climate change (Keen et al. 2022; Keen 2020a), the role of energy in production (Garrett, Grasselli, and Keen 2020; Keen, Ayres, and Standish 2019), the causes of financial instability (Keen 2016, 2015, 1995), and flaws in Neoclassical (Keen and Standish 2010; Keen 2005, 2004a, 2004b) and Marxian economics (Keen 1993b, 1993a). He is the designer of the Open-Source system dynamics program Minsky (https://sourceforge.net/projects/minsky/).

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# Contents

1	Introduction		
2	A fail	ure of peer review	2
3	Clima	te Change Groupthink	4
4	Confu	sing Climate and Weather	7
	4.1 T	he ozone layer and Arctic summer sea-ice	7
	4	.1.1 From 3 circulation cells to one?	9
	4	.1.2 Famine and the AMOC	
	4	.1.3 Tipping Cascades and "Hothouse Earth"	14
5	lmagi	nary Numbers	16
	5.1 E	numeration—it's what you don't count that counts	17
		.1.1 Follow the Leader	
		.1.2 "Carefully controlled environments"	19
	5.2 S	urveys of economists on climate change	26
	5.3 E	quating time and space	28
	5.4 E	xtrapolating sub-1°C economic & temperature data	31
	5.5 U	Ising models to generate empirical data	33
	5.6 T	ipping points	33
	5.7 G	Quadratic extrapolation	34
6	More	appropriate damage functions	37
	6.1 D	Oata Sources	37
	6.2 A	nalysis	39
	6.3 D	NCE with different damage functions	45
7	Econo	mics, Production Functions, and Energy	47
8	Discou	unting science as well as the future	51
	8.1 D	Pr Pangloss	51
	8.2 N	legative discounting for risk	53
9	Corres	spondence with pension and other funds on climate change	56
10	Suppo	orting Recommendations	62
	10.1 T	he peer review process in climate change	62

	10.2 Pension fund and other financial institutions assessment of climate change risks	62
	10.3 NGFS and Hothouse Earth	62
11	Appendix	63
	11.1 Economists' damage estimates	63
	11.2 Papers in economics journals critical of mainstream climate change economics	67

# 1 Introduction

This supporting document details how the failures in academic research that were noted in *Loading* the DICE against Pensions occurred. We start with the issue of why the errors we identified were not picked up by peer review.

# 2 A failure of peer review

Advisory firms and government authorities have justifiably relied upon the peer-reviewed economic literature on climate change, implicitly accepting that the refereeing process ensured that published papers met scientific standards.

Unfortunately, the refereeing process for the economics on climate change failed, for two primary reasons.

Firstly, the economic impact of climate change is a cross-disciplinary topic, involving both Climate Science and Economics. In an ideal world, both climate scientists and economists would have been approached to referee papers in this area. Scientists would have evaluated the strictly earth-sciences aspects of the papers—such as Nordhaus's 1991 assumption that 87% of the USA's GDP would be unaffected by global warming, because it took place in "carefully controlled environments" (Nordhaus 1991, p. 930)—and economists would have evaluated the economic aspects.

However, in the real world, editors of economic journals almost exclusively ask economists to referee papers, including those on the economics of climate change. Consequently, papers that should have been rejected for their obvious lack of understanding of the science of climate change were passed by referees who, as economists rather than climate scientists, also lacked a scientific understanding of climate change.

Secondly, peer review is not an ideal system. Locating referees for peer review is a demanding task for journal editors, who approach academics who have already published in an area to be referees for new papers in that area. Such academics have no obligation to comply, since refereeing is an unremunerated, voluntary activity.<sup>1</sup>

If a field is popular within the discipline, and has many active researchers, this does not necessarily lead to systemic problems: some academics will agree to referee, and there is a large pool of potential referees. But when the topic is unpopular in a field, with very few researchers undertaking it, then the refereeing process can be a way in which the views of the existing small group of researchers can be defended, rather than critically evaluated.

Given the seriousness of the issue, one might expect that this would not be a problem in climate change research. But in economics, *climate change is an unpopular topic*. Oswald and Stern reported that the most prestigious journal in economics, the *Quarterly Journal of Economics* (published by Harvard University), has published **no articles at all** on climate change.

How many articles has the famous QJE published on climate change? We are sorry to report that the answer is zero. This is fewer than the QJE has published on either baseball or basketball. (Oswald and Stern 2019a)

This was not a quirk of just one journal: as of August 2019, the top nine generalist economics journals had published a mere 57 papers on climate change, out of an estimated 77,000 articles (Oswald and Stern 2019a)—see Table 1. This amount to less than 0.1% of all articles published in these journals.

<sup>&</sup>lt;sup>1</sup> See <a href="https://www.chronicle.com/article/is-it-time-to-pay-peer-reviewers">https://www.chronicle.com/article/is-it-time-to-pay-peer-reviewers</a>.

TABLE 1: THE PAUCITY OF CLIMATE-CHANGE RESEARCH IN MAINSTREAM ECONOMIC JOURNALS (OSWALD AND STERN 2019A, TABLE 1)

Journal Name	Number of articles ever published on climate change
QJE (Quarterly Journal of Economics)	0
EJ (Economic Journal)	9
Review of Economic Studies	3
Econometica	2
AER (American Economic Review)	19
JEEA (Journal of the European Economic Association)	8
Economica	4
JPE (Journal of Political Economy)	9
AEJ-Applied (American Economic Journal - Applied Economics)	3

Oswald and Stern explain that consequently, working on the economics of climate change is seen by most economists, not as a way to advance their academic careers, but as a way to retard them. It is safer to pick other topics that journal editors and referees have indicated they are interested in:

the lack of climate-change research in economics stems, in large measure, from risk-aversion among younger (and some older) economists ... the reason there are few economists who write climate-change articles is because other economists do not write climate-change articles. (Oswald and Stern 2019b)

The consequence of this is that the group of economists who work on climate change—and most crucially, those who have developed numerical estimates of the impact of global warming on global GDP—is extremely small and tight-knit, so that neither their methods nor their estimates are independent. Even Richard Tol—the developer of the FUND IAM, editor of the journal Energy Economics, and a strident defender of the approach that mainstream economists have taken to climate change—quantified the trivial number of economists involved, and conceded that this tiny sub-group within economics could be subject to "group-think, peer pressure, and self-censoring":

it is quite possible that the estimates are not independent, as there are only a relatively small number of studies, based on similar data, by authors who know each other well...

marginal damage cost estimates are derived from total cost estimates... the 200-plus estimates of the social cost of carbon are based on nine estimates of the total effect of climate change...

although the number of researchers who published marginal damage cost estimates is larger than the number of researchers who published total impact estimates, it is still a reasonably small and close-knit community who may be subject to group-think, peer pressure, and self-censoring. (Tol 2009, pp. 37, 39, 42-43. Emphasis added)

Groupthink, peer pressure and self-censoring in turn mean that, once a proposition is made by a prominent member of the group, it tends to be preserved, rather than subjected to critical evaluation.<sup>2</sup>

<sup>&</sup>lt;sup>2</sup> Criticisms have been raised within the economics literature, but none of them have been heeded. See Section 11.2 on page 51 for a list of critical papers by economists.

# 3 Climate Change Groupthink

A recent survey of the opinions of economists on climate change by Howard and Sylvan, "Gauging Economic Consensus on Climate Change" (Howard and Sylvan 2021), unwittingly exposes the scale of groupthink amongst the mainstream economists working on climate change, both in the questions it posed, and the answers they received.

Howard and Sylvan contacted 2169 economists with publications on climate change in "the top 25 economics journals, top seven environmental economics journals, and top seven development economics journals" (Howard and Sylvan 2021, p. 6), and received responses from 738 of those—a 34% response rate. Their crucial question was Q11, which asked them to estimate the impact on GDP of temperature rises of 1.2, 3, 5 and  $7^{\circ}\text{C}$ —see Figure 1. About 40% of the respondents answered this question, and their predictions are shown in Figure 13. The median predictions were that  $5^{\circ}\text{C}$  of warming would reduce GDP by 10%, and  $7^{\circ}\text{C}$  would reduce it by 20%, relative to what it would have been in the absence of global warming.<sup>3</sup>

In contrast, climate scientists have described 2°C of warming as a temperature at which "tipping cascades" could occur, leading to conditions that would be "inhospitable to current human societies" (Steffen et al. 2018, pp 8253-4), while they have described more than 5°C as "unknown, implying beyond catastrophic, including existential threats" (Xu and Ramanathan 2017, p. 10315). This survey thus quantifies the "huge gulf" noted by Lenton "between natural scientists' understanding of climate tipping points and economists' representations of climate catastrophes in integrated assessment models (IAMs)" (Lenton and Ciscar 2013, p. 585).

 $<sup>^3</sup>$  The temperature changes considered, as summarized by Tol (Tol 2022, Table 1), ranged from minus  $0.6^{\circ}$ C (i.e., a fall in global average temperature) to plus  $16.7^{\circ}$ C, while the changes to GDP at the end date ranged from plus 5.1% to minus 78.9%. For temperature increases of between  $4-6^{\circ}$ C, the estimates of effect on future GDP, compared to GDP in the absence of climate change, ranged from plus 5.6% to minus 16.1%. These figures were generated by Tol, and often cannot be found explicitly in the source papers. Tol's numerical summaries of the literature are relied upon by other researchers, despite frequent criticism of his work, and past corrections of his errors by journals (Gelman 2014, 2015, 2019; Editors 2015).

# FIGURE 1: QUESTION 11 IN (HOWARD AND SYLVAN 2021) ASKING ECONOMISTS TO QUANTIFY EXPECTED DAMAGES FROM GLOBAL WARMING<sup>4</sup>

#### Climate Damage Estimates

Q11. Please provide your best estimates for how the following climate scenario would affect global GDP over time.

Please enter your median/ $50^{th}$  percentile estimate and your  $95^{th}$  percent confidence interval of the impact on global output. To avoid (over)confidence and anchoring biases, please fill out the  $95^{th}$  percent confidence interval before selecting the 50th percentile.

Please include <u>non-market</u> and <u>market</u> impacts, and factor in <u>adaptation</u> to climate change and its corresponding costs. Please also consider the <u>level of global GDP</u> and <u>rate of temperature change</u>, in addition to overall temperature change (some researchers theorize that society is more capable of adapting to climate change with slower rates of temperature change and/or higher levels of global economic output).

Please provide your answer as a % of global GDP. If you believe these impacts will increase GDP rather than decrease it, please indicate this with a (+).

Scenario	Scenario 1 - 2025	Scenario 1 - 2075	Scenario 1 - 2130	Scenario 1 - 2220
Year	2025	2075	2130	2220
Temperature increase (relative to pre-industrial era)	1.2°C	3°C	5°C	7°C
Average annual temperature increase over previous 30 years	0.03°C	0.04°C	0.03°C	0.01°C
Estimated global GDP without climate change (trillions in 2019 USD)	173.3	595.1	1430.4	3654.5

	Scenario 1 - 2025 Climate Damage (% of GDP)	Scenario 1 - 2075 Climate Damage (% of GDP)	Scenario 1 - 2130 Climate Damage (% of GDP)	Scenario 1 - 2220 Climate Damage (% of GDP)
5 <sup>th</sup> Percentile				
50th Percentile				
95 <sup>th</sup> Percentile				

#### FIGURE 2: MEDIAN AND MEAN RESPONSES TO Q11

## **Climate Damage Estimates**

Year	2025	2075	2130	2220
Temperature increase (relative to pre-industrial era)	1.2°C	3°C	5°C	7°C
Economic damages (% of global GDP) - Median estimate	-1%	-5%	-10%	-20%
Economic damages (trillions of 2019 USD) - Median estimate	-\$1.7	-\$29.8	-\$143.0	-\$730.9
Economic damages (% of global GDP) - Mean estimate	-2.2%	-8.50%	-16.10%	-25.20%
Economic damages (trillions of 2019 USD) - Mean estimate	-\$3.8	-\$50.6	-\$230.3	-\$920.9
Standard deviation	2.9	7.6	13.3	20.7

Results above reflect the trimming of outlier estimates below the  $5^{th}$  percentile or above the  $95^{th}$  percentile of total responses.

<sup>&</sup>lt;sup>4</sup> Q11's estimates of GWP in the absence of global warming come from Nordhaus's DICE-2016 model.

These answers imply that economic growth will continue, even at levels of global warming at which scientists argue that no human society would be feasible. They also imply a trivial impact of global warming—even of  $7^{\circ}$ C—on the average annual rate of economic growth.

TABLE 2: SURVEY MEDIAN ESTIMATES OF THE IMPACT OF GLOBAL WARMING (GW) ON THE GROWTH RATE OF GWP

		Annual Average Growth Rate from 2025			
Year	GW in °C	Without GW (from DICE)	With GW (survey median)	Difference	
2025	1.2				
2075	3	2.48%	2.46%	0.015%	
2130	5	1.34%	1.33%	0.017%	
2220	7	0.82%	0.80%	0.021%	

The median estimate, that global warming will reduce the average annual rate of economic growth by a mere 0.02% (see Table 2), puts numerical flesh on the comment made by one respondent to Nordhaus's 1994 survey, that "it takes a very sharp pencil to see the difference between the world with and without climate change or with and without mitigation" (Nordhaus 1994a, p. 48): 0.02% is well below the margin of error in the measurement of today's annual rate of economic growth.

This survey also helps explain the failure of the refereeing process noted in the previous section. The responses of 276-301 economists to this specific question (Howard and Sylvan 2021, p. 42) is statistically representative of the opinions that the 2169 economists they surveyed have about the economic impact of global warming. This same cohort would be approached by journal editors to referee papers on the economics of global warming.

Finally, though the absolute number of economists whom Howard and Sylvan identified as having published on the economics of climate change is large, it is still a small fraction of the total population of academic economists. Though no definitive count of the number of academic economists exists, the website RePEc (Research Papers in Economics) has 65 thousand registered authors. This implies that 2-3% of academic economists have published on the economics of climate change.

# 4 Confusing Climate and Weather

A key failing in the economic literature is an identification of "exposed to damages from climate change" with "exposed to damages from the weather".

Nordhaus's 1991 paper "To Slow or Not to Slow: The Economics of The Greenhouse Effect", published in the prestigious *Economic Journal*—one of only 9 papers that this journal has ever published on climate change (see Table 1)— kicked off the practice of economists estimating the economic effects of climate change. In it, Nordhaus assumed that 87% of America's GDP—manufacturing, mining, utilities, retail and wholesale services, government, and finance—would be "negligibly affected by climate change", because these activities take place in "carefully controlled environments that will not be directly affected by climate change" (Nordhaus 1991, p. 930).

This is confusing weather with climate.<sup>5</sup> Since this is a widely shared confusion, we open with an explanation, by way of examples, of what climate change could actually entail.

Standard definitions of weather and climate, such as this one by the USA's NOAA, make it difficult to comprehend what climate change means:

Weather is what you see outside on any particular day... Climate is the average of that weather... when we are talking about climate change, we are talking about changes in long-term averages of daily weather. In most places, weather can change from minute-to-minute, hour-to-hour, day-to-day, and season-to-season. Climate, however, is the average of weather over time and space.

With this definition, global warming can seem innocuous, especially to people residing in colder countries like the UK: what's the problem with getting a few degrees warmer?

The problem is the structural and qualitative changes that higher temperatures could cause, and the threats they pose to the habitability of the planet. We give three examples: the destruction of the ozone layer, which would jeopardise the habitability of the planet (especially the USA and the Northern Hemisphere); the collapse of the 3 tropospheric circulation cells (the Hadley, Ferrer and Polar cells) into one; and a global famine triggered by a weakening in the Atlantic Meridional Overturning Circulation (the "Gulf Stream"). According to scientific research, all these events could occur within the investment horizon of people alive today.

# 4.1 The ozone layer and Arctic summer sea-ice

The main author of "Coupling free radical catalysis, climate change, and human health" (Anderson and Clapp 2018)<sup>6</sup> is <u>Dr James Anderson</u>, who is Professor of Atmospheric Chemistry at Harvard University. He was a leading figure in the successful campaign to close the hole in the ozone layer over Antarctica late last century. Anderson and Clapp argue that:

The complete loss of summer sea ice in the Arctic, which they expect to occur in the next ten
to twenty years (but see Zhang 2021)<sup>7</sup> will, in conjunction with an additional 75-80PPM of

<sup>&</sup>lt;sup>5</sup> It is also ignoring the extent to which manufacturing etc. rely on inputs from the natural world, especially that of energy. We discuss this topic in Chapter 7, starting on page 44.

<sup>&</sup>lt;sup>6</sup> The paper is open access; its short URL is shorturl.at/kmMR4.

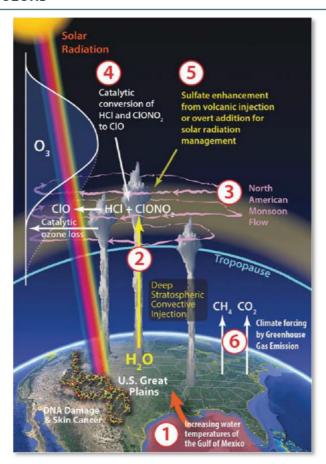
<sup>&</sup>lt;sup>7</sup> The linear trend in sea-ice volume decline that Anderson and Clapp extrapolated forward has continued, though the lowest volume was in 2017-see <a href="http://psc.apl.uw.edu/research/projects/arctic-sea-ice-volume-anomaly/">http://psc.apl.uw.edu/research/projects/arctic-sea-ice-volume-anomaly/</a>. The minimum Arctic summer sea ice area occurred in 2012, and the area has risen since then.

CO2, cause the current 3-cell circulation pattern in the Northern Hemisphere to break down into just one cell;

- This will increase the transportation of moisture from the troposphere into the stratosphere;
- This moisture will carry with it chlorine and bromide chemicals, which will cause a 100-fold increase in the rate of destruction of ozone—particularly over the continental United States;
- This decrease in ozone will have serious implications for the habitability of planet, especially the Northern Hemisphere, and particularly the United States.

This is not merely a hypothetical proposition, but an extrapolation from events that have already been observed by Anderson's research group. Global warming is already enabling storms that used to be restricted to the troposphere—thus keeping the stratosphere dry—to penetrate the stratosphere over the US Great Plains region (see Figure 3). This unexpected discovery is what motivated Anderson to form his ozone destruction hypothesis in the first place (Anderson and Clapp 2018, p. 10583).

FIGURE 3: FIGURE 7 FROM (ANDERSON AND CLAPP 2018, P. 10574) GLOBAL WARMING ENABLES STORMS OVER THE GREAT PLAINS TO TRANSPORT H₂O LACED WITH CHLORINE AND BROMIDE FROM THE TROPOSPHERE INTO THE STRATOSPHERE, WHERE THEY DRAMATICALLY ACCELERATE THE DESTRUCTION OF OZONE



Zhang explains that this is itself a nonlinear by-product of rising temperatures: the decline in sea-ice in the Arctic is the result of a dynamic between not only ice creation during winter and destruction of ice during summer, but also the "export" of ice from the Arctic ocean to other oceanic basins. The thinner ice being produced because of global warming is less prone to being exported by ocean currents to other oceans, and so the area retained in the Arctic has increased—though it is much thinner, so the volume decline trend has continued, but with substantial annual variation.

Anderson hypothesises that, when the North Pole no longer has sea ice during summer, and CO2 concentrations hit 500ppm (which, on current trends, will occur by 2050), the climate will be:

characterized by a very small temperature difference between the tropics and the polar regions; as well as a moist stratosphere that would lead ... to catastrophic stratospheric ozone loss globally... increasing the overall ozone loss rate by some two orders of magnitude over that of the unperturbed state (Anderson and Clapp 2018, p. 10570. Emphasis added).

Given the fragility of the ozone layer, this loss would have severe impacts on human health:

detailed medical research has demonstrated that a 1% reduction in column ozone concentration over the US translates to a 3% increase in new skin cancer cases each year... the incidence of skin cancer in the US has increased by 300% since 1992 to 3.5 million new cases a year. (Anderson and Clapp 2018, pp. 10582-3)

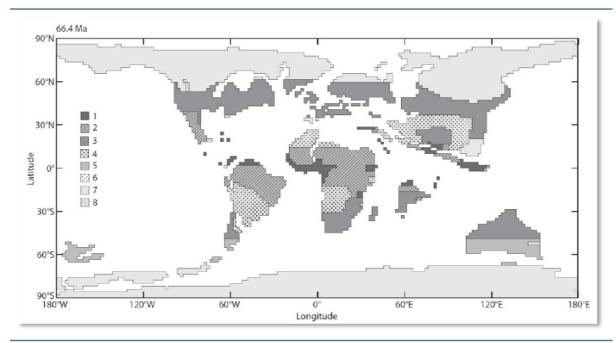
<u>Animal, plant and oceanic life would also be damaged</u>, with obvious flow-on implications for food production.

### 4.1.1 From 3 circulation cells to one?

The loss of the Northern Hemisphere's three circulation cells (the "Hadley Cell" from  $0-30^\circ N$ , the "Ferrer Cell" from  $30-60^\circ N$ , and the Polar Cell from  $60-90^\circ N$ ) and the transition to a single cell would have enormous implications for the sustainability of economic activity in the Northern Hemisphere in its own right. Anderson, as a specialist in the ozone layer, did not consider these. However, palaeontological research shows that the drastically different climate during a previous "equable climate" period supported a fundamentally different pattern of plant and animal life to that which has underpinned the development human civilisation during the Holocene.

In the late Cretaceous period, the USA and Europe were covered by tropical rainforests, while temperate evergreen broad-leaved and coniferous forests, which characterised these land masses before human sedentary agriculture developed, were confined to the southern extremities of Australia and South America (see Figure 4). A global-warming-induced rapid transition to such a different climate would occur faster than human agriculture can relocate, and far faster than topsoil can develop in the regions into which human civilisation would be pushed. This would lead to a collapse in food production.

FIGURE 4: FIG. 6.3. FROM (MICHAEL 2013, P. 114) "THE DISTRIBUTION OF VEGETATION TYPES OVER EARTH'S SURFACE DURING THE LATE CRETACEOUS AS INFERRED FROM A MODEL GUIDED BY DATA. (1) TROPICAL RAINFOREST; (2) TROPICAL SEMIDECIDUOUS FOREST; (3) SUBTROPICAL BROAD-LEAVED EVERGREEN FOREST AND WOODLAND; (4) DESERT AND SEMIDESERT; (5) TEMPERATE EVERGREEN BROAD-LEAVED AND CONIFEROUS FOREST; (6) TROPICAL SAVANNAH (NOT USED HERE); (7) POLAR DECIDUOUS FOREST; (8) BARE SOIL. A LARGE AREA OF THE CONTINENTS CURRENTLY COVERED BY GRASSLANDS AND DESERTS WAS FORESTED DURING THE LATE CRETACEOUS"



Anderson may well be wrong about what will trigger the breakdown of the Northern Hemisphere's three circulation cells. Other researchers, using mathematical modelling techniques, estimated that the disappearance of Arctic summer sea ice would not be sufficient on its own, and that this climate flip would not happen, even under the IPCC's high-trajectory RCP8.5 scenario, until 2170 (Kypke, Langford, and Willms 2020, p. 399).

But what if Anderson is right, and this process occurs in the next 1-2 decades? Can we reverse it?

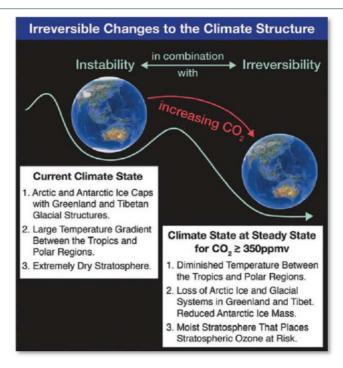
The answer, from Anderson and many other climate scientists (Lenton et al. 2008b; O'Riordan and Lenton 2013; Steffen et al. 2018; Lenton et al. 2019; Xu et al. 2020; Brovkin et al. 2021; Kemp et al. 2022), is a resounding no.

Even eliminating the industrial leakage of Chlorine and Bromide into the atmosphere wouldn't end the ozone depletion problem, because volcanoes generate Chlorine too (Johnston 1980). What matters is the change in the structure of the atmosphere that enables tropospheric moisture to penetrate the stratosphere. The only way to end that process would be to re-freeze the Arctic.

Not only is the scale of engineering needed to do this enormous, and the techniques unproven (Field et al. 2018), but the complete loss of Arctic summer sea ice could also increase temperatures by as much as would another 25 years of current CO2 emissions. The reversal of "the albedo effect", as the Arctic goes from reflecting 90% of solar energy during summer to absorbing 90% of it, could also trigger the release of CO2 stored in permafrost and ocean methane hydrates. Anderson estimates these systems contain more than twice as much carbon as is already in the atmosphere (Anderson and Clapp 2018, p. 10572). Their release could overwhelm anything we tried to do to refreeze the Arctic, even if this hypothetical technology could be successfully deployed at scale. The triggered release of these gases would therefore be unstoppable by human intervention.

Anderson illustrates this in Figure 5, where increasing  $CO_2$  tips the climate from its situation now, with ice caps on both poles and three distinct circulation cells, to another with no summer ice cap at the North Pole, and just one Northern Hemisphere cell. Once human action has pushed the biosphere over the hump, our current climate becomes unattainable by human action: there is no going back.

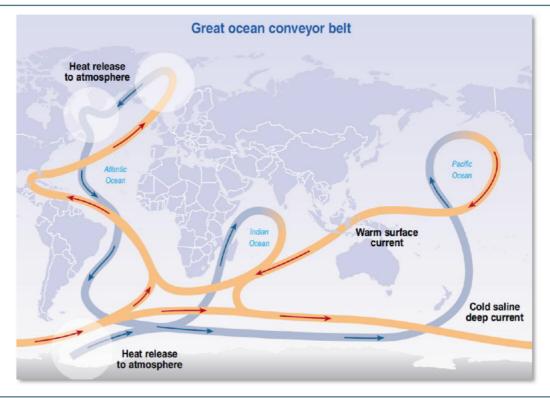
FIGURE 5: FIGURE 1 FROM (ANDERSON AND CLAPP 2018, P. 10570) "FIG. 1 THE CURRENT CLIMATE STATE CHARACTERIZED BY POLAR ICE SYSTEMS IN BOTH HEMISPHERES, A LARGE TEMPERATURE GRADIENT BETWEEN THE TROPICS AND THE POLAR REGIONS, IN COMBINATION WITH A VERY DRY STRATOSPHERE WILL, AS THE PALEO-RECORD DEMONSTRATES, TRANSITION TO A MARKEDLY DIFFERENT CLIMATE STATE AT CO2 MIXING RATIOS GREATER THAN ABOUT 350 PPMV. THAT NEW CLIMATE STATE, IN ADDITION TO MORE INTENSE STORM SYSTEMS, IS CHARACTERIZED BY A SHARPLY REDUCED TEMPERATURE GRADIENT BETWEEN THE TROPICS AND POLAR REGIONS, THE ABSENCE OF CRYO-SYSTEMS IN THE NORTHERN HEMISPHERE, MARKEDLY HIGHER SEA LEVELS AND A MOIST STRATOSPHERE."



### 4.1.2 Famine and the AMOC

The "Atlantic Meridional Overturning Circulation" (AMOC), which is often confused with the "Gulf Stream", is part of an enormous ocean circulation system known as the Thermohaline Circulation (THC), which is driven by temperature and salinity differences across the world's oceans—see Figure 6.

FIGURE 6: (WATSON AND IPCC 2001, FIGURE 4-2, P. 83 ) SCHEMATIC OF THE THERMOHALINE CIRCULATION



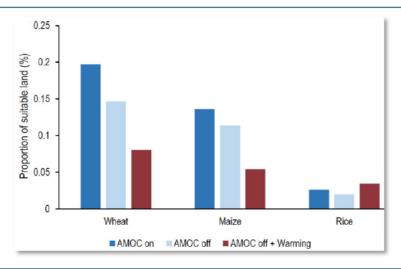
The AMOC is vulnerable to being "turned off" as ice melt reduces salinity in the north Atlantic. If this happened, it would cause "a drop of 3°C to 8°C in annual mean surface air temperature" in Europe (OECD 2021, p. 147), and also changes in the distribution of heat and precipitation across the globe. It has weakened by about 15% since the 1950s (Robson et al. 2014), and, while earlier studies concluded that its breakdown was unlikely this century (Lenton et al. 2008b, Table 1, p. 1788), the OECD decided that it was "as likely as not" (33-66% probability) at 1.5-2°C global warming above pre-industrial temperatures" (OECD 2021, p. 146).

In 2016, economists using the *FUND* IAM modelled 4 scenarios from a 7% to a 67% decline in the strength of the AMOC, and concluded that a 2/3rds fall in the strength of the AMOC would **boost** global incomes by 1.3%:

If the THC slows down a little, the global impact is a positive 0.2-0.3 percent of income. This goes up to 1.3 percent for a more pronounced slowdown. (Anthoff, Estrada, and Tol 2016, p. 604)

To put it mildly, the OECD was rather less optimistic. Its study of the AMOC in (OECD 2021) modelled its complete shutdown, in conjunction with global temperature reaching 2.5 °C above pre-industrial level. It then mapped the changed temperature and precipitation patterns across the globe against those needed for the cultivation of wheat, corn and rice. This mapping predicted that the fraction of the Earth's land surface that was suitable for wheat farming would drop from 20% to 7%; corn would drop from 14% to 6%, while the area suitable for rice would expand from 2% to 3%—see Figure 7.

FIGURE 7: (OECD 2021, FIGURE 3.20, P. 153)"BAR CHART SHOWING THE PERCENTAGE OF TOTAL LAND GRID BOXES SUITABLE FOR CROP GROWTH IN EACH SIMULATION"



The OECD Report concluded that:

an AMOC collapse would clearly pose a critical challenge to food security. Such a collapse combined with climate change would have a catastrophic impact. (OECD 2021, p. 151. Emphasis added)

The reason for the huge discrepancy between the results of the economists' study and that of the OECD's was that the OECD employed a set of GCMs ("Global Circulation Models"), which include the dynamics of precipitation as well as temperature. FUND, on the other hand, has a key weakness that it shares with all other IAMs: *it includes the effect of temperature change* on agricultural output (the main component of GDP modelled in IAMs, given the "carefully controlled environments" assumption) *but not precipitation*. The Dietz et al study on the economic impact of tipping points (Dietz et al. 2021a), discussed later in this document, relied exclusively upon (Anthoff, Estrada, and Tol 2016) for its evaluation of the impact of an AMC shutdown, and noted this shared weakness:

AMOC slowdown is expected to have physical effects other than temperature change, for instance effects on precipitation and regional sea levels (68), but these have yet to be incorporated in economic studies. (Dietz et al. 2021b, p. 25. Emphasis added)

With temperature as the only variable in its damage function, and the assumption that there was an optimum temperature for agriculture, *FUND* concluded that a reduced AMOC would be beneficial, because its cooling effect on Europe would counteract increased heat due to global warming:

The impact of warming (or cooling) depends on whether it pushes a country toward or away from its climate optimum... Global warming is assumed to be 3.2°C ... As the cooling is small relative to the assumed warming, and as 3.2°C of global warming would push most countries beyond their climate optimum, THC cooling is best seen as reduced warming. The effects on welfare are therefore by and large positive. (Anthoff, Estrada, and Tol 2016, p. 604)

Anthoff, Estrada, and Tol rationalised ignoring the impact of of climate change on precipitation thus:

Integrated assessment models often assume that other climate variables scale with temperature, but the relationship may be different for greenhouse warming and THC cooling. (Anthoff, Estrada, and Tol 2016, p. 605)

The assumption that "other climate variables scale with temperature" means that these economists explicitly assumed (and others in this literature implicitly assume) that, if temperature moves towards an optimum level, then so will precipitation. This is a manifestly false assumption, and the conclusions which emanate from it are easily dismissed. We are left with the conclusion of scientists, that an AMOC collapse would have "a catastrophic impact".

The remaining question is when this could be expected to happen. Early research by scientists into tipping points classified the AMOC as a gradual process, acting out on the timescale of a century, and requiring 3-5°C of global warming (Lenton et al. 2008b, Table 1, p. 1788). But recent empirical research (Rahmstorf et al. 2015; Robson et al. 2014), combined with models that treat the AMOC as a bi-stable system—having two primary states, with the system being able to be tipped from one to the other by increases in temperature and changes in salinity—has led to the conclusion that:

the recently discovered AMOC decline during the last decades is not just a fluctuation related to low-frequency climate variability or a linear response to increasing temperatures. Rather, the presented findings suggest that this decline may be associated with an almost complete loss of stability of the AMOC over the course of the last century, and that the AMOC could be close to a critical transition to its weak circulation mode. (Boers 2021, p. 687. Emphasis added)

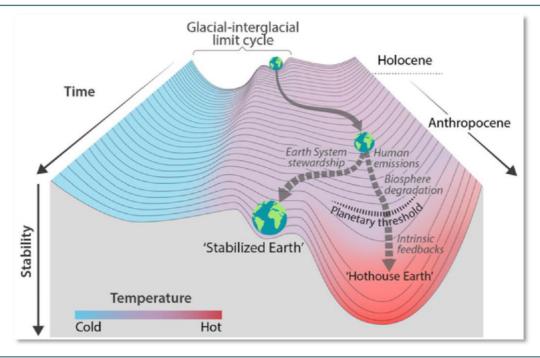
While a precise date for this transition cannot be given, scientific data collection and analysis since (Lenton et al. 2008b) implies that the time frame for this transition is in decades rather than centuries, and at levels of global warming well below 3°C. This carries the prospect of a global famine—with a potential decline of the order of 50-70% in wheat and corn production—within the investment horizon of today's pensioners.

### 4.1.3 Tipping Cascades and "Hothouse Earth"

These phenomena are instances of "tipping cascades", where a significant qualitative change in one system (the Arctic going from complete ice-cover during summer to no ice coverage) causes others (the release of permafrost carbon and ocean methane-hydrate methane), leading to a much hotter and qualitatively different climate that Steffen et al. christened "Hothouse Earth". This prospect presents humanity with a policy choice between a path leading to "Hothouse Earth", and a deliberately stabilised climate, as illustrated in Figure 8:

FIGURE 8: FIG. 2. IN (STEFFEN ET AL. 2018, P. 8254) "STABILITY LANDSCAPE SHOWING THE PATHWAY OF THE EARTH SYSTEM OUT OF THE HOLOCENE AND THUS, OUT OF THE GLACIAL—INTERGLACIAL LIMIT CYCLE TO ITS PRESENT POSITION IN THE HOTTER ANTHROPOCENE. THE FORK IN THE ROAD ... IS SHOWN HERE AS THE TWO DIVERGENT PATHWAYS OF THE EARTH SYSTEM IN THE FUTURE (BROKEN ARROWS). CURRENTLY, THE EARTH SYSTEM IS ON A HOTHOUSE EARTH PATHWAY DRIVEN BY HUMAN EMISSIONS OF GREENHOUSE GASES AND BIOSPHERE DEGRADATION TOWARD A PLANETARY THRESHOLD AT ~2°C ... BEYOND WHICH THE SYSTEM FOLLOWS AN ESSENTIALLY IRREVERSIBLE PATHWAY DRIVEN BY INTRINSIC BIOGEOPHYSICAL FEEDBACKS. THE OTHER PATHWAY LEADS TO STABILIZED EARTH, A PATHWAY OF EARTH SYSTEM STEWARDSHIP GUIDED BY HUMAN-CREATED FEEDBACKS TO A QUASISTABLE, HUMAN-MAINTAINED BASIN OF ATTRACTION. "STABILITY" (VERTICAL AXIS) IS DEFINED HERE AS THE INVERSE OF THE POTENTIAL ENERGY OF THE SYSTEM. SYSTEMS IN A HIGHLY STABLE STATE (DEEP VALLEY) HAVE LOW POTENTIAL ENERGY, AND CONSIDERABLE ENERGY IS REQUIRED TO MOVE THEM OUT OF THIS STABLE STATE. SYSTEMS IN AN UNSTABLE STATE (TOP OF A HILL) HAVE HIGH POTENTIAL ENERGY, AND THEY REQUIRE ONLY A

# LITTLE ADDITIONAL ENERGY TO PUSH THEM OFF THE HILL AND DOWN TOWARD A VALLEY OF LOWER POTENTIAL ENERGY"



If we fall into it, the "Hothouse Earth" system could persist "for tens to hundreds of thousands of years" (Steffen et al. 2018, p. 8253), and would "potentially lead to conditions that resemble planetary states that were last seen several millions of years ago, conditions that would be *inhospitable to current human societies* and to many other contemporary species" (Steffen et al. 2018, p. 8253. Emphasis added). Given the irreversible nature of these changes, and the drastic—possibly terminal—impact that they could have on human civilisation, Steffen et al. recommended a hard 2°C limit to the amount of global warming that should be tolerated:

We suggest 2°C because of the risk that a 2°C warming could activate important tipping elements (12, 17), raising the temperature further to activate other tipping elements in a domino-like cascade that could take the Earth System to even higher temperatures (Tipping Cascades). (Steffen et al. 2018)

That is what is meant by climate change over time—dramatic changes in the structure and volatility of the circulation systems of the biosphere, driven by human actions that significantly increase the amount of solar radiation trapped by the Earth's atmosphere. These huge qualitative changes in the biosphere could cause not merely a fall in GDP, but also could create conditions that are "inhospitable to current human societies".

The far more benign outcomes predicted by economists have ignored these existential risks, using empirical and modelling techniques that do not meet scientific standards.

# 5 Imaginary Numbers

for the bulk of the economy—manufacturing, mining, utilities, finance, trade, and most service industries—it is difficult to find major direct impacts of the projected climate changes over the next 50 to 75 years. (Nordhaus 1991, p. 932)

Lord Stern (Stern 2022, p. 1273) acknowledges that the estimation of the economic impact of climate change began with Nordhaus's paper "To Slow or Not to Slow: The Economics of The Greenhouse Effect" (Nordhaus 1991).<sup>8</sup> Nordhaus concluded that 3°C warming would reduce future global GWP (Gross World Product) by between 0.25% and 2%, relative to what global GWP would be if global warming did not occur:

We estimate that the net economic damage from a 3 °C warming is likely to be around ¼% of national income ... We might raise the number to around 1% of total global income to allow for these unmeasured and unquantifiable factors, although such an adjustment is purely ad hoc. ... my hunch is that the overall impact upon human activity is unlikely to be larger than 2% of total output. (Nordhaus 1991, pp. 932-3. Emphasis added).

Three decades later, after about 50 more studies of the total economic costs of climate change had been undertaken (Tol 2022), the economics chapter of the <u>IPCC's Sixth Assessment Report</u>, "Key Risks across Sectors and Regions", predicted a 10-23% fall in GDP from 4°C of warming by 2100:

With historically observed levels of adaptation, warming of  $\sim 4^{\circ}$ C may cause a 10–23% decline in annual global GDP by 2100 relative to global GDP without warming, due to temperature impacts alone. (IPCC 2022, p. 2459)

Since economists also assumed that economic growth would continue over this 80-year period, this 10-23% decline would still result in a per capita GDP of the order of four times higher than today, rather than (say) five times larger in the absence of global warming. Though the economic damage estimates in the last IPCC report are higher than those implied by Stuart Kirk (then HSBC head of responsible investment, now a Financial Times columnist) in <a href="https://doi.org/10.1007/jib.2007/jib.

The first argument they often give is that it's going to hurt future growth... The common argument used even by the IPCC is that it's going to hit GDP in ... 2100... Their worst-case models lop off 5 [% from GDP in 2100]. What they fail to tell everybody of course, is between now and 2100 economies are going to grow a lot... The world is going to be between 500 and 1000% richer... if you lop 5% off that in 2100, who cares? You will never notice. (Kirk 2022)

Economists generated these hypothetical numbers for future GDP with global warming using a range of empirical methods that do not stand up to scientific scrutiny.

<sup>&</sup>lt;sup>8</sup> Cline's book The Economics of Global Warming (Cline 1992), which Stern also acknowledges as a pioneering contribution, made similarly trivial predictions of economic damages from climate change: "Overall, damages suffered in the United States for 2.5°C warming would be close to 1% of GDP. Intangible losses, particularly species loss but also human disamenity, could raise the costs to 2% of GDP". (Cline 1992, p. 6) <sup>9</sup> Tol's paper says there were 33 studies in total—" Table 1 shows 61 estimates, from 33 studies" (Tol 2022, p. 2)—but his Table 1 list 39 (Tol 2022, Table 1, p. 19). There are also additional estimates using different methods noted by Tol, bringing the total number of studies to about 50.

These methods have been categorised as:

- Enumeration;
- Expert elicitation, using personal and literature surveys;
- Statistical, cross-sectional or econometric studies, with two sub-groups:
  - · Correlations of regional temperature today with income today; and
  - Correlations of change in temperature over the last 50 years with income or the change in income over the last 50 years; and
- Model output (generally, but not exclusively, "Computable General Equilibrium" models).

Had the papers applying these methods been refereed by climate scientists, it is feasible that all of them would have rejected, primarily because they are based upon serious misunderstandings of what global warming actually entails.

## 5.1 Enumeration—it's what you don't count that counts

The enumerative method was first used by Nordhaus in his seminal 1991 paper. It is innocuously described by Tol as involving putting monetary valuations on damage estimates from science papers:

estimates of the "physical effects" of climate change are obtained one by one from natural science papers ... The physical impacts must then each be given a price and added up. (Tol 2009, pp. 31-32)

What Tol does not say is that the method ignores any activities undertaken in what Nordhaus first described as "carefully controlled environments that will not be directly affected by climate change". Though Nordhaus gave two extreme examples—"cardiovascular surgery or microprocessor fabrication in 'clean rooms"—in practice, he applied this classification to 87% of America's GDP:

Table 5 [see Table 3 below] shows a sectoral breakdown of United States national income, where the economy is subdivided by the sectoral sensitivity to greenhouse warming. The most sensitive sectors are likely to be those, such as agriculture and forestry, in which output depends in a significant way upon climatic variables. At the other extreme are activities, such as cardiovascular surgery or microprocessor fabrication in 'clean rooms', which are undertaken in carefully controlled environments that will not be directly affected by climate change. Our estimate is that approximately 3% of United States national output is produced in highly sensitive sectors, another 10% in moderately sensitive sectors, and about 87 % in sectors that are negligibly affected by climate change. (Nordhaus 1991, p. 930. Emphasis added)

Table 3 is based on Nordhaus's Table 5, in which he *simply assumed* that the biggest sectors of the economy were "negligibly affected by climate change": all manufacturing and *mining*; non-water-based transportation and communication, the entire *FIRE* (Finance, Insurance and Real Estate) sector minus only coastal real estate, wholesale and retail trade, government services; and even the "Rest of the World".

TABLE 3: TABLE 5 FROM NORDHAUS 1991, P. 931: "BREAKDOWN OF ECONOMIC ACTIVITY BY VULNERABILITY TO CLIMATIC CHANGE"

	National income		
	Value	Percentage of	
	(billions)	total	
Sector			
Total National Income	2415.1	100	
Potentially severely impacted		3.1	
Farms	67.1	2.8	
Forestry, fisheries, other	7.7	0.3	
Moderate potential impact		10.1	
Construction	109.1	4.5	
Water transportation	6.3	0.3	
Energy and utilities			
Energy (electric, gas, oil)	45.9	1.9	
Water and sanitary	5.7	0.2	
Real Estate			
Land-rent component	51.5	2.1	
Hotels, lodging, recreation	25.4	1.1	
		2.5	
Negligible effect		86.9	
Manufacturing and mining	627.4	26	
Other transportation and communication	132.6	5.5	
Finance, insurance, and balance real	274.8	11.4	
estate			
Trade and other services	674.6	27.9	
Government services	337	14	
Rest of World	50.3	2.1	

The only thing these industries have in common is that they occur under cover (if one ignores, as Nordhaus evidently did in 1991, open-cut mining), and therefore they are not directly exposed to the weather. The industries he said would be "potentially severely impacted"—farming, forestry and fishing—are affected by the weather. Nordhaus therefore effectively equated being exposed to climate change to being exposed to the weather.

### 5.1.1 Follow the Leader

In keeping with the groupthink problem noted earlier, the assumption that indoor activities are sheltered from climate change has been replicated by all subsequent studies. The 2014 IPCC Report repeated Nordhaus's assertion that indoor activities will be unaffected. The only change between Nordhaus in 1991 and the IPCC Report 23 years later was that it no longer lumped mining in the "not really exposed to climate change" bracket:

FAQ 10.3 | Are other economic sectors vulnerable to climate change too?

Economic activities such as agriculture, forestry, fisheries, and mining are exposed to the weather and thus vulnerable to climate change. Other economic activities, such as manufacturing and services, largely take place in controlled environments

and are not really exposed to climate change. (IPCC et al. 2014, p. 688. Emphasis added)

The inclusion of mining was a concession to the fact that many mines today are open cut, as Nordhaus himself acknowledged in 1993 by noting that only "underground mining" was safe from climate change:

In reality, most of the U.S. economy has little direct interaction with climate... More generally, underground mining, most services, communications, and manufacturing are sectors likely to be largely unaffected by climate change—sectors that comprise around 85 percent of GDP" (Nordhaus 1993, p. 15. Emphasis added)

That said, none of the enumerative studies actually considered the impact of climate change on mining, while all the papers subsequent to Nordhaus in 1991 maintained his "carefully controlled environments" assumption: neither manufacturing, nor mining, transportation, communication, finance, insurance and non-coastal real estate, retail and wholesale trade, nor government services, appear in the "enumerated" industries in the "Coverage" column of Table SM10-1 of the 2014 IPCC Report (reproduced in Table 7 on page 64). \*\*In All these studies have simply assumed that these industries, which account for of the order of 85% of GDP, will be unaffected by climate change.

This confusion of weather with climate (and, believe it or not, also a confusion of time with space—see Section 5.3 on page 28) has been a feature of the analysis of climate change by Neoclassical economists ever since.

### 5.1.2 "Carefully controlled environments"

The proposition that "carefully controlled environments" can insulate economic activity from the effects of climate change is wrong on at least three fronts.

Global warming will cause:

The destruction of capital equipment

The most dramatic manifestation of climate change is the damage done to infrastructure from storms and fires that were made far stronger and/or frequent than they would have been without climate change, or which herald a transition from one localised climate—say, one suited to wheat farming—to another—say, a desert. The destruction of the small town of Lytton in Canada by wildfires triggered by temperatures that peaked at 49.6°C in July 2021 was a stark illustration of this.

<sup>&</sup>lt;sup>10</sup> Table 1 from (Tol 2022, p. 19) "Estimates of the comparative static impact on global economic welfare", shows no enumerative studies after 2013.

# FIGURE 9: PHOTO FROM THE GUARDIAN ARTICLE "'THERE'S NOTHING LEFT IN LYTTON': THE CANADIAN VILLAGE DESTROYED BY WILDFIRE - PICTURE ESSAY"



Stranded capital, from forced migration and deaths caused by climate change

Factories cannot operate without people. Deaths, and the forced migrations that are expected to result from global warming will leave the factories in those regions as stranded assets—perfectly capable of producing output, but lacking the employees needed to make that possible.

The unavailability of essential inputs, especially energy

Factories also cannot operate without essential inputs—especially energy (Keen, Ayres, and Standish 2019). At present, about 85% of the energy human civilisation consumes comes from fossil fuels. If climate change forces a significant reduction in energy usage before non-carbon-generating energy sources have dramatically reduced our dependence on fossil fuels, then production will plunge.

One would hope that such facts would be self-evident to economists, but courtesy of the assumption that a "carefully controlled environment" can protect you from climate change, these facts have been ignored. This has affected not only the manner in which economists have generated low numbers purporting to show the economic impact of climate change, but also the manner in which they have modelled the impact of global warming on the productive system that creates GDP: they have assumed that the machinery used to produce the output of the agricultural, industrial and services sectors will be unaffected by global warming.

#### 5.1.2.1 Impervious capital

Economists have normally assumed that climate change has no impact on capital equipment. They model global warming as affecting the output from the productive system—GDP, and especially consumption—but as leaving the productive apparatus itself unscathed.

DICE, the first "Integrated Assessment Model" (IAM), incorporated the damage done to the economy via a "damage function", and all subsequent IAMs have followed this approach. In keeping with his assumption that non-agricultural production was undertaken in "carefully controlled environments", Nordhaus modelled damages as applying to the output of his production function, but not to the

capital equipment that made that production possible. The rate of investment is affected, because part of current output adds to existing capital stock, but existing capital stock is treated as unaffected by climate change. Yumashev puts it this way in the latest specification of the PAGE model:

Possible endogenous effects of climate impacts on economic growth affecting the investment in the Solow model are not considered in the default PAGE setting, which means the impacts are assumed to be repaired in each year... the consumption-only approach (sometimes referred to as level effects of climate change, as opposed to growth effects) provides a conservative estimate for the climate impacts globally. (Yumashev 2020, p. 160)

[a] given country could experience either the level effects, short-term growth effects or persistent growth effects associated with climate impacts on economy ... we use a more conservative assumption that all the climate driven losses are fully repaired in the end of each year, which corresponds to the level effects. This implies that ... the impacts do not propagate beyond the year during which they occur. (Yumashev 2020, p. 182. Emphasis added)

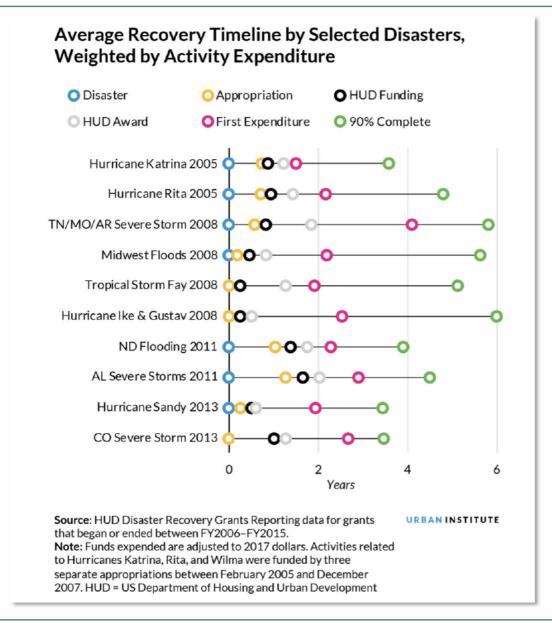
This is an empirically absurd assumption. For example, we know for a fact that the damage Katrina did to New Orleans was not repaired in 2005, but has lingered for decades:

"What started out as a natural disaster became a man-made disaster — a failure of government to look out for its own citizens," the president said in a speech at a newly opened community center in the Lower Ninth Ward, a predominantly black neighborhood that was devastated by Katrina. ("Obama: Katrina A 'Man-Made' Disaster Caused By Government Failure", NPR August 27 2015)

This is the norm, not the exception: the damage done by climate catastrophes—such as, in 2022, Cyclone Ian in Florida, and the floods in Pakistan and Australia—lingers for years, if not decades. The assumption that those damages are completely repaired in the year in which they occur is not a "simplifying assumption", but a counter-factual one.

Katrina, simplifying assumptions & lingering impacts - would be useful to pull data for US/global on average length of time from disaster to insurance payout. Research from US disasters shows some Govt schemes did not start distributing rebuilding funds until 20 months after the event, and were still distributing funds 20 months after that <a href="https://www.urban.org/urban-wire/why-does-disaster-recovery-take-so-long-five-facts-about-federal-housing-aid-after-disasters">https://www.urban.org/urban-wire/why-does-disaster-recovery-take-so-long-five-facts-about-federal-housing-aid-after-disasters</a>

FIGURE 10: SOURCE HTTPS://WWW.URBAN.ORG/URBAN-WIRE/WHY-DOES-DISASTER-RECOVERY-TAKE-SO-LONG-FIVE-FACTS-ABOUT-FEDERAL-HOUSING-AID-AFTER-DISASTERS



The parameters in these models were derived from assumptions that already dramatically downplayed the dangers of climate change—such as the enumerative method assumption that anything done under cover will be unaffected by climate change. The modelling assumption that climate change damages output, but not the machinery that produced that output, further minimises the forecast damages from climate change. This compounds the problem of the unrealistically low estimates of damages.

#### 5.1.2.2 Exogenous population and technology and capital growth

Similarly, population is modelled as if it will be unaffected by climate change. Nordhaus assumes that population will grow at a diminishing rate until it tapers to 11.5 billion people in the year 2500

### Supporting Document to the DICE against pensions: how did we get here?

(Nordhaus and Sztorc 2013b, p. 96).<sup>11</sup> Nordhaus's population function is unaffected by global warming.

In both PAGE and FUND, not only population but also GDP are exogenous variables:

**PAGE:** Future GDP and population projections in the 8 world regions follow exogenous scenarios from IPCC (SRES or SSPs). (Yumashev 2020, p. 160)

**FUND:** Population and per capita income follow exogenous scenarios... The FUND scenario is based on the EMF14 Standardised Scenario, and lies somewhere in between the IS92a and IS92f scenarios (Leggett et al., 1992). The other scenarios follow the SRES A1B, A2, B1 and B2 scenarios (Nakicenovic and Swart, 2001), as implemented in the IMAGE model (IMAGE Team, 2001). (Tol and Anthoff 2022, http://www.fund-model.org/MimiFUND.jl/latest/)

These are factors that consumers of this research would rightly expect to be *outputs* of these models—in other words, that they should be *endogenous* variables, which are determined in large part by the future impacts of climate change. Instead, these models show climate change as damaging part of the output of the productive system, but the system itself is assumed to sail through unscathed. Similarly, global population, though it is distributed differently between regions in some models because of climate change, is still assumed to continue growing regardless of climate change in both DICE and the SSP (Samir et al. 2010; Crespo Cuaresma 2017).

All these AlMs use the well-known "Cobb-Douglas Production Function" (Cobb and Douglas 1928),<sup>12</sup> in which GDP is generated by a combination of technology, capital, and labour. In DICE, technology is assumed to grow at a declining rate over time, without being affected by global warming. In the SSP, technology growth is a function of demographics and the convergence of economic growth rates (Crespo Cuaresma 2017, p. 5). In both DICE and the SSP therefore, population and capital are assumed to be unaffected by global warming—see Figure 11.<sup>13</sup>

<sup>&</sup>lt;sup>11</sup> Though the DICE manual gives a maximum value of 10.5 billion people, the latest version of DICE (DICE2016R-091916ap.gms) uses 11.5 billion.

<sup>&</sup>lt;sup>12</sup> DICE uses a standard Cobb-Douglas Production Function (CDPF); the SSP uses a modified CDPF with two ages groups and 4 education levels for workers (Crespo Cuaresma 2017, p. 4).

<sup>&</sup>lt;sup>13</sup> Investment is damaged in DICE by the small reduction in GDP from climate damages, but existing capital stock is assumed to be unaffected.

FIGURE 11: FUTURE POPULATION AND GDP LEVELS ARE ASSUMED IN THE IMAGE IAM (AND HENCE SSP) <a href="https://models.pbl.nl/image/index.php/drivers/model\_drivers">https://models.pbl.nl/image/index.php/drivers/model\_drivers</a>

Driver	Description	Source	Use	
Population pro		Source	USE	
Population	Number of people per region.	UN > Energy supp future: exogenous input > Agricultural economy > Climate polic > Energy dema		
Population - grid	Number of people per gridcell (using downscaling).	UN > Land-use own downscaling allocation > Nutrients > Flood risk > Human developm		
Urban population fraction	Urban/rural split of population.	UN > Human future: exogenous development input		
Economic deve	elopment			
Capital supply	Capital available to replace depreciated stock and expand the stock to support economic growth.	GTAP database	> Agricultural economy	
GDP per capita	Gross Domestic Product per capita, measured as the market value of all goods and services produced in a region in a year, and is used in the IMAGE framework as a generic indicator of economic activity.	World Bank database future: exogenous input	> Energy supply and demand > Agricultural economy > Human development > Climate policy > Emissions > Energy demand	
GDP per capita - grid	Scaled down GDP per capita from country to grid level, based on population density.	Own downscaling	> Nutrients > Flood risks > Ecosystem services	

With population, technology, and capital all assumed to be growing independently of climate change, both DICE and the SSP (and therefore PAGE and FUND) project that economic growth will continue, regardless of climate change. The different SSPs, and different country blocks, result in different growth rates across time and regions, but global warming is a factor in none of these variations—see Figure 12, where the lowest assumed average growth rate of per capita real GDP between 2010 and 2100 is 0.8% per annum. This, again, is the result of the assumptions made by

economists, in which the key factors that determine GDP—technology, capital and labour in their models—are unaffected by climate change. Since these assumptions are false, so are these forecasts of future growth.

FIGURE 12: THE SSP PROJECTIONS FOR GDP GROWTH RATES (CRESPO CUARESMA 2017, P. 13)

			High income	Middle income	Low income
	Period	World	countries	countries	countries
	2010-2040	3.2%	1.7%	4.8%	4.1%
SSP1	2040-2100	1.5%	1.3%	1.5%	2.7%
	2010-2100	2.1%	1.4%	2.6%	3.2%
	2010-2040	2.8%	1.6%	4.4%	3.1%
SSP2	2040-2100	1.2%	1.1%	1.3%	2.5%
	2010-2100	1.7%	1.3%	2.3%	2.7%
	2010-2040	1.9%	0.9%	3.9%	1.7%
SSP3	2040-2100	0.3%	1.1%	0.5%	0.7%
	2010-2100	0.8%	1.0%	1.6%	1.0%
	2010-2040	2.2%	1.6%	3.8%	1.9%
SSP4	2040-2100	0.5%	1.1%	0.5%	1.5%
	2010-2100	1.1%	1.3%	1.6%	1.7%
	2010-2040	3.5%	1.9%	5.2%	4.6%
SSP5	2040-2100	2.2%	1.7%	2.2%	3.5%
	2010-2100	2.6%	1.7%	3.2%	3.9%

Table 4: World GDP per capita: Projected growth rates by income group and by SSP scenario

### 5.1.2.3 Production without energy

One of the most telling statements in this literature is the quote from Nordhaus which heads this Section:

for the bulk of the economy - manufacturing, mining, utilities, finance, trade, and most service industries - it is difficult to find major direct impacts of the projected climate changes over the next 50 to 75 years. (Nordhaus 1991, p. 932)

An obvious riposte here is that these industries rely upon inputs from the environment, and the fact that most of our energy is produced by burning fossil fuels is what is causing global warming. What will happen to GDP if climate catastrophes lead to the decision to terminate fossil fuel usage—or even to reduce it more aggressively?

IAMs like DICE, FUND and PAGE cannot tell us, because energy is not a factor in their models of production. Instead, they all follow conventional economic theory in showing output as a function of inputs of technology, labour, and capital (machinery)—but not of inputs from the natural world such as raw materials and energy. The equation for GDP in DICE and the SSP (on which both PAGE and FUND rely) is the "Cobb-Douglas Production Function" (CDPF), whose basic form 14 is shown below:

<sup>&</sup>lt;sup>14</sup> The actual form is  $Output = Technology \times Labour^{1-\alpha} \times Capital^{\alpha}$ , where the exponent a is based on capital's share of GDP. Economists habitually use  $\alpha = 0.3$ , but excellent empirical research by Gregory Mankiw showed that "when calibrating the neoclassical model, the capital share, a, should be set at about 0.8... a parameter value of this magnitude makes the neoclassical model conform much more closely to international experience" (Mankiw, Phelps, and Romer 1995, p. 294). This research has been ignored by

$$Output = Technology \times LabourFunction \times CapitalFunction$$
 (0.1)

Energy plays no role in these equations, <sup>15</sup> so it is basically treated as irrelevant. <sup>16</sup> But In the real world, as Keen et al. 2019 put it, "*labour without energy is a corpse, while capital without energy is a sculpture*" (Keen, Ayres, and Standish 2019, p. 41. Emphasis added). Nothing can be produced without energy, and since we rely upon fossil fuels for of the order of 85% of our energy, a climate-change-induced reduction in energy consumption would dramatically reduce GDP.

We return to this issue later, but the key point here is that the difficulty that Nordhaus felt in identifying "major direct impacts" on "manufacturing, mining, utilities, finance, trade, and most service industries" arose from a blindspot amongst Neoclassical economists about the role of energy in production, and not from any genuine insulation of these industries from the effects of climate change.

# 5.2 Surveys of economists on climate change

Nordhaus has conducted two surveys, one of individuals (Nordhaus 1994a), the other of academic literature (Nordhaus and Moffat 2017). Expert surveys are a legitimate research tool, especially in areas where hard data is unavailable (Lenton et al. 2008b, p. 1791). However, neither of Nordhaus's surveys met scientific standards.

The first survey was of 19 individuals, 10 of whom were economists, and 8 of whom Nordhaus described as coming from "other subdisciplines" of economics (those whose principal concerns lie outside environmental economics" (Nordhaus 1994a, p. 82).

The crux of the survey was a set of scenarios (labelled A to C) about the economic damages that his respondents expected from:

- 3 degrees warming by 2090;
- 6 degrees by 2175; and
- 6 degrees by 2090.

Donella Meadows, one of the three primary authors of the *Limits to Growth* (Meadows, Meadows, and Randers 2005; Meadows, Randers, and Meadows 1972), wrote to Nordhaus about this survey's key weaknesses:

Why was your survey sample weighted so outrageously in favor of economists? Why was there only one ecologist, when the integrity and adaptability of ecosystems is the central link between climate and economy? ... why did you impose your own discipline's bias on the entire survey by asking to measure consequences through impact on GWP? ... If I had been one of your

economic modellers—presumably because it undermines the Neoclassical theory of income distribution in which the wage equals the marginal product of labour.

<sup>15</sup> The manual for Nordhaus's DICE IAM claims that energy is an input to its production function: "Output is produced with a Cobb-Douglas production function in capital, labor, and energy. Energy takes the form of either carbon-based fuels (such as coal) or non-carbon-based technologies..." (Nordhaus and Sztorc 2013b, p. 10). However, this is incorrect. The actual equation in DICE is "YGROSS(t) =E= (al(t)\*(L(t)/1000)\*\*(1-GAMA))\*(K(t)\*\*GAMA)" (Nordhaus and Sztorc 2013b, p. 100), with technology, labour and capital, but no role for energy.

<sup>&</sup>lt;sup>16</sup> When economists do include energy, they add it on as a third factor, where the function used gives energy a very small role in production: "a drop in energy … of 10% reduces production by … 0.4%" (Bachmann et al. 2022, p. 3)

### Supporting Document to the DICE against pensions: how did we get here?

respondents, I would have estimated the impact of the scenario C as 200-500% of GWP.) ... (Meadows 1994)<sup>17</sup>

Nordhaus included numerous quotes from the economists and scientists <u>in his paper</u>, and these illustrate the extent to which economists assume that capitalism can cope with any shock, and therefore that climate change cannot be a major problem:

What might lead to such a difference in outlook? One respondent suggested whimsically that it was hardly surprising, given that the economists know little about the intricate web of natural ecosystems, whereas scientists know equally little about the incredible adaptability of human economies. (p. 48)

"global warming is way down the list of people's concerns, especially compared to the conventional economic concerns". (p. 48)

The second impression that arises from this survey is that for most respondents the best guess of the impact of a 3-degree-warming by 2090, in the words of respondent 17, would be "small potatoes". (p. 48)

"I am impressed with the view that it takes a very sharp pencil to see the difference between the world with and without climate change or with and without mitigation". (p. 48)

One was concerned that society's response to the approaching millennium would be akin to that prevalent during the Dark Ages, whereas another respondent held that the degree of adaptability of human economies is so high that for most of the scenarios the impact of global wanning would be "essentially zero". (p. 49)

One economist stated there would be little impact through ecosystems: "For my answer, the existence value [of species] is irrelevant—I don't care about ants except for drugs". (50)

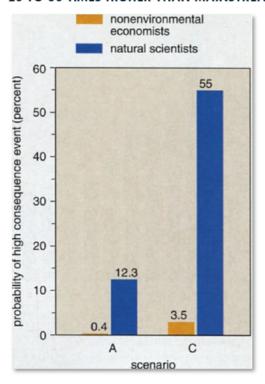
The scientists, on the other hand, were much more worried—so much so, that one of the three scientists Nordhaus surveyed refused to answer his questions linking degrees of global warming to economic damages, with the observation that:

"I marvel that economists are willing to make quantitative estimates of economic consequences of climate change where the only measures available are estimates of global surface average increases in temperature. As [one] who has spent his career worrying about the vagaries of the dynamics of the atmosphere, I marvel that they can translate a single global number, an extremely poor surrogate for a description of the climatic conditions, into quantitative estimates of impacts of global economic conditions." (51)

Referring to the two scientists who did answer those questions, Nordhaus noted that "Natural scientists' estimates were 20 to 30 times higher than mainstream economists" (see Figure 13).

<sup>&</sup>lt;sup>17</sup> Meadow's comment about damages reaching 200-500% of GDP is a reference to damages to the capital equipment and general infrastructure of the economy—factories, houses, roads, etc.—which is worth many times a single year's GDP. Notably, Nordhaus's DICE model and most IAMs assume that global warming will cause damages to GDP, but will not damage the capital stock that creates GDP.

FIGURE 13: FIGURE 4 FROM (NORDHAUS 1994A, P. 49). "DIFFERENCE IN ACADEMIC DISCIPLINE SEPARATED THOSE MAKING HIGH ESTIMATES OF THE ECONOMIC IMPACTS FROM GLOBAL WARMING FROM THOSE WHO WERE COMPARATIVELY UNCONCERNED. NATURAL SCIENTISTS' ESTIMATES WERE 20 TO 30 TIMES HIGHER THAN MAINSTREAM ECONOMISTS."



Despite Nordhaus's observation that "This difference of opinion is on the list of interesting research topics" (Nordhaus 1994a, pp. 49-50), his subsequent literature survey (Nordhaus and Moffat 2017) compounded these weaknesses by exclusively surveying economic literature. A later paper (Peter Harrison 2020) was also a survey of economists only on climate change. None of these surveys were therefore able to explore the enormous gap that Nordhaus himself identified between the expectations of scientists about economic damages from climate change, and those of economists.

## 5.3 Equating time and space

Nordhaus conflated the variation of climate at a point in time across the globe, with climate change over time, in the statement that:

First, it must be recognised that human societies thrive in a wide variety of climatic zones. For the bulk of economic activity, non-climate variables like labour skills, access to markets, or technology swamp climatic considerations in determining economic efficiency. (Nordhaus 1991, p. 930)

If this paper had been refereed by scientists, this statement would have been a red flag: it is true, but irrelevant to climate change. But in economics, this statement was passed by referees for *The Economic Journal*, which is arguably the second-most prestigious journal in economics.

Subsequently, the assumption that data on economic activity and climate at a point in time could be used to proxy the impact of global warming on the economy over time was added to the means by which economists generated numbers purporting to predict the impact of global warming on the economy. Tol acknowledges Mendelsohn as the first economist to apply this assumption:

### Supporting Document to the DICE against pensions: how did we get here?

Mendelsohn's work (Mendelsohn, Morrison, Schlesinger, and Andronova, 2000; Mendelsohn, Schlesinger, and Williams, 2000) can be called the statistical approach. It is based on direct estimates of the welfare impacts, using observed variations (across space within a single country) in prices and expenditures to discern the effect of climate. Mendelsohn assumes that the observed variation of economic activity with climate over space holds over time as well; and uses climate models to estimate the future effect of climate change. (Tol 2009, p. 32. Emphasis added)

Tol expresses surprise that the numbers generated by this method are similar to those produced by the enumerative method, and treats this as a form of confirmation: "Given that the studies ... use different methods, it is striking that the estimates are in broad agreement on a number of points" (Tol 2009, p. 33). This is specious, since several of the statistical studies also made the enumerative method assumption that only industries exposed to the weather would be affected by climate change:

This book applies advanced economics methodologies to assess the impact of climate change on potentially vulnerable aspects of the US economy: agriculture, timber, coastal resources, energy expenditure, fishing, outdoor recreation. (Mendelsohn and Neumann 1999, Book sleeve note. Emphasis added)

GIM is a spreadsheet model that begins with a country specific set of climate changes and then predicts market impacts. A separate model is designed for each sensitive market sector: agriculture, forestry, energy, water, and coastal structures. A separate calculation is made for each sector and country that combines the change in climate, sector data, and a climate-response function. This leads to calculations of damages or benefits by sector and country. (Mendelsohn, Schlesinger, and Williams 2000, p. 39. Emphasis added)

The response functions to climate change in GIM are based on empirical studies that have been carefully designed to include adaptation by firms and people to climate change. Separate response functions are estimated for agriculture, forestry, coastal resources, commercial and residential energy, and water. (Mendelsohn et al. 2000, p. 557. Emphasis added)

The most obvious problem with this method is simple: space is not time! Data about the correlation between income today (or life satisfaction: Maddison 2003; Rehdanz and Maddison 2005; Maddison and Rehdanz 2011) and temperature today tell us nothing about the impact of climate change on income in the future.

For those to whom this is not obvious, there is a clear statistical flaw in comparing the income levels of a warm and a cold location today as a function of temperature today: *these incomes are not independent*.

Alaska's income depends on Maryland's climate, because "exports" from Alaska to Maryland (and other U.S. states, and the rest of the world) and vice-versa enable Alaskans to prosper in its harsh, cold environment. Similarly, Florida residents eat grain products produced in lowa, and generate some of the income needed to buy that grain by tourism from lowa (and the rest of the world). To quote Tol, "Climate is not a primary driver of income" *today* only because trade across space enables the economy of a given region to reach a size that would be impossible if it had to produce all its needs locally.

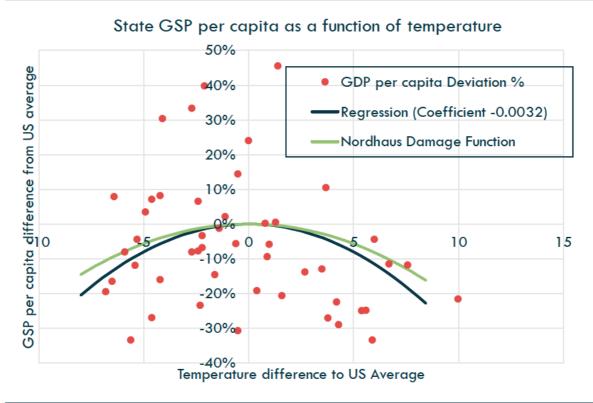
The only way that this statistical approach could even begin to approximate the economic effects of global warming over time would be if the statistics were restricted to those products which could be produced and consumed within each State: then the relationship between a State's income and

its average temperature would depend on its temperature alone, and not be boosted by sales to other colder, hotter or more temperate climes. If this were done, it is likely that the incomes of Florida and Alaska would be much lower than those of Maryland and lowa, and a much steeper relationship would have been found between income and GDP.

This was not done by these economists, so that they found a very weak relationship between temperature today and income today—which they then treated as a proxy for what global warming would do to the economy. Like the enumerative method, with its assumption that anything done under cover would be unaffected by climate change, this resulted in trivial estimates of the economic impact of global warming.

Figure 14 gives an illustrative example of this method, using USA temperature data by State and Gross State Product per capita as the inputs. <sup>18</sup> The x-axis shows the deviation of each State from the USA average temperature, and the y-axis the deviation of each State GSP per capita from the USA average. The red dots are the data; the black line is a pure quadratic fitted to the data (the green line is Nordhaus's damage function from Nordhaus 2018). Used as a proxy for the impact of global warming, this quadratic fit yields the "prediction" that a 6°C increase in global temperature would reduce per capita income by 11.5%.

FIGURE 14: EXAMPLE OF "THE CROSS-SECTIONAL METHOD" USING USA STATE GSP PER CAPITA DATA



As low—and as irrelevant to climate change—as this is, it is a *higher* prediction of damages than given by Nordhaus's DICE model, in which his damage function  $D(\Delta T)$  is also a pure quadratic:

<sup>&</sup>lt;sup>18</sup> Temperature data is taken from <a href="https://www.currentresults.com/Weather/US/average-annual-state-temperatures.php">https://www.currentresults.com/Weather/US/average-annual-state-temperatures.php</a>. Gross State Product data comes from the BEA (<a href="https://apps.bea.gov">https://apps.bea.gov</a>); State population data is taken from the US Census.

$$D(\Delta T) = -0.00227 \times \Delta T^2 \tag{0.2}$$

The fact that, following Nordhaus, most IAMs also use quadratics for their damage functions, can be used to point out why this "data" has nothing to do with climate change. Quadratics are symmetric, and therefore provide predictions for the economic impact of "global cooling" as well as global warming. Nordhaus's damage function predicts that a 5°C decrease in global average temperature—which would return the world to the temperatures of the last Ice Age—would reduce GDP by less than 5%. This is absurd: that much global cooling would put the North America north of New York under a kilometre of more of ice. It would therefore have somewhat more than a 5% deleterious impact on GDP.

The core weakness of this method—treating space as a proxy for time—was admitted by some economists working on climate change:

Firstly, the literature relies primarily on the cross-sectional approach (see, for instance, Sachs and Warner 1997, Gallup et al. 1999, Nordhaus 2006, and Dell et al. 2009), and as such does not take into account the time dimension of the data (i.e., assumes that the observed relationship across countries holds over time as well). (Kahn et al. 2019, p. 2. Emphasis added)

the literature that relies on the cross-sectional approach (e.g., Sachs and Warner, 1997, Gallup et al., 1999, Nordhaus, 2006, and Kalkuhl and Wenz, 2020) is hindered by the temporal invariance of climate over the studied time-frames (Kahn et al. 2021, p. 2. Emphasis added)

That led to the next statistical technique, of deriving a relationship between the change in temperature and change in GDP over time in existing data. While this resulted in generally larger damage estimates, this technique—which we call the Extrapolative Method—is still flawed in both concept and execution.

# 5.4 Extrapolating sub-1°C economic & temperature data

Whereas the cross-sectional method derives a nonlinear—and typically quadratic—relationship between temperature and GDP today, and uses that quadratic function to predict the impact of global warming on the level of GDP, the Extrapolative Method derives a nonlinear statistical relationship between the change in temperature and change in GDP over the period from the 1960s till the 2010s—also typically quadratic, though sometimes cubic or piecewise linear—and then extrapolates this relationship forward in time (and, given global warming, temperature) to predict changes in the rate of growth of per-capita income or consumption:

we test the predictions of our theoretical growth model using cross-country data on per-capita GDP growth and deviations of temperature and precipitation from their moving average historical norms over the past fifty-five years (1960–2014).... if temperature rises (falls) above (below) its historical norm by 0.01\$ °C annually for a long period of time, income growth will be lower by 0.0543 percentage points per year. (Kahn et al. 2021, pp. 2-3)

Extrapolation has been linear is all these studies. This in evident in (Kahn et al. 2021) from the shaded area in Figure 15. This assumes that there will be no structural break in climatic variables between now and 2100, which is clearly an untenable assumption.

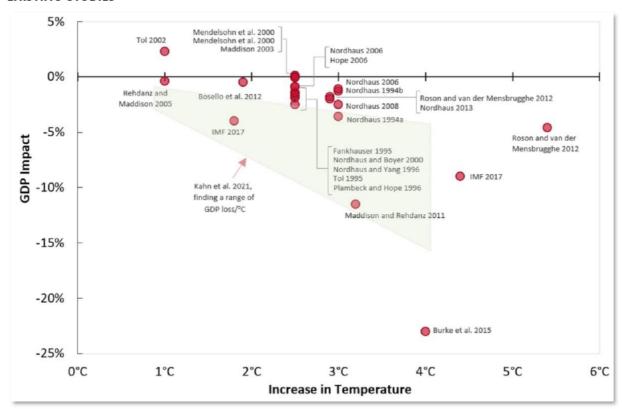


FIGURE 15: FIG. 2 IN KAHN ET AL. 2021 (P. 4), COMPARING THEIR EXTRAPOLATED RESULTS TO EXISTING STUDIES

Similarly, the most substantial prediction of economic damages from global warming in this entire literature—that "unmitigated warming" of 4°C will reduce global incomes by 23% by 2100—was generated by linearly extrapolating the 1960-2010 relationship between temperature and change in GDP out to 2100, via the assumption that "future adaptation mimics past adaptation":

We show that overall economic productivity is nonlinear in temperature for all countries, with productivity peaking at an annual average temperature of 13 °C and declining strongly at higher temperatures. ... If future adaptation mimics past adaptation, unmitigated warming is expected to reshape the global economy by reducing average global incomes roughly 23% by 2100. (Burke, Hsiang, and Miguel 2015a, p. 235. Emphasis added)

Burke et al. also imposed an arbitrary limit of 30°C on their extrapolations, on the intellectually unacceptable grounds that pure extrapolation (a) involved making out-of-sample predictions, and (b) led to higher damage estimates than they reported:

We do not know how economic production responds to temperatures that have never been observed historically. Thus, when countries warm beyond the highest observed temperatures in the historical data, we have two options: either we extrapolate the function h(.) beyond the support of historically observed data, or we assume that productivity is equal to the boundary value for all observations beyond the boundary of the support, i.e.  $h(T) = h(T_{max})$  for all  $T > T_{max}$ . We opt for the latter approach because we view it as more conservative, since extrapolation of h(.) causes income to fall even more rapidly at higher temperatures. We cap  $T_{it}^+$  at 30 °C, which is the upper bound of the annual average temperatures observed in our sample period." (Burke, Hsiang, and Miguel 2015b, p. 24. Emphasis added)

The justification that this procedure avoids out of sample prediction is moot, since out-of-sample prediction is the entire point of attempting to quantify the relationship between global warming and economic activity. The decision not to publish the results of their extrapolation because "extrapolation of h(.) causes income to fall even more rapidly at higher temperatures" is also unscientific: what is required is not "more conservative" estimates of the economic damages of climate change, but more accurate ones.

### 5.5 Using models to generate empirical data

Several of the data points in economists have used to calibrate their models of the economic damages from climate change have themselves been generated by models of the economic damages from climate change (Stanton, Ackerman, and Kartha 2009) (Warren et al. 2021; Roson and Mensbrugghe 2012; Bosello, Eboli, and Pierfederici 2012), which were calibrated on the estimates by economists of the economic damages from climate change. The circularity of this process should be evident.

These studies have also produced the lowest estimates of damages from climate change, relative to the temperature increase being considered. Bosello et al. explain that this is because these models were calibrated to "bottom-up, partial equilibrium estimates" and the "market-driven adaptation" in general equilibrium "... partly reduces the direct impacts of temperature increases, leading to lower estimates". (Bosello, Eboli, and Pierfederici 2012, p. 20)

### 5.6 Tipping points

Papers that have attempted to summarize the findings of studies of tipping points in the climate science literature (Kemp et al. 2022; Song et al. 2021; Brovkin et al. 2021; Xu et al. 2020; Lenton et al. 2019; Lenton and Ciscar 2013; Lenton et al. 2008b; Hansen et al. 2015; Steffen et al. 2018) have coalesced on treating 2-3°C as the range in which climatic discontinuities caused by global warming will make the future climate both unpredictable from today's climate, and possibly inimical to the continued existence of human civilisation (with the caveat that some significant tipping elements—especially Arctic summer sea ice (Lenton et al. 2008b, p. 1789), but also perhaps the Greenland (Boers and Rypdal 2021) and West Antarctic ice sheets—may already have been tipped).

Hansen described 2°C of warming as "dangerous" (Hansen et al. 2015, p. 20059); Steffen et al. "suggest 2°C because of the risk that a 2°C warming could activate important tipping elements, raising the temperature further to activate other tipping elements in a domino-like cascade that could take the Earth System to even higher temperatures (Tipping Cascades)" (Steffen et al. 2018, p. 8254); Lenton et al. stated that "tipping points could be exceeded even between 1 and 2°C of warming" (Lenton et al. 2019, p. 592); and a recent survey paper declared that:

Academic studies have warned that warming above 5 °C is likely to be "beyond catastrophic", and above 6 °C constitutes "an indisputable global catastrophe". ... We have set global warming of 3 °C or more by the end of the century as a marker for extreme climate change. (Kemp et al. 2022, pp. 3-4)

In contrast, an attempt by economists to quantify the economic impact of tipping points focused solely on research by economists (Dietz et al. 2021a), and reduced the impact of tipping points to a small additional increase in the global average temperature. It concluded that triggering 8 major tipping points— Arctic summer sea ice, the Greenland and West Antarctic Ice Sheets, the Atlantic

### Supporting Document to the DICE against pensions: how did we get here?

Meridional Overturning Circulation, the Amazon Rainforest, Permafrost, Ocean Methane Hydrates, and the Indian Monsoon —would add only a modicum of additional damages to those caused by temperature change alone: a 1% increase in damages at 3°C, and 1.4% at 6°C:

Tipping points increase the temperature response to GHG emissions over most of the range of temperatures attained ... **Using a second-order polynomial to fit the data**, 2°C warming in the absence of tipping points corresponds to 2.3°C warming in the presence of tipping points, for instance. ... Tipping points reduce global consumption per capita by around 1% upon 3°C warming and by around 1.4% upon 6°C warming, **based on a second-order polynomial fit of the data**. (Dietz et al. 2021a, p. 5. Emphasis added)

Keen et al. (Keen et al. 2022) note several failures by this paper to take account of weaknesses in the underlying studies. One of several weaknesses not covered in that letter<sup>19</sup> is the fact that IAMs consider only changes in temperature, ignoring changes in precipitation and other climatic variables:

AMOC slowdown is expected to have physical effects other than temperature change, for instance effects on precipitation and regional sea levels (68), but these have yet to be incorporated in economic studies. (Dietz et al. 2021a, p. 25. Emphasis added)

This paper is also exemplary of a systemic weakness in economic studies of climate change: the use of quadratic functions to extrapolate from current data, despite numerous criticisms of this practice by scientists and some other economists.

### 5.7 Quadratic extrapolation

One of the key aspects of this literature that other economists have attacked is the use of quadratic damage functions to predict damages from global warming. But despite sustained and cogent criticism of this practice (Pindyck 2017; Stanton, Ackerman, and Kartha 2009; Weitzman 2012b), three more papers using quadratic damage functions were published in 2021—including one purporting to predict the economic damages from tipping points (Dietz et al. 2021a; Kahn et al. 2021; Warren et al. 2021).<sup>20</sup>

Though the details vary from one "Integrated Assessment Model" (IAM) to another, the approach that economists have taken to climate change is to multiply an equation for GDP in the absence of climate change by a function of the predicted temperature increase:

 $GDP(TemperatureIncrease) = GDP \times DamageFunction(TemperatureIncrease)$ Nordhaus was the first economist to use this method in 1992—see Table 4.

<sup>&</sup>lt;sup>19</sup> The criticisms were limited by the 500-word limit to a letter to PNAS.

<sup>&</sup>lt;sup>20</sup> We explain why this is important in Section 5.4.

TABLE 4: NORDHAUS'S DAMAGE FUNCTION OVER THE YEARS

Year	Function	Parameter values
1992 (Nordhaus 1992)	1	c = 0.00144
	$\overline{1+c\times T^2}$	
1999 (Nordhaus and Boyer 1999)	1	b = 0.0045, c = 0.0035000
	$1+b\times T+c\times T^2$	
2008 (Nordhaus 2008b)	1	c = 0.0028388
2013 (Nordhaus and Sztorc 2013b)	$\overline{1+c\times T^2}$	c = 0.0026700
2017 (Nordhaus 2017)	$1-c\times T^2$	c = 0.0023600
2018 (Nordhaus 2018)		c = 0.0022700
2023 (Nordhaus and Barrage 2023) <sup>21</sup>		c = 0.003467

The use of quadratics to extrapolate regression results has since become a convention amongst climate change economists, despite sustained criticism of this practice. In 2009, Stanton et al. observed that:

Our review of the literature uncovered no rationale, whether empirical or theoretical, for adopting a quadratic form for the damage function—although the practice is endemic in IAMs. (Stanton, Ackerman, and Kartha 2009, p. 172.)

Weitzman severely criticized the use of quadratic functions in IAMs, rhetorically asking:

how much we might be misled by our economic assessment of climate change when we employ a conventional quadratic damages function and/or a thin-tailed probability distribution for extreme temperatures... These numerical exercises suggest that we might be underestimating considerably the welfare losses from uncertainty by using a quadratic damages function." (Weitzman 2012a, p. 221. Emphasis added)

Commenting on the DICE model, Pindyck observed that its damage function:

is made up out of thin air. It isn't based on any economic (or other) theory or any data. Furthermore, even if this inverse quadratic function were somehow the true damage function, there is no theory or data that can tell us the values for the parameters or the correct probability distributions for those parameters, or even the correct means and variances. (Pindyck 2017, p. 104. Emphasis added)

He also noted that while other IAMs, such as PAGE (Plambeck and Hope 1996; Warren et al. 2021), have "a more complex and disaggregated set of damage functions ... these ... are typically calibrated to give GDP losses for moderate temperature increases (5°C or less) that match the 'common wisdom,' and thus are very similar" (Pindyck 2017, p. 108). See also (Ackerman and Munitz 2012; Ackerman, Stanton, and Bueno 2010; Diaz and Moore 2017) for critiques of the damage functions in DICE, HOPE and PAGE.

<sup>&</sup>lt;sup>21</sup> This increase in the quadratic coefficient is the first since 1999: every other revision has reduced, rather than increased, his estimates of damages from climate change. The main reasons for this slight upward revision were the inclusion of a new study in this tradition (Piontek et al. 2021), Dietz et al.'s paper of tipping points (Dietz et al. 2021a)—" Second, we have added the results of a comprehensive study of tipping points (Dietz et al. 2021), which estimates an additional 1% loss of global output due to 3°C warming."—and an increase in "the judgmental adjustment for other excluded impacts to 0.5% of output at 3 °C warming" (Nordhaus and Barrage 2023, p. 9).

### Supporting Document to the DICE against pensions: how did we get here?

In 2017, the U.S. National Academy of Sciences (NAS) published Valuing Climate Damages: Updating Estimation of the Social Cost of Carbon Dioxide. The deliberations of a 31-member committee formed "to inform future revisions to estimates of the social cost of carbon (SCC)" (National Academies of Sciences and Medicine 2017, p. 24), the report criticised the use of quadratics for extrapolation (see Table 5.1, pp. 131-2 and pages 137-8), in a wide-ranging critique of the practices of economists:

The committee notes that the Interagency Working Group on the Social Cost of Carbon (2010) identified a number of potential shortcomings and critiques of the current damage formulations, which are discussed further below. These include:

- incomplete treatment of non-catastrophic damages;
- incomplete treatment of potential catastrophic damages;
- uncertainty in extrapolation of damages to high temperatures;
- incomplete treatment of adaptation and technological change;
- omission of risk aversion with respect to high-impact damages;
- failure to incorporate intersectoral and interregional interactions; and
- imperfect substitutability of consumption for environmental amenities. (National Academies of Sciences and Medicine 2017, p. 138. Emphasis added)

Presumably, this report was intended to prompt climate economists to respond to criticism with action, and therefore to modify their methods. Unfortunately, no substantive changes have resulted. In particular, quadratic extrapolation of estimates of damages from current data to much higher temperatures remains a keystone of IAMs in papers published in 2021 (Warren et al. 2021, p. 3; Dietz et al. 2021b), 4 years after the NAS report was published. This was the case even in a paper purporting to quantify the impact of tipping points (Dietz et al. 2021a). Keen et al. (Keen et al. 2022) document the use of an arbitrarily calibrated quadratic in Dietz et al. to extrapolate environmental damages from tipping points, in addition to the two uses noted above (Dietz et al. 2021a, p. 5) and 3 other uses of quadratics in their supplementary information (Dietz et al. 2021b, pp. 21, 23, 72).

In the next section, we replicate the approach of economists to quantifying the damages from climate change, by extrapolating from existing data, but do this extrapolation using far more suitable mathematical functions.

# 6 More appropriate damage functions

Here we reproduce one essential feature of the economic literature criticised above—the extrapolation of existing data using simple functional forms—while avoiding its key weaknesses—the use of author-developed empirical estimates of damages, the failure to consider damages to industries not directly exposed to the weather, and the extrapolation of these damages using only a quadratic or other low-order polynomial.

We use a database which is maintained by a government body, and which includes damages from all environmental causes to all aspects of economic life. We then combine this damages data with data on the recorded relationship between higher CO2 levels and higher temperatures. This global warming temperature anomaly to damages data is then fitted by three functions—a quadratic, as is the unwarranted convention in the existing literature; an exponential; and a logistic function.

The first two of these are fed as alternative damage estimates into DICE, to derive two new estimates of the social cost of carbon.<sup>22</sup> Though the former is larger than the norm for this literature, it is done only for comparison purposes, and the functions that better extrapolate from existing damages to potential damages to the economy from global warming are the exponential (from which a SCC can be calculated) and the logistic.

### 6.1 Data Sources

The NOAA (National Oceanic and Atmospheric Administration: <a href="https://www.noaa.gov/">https://www.noaa.gov/</a>) maintains a dataset of weather and climate events with a damage level greater than \$1 billion per event in 2015 constant dollars, called the *Billion-Dollar Weather and Climate Disasters* database. <sup>23</sup> The data spans the period 1980 till 2021, over which period global warming has increased the global average temperature from 0.28 to 0.84°C above the 1880-2021 average. <sup>24</sup> The NOAA notes that

these statistics were taken from a wide variety of sources and represent, to the best of our ability, the estimated total costs of these events—that is, the costs in terms of dollars that would not have been incurred had the event not taken place. (NCEI 2022)

The advantages of this database over the author-derived damage estimates used in all other total cost of climate change studies to date are:

- The series covers a period of rising CO2 and rising global average temperature, as in the
  Extrapolative Method: we thus replicate the assumption that current data contains a footprint
  of the economic impact of global warming, from which future damages can be extrapolated;
  however,
- The data has been gathered by an independent authority, rather than by the authors—as
  is the case for all the economic studies detailed above; and
- No industry sector was excluded from consideration.

 $<sup>^{22}</sup>$  Though there are issues with using the exponential function, these are the same as already exist with the quadratic: both imply damages accelerate as 100% damages are approached, and then exceed 100% of GDP. The logistic would have been a better function to use, since damages taper to 100% of GDP as 100% of GDP is approached; however, the GAMS software in which DICE is written was unable to run with a logistic damages function.

<sup>&</sup>lt;sup>23</sup> Damages data is provided in CPI-adjusted and unadjusted form.

<sup>&</sup>lt;sup>24</sup> https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/global/time-series/globe/land\_ocean/ytd/12/1880-2021.

The NOAA data can be regarded as containing both a signal related to the background, preglobal-warming level of disasters, and a signal related to the trend imparted to disasters by global warming. The background level of disasters is captured by the constant in the functions and regressions below; the global warming trend is captured by the components driven by the increase in CO2 above the pre-industrial level of 278 ppm.

Five data sets were used in this study:

- The NOAA Billion-dollar damages database covering 1980 till 2021, using the unadjusted for inflation series (<a href="https://www.ncei.noaa.gov/access/billions/">https://www.ncei.noaa.gov/access/billions/</a>);
- Annual Gross Domestic Product data from 1929 till 2021, from the St Louis FRED database (<a href="https://fred.stlouisfed.org/series/GDPA">https://fred.stlouisfed.org/series/GDPA</a>);
- The NOAA recorded CO<sub>2</sub> levels database covering 1959 till 2021 (<a href="https://gml.noaa.gov/webdata/ccgg/trends/co2/co2">https://gml.noaa.gov/webdata/ccgg/trends/co2/co2</a> annmean mlo.txt);
- Historic CO2 levels from 1750 till 2017 from the European Environmental Agency (<a href="https://www.eea.europa.eu/data-and-maps/daviz/atmospheric-concentration-of-carbon-dioxide-5/download.csv">https://www.eea.europa.eu/data-and-maps/daviz/atmospheric-concentration-of-carbon-dioxide-5/download.csv</a>);<sup>25</sup> and
- 5. The NOAA Global Surface Temperature Anomalies data from 1880-2021, using the annual time series for land and ocean, with the anomaly recorded relative to the 1901-2000 average (<a href="https://www.ncei.noaa.gov/access/monitoring/alobal-temperature-anomalies/anomalies">https://www.ncei.noaa.gov/access/monitoring/alobal-temperature-anomalies/anomalies</a>). This data set was adjusted relative to the 1900 global temperature average, since this is the base year used by DICE.

Table 5 shows extracts from the complete data set.

TABLE 5: INDICATIVE EXTRACTS FROM THE FULL DATA SET

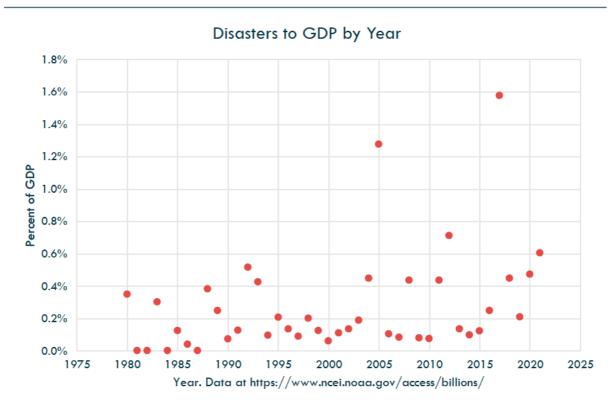
Data Row	Year	Y_wrt_1900	Disasters/GDP	CO2	T_Anomaly_wrt_1900
1	1750	-150		278.00	
2	1751	-149		278.00	
3	1752	-148		278.00	
4	1 <i>75</i> 3	-147		278.00	
5	1754	-146		278.00	
16	1765	-135		278.00	
17	1766	-134		278.12	
18	1767	-133		278.24	
19	1768	-132		278.36	
20	1769	-131		278.48	
131	1880	-20		290.70	-0.05
132	1881	-19		291.16	-0.01
133	1882	-18		291.62	-0.02
134	1883	-1 <i>7</i>		292.08	-0.10
135	1884	-16		292.54	-0.19
136	1885	-15		293.00	-0.18
231	1980	80	0.0035	338.76	0.35
232	1981	81	0.0000	340.12	0.39
233	1982	82	0.0000	341.48	0.26

<sup>&</sup>lt;sup>25</sup> This provides annual data from 1978 and five-yearly estimates before then, from 1750 till 1975. Annual data points were interpolated between the five-yearly estimates using Excel's Fill function with the options of growth and trend set.

234	1983	83	0.0030	343.15	0.43
235	1984	84	0.0000	344.87	0.24
236	1985	85	0.0012	346.35	0.23
268	2017	117	0.0158	406.76	0.97
269	2018	118	0.0045	408.72	0.89
270	2019	119	0.0021	411.66	1.01
271	2020	120	0.0047	414.24	1.05
272	2021	121	0.0060	416.45	0.91

Series 1 and 2 were combined to derive billion-dollar damages as a percentage of GDP—see Figure 16.

FIGURE 16: THE NOAA DATA EXPRESSED AS A PERCENTAGE OF GDP BY YEAR



## 6.2 Analysis

This annual data has to be mapped to data on global warming caused by rising CO2 levels before it can be used. It is then extrapolated to hypothetical future temperatures (caused by CO2 alone) to enable a damage forecast to be made out to 2100.

To derive the CO2 series, series 3 and 4 were combined to derive a CO2 series spanning 1750 till 2021, and ranging from 278 ppm to 416.45 ppm. The CO2 PPM data was used to derive a predicted level of CO2 PPM from 1980 until 2100—the date usually used by Neoclassical economists to estimate damages to GDP (expressed as the fall in GDP by that date relative to a hypothetical future GDP without global warming)—on the thus-far eminently accurate assumption that the exponential growth in CO2 levels will continue unabated—see Figure 17 (which extends out only to 2050). We also assumed that the pre-industrial base level for CO2 PPM was 278 PPM, which is the level estimated by the *European Environmental Agency* for 1750 till 1765.

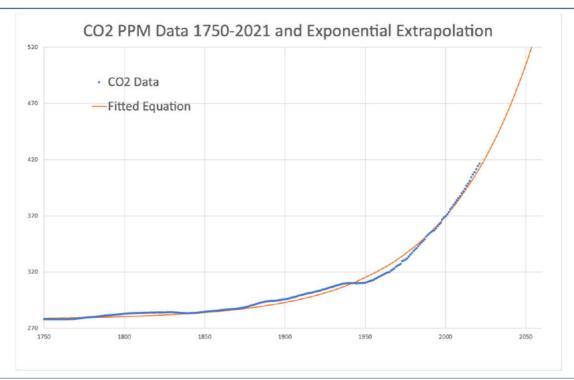
Equation (1.4) was fitted to the 1750-2021 data (using the program NLREG)<sup>26</sup>

$$CO_2 = 278 + a \times e^{b \times Year\_wrt\_1900}$$
 (0.3)

The fitted equation was:

$$CO_2(t-1900)=278+15.019\times e^{0.0181\times(t-1900)}$$
 (0.4)

FIGURE 17: EMPIRICAL DATA ON CO2 PPM AND EXPONENTIAL EXTRAPOLATION TO 2050

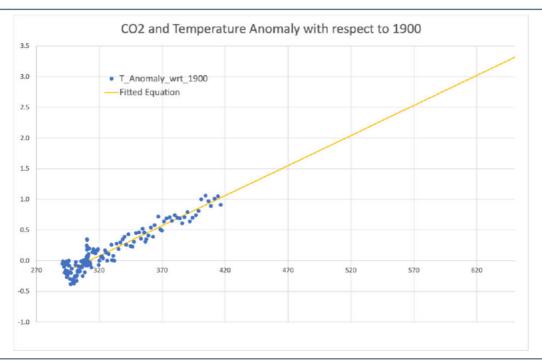


Series 5 was recalibrated to be with respect to the 1900 global average temperature, since Nordhaus' DICE uses 1900 as the base year for deviations from global average temperature. We then derived a fit for CO2 to the temperature anomaly, using the well-known linear relationship between CO2 PPM and the temperature anomaly (prior, of course, to the triggering of substantial tipping point effects)—see Figure 18:

$$T_{Anomaly\ wrt\ 1900}(CO_2) = -3.06 + 0.0098 \times CO_2$$
 (0.5)

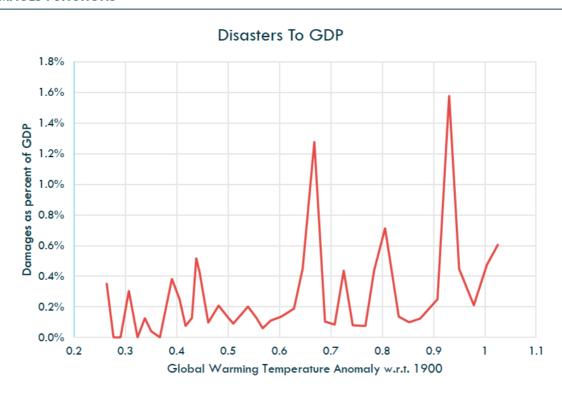
<sup>&</sup>lt;sup>26</sup> See <a href="http://www.nlreg.com/">http://www.nlreg.com/</a>.

FIGURE 18: EMPIRICAL DATA ON CO2 AND TEMPERATURE ANOMALY WITH EXTRAPOLATION TO 600 PPM



This value for the temperature anomaly was plotted against the recorded damages as a fraction of GDP to provide a data set from which a quadratic, exponential and logistic damages function could be derived—see Figure 19. The projected temperature anomaly from 2022 till 2100 was then used to express projected damages to GDP from global warming out to 2100 using these functions—see Figure 22.

FIGURE 19: THE DATASET USED TO CALIBRATE THE QUADRATIC, EXPONENTIAL AND LOGISTIC DAMAGES FUNCTIONS



The functions, and the values of their parameters derived by regressions on the data, are shown below:

 $D(\Delta T) = a + b \times \Delta T^2$ 

$$a=0.0009644$$

$$b=0.004272$$

$$D(\Delta T) = a + b \times e^{c \times \Delta T}$$

$$a=0.0004023$$

$$b=0.0005223$$

$$c=2.2635$$

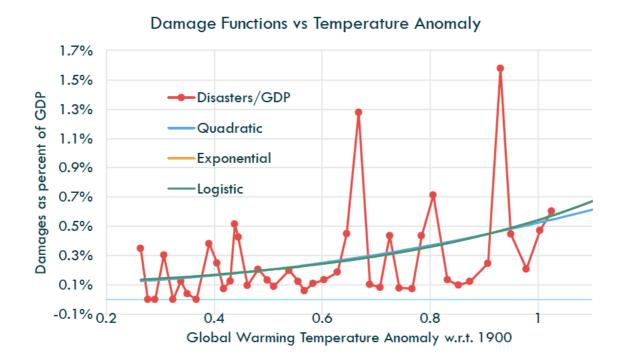
$$D(\Delta T) = Min + \frac{1 - Min}{1 + e^{\frac{4 \times Slope \times \frac{Halfway - \Delta T}{1 - Min}}}$$

$$Min = 0.001234$$

$$Slope = 0.6229$$
Halfway=3.0277

The regressions returned low and almost identical  $R^2$  coefficients (0.1337, 0.1345 and 0.1345 respectively), and their fits to the data are indistinguishable from each other—see Figure 20.

FIGURE 20: TEMPERATURE ANOMALY-->DAMAGES DATA AND FUNCTIONAL REGRESSIONS



Therefore, the implications of this data for the economic impact of future climate change depends on the functional form used to extrapolate the trends in this data: the data itself cannot be used to determine which functional form is the correct one.

As Figure 21 shows, these functions diverge dramatically as the temperature anomaly rises. The quadratic function returns results in the same ballpark as those in the existing economic literature: damages of under 20% of GDP at a temperature increase of 6°C. However, the exponential and logistics functions predict far higher, and far more immediate, damages. The exponential predicts 100% damages to the economy at 3.3°C, while the logistic curve predicts 50% damages at 3.3°C, and 100% damages at 5°C.

FIGURE 21: EXTRAPOLATION OF FUNCTIONAL FORMS AGAINST CO2-PREDICTED TEMPERATURE ANOMALY BY 2100

## Extrapolation of Damage Functions vs Temperature Anomaly

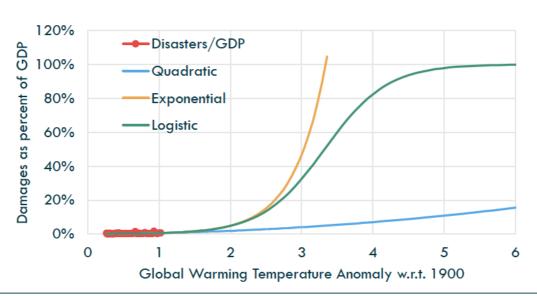
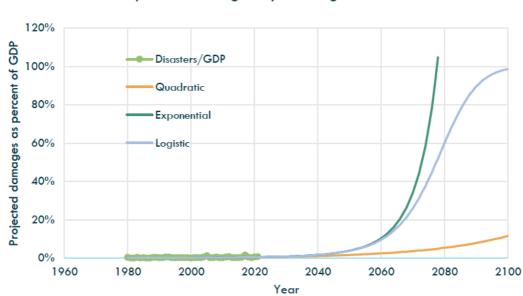


Figure 22 plots these functional forms against time. The quadratic damage functions imply small damages during the 21<sup>st</sup> century, even from unabated climate change. The logistic and exponential functions, on the other hand, imply complete destruction of the global economy by the mid to late 21<sup>st</sup> century.

#### FIGURE 22: EXTRAPOLATION OF FUNCTIONAL FORMS AGAINST TIME TO 2100



#### Projected Damages by Damage Function

Since the functions cannot be distinguished from each other based on their fit to current data, and given the huge differences in their implications about both the threat from global warming and its immediacy, it is vitally important to decide which functional form is more plausible.

The quadratic can be ruled out for the reasons given above, and also because its mathematical characteristics contradict the concept of tipping points, as defined by Lenton et al. (Lenton et al. 2008b, 2008a). In particular, since the third derivative of a quadratic is zero, it cannot show a change in the acceleration of damages from global warming, and economic damages resulting from it—which will happen as tipping points add to the increase in temperature caused by the increase in greenhouse gases alone.

Both the exponential function and the logistic can show such an acceleration, and their numerical predictions—that a complete economic collapse will occur at temperatures  $3-5^{\circ}C$  above preindustrial levels—are much closer to the predictions of scientists than any paper in the economics canon.

The exponential function implies that damages accelerate indefinitely, even as damages to the economy approach 100%—something that also applies to quadratic damage functions, though more gradually, and at far higher temperature levels. The logistic, on the other hand, slows down as full destruction of the economy approaches, simply because the limit to destruction is 100%. With the caveat that no smooth function can properly characterise the impact of tipping points, the logistic is the simplest continuous function that approximates the manner in which the economy will deteriorate as tipping points are triggered.

We emphasise that we find the assumption on which all work by mainstream climate change economists has been based—that current data contains a footprint of global warming from which its future economic impact can be predicted—to be tenuous at best, while the empirical work done in this tradition does not stand up to scientific scrutiny. However, by replicating their empirical methods using an independently developed database of severe weather and climate impacts, and by fitting several damage functions rather than just a quadratic, we have both reached results that

are consistent with the scientific literature, and which show that previous assurances by economists that damages from global warming are minor and distant cannot be trusted.

### 6.3 DICE with different damage functions

These better-grounded forecast of future damages results in a far higher estimate of the social cost of carbon when fed into a standard economics IAM—in this case, Nordhaus's DICE. Indeed, with our exponential damage function, DICE recommends the cessation of the use of fossil fuels by 2035.

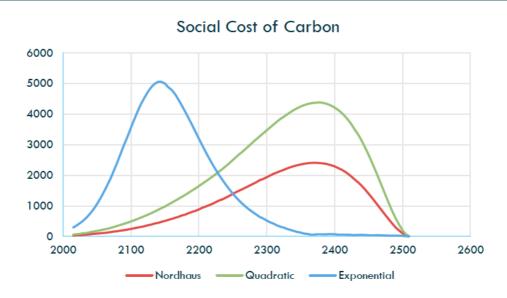
For technical reasons, we do not consider the logistic function.<sup>27</sup> Instead, we compare Nordhaus's quadratic damage function—calibrated using the flawed methods detailed earlier—with our quadratic and exponential functions, calibrated on the NOAA database. We expect that the results of the logistic would be similar to those for the exponential, given their numerical similarity out to 20% damage to GDP—see Figure 21.

This section compares the results of a standard run of DICE, with Nordhaus's quadratic damage function and its coefficient as of 2018 (Nordhaus 2018, p. 345) to the quadratic and exponential functions derived from the NOAA data. The three damage functions being compared are:

Nordhaus 
$$D(\Delta T) = 0.00227 \times \Delta T^2$$
 
$$NOAA\_Quadratic \qquad D(\Delta T) = 0.000964 + 0.00427 \times \Delta T^2$$
 
$$NOAA\_Exponential \qquad D(\Delta T) = 0.000402 + 0.000522 \times e^{2.264 \times \Delta T}$$
 (0.9)

As expected, the exponential fit returns a far higher social cost of carbon than the quadratic extrapolations in this paper, and all of the SCC estimates reported by Tol—see Figure 23.

FIGURE 23: SOCIAL COST OF CARBON FROM DICE USING 3 DAMAGE FUNCTIONS



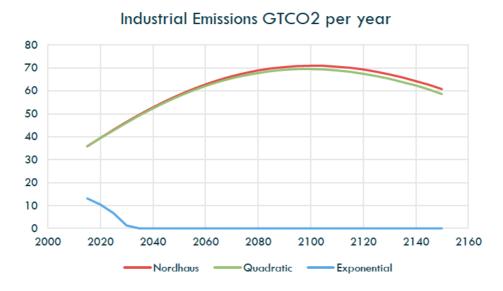
 $<sup>^{27}</sup>$  GAMS, in which DICE is written, cannot handle the exponential or logistic functions natively. We used a  $12^{th}$  order series expansion of the exponential function; there is no convergent series expansion for the logistic function over its entire domain.

This results in a far higher carbon price—so high, in fact, that it triggers an assumption in DICE, that there is a carbon-free "backstop technology" which will be employed at a sufficiently high carbon price:

the backstop technology replaces 100 percent of carbon emissions ... For the global DICE-2013R model, the 2010 cost of the backstop technology is \$344 per ton CO2 at 100% removal. The cost of the backstop technology is assumed to decline at 0.5% per year. (Nordhaus and Sztorc 2013b, p. 13)

Accordingly, industrial emissions of CO2 cease by 2035 in DICE—see Figure 24.

FIGURE 24: INDUSTRIAL EMISSIONS FROM DICE USING 3 DAMAGE FUNCTIONS



It is this backstop technology, and not the Social Cost of Carbon (nor the carbon price), which brings about the economic and ecological results in this run of DICE. Given the assumed existence of a backstop technology which can replace fossil fuel usage entirely, industrial emissions fall to zero by 2035, with the lost energy from burning fossil fuel replaced by a backstop technology with zero carbon emissions.

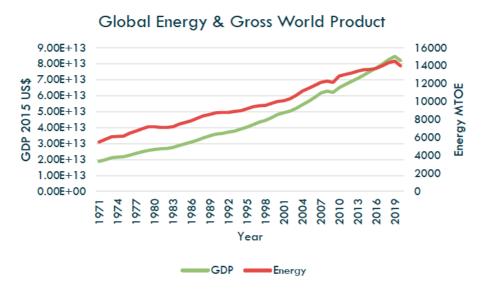
These predictions from DICE are however moot, since in the real world, there is no "backstop technology" which can replace the use of fossil fuels at the scale needed to maintain current GWP. Instead, the only way that the real world could achieve the level of industrial emissions generated by DICE with an exponential damages function would be to end fossil fuel usage entirely in 2035. This would also cause a fall in energy consumption of the order of 75%—given that, at present, only about 15-20% of global energy is supplied by non-fossil-fuel based means—and a concomitant fall in GWP.

The dependence of economic output on energy inputs is another aspect of the real world that economic models in general, as well as the production functions in IAMs, get badly wrong.

### 7 Economics, Production Functions, and Energy

The data makes it obvious that a reduction in energy usage will cause an almost identical fall in GDP. Figure 25 shows global energy usage and gross world product since 1971, with energy measured in million tons of oil equivalent and GWP in US\$ 2015 dollars.<sup>28</sup>

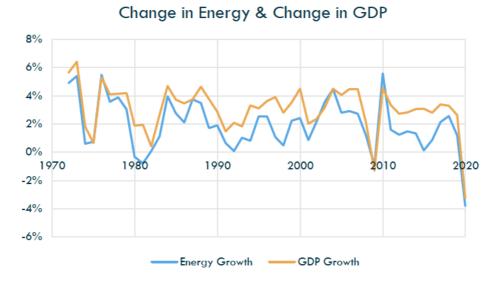
FIGURE 25: WORLD ENERGY USE AND GROSS WORLD PRODUCT, 1971-2020



The two have moved in lock step, including during the downturns in 2008 and 2020. More tellingly, the annual rates of growth of energy and GWP are virtually identical—see Figure 26. Not only are these series highly correlated (the correlation coefficient is 0.86), but the magnitude of the changes is almost the same as well (though the change in GDP is normally larger than the change in energy).

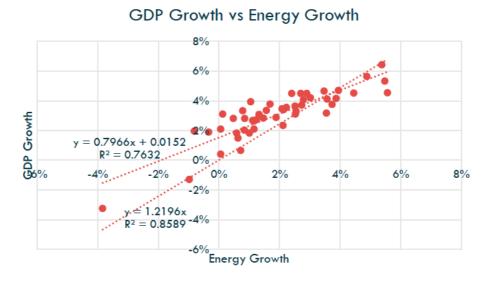
<sup>&</sup>lt;sup>28</sup> The data sources are <a href="https://data.oecd.org/energy/primary-energy-supply.htm">https://data.oecd.org/energy/primary-energy-supply.htm</a> for energy and <a href="https://data.worldbank.org/indicator/NY.GDP.MKTP.KD">https://data.worldbank.org/indicator/NY.GDP.MKTP.KD</a> for Gross World Product.

FIGURE 26: CHANGE IN ENERGY AND CHANGE IN GWP CORRELATION IS 0.86



Two linear regressions (one the default with a non-zero intercept, the other with a forced zero intercept) returned a 0.8:1 and a 1.2:1 relationship between change in energy and change in GDP—see Figure 27.<sup>29</sup> The simplest interpretation of the data is that there is roughly a 1:1 relationship between change in energy and change in GDP.

FIGURE 27: SCATTER PLOT AND LINEAR REGRESSIONS OF ENERGY AND GDP CHANGE



In contrast, when Neoclassical economists do include energy in their production functions (Engström and Gars 2016; Bachmann et al. 2022), they give it a very low weight. Rather than a 10% fall in energy causing a 10% fall in GDP, which is consistent with the data, they typically argue that a 10% fall in energy would cause only a 0.3-0.4% fall in GDP:

"a drop in energy ... of 10% reduces production by ... 0.4%" (Bachmann et al. 2022, p. 3)

<sup>&</sup>lt;sup>29</sup> The regression with an enforced zero intercept has a higher R<sup>2</sup> than the default regression.

The basis of this tiny and obviously empirically false prediction is the Cobb-Douglas Production Function (CDPF), which shows output as a function of technology, multiplied by the inputs raised to a power, where the sum of those powers is 1.

This constraint on the sum of the exponents is due to the quite reasonable assumption of "constant returns to scale": if you double all inputs, you double output. The problems arise with the value of the exponents used for individual inputs.

Economists base these exponents on the share that the relevant "factor of production" gets of national income. In the standard CDPF with just two factors, Labour (L) and Capital (K), the exponent for Capital is set to 0.3, so that the exponent for Labour is 0.7:

$$Y(t) = A(t) \cdot L(t)^{0.7} \cdot K(t)^{0.3}$$
(0.10)

When the production function is modified to include energy (E), it is accorded the same treatment. Since the energy sector accounts for 3-4% of GDP, economists use 0.03-0.04 for the value of its exponent:

We choose the parameter  $\alpha$  in the CES production function<sup>30</sup> so as to match the share of consumption of gas, oil and coal in German GNE which is given by about 4%. (Bachmann et al. 2022, p. 15)

They normally keep Capital's exponent at 0.3, and reduce the exponent for Labour, so that their modified equation for production as a function of energy as well as labour and capital is:

$$Y(t) = A(t) \cdot L(t)^{0.66} \cdot K(t)^{0.3} \cdot E(t)^{0.04}$$
(0.11)

The predicted impact of a change in energy on output can be found by differentiating Y with respect to E. This yields the prediction that the in GDP will be 4% of the change in energy, so that a 10% fall in Energy input—while inputs of Labour and Capital are held constant—would cause only a 0.4% fall in GDP.

$$\frac{dY}{Y} = 0.04 \cdot \frac{dE}{E} \tag{0.12}$$

The empirical data shown in Figure 25 to Figure 27 shows that this is quite clearly wrong, and a more accurate empirical estimate is a linear relationship between change in energy and change in GDP, with a minimum of 0.8—twenty times the coefficient used by Neoclassical economists.

This linear relationship between output and energy is very similar to the linear relationship found empirically between output and the capital stock, which is known as the "Leontief Production Function". Mainstream conomists reject this model of production, on the basis that it contradicts Neoclassical economic theory.

<sup>&</sup>lt;sup>30</sup> The CES production function is a generalisation of the Cobb-Douglas that allows variable rates of substitution between the inputs. At one extreme for substitution it generates the CDPF; at the other it generates the linear relationship between energy and output found in the data. Using a CES function with the elasticity parameter set at 0.04—rather than the level of 1 which returns the CDPF—Bachmann et al. predicted that a 10% fall in energy would cause only a 1.5% fall in GDP: "We argue that economic losses from a -10%

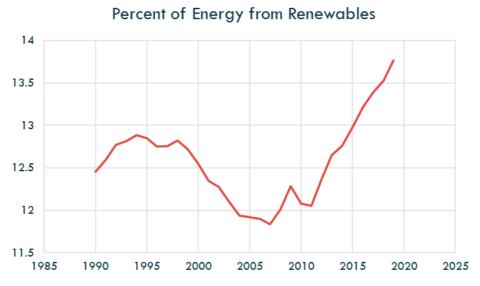
energy shock could be up to 1.5% of German GNE" (Bachmann et al. 2022, p. 1). This is still 1/6<sup>th</sup> of the level of damage implied by the data—though Germany could avoid such a steep fall in its GDP by finding alternative energy sources.

The strict Leontief case makes nonsensical predictions with regard to the evolution of marginal products, prices and expenditure shares... If factors markets are competitive so that factor prices equal marginal products, this then implies that similarly the price of energy jumps to  $1/\alpha$  and the prices of other factors fall to zero... this then also implies that the expenditure share on energy jumps to 100% whereas the expenditure share on other factors falls to 0%. We consider these predictions to be economically nonsensical. (Bachmann et al. 2022, p. 11. Emphasis added)

These predictions are indeed nonsensical, but the empirical reality that there is a roughly 1:1 relationship between energy and GDP remains. The only conclusion is that the Neoclassical assumptions that Bachmann made—that "factors markets are competitive so that factor prices equal marginal products"—are false, while the Leontief production function, with a linear relationship between GDP and energy, is correct.

This emphasises the extreme fragility of the global economy to a cessation of the use of fossil fuels. The superficially dramatic growth of renewable energy sources in the last few years has made only a modest difference to the percentage of our energy that is supplied by renewable energy. Figure  $28^{31}$  shows that the proportion of energy coming from renewable sources fell from 1995 till 2005, and has only risen substantially since 2011. The growth in the ratio since 2011 amounts to a 0.2% increase in the ratio per year, which would take until 2050 to increase the renewable proportion of total energy to 20%. A tenfold increase in the rate of growth of this ratio—from 0.2% per year to 2% per year—would be needed for renewable energy to supply 75% of our energy by 2050.

FIGURE 28: RENEWABLE ENERGY SOURCES CURRENTLY PROVIDE LESS THAN 15% OF OUR ENERGY SUPPLIES



The prospect therefore exists that catastrophic climate events like those discussed in Section 4 could occur when non-fossil-fuel based energy supplies well under half our total energy needs. Should these catastrophes lead to the political decision to terminate fossil fuel usage, then a dramatic fall in both energy usage and GDP would result.

<sup>31</sup> The data source is <a href="https://data.oecd.org/energy/renewable-energy.htm">https://data.oecd.org/energy/renewable-energy.htm</a>.

### 8 Discounting science as well as the future

As is well-known, Nordhaus applies a high discount rate to damages from climate change. We expect that most people would think this is the source of his low estimates of future damages—the primary author of this report certainly did, before embarking on this research project in 2019 (Keen 2020).

However, this is not the case. As Nordhaus himself explained, the role of the discount rate is not to minimise damages in general, but to stop damages from the indefinite future overwhelming "the relatively small damages in the next two centuries":

How do damages that average around 1% over the next century turn into 14.4% cuts "now and forever"? The answer is that, with the low interest rate, the relatively small damages in the next two centuries get overwhelmed by the high damages over the centuries and millennia that follow 2200. In fact, if the Stern Review's methodology is used, more than half of the estimated damages "now and forever" occur after 2800. (Nordhaus 2007a, p. 202. Emphasis added)

Nordhaus's statement about the scale of damages in the next two centuries was based on what can only be described as a Panglossian misreading of the scientific literature.

### 8.1 Dr Pangloss

Pangloss sometimes said to Candide: "There is a concatenation of events in this best of all possible worlds: for if you had not been kicked out of a magnificent castle for love of Miss Cunegonde: if you had not been put into the Inquisition: if you had not walked over America: if you had not stabbed the Baron: if you had not lost all your sheep from the fine country of El Dorado: you would not be here eating preserved citrons and pistachio-nuts."

"All that is very well," answered Candide, "but let us cultivate our garden." (Voltaire)

Nordhaus justifies using a quadratic to describe such an inherently discontinuous and accelerating process as climate change by an extraordinary misrepresentation of the scientific literature—specifically, the careful survey of expert opinions carried out by Lenton et al. in "Tipping elements in the Earth's climate system" (Lenton et al. 2008b).

The paper's conclusion begins with a warning against the use of smooth functions (which a quadratic is), notes that discontinuous climate tipping points were likely to be triggered this century, and states that the greatest immediate threats were Arctic summer sea ice and Greenland:

#### Conclusion

Society may be lulled into a false sense of security by smooth projections of global change. Our synthesis of present knowledge suggests that a variety of tipping elements could reach their critical point within this century under anthropogenic climate change. The greatest threats are tipping the Arctic sea-ice and the Greenland ice sheet, and at least five other elements could surprise us by exhibiting a nearby tipping point. (Lenton et al. 2008b, p. 1792. Emphasis added)

Nordhaus makes the following statement about this paper in his DICE manual, and repeats it in (Nordhaus and Moffat 2017, p. 35):

The current version assumes that damages are a quadratic function of temperature change and does not include sharp thresholds or tipping points, but this is consistent with the survey by Lenton et al. (2008) (Nordhaus and Sztorc 2013a, p. 11. Emphasis added)

In The Climate Casino (Nordhaus 2013), Nordhaus states that:

There have been a few systematic surveys of tipping points in earth systems. A particularly interesting one by Lenton and colleagues examined the important tipping elements and assessed their timing... Their review finds no critical tipping elements with a time horizon less than 300 years until global temperatures have increased by at least 3°C. (Nordhaus 2013, p. 60. Emphasis added)

These claims are a blatant misrepresentations of "Tipping elements in the Earth's climate system" (Lenton et al. 2008b).

I consulted Lenton on whether there were any grounds for Nordhaus's interpretation of his paper that I might have missed (Keen and Lenton 2020). He replied that there were not, that my interpretation of the paper was correct, and that there were several other papers which also strongly reject the proposition that a smooth function is appropriate for assessing the dangers from climate change (Cai, Lenton, and Lontzek 2016; Kriegler et al. 2009; Lenton et al. 2019; Lenton and Ciscar 2013).

The very first element in Lenton et al.'s table of findings meets the two numerical criteria that Nordhaus gave: Arctic summer sea-ice could be triggered by global warming of between 0.5–2°C, and in a timespan measured in decades—see Figure 29.

### FIGURE 29: AN EXTRACT FROM TABLE 1 OF "TIPPING ELEMENTS IN THE EARTH'S CLIMATE SYSTEM", (LENTON ET AL. 2008B, P. 1788)

Table 1. Policy-relev considered but faile	A CONTRACTOR OF THE PROPERTY O	e tipping elements in t t list*	the climate syste	em and (belov	w the empty line)	candidates that we
Tipping element	Feature of system, F (direction of change)	Control parameter(s), p	Critical value(s),† p <sub>crit</sub>	Global warming†‡	Transition timescale,† <i>T</i>	Key impacts
Arctic summer sea-ice	Areal extent (–)	Local $\Delta T_{ m air}$ , ocean heat transport	Unidentified§	+0.5-2°C	~10 yr (rapid)	Amplified warming, ecosystem change

Nordhaus justifies his omission via a third criterion of "level of concern" in his table N1 (Nordhaus 2013, p. 333), where Arctic summer sea ice receives the lowest ranking (\*). This apparently justifies his statement that there was "no *critical* tipping point" in less than 300 years, and with less than a 3°C temperature increase.

#### FIGURE 30: NORDHAUS'S TABLE PURPORTING TO SUMMARISE LENTON'S FINDINGS

Tipping element	Time scale (years)	Threshold warming value	Level of concern (most concern = ***)	Concern
Arctic summer sea ice	10	+0.5-2°C	*	Amplified warming, ecosystem
Sahara/Sahel and West African monsoon	10	+3-5°C	**	Wet period

However, no such column exists in Table 1 of Lenton, Held et al. (2008), 32 while their discussion of the ranking of threats puts Arctic summer sea ice first, not last:

We conclude that the greatest (and clearest) threat is to the Arctic with summer sea-ice loss likely to occur long before (and potentially contribute to) GIS melt (Lenton et al. 2008b, pp. 1791-92. Emphasis added).

Their treatment of time also differs substantially from that implied by Nordhaus, which is that decisions about tipping elements with time horizons of several centuries can be left for decision makers several centuries hence. While Lenton et al. do give a timeframe of more than 300 years for the complete melting of the Greenland Ice Sheet (GIS), for example, they note that they considered only tipping elements whose fate would be decided this century:

Thus, we focus on the consequences of decisions enacted within this century that trigger a qualitative change within this millennium, and we exclude tipping elements whose fate is decided after 2100. (Lenton et al. 2008b, p. 1787. Emphasis added)

Thus, while the GIS might not melt completely for several centuries, the human actions that will decide whether that happens or not will be taken in this century, not in several hundred years from now.

### 8.2 Negative discounting for risk

That said, there is also an error in applying only a positive rate of discount on the basis of the time value of money. The risk that our current estimates of damages underestimate what damages will in fact be—which is more of a certainty than a risk when applied to the economic literature—requires that a negative rate of discount be applied to future estimates of damages from climate change (Hanley and Keen 2022).

Consider a project with an expected positive revenue stream E(t), and an actual positive revenue stream A(t), both of which start at the same initial value of income G, and grow at different rates  $g_E$  and  $g_A$  respectively. The expected and actual returns are:

<sup>&</sup>lt;sup>32</sup> The column "Critical values" in Lenton, Hand et al.'s Table 1 relates to whether there is a known empirical magnitude that will trigger the tipping point, not whether the tipping point itself is of critical significance. The symbol next to the word "Unidentified", which is used to describe Arctic summer sea ice, states that "Meaning theory, model results, or paleo-data suggest the existence of a critical threshold but a numerical value is lacking in the literature." (Lenton, Hand et al. 2000, p. 1788)

$$E(t) = G \cdot e^{g_E \cdot t}$$

$$A(t) = G \cdot e^{g_A \cdot t}$$

$$G, g_E, g_A > 0$$
(0.13)

The discounted value of those cash flows, respectively  $E_{stp}$  and  $A_{stp}$ , subtracts a positive term for the "pure rate of social time preference" (Nordhaus 2007b, p. 690),  $d_{stp}$ , from both exponents:

$$E_{stp}(t) = G \cdot e^{(g_E - d_{stp}) \cdot t}$$

$$A_{stp}(t) = G \cdot e^{(g_A - d_{stp}) \cdot t}$$

$$G, g_E, g_A, d_{stp} > 0$$

$$(0.14)$$

Now consider the relevant risk in the case of positive expected and actual return, that actual returns will be below expected returns. It is possible for a project with a positive future income stream to be net present value positive on a time value of money basis, but lower—or even negative—on a risk-adjusted basis. Thus, a risk adjustment rate,  $d_{rar}$ , is applied  $E_{stp}$  to generate  $E_{rar}$ , which covers the risk that actual returns will be lower than expected returns:  $g_A < g_E$ . There is no need to apply  $d_{rar}$  to actual returns, since they are actual returns. Therefore  $A_{rar} = A_{stp}$ :

$$E_{rar}(t) = G \cdot e^{(g_E - d_{ztp} - d_{rar})t}$$

$$A_{rar}(t) = G \cdot e^{(g_A - d_{ztp})t}$$
(0.15)

The correct value for  $d_{rar}$  (which cannot be known in advance) equates the expected stream to the actual stream. Call this  $d_R$ : to calculate it, we substitute  $d_R$  for  $d_{rar}$  in Equation (0.15) so that  $E_{rar} = A_{rar}$ :

$$E_{rar} = A_{rar}$$
 
$$if$$
 
$$g_E - d_{stp} - d_R = g_A - d_{stp}$$
 (0.16)

We can therefore conclude that  $d_R$  must be positive, as expected:

$$g_E - g_A = d_R > 0 (0.17)$$

Now let us consider a calamity, with an expected negative stream of damages  $D_E$  and an actual negative stream of damages  $D_A$ . As with the positive income stream example, we assume both  $D_E$  and  $D_A$  start from the same initial loss L and then grow at different rates  $g_E$  and  $g_A$ .

$$D_{E}(t) = L \cdot e^{g_{E} \cdot t}$$

$$D_{A}(t) = L \cdot e^{g_{A} \cdot t}$$
(0.18)

As before, a social time preference discount  $d_{stp}$  is applied to both loss streams, since losses at a future date are less concerning than losses in the present:

$$D_{E}^{stp}(t) = L \cdot e^{(g_{E} - d_{stp})t}$$

$$D_{A}^{stp}(t) = L \cdot e^{(g_{A} - d_{stp})t}$$
(0.19)

As before, we introduce a discount for risk  $d_{rar}$ , which is applied only to expected losses:

$$\begin{split} D_{E}^{rar}\left(t\right) &= L \cdot e^{\left(g_{E} - d_{ztp} - d_{rar}\right) \cdot t} \\ D_{A}^{rar}\left(t\right) &= D_{A}^{stp}\left(t\right) \\ D_{A}^{rar}\left(t\right) &= L \cdot e^{\left(g_{A} - d_{ztp}\right) \cdot t} \end{split} \tag{0.20}$$

In the case of future losses, the risk is that these will be *larger* than expected:  $g_A > g_E$ . To find  $d_R$ , the value of  $d_{rar}$  that will account for true losses of a larger magnitude than expected losses, we substitute  $d_R$  for  $d_{rar}$  in Equation (0.20):

$$D_{E}^{rar} = D_{A}^{rar}$$

$$if$$

$$g_{E} - d_{stp} - d_{R} = g_{A} - d_{stp}$$

$$(0.21)$$

We can therefore conclude that, in the case of risk discounting for future losses,  $d_R$  must be negative:

$$g_E - d_{stp} - d_R = g_A - d_{stp}$$
  
 $g_E - g_A = d_R < 0$  (0.22)

Since  $d_R$  is subtracted from the exponent, the effect of discounting for risk in the case of expected future losses—as applies in the case of global warming—is to make the total discount *smaller*, not larger, when risk is taken into account.

In practice, this proof supports applying a low (or even zero) rate of discount for future losses, since the risk that actual damages from global warming will exceed predicted damages, given how poorly these have been estimated, is extremely high. The danger that this allows damages from the distant future to overwhelm "the relatively small damages in the next two centuries" (Nordhaus 2007a, p. 202) can be addressed by restricting the time horizon to the next century—when the damages anticipated by scientists from a "business as usual" approach are not small, but existential.

### 9 Correspondence with pension and other funds on climate change

#### Case Studies in the Use in Climate Risk Advice by Pension Schemes

We turn here to three case studies where trustees, members of the public or trade union representatives ask Pension Scheme officers how the advice is being used to manage risk.

Derbyshire Local Authority Pension Scheme

This document is from 2020 -

https://democracy.derbyshire.aov.uk/documents/s2989/5.%20a%20Climate-Related%20Disclosures.pdf

This correspondence is taken from the minutes of the Derbyshire Pensions & Investments Committee meeting on 18 January 2023

#### **Public Questions & Fund Answers**

Sue Owen, on behalf of Derbyshire Pensioners Action Group

Q. Your 2020 and 2021 Climate Related Disclosures reports have the following analysis of resilience of the Pension Fund's investment strategy:

- A 2°C scenario would have a positive impact on the Fund's returns considering both a timeline to 2030 and to 2050. This positive impact is boosted under the Strategic Asset Allocation reflecting the 3% allocation to Global Sustainable Equities.
- A 3°C scenario (which is in line with the current greenhouse gas trajectory) has a relatively muted impact on the Fund's annual returns.
- A 4°C scenario would reduce the Fund's annual returns, with most asset classes expected to experience negative returns

I am sure you are aware that currently the world is at 1.2 degrees of warming, which has resulted in unprecedented temperatures, e.g. 40 degrees in UK in 2022, unstoppable fires and devastating floods. This has resulted in trillions of pounds of damage globally. The world will have large areas that are uninhabitable by humans if we reach 3 degrees. There will be a shortage of fresh water and food, rising sea levels and hundreds of millions of climate refugees. Everything will change. The analysis that 3C warming will have a muted impact on the fund's returns seems to lack recognition of the reality of what will happen and seems incredibly complacent. Can you explain where this analysis has come from and whether you think it represents a realistic analysis of the future?

#### **Derbyshire Pension Fund Response**

A: The climate scenario analysis conducted by Mercer LLC (Mercer) was included in LGPS Central Limited's 2020 Climate Risk Report, which was the first such report commissioned by the Fund. Mercer is widely regarded as a leading consultancy firm in terms of developing, and reporting on, climate change scenario analysis.

For the climate scenario analysis included in the 2022 LGPS Central Limited Climate Risk Report, which is being presented to Committee today, Mercer has partnered with Ortec Finance and Cambridge Econometrics to develop climate scenarios that are grounded in the latest climate and economic search.

As noted in the 2022 Climate Risk Report, there remains a great deal of uncertainty for investors around the market reaction to climate risks and to changing climate policies. Climate scenario analysis forecasts different possible eventualities across a range of scenarios. As a developing field, which by necessity uses assumptions about inherently unpredictable matters over long time horizons, it is prudent to view the outputs from the analysis as directional information on the sensitivity of the Fund's portfolio to different climate scenarios to be considered in tandem with all the other factors which have the potential to impact on investment returns".

2022 Derbyshire climate risk analysis which includes the findings of Mercer's new model built in from P16

 $\frac{\text{https://democracy.derbyshire.gov.uk/documents/s18218/Enc.\%201\%20for\%20Climate\%20Risk}{\%20Report.pdf}$ 

RAPID 15 years -0.1% -0.1% 40 years 5 years -0.1% -0.1% **ORDERLY** 15 years 0.0% 0.0% 0.0% 0.0% 40 years 5 years 0.1% 0.1% **FAILED** 15 years 40 years ≥ 10 bps ≤ - 10 bps > -10 bps, < 10bps

TABLE 4.2.1.2 ANNUALISED CLIMATE CHANGE IMPACT ON PORTFOLIO RETURNS - TO 5, 15 AND 40 YEARS

#### PRH-1274 Appendix 2 - LGPSC Climate Risk Report.pdf (derbyshire.gov.uk)

The current portfolio or Asset allocation (column 1) which is on P18 would lose 1.4% (circled in Yellow below) in value every year as a result of climate change in the first 5 years under a rapid transition scenario that keeps the world to below 1.5c.

		CURRENT ASSET ALLOCATION	ALTERNATIVE ASSET ALLOCATION
	5 years	-1.4%	-1.3%
RAPID	15 years	-0.4%	-0.4%
	40 years	-0.1%	-0.1%
	5 years	-0.1%	-0.1%
ORDERLY	15 years	0.0%	0.0%
	40 years	0.0%	0.0%
	5 years	0.1%	0.1%
FAILED	15 years	-0.6%	-0.7%
	40 years	-1.0%	-1.0%
		≤ - 10	) bps

TABLE 4.2.1.2 ANNUALISED CLIMATE CHANGE IMPACT ON PORTFOLIO RETURNS - TO 5, 15 AND 40 YEARS

In effect, the advice to the pension scheme and the responses to public questions is that under the failed transition scenario (over 4C by 2100) the current portfolio will lose an average of -1% (circled in black) per annum to climate change affects for the next 40 years.

#### **Shropshire County Pension Fund**

The public Q&A at SCPF Pensions Committee meeting of 17.09.21 can be found at <a href="https://shropshire.gov.uk/committee-">https://shropshire.gov.uk/committee-</a>

 $\frac{services/documents/s28658/Pensions\%20Committee\%20Public\%20Questions\%20and\%20Responses\%2017th\%20September\%202021.pdf$ 

An answer to a public question by a union representative, not provided live during a SCPF Pensions Committee meeting, but provided by email in February 2021 and disclosed to Carbon Tracker in Octoner 2021, is as follows:

#### Question:- Given the statement in Climate-Related Disclosures Report page 11:-

"Over the coming decade, a 2°C outcome is, according to the model used, the best climate scenario from a returns perspective (adding 0.05% in annual returns to the Asset Allocation on a timeline to 2030) while a 4°C outcome is the worst of the three considered (detracting by 0.06% annually over the same period)"

Q. Could the committee tell us what the 4 degrees temperature rise would mean? We understand it will have a catastrophic impact on the planet. Some predicted outcomes at 4 degrees are:-

- 1. the inundation of coastal cities;
- 2. increasing risks for food production potentially leading to higher malnutrition rates; many dry regions becoming dryer and wet regions wetter;
- 3. unprecedented heat waves in many regions, especially in the tropics;
- 4. substantially exacerbated water scarcity in many regions;
- 5. increased frequency of high-intensity tropical cyclones;
- 6. irreversible loss of biodiversity, including coral reef systems.

We don't quite see that the figure 0.06% can be correct. Could the committee look into the predictions and explain how the figure of 0.06% drop in returns could possibly occur given a 4 degree rise, as the science says this will cause catastrophic climate events.

#### Reply:-

LGPS Central uses an external service provider to conduct the Climate Scenario Analysis for the Climate Risk Reports. The service provider's model classifies a 4°C outcome as – 'reflecting a fragmented policy pathway where current commitments are not implemented and there is a serious failure to alleviate anticipated physical damages'. At a high level, the long-term physical risk factors that the model reflects is split into two categories;

- Impact of natural catastrophes: physical damages due to acute weather incidence/severity; for example, extreme or catastrophic events such as hurricanes and coastal flooding
- Resource availability: long-term weather pattern changes for example, in temperature or
  precipitation leading to increases in rainfall and drought impacting the availability of natural
  resources like water

The -0.06% impact on SCPF's asset allocation under a 4°C scenario refers to the annual climate change impact on return. When viewed on a cumulative basis, rather than an annual basis, this return impact provides a more meaningful insight into the effects of this scenario on the Fund's asset allocation. A 2°C and a 4°C scenario are impacted by different risks which affect the Fund's asset allocation.

In a 2°C scenario, climate-related transition risks are prominent, while climate-related physical risks are depressed as the world mitigates the impacts of climate change. In a 4°C scenario, where little corrective action is taken to tackle climate change, climate-related physical risks are higher and climate-related transition risks are lower. Therefore, an important consideration to note is that climate-related transition and physical risks impact asset classes differently across the climate change scenarios.

SCPF's asset allocation has a low allocation to real assets — which are most vulnerable to physical risks — and a large allocation in fixed income assets — which are relatively less sensitive to the different climate scenarios. The analysis undertaken on behalf of SCPF is a scenario analysis, rather than a deterministic prediction of future investment returns, and gives an indication of the direction of travel and the impact on different asset classes relative to each other. SCPF will periodically utilise Climate Scenario Analysis, along with a variety of other methods, to assess the level of climate risk the Fund is exposed to. There are difficulties in modelling the impacts and implications of climate change on a multi asset investment portfolio and SCPF will stay up to date on the best methodologies and tools available in the market for future Climate Scenario Analysis".

#### **Cheshire Pension Fund**

The questions posed to the Cheshire Pension Fund Joint Committee at a public meeting on November  $20^{th}$  2020 can be found at:

 $\frac{https://www.cheshirepensionfund.org/members/wp-content/uploads/sites/2/2020/11/Joint-committee-20.11.20-public-Qs.pdf$ 

Question from the public: Cheshire Pension Fund's publicly available summary of their climate risk report (prepared by LGPS Central) concludes that the impact of 2°C, 3°C and 4°C global heating on investment returns would be minimal and describes 4°C as likely to present "a slight drag" on the fund.

Please provide references to climate science studies that support LGPS Central's core assumption that the world will be so unaffected by 3°C and 4°C of warming that financial processes will be able to function and continue with minimal loss of revenue.

**Answer**: The Climate Scenario Analysis was undertaken utilising the services of Mercer LLC. Mercer utilise a model to assess the impact of the Fund under a 2°C, 3°C and 4°C scenario. The model captures developments in the collective understanding of environmental science, and climate change-related political and technological developments, since 2015. This draws on Cambridge Econometrics global E3ME model, with comprehensive regional and sector data.

E3ME is recognised globally as one of the leading models for comprehensive economic modelling of policy and technology scenarios. The three climate change scenarios were developed using existing climate change models and through an extensive literature review. According to the analysis done by Mercer, the reason for the minimal impact on Cheshire Pension Fund's climate-related returns is due to the Fund's diversification, and in particular the Fund's high allocation to fixed income (UK Gilts and Multi-Asset Credit) which is relatively insensitive to the different climate scenarios. Further information on the modelling approach and literature used to inform Mercer's Climate Scenario Analysis can be found in their publicly available report "Investing In a Time Of Climate Change – The Sequel".

#### Public sector transparency vs outsourcing of advice and commercial secrecy

A consequence of the recent move to the outsourcing of public services is that, in place of a default setting of transparency and disclosure as to how public money is being spent—and investment decisions made by local government administrators of LGPS funds—advice provided by external investment consultants is deemed commercially sensitive.

Too often, details of important advice informing council decisions is withheld from pension scheme members and the general public, on the debatable basis that its disclosure could harm the commercial interests of the firm providing it.

The counter argument is seldom considered that, if external advice is inadequate, and councils rely upon it without effective scrutiny, then significant investment losses will result. This is occurring, despite the fact many LGPS pension funds identify over-reliance on poor external advice as a significant risk to their operations.

#### The London Borough of Merton

The London Borough of Merton's corporate risk register - disclosed via FOIA identifies the following risks to councils investments:

<u>Carbon Bubble Risk, Pension Fund Fiduciary Duty & Risks To Local Taxpayers Through LGPS</u>
<u>Underfunding and Exposure to Investment Losses in Defined Benefit Schemes - a Freedom of Information request to Merton Borough Council</u>

#### www.whatdotheyknow.com

"Underperformance of investments due to wrong investment advice from Independent Adviser - Inappropriate advice from Independent Adviser may lead to wrong investment decisions."

The consequences of this risk materialising could be: "Investment performance falls and fund may fail to meet its funding objectives in the medium term. High cost of changing investment decision"

To mitigate this risk, the council suggests: "Taking second opinion when major investment decisions are being made, & reviewing investment advice given."

During the research phase of this report - Freedom of Information Act (FOIA) requests were sent to the council administrators of LGPS funds requesting the advice they have sought and received on managing climate risk. Merton - which is <u>advised by Hymans Robertson</u>, refused the <u>FOIA request for information</u> on the basis that:

"Disclosure of this information would be likely to prejudice the council's commercial interests, because any advice for is commissioned for the Merton pension Fund and the pension committee. If this advice were shared to the public, which an FOI disclosure is, we would be releasing specialist information from our consultants. This information could then be used by other organisations without renumeration to the consultant. The consultant would lose income and the council would damage its reputation with the consultant which may damages the Councils ability to procure future advice."

It is not clear from publicly available information whether Merton has critically analysed Hymans Robertson's advice on climate risk, or sought a second opinion - in line with its stated approach to risk management set out in the risk register.

In contrast to Merton and its tightly managed advisory relationship with Hymans Robertson, the following analysis of Mercer's climate risk advice has only been made possible due to Mercer's release of climate risk advice into the public realm.

While critical of Mercer's approach to modelling climate risk, which we note for accuracy show openness to update and revision, we commend Mercer for publishing its advice so that it can be analysed, critiqued and improved upon - and we urge Mercer's competitors in this space, Aon, Hymans Robertson, Barnet Waddingham, Towers Watson, and Allenbridge Epic to make public their advice to clients on climate risk, for the benefit of scheme members and taxpayers and to improve climate risk management practice.

In response to this paper, Mercer explains that their approach has evolved. The scenarios they are currently modelling include a 'Failed Transition' that shows materially greater falls in GDP and there is therefore, they believe, much more aligned to climate scenarios.

#### Mercer's 2023 Scenarios

As of this year, Mercer is currently working with clients to assess climate risk using three scenarios, a Rapid Transition, an Orderly Transition and a Failed Transition.

Under the 'Failed Transition' the expected warming by 2100 is 4.3C. The Scenario focuses on the 40-year period to 2062. By 2062 the projected warming is around 2.5C. The climate impact on global GDP under the Failed Transition up to 2062 is a reduction of around 25%. The impact of a Failed Transition on a global equity portfolio under Mercer's updated scenarios shows a reduction in value of between 35% and 40% compared to a baseline scenario that represents what Mercer think the market is currently pricing in.

### 10 Supporting Recommendations

### 10.1 The peer review process in climate change

In future, all economics of climate change papers should be refereed by climate scientists as well as economists. The climate scientists should be charged with determining whether the empirical assumptions made by the economists are valid. Any economic paper in which the empirical assumptions about climate change by economists are rejected by scientific reviewers should be refused publication in refereed journals.

# 10.2 Pension fund and other financial institutions assessment of climate change risks

We accept that pension funds and other financial institutions cannot themselves be experts on climate change, and have to rely upon external experts. In future, such bodies should engage not only management consultant firms, but also climate scientists. If the climate scientist recommendations clash with the management consultants, then the climate scientist recommendations should prevail.

#### 10.3 NGFS and Hothouse Earth

NGFS should commission climate scientists to develop a proper hot-house world scenario (Steffen et al. 2018) that views climate a systemic risk, linking up to geopolitical risk, migration, tipping points, links to other natural systems, physical health, psychological impacts on populations, etc.

### 11 Appendix

### 11.1 Economists' damage estimates

Nordhaus's "enumerative" estimates of damages from climate change in 1991.

TABLE 6: TABLE 5 FROM NORDHAUS 1991, P. 931: "IMPACT ESTIMATES FOR DIFFERENT SECTORS, FOR DOUBLING OF CO2, U.S. (POSITIVE NUMBER INDICATES GAIN; NEGATIVE NUMBER LOSS)"

Sectors Billions (1981, \$)				
Total National Income	Worst	Best	Average	
Severely impacted sectors				
Farms	-10.6	9.7	-0.45	
Forestry, fisheries, other	Small -	⊦ or -		
Moderate impacted sectors				
Construction	+			
Water transportation	Ś			
Energy and utilities				
Energy (electric, gas, oil)				
Electricity Demand	-1.6	-1.65		
Non-electric space heating	1.1	1.16		
Water and sanitary	-ŝ			
Real Estate				
Land-rent component				
Estimate of damage from sea level rise				
Loss of land	-1.5	55	-1.55	
Protection of sheltered areas	-0.	-0.9		
Protection of open coasts	-2.8	-2.84		
Hotels, lodging, recreation	Ś	Ś		
Central Estimate				
Billions, 1981 level of national income			-6.23	
Percentage of national income			-0.26	

The list of studies of the total costs of global warming prepared by the economics section of the IPCC in 2014. Note that none of the industries that Nordhaus assumed would be "negligibly affected by climate change" appear in the Coverage column.

TABLE 7: TABLE SM10-1, P. SM10-4 OF IPCC 2014 CHAPTER "KEY ECONOMIC SECTORS"

Authors (with citations where	Year	Warming (°C)	Impact (%	Method	Coverage
available)			GDP)		
(Nordhaus 1994b)	1994	3	-1.3	Enumeration	Agriculture, energy demand, sea level rise
(Nordhaus 1994a)	1994	3	-3.6	Expert elicitation	Total welfare
(Fankhauser 1995)	1995	2.5	-1.4	Enumeration	Sea level rise, biodiversity, agriculture, forestry, fisheries, electricity demand, water resources, amenity, human health, air pollution, natural disasters
(Tol 1995)	1995	2.5	-1.9	Enumeration	Agriculture, biodiversity, sea level rise, human health, energy demand, water resources, natural disasters, amenity
(Nordhaus and Yang 1996)	1996	2.5	-1 <i>.7</i>	Enumeration	Agriculture, energy demand, sea level rise
(Plambeck and Hope 1996)	1996	2.5	-2.5	Enumeration	Sea level rise, biodiversity, agriculture, forestry, fisheries, electricity demand, water resources, amenity, human health, air pollution, natural disasters
(Mendelsohn et al. 2000)	2000	2.2	0	Enumeration	Agriculture, forestry, sea level rise, energy demand, water resources
(Nordhaus and Boyer 2000)	2000	2.5	-1.5	Enumeration	Agriculture, sea level rise, other market impacts, human health, amenity, biodiversity, catastrophic impacts
(Mendelsohn et al. 2000)	2000	2.2	0.1	Statistical	Agriculture, forestry, energy demand
(Tol 2002)	2002	1	2.3	Enumeration	Agriculture, forestry, biodiversity, sea level rise, human health, energy demand, water resources
(Maddison 2003)	2003	2.5	-0.1	Statistical	Household consumption
(Rehdanz and Maddison 2005)	2005	1	-0.4	Statistical	Self-reported happiness
(Hope 2006)	2006	2.5	-0.9	Enumeration	Sea level rise, biodiversity, agriculture, forestry, fisheries, energy demand, water, resources, amenity, human health, air pollution, natural disasters
(Nordhaus 2006)	2006	3	-0.9	Statistical	Economic output
(Nordhaus 2008a)	2008	3	-2.6	Enumeration	Agriculture, sea level rise, other market impacts, human health, amenity,

					biodiversity, catastrophic impacts
(Maddison and Rehdanz 2011)	2011	3.2	-12.4	Statistical	Self-reported happiness
(Bosello, Eboli, and Pierfederici 2012)	2012	1.9	-0.5	CGE	Energy demand; tourism; sea level rise; river floods; agriculture; forestry; human health
(Roson and Mensbrugghe 2012)	2012	2.9	-2.1	CGE	Agriculture, sea level rise, water resources, tourism, energy demand, human health, labor productivity
(Roson and Mensbrugghe 2012)	2012	5.4	-6.1	CGE	Agriculture, sea level rise, water resources, tourism, energy demand, human health, labor productivity

Figure 31 lists the studies identified by (Tol 2022) as providing numerical estimates of the impact of global warming on future GWP.

FIGURE 31: ECONOMIC STUDIES OF GLOBAL WARMING AS OF 2021. ADAPTED FROM (TOL 2022)

		Authors					
Study	Year	Lead authors	Others	Method	SCC	GW	DGDP
1	1979	d'Arge		enum	92	-1	-0.6
2	1982	Nordhaus		enum	74	2.5	-3
3	1991	Nordhaus		enum	17	3	-1
4	1994	Nordhaus		enum	23	3	-1.3
5	1994	Nordhaus		elicit	62	3	-3.6
5	1994	Nordhaus		elicit	29	6	-6.7
6	1995	Fankhauser		enum	35	2.5	-1.4
7	1995	Berz		enum	37	2.5	-1.5
8	1995	Schauer		elicit	129	2.5	-5.22
9	1995	Tol		enum	47	2.5	-1.9
10	1996	Nordhaus, Yang		enum	35	2.5	-1.4
11	1996	Plambeck, Hope		enum	71	2.5	-2.9
12	2000	Mendelsohn, Schlesinger, Williams		ectric	-0.7	2.5	0.03
12	2000	Mendelsohn, Schlesinger, Williams		ectric	0	2.5	0.1
12	2000	Mendelsohn, Schlesinger, Williams		ectric	0	4	-0.01
12	2000	Mendelsohn, Schlesinger, Williams		ectric	0	4	-0.04
12	2000	Mendelsohn, Schlesinger, Williams		ectric	0	5.2	-0.01
12	2000	Mendelsohn, Schlesinger, Williams		ectric	0	5.2	-0.13
13	2000	Nordhaus, Boyer		enum	37	2.5	-1.5
14	2002	Tol		enum	- 355	1	2.3

15	2003	Maddison		ectric	-0.8	2.5	0
16	2005	Rehdanz, Maddison		ectric	77	0.6	-0.2
16	2005	Rehdanz, Maddison		ectric	48	1	-0.3
17	2006	Hope		enum	24	2.5	-1
18	2006	Nordhaus		ectric	16	3	-0.9
18	2006	Nordhaus		ectric	18	3	-1.1
18	2008	Nordhaus		enum	43	3	-2.5
19	2009	Horowitz		ectric	587	1	3.8
20	2010	Eboli, Parrado, Roson		CGE	23	3	-1.35
21	2011	Hope		enum	12	3	-0.7
22	2011	Maddison, Rehdanz		ectric	77	3.2	-5.1
23	2011	Ng, Zhao		ectric	209	1	-1.35
23	2011	Ng, Zhao		ectric	249	1	-1.61
24	2012	Bosello, Eboli, Pierfederici		CGE	21	1.9	-0.5
25	2012	Roson, van der Mensbrugghe		CGE	33	2.9	-1.8
25	2012	Roson, van der Mensbrugghe		CGE	24	5.4	-4.6
26	2013	McCallum, Bosello, Horrocks	18	CGE	27	2	-0.7
27	2013	McCallum	+	CGE	17	4	-1.8
28	2013	Nordhaus		enum	37	2.9	-2
29	2015	Desmet, Rossi-Hansberg		ectric	-37	4.6	5.1
29	2015	Desmet, Rossi-Hansberg		ectric	9	9.3	-4.9
29	2015	Desmet, Rossi-Hansberg		ectric	20	13.6	-24.1
29	2015	Desmet, Rossi-Hansberg		ectric	44	16.7	-78.9
30	2016	Sartori, Roson		CGE	12	3	-0.7
31	2018	Kompas, Pham, Che		CGE	72	1	-0.5
31	2018	Kompas, Pham, Che		CGE	41	2	-1.1
31	2018	Kompas, Pham, Che		CGE	32	3	-1.8
31	2018	Kompas, Pham, Che		CGE	27	4	-2.8
32	2019	Dellink, Lanzi, Chateau		CGE	49	2.5	-2
33	2019	Takakura, Fujimori, Hanasaki	15	CGE	43	2	-1.1
33	2019	Takakura, Fujimori, Hanasaki		CGE	37	4	-3.9
33	2019	Takakura, Fujimori, Hanasaki		CGE	39	6	-9.1
34	2020	Howard, Sylvan		elicit	158	3	-9.2
35	2020	Kalkuhl, Wenz		ectric	355	1	-2.3
36	2021	Conte, Desmet, Rossi-Hansberg	1	ectric	42		3.7
37	2021	Cruz, Rossi-Hansberg		ectric	15	7.2	-5
38	2021	Howard, Sylvan		elicit	236	1.2	-2.2
38	2021	Howard, Sylvan		elicit	146	3	-8.5
38	2021	Howard, Sylvan		elicit	100	5	-16.1
38	2021	Howard, Sylvan		elicit	79	7	-25
39	2021	Newell, Prest, Sexton		ectric	-47	4.3	5.63
39	2021	Newell, Prest, Sexton		ectric	-30	4.3	3.61
39	2021	Newell, Prest, Sexton		ectric	14	4.3	-1.71
39	2021	Newell, Prest, Sexton		ectric	14	4.3	-1.63
39	2021	Newell, Prest, Sexton		ectric	18	4.3	-2.17
39	2021	Newell, Prest, Sexton		ectric	5	4.3	-0.64

39	2021	Newell, Prest, Sexton	ectric	15	4.3	-1.82
39	2021	Newell, Prest, Sexton	ectric	15	4.3	-1.75
39	2021	Newell, Prest, Sexton	ectric	18	4.3	-2.16

# 11.2 Papers in economics journals critical of mainstream climate change economics

- Ackerman, Frank, and Charles Munitz. 2012. 'Climate damages in the FUND model: A disaggregated analysis', Ecological Economics, 77: 219-24.
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From: <u>Jenifer Schramm</u>

To: KERSGAARD Jennifer; OIC Public Comments

Subject: written comments to OIC for submission

Date: Saturday, September 9, 2023 4:15:39 PM

Attachments: written comments to OIC from Jenifer Schramm.docx

This email is from a party external to Treasury. Use care with links and attachments.

Jennifer,

I hope this finds you well. Please submit the attached comments. Jenifer

Jenifer Schramm, co-lead of Divest Oregon:

Time is running out to address risk to the PERS portfolio. The time to act is now.

The Treasurer leans heavily on an engagement strategy in his decarbonization framework. Shareholder engagement has had no meaningful impact on big oil, even when the shareholder is a huge investor like CalPERS meeting directly with management. The oil major's small investment in clean energy is an economic decision divorced from shareholder pressure. Commitments to net zero by 2050 have been abandoned when short-term profit calculations have shifted. My written comments document this.

You don't like the term divestment. Fine. Call it reinvestment of funds that are currently at risk. Fossil fuel investments need to be ended and phased out of the portfolio. Then the Treasury can engage with other corporations as to meaningful emission reduction that transcends offsets.

The Treasurer often draws a distinction between his personal values and his mandated professional duty to maximize returns. Investing in the volatile and declining fossil fuel industry is not a way to maximize long-term returns. Further, under ORS 293.726 there is an additional mandate of risk analysis and of prudence appropriate for a pension fund. The risk of fossil fuel investment and resulting climate extremes is increasingly apparent and pressing.

The fossil fuel industry has been extremely good at predicting climate consequences of fossil fuel use. They have also been extremely good at waging a shockingly cynical decades-long disinformation campaign. They continue to spew out misdirection on "natural gas." But climate risk evidence is growing, faster and faster, so even the oil majors are publicly acknowledging that reality. For example, Exxon's Global Outlook published last week said their projection shows emissions will fail to meet a 2°C global warming cap by 2050.

The Treasury has loaded up OPERF with high-risk fossil fuel investments – including billions locked up in new private investments. The Treasury's response to increasing knowledge about fossil fuel investment risk has been to double down on rolling the climate-risk dice.

Fossil fuels are poor long-term investments. They are dangerous investments. They are capable of wrecking the economies on which good, steady OPERF returns depend.

Thank you for your service.

From: Nichole Heil

To: <u>OIC Public Comments</u>

 Subject:
 Public Comment for next week"s OIC meeting

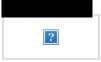
 Date:
 Wednesday, August 30, 2023 3:00:33 PM

 Attachments:
 20230906 OIC Public Comment.pdf

## This email is from a party external to Treasury. Use care with links and attachments. Hello,

My name is Nichole Heil from the Private Equity Stakeholder Project. I will be delivering inperson public comment at next week's meeting. You can find my comment attached. Thanks!

Nichole Heil (she/her)
Research & Campaign Coordinator
Private Equity Stakeholder Project (PESP)
nichole.heil@PEstakeholder.org





## **Oregon Investment Council Public Comment**

September 6, 2023

Good afternoon madam chair and board, my name is Nichole Heil with the Private Equity Stakeholder Project. We are a non-profit organization that seeks to understand the impacts of private equity on people and the planet. I'm here today to talk about three OIC investments in risky fossil fuel assets that combined release the equivalent of approximately 72 coal-fired power plants worth of carbon dioxide emissions every year. OIC is one of the largest investors of NGP Capital, an oil and gas-focused private equity firm. OIC has committed a billion dollars since 2018 across nearly all of NGP's oil and gas funds. This includes a recent \$250 million investment in NGP's latest fund, Natural Resources XIII in 2023. Our partner Global Energy Monitor's analysis concluded that from 2014-2021, NGP portfolio companies generated at least an estimated total of 97 million metric tons of carbon dioxide equivalent or about the annual emissions of 26 coal power plants.

The OIC is also invested in the controversial Rio Grande LNG export terminal which is facing <u>community</u> and <u>legal opposition</u>, via a \$251 <u>million commitment</u> plus a \$99 million sidecar to Global Infrastructure Fund V. If built, this project is estimated to emit the equivalent <u>emissions of 44 coal power plants every year, about 163 million tons of carbon dioxide equivalent.</u>

Finally, I'd like to highlight an actual coal-fired power plant in the OIC's portfolio. The OIC made a \$500 million investment in Blackstone Capital Partners VII in 2016 which invested in the Gavin Coal Plant, a 2,600-MW, coal-fired plant, located in Cheshire, OH, the largest in the state. In 2021 it was the <u>fourth-largest power plant CO2 emitter in the country</u>, producing over 7.3 million tons of CO2. In addition, Gavin is the "most deadly remaining coal-fired power plant" in the U.S. according to a 2023 <u>Sierra Club analysis</u> of particulate matter impacts.

These private market fossil fuel investments contain climate and financial risks. A recent <u>New York Times column</u> highlighted new research showing Oregon's pension fund is over 40 percent more volatile than its own reported statistics. Given the risk of OIC's private equity portfolio and the <u>Treasurer's decarbonization framework</u>'s goal to achieve

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<sup>&</sup>lt;sup>1</sup> The annual coal plant equivalent emissions were calculated using the <u>EPA's Greenhouse Gas</u> <u>Equivalencies Calculator</u> for NGP's emissions (97 million metric tons of CO2e which is equivalent to 26 coal power plants), Rio Grande LNG emissions (163 million metric tons of CO2e which is equivalent to 44 coal power plants), and Gavin Coal Plant (at least 7.3 million tons of CO2e which is equivalent to 2 coal power plants) for a total of 72 coal fired power plants worth of emissions



50% decarbonization across the entire portfolio by 2035, the Board should do the following to derisk the portfolio:

- 1. Disclose climate risks throughout the portfolio, in public and private markets
- 2. Engage private asset managers to transition current fossil fuel investments
- 3. Cease new investments in fossil fuels
- 4. Invest in climate solutions

Thank you for your time today and allowing me to speak.

Sincerely,

Nichole Heil Research and Campaign Coordinator Private Equity Stakeholder Project From: GaryLinda Wallmark
To: OIC Public Comments

Subject: October 25 OIC meeting -- public comment

Date: Wednesday, October 18, 2023 11:46:28 AM

### This email is from a party external to Treasury. Use care with links and attachments.

Here is a copy of the testimony I intent to present at the October 25 meeting.

My name is Gary Wallmark. I am a retired attorney, a career PERS member, and a volunteer with Divest Oregon. I drove roughly two hours today from my home in Eugene to provide testimony regarding the necessity for the OIC to act independently in performing its duties.

The Oregon Treasury hired a consultant, many would say of dubious reputation, to create a plan you will be asked to adopt. For the Oregon Investment Council to be able to vote on adopting it as the **OIC's** Decarbonization plan, Divest Oregon believes the OIC needs its own independent consultants to conduct the necessary plan review. This consultant would need all the background information that was given to McKinsey.

OIC may very well already have a consultant on contract who could do this review, such as Meketa, who in 2018 advised the New York City comptroller on the financial impact of divestment and the divestment process. Whomever you choose, they need to have expertise in reviewing decarbonization plans and must be well versed in net zero strategies, such as being a signatory to the Net Zero Consultants Initiative.

That review should answer the following questions:

- Are the details of the plan ambitious enough to attain significant decarbonization by 2030 or 2035 which has been cited as critical for both financial and climate risk maintenance?
- Does the plan combine engagement with concrete action, such that a failure to change fossil fuel business practices within 3-5 years leads to divestment?
- Will the resulting decarbonization goals and subsequent movement towards those goals be communicated to the OIC and stakeholders in a timely, transparent manner?

Divest Oregon's recommendation for an Independent Review of the decarbonization plan is made in light of the failure of the **previous** OIC to order a **mandatory internal audit** by the Oregon Treasury.

As I'm sure you are aware, ORS 293.776, enacted in 1967, requires the OIC to provide for an examination and audit of OPERF's investment program at least once every FOUR years, and report the results. The statute directs that the examination, audit, and report "shall include an evaluation of current investment funds investment policies and practices and of specific investments..."

The last such examination and audit was conducted **SEVEN years ago** in September 2016. This 2016 audit report was obtained by Divest Oregon in early 2023 via a public records request. This means the Treasury and the OIC are **THREE years late** in meeting their quadrennial investment-audit statutory requirements.

The **previous** OIC did not exercise its oversight function in mandating audits by the Treasury, and so we are strongly advocating for the **current** OIC to do its own due diligence of the Treasurer's Plan before embracing and adopting it as the Oregon Investment Council's own Decarbonization Plan.

Thank you for your consideration and for your valuable independent public service.

Gary Wallmark Eugene From: Pete Farrelly

To: <u>OIC Public Comments</u>
Subject: OIC mtg public comment

**Date:** Thursday, August 31, 2023 7:16:35 AM

Attachments: OIC letter - 8-23.pdf

# This email is from a party external to Treasury. Use care with links and attachments. Hello,

Please acknowledge receipt of this email and the attached letter. It is for next week's OIC meeting.

Thank you for considering.

Best, Pete Hello,

I am submitting public comment to the Oregon Investment Council (OIC) regarding their fiduciary duty to produce risk-adjusted returns for Oregonians. Specifically, the OIC is not sufficiently protecting against the threat of climate-related financial risk in Oregon's investments. I suggest one quick and easy solution is simply to document the OIC's commitment to produce risk-adjusted returns.

#### ASK:

Add a tenth item to the <u>Statement of OIC Investment and Management Beliefs</u> – **10. Specifically manage climate and transition risks.** 

Uncontroversial Facts about this request:

- This is simple it is a clear commitment to addressing climate change's systemic market risk.
- This is easy it only requires three votes from the OIC; most critically, CIO Mr. Rex Kim's vote.
- It is transparent.
- It would increase trust, and improve the reputation of the OIC, Treasury, and PERS.
- It supports many of the recommendations from the Oct. 2021 OST Climate Scan Report that the OIC requested more than two years ago.
- It is required by the OIC's primary fiduciary duty.

This should be enough information to make this simple improvement. Please take this action as soon as possible.

As an unfortunate aside, it is important to point out that items 8 & 9, which relate to ESG investments in the <u>Statement of OIC Investment and Management Beliefs</u>, do not adequately address the systemic market risk posed by climate change for many reasons.

ESG investments are:

- 1. Inherently difficult to measure,
- 2. Subject to greenwashing to meaninglessness, or may even increase climate and transition risks,
- 3. Unnecessarily broad, and
- 4. A less fundamentally sound approach to managing risk-adjusted returns for Oregonians.

That said, OIC members in the past have confused managing climate risk with ESG investments for the last 3.5 years I have been submitting testimonies. Please disabuse yourselves of this confusion at your earliest convenience.

Thank you for your work. Thank you for considering this request. Best of luck going forward.

Pete Farrelly, P.E.

PERS member, former OSGP Advisory Committee chair

From: <u>Carolynn Kohout</u>
To: <u>OIC Public Comments</u>

Subject: Public Comment for 10-25-"23 OIC Meeting Date: Wednesday, October 18, 2023 8:23:33 AM

## This email is from a party external to Treasury. Use care with links and attachments.

Dear Readers:

## My comments are below:

I do not like and am not comfortable with the Oregon Investment Council investing in private equity firms, which invest in fossil fuels and its related industries. This is because:

- 1- There is secrecy from the OIC to beneficiaries in conflicting with the transparency <u>required</u> in a fiduciary or trustee relationship here, between retirement plan managers and state employees/beneficiaries regarding private equity;
- 2- Private investments are concealed. Thus it is <u>not</u> possible to track whether or not our pension fund is increasing its support of the fossil fuel industry or divesting from it;
- 3- Private equity pumps hundreds of <u>b</u>illions of dollars into buying up offshore drilling in the Gulf of Mexico propping up fracking operations;

which expand infrastructure through pipelines and export terminals;

which spew pollution from gas and coal power plants

- -withOUT comprehensive disclosures of their holdings and
- -with NO Environmental Impact Statements re: environmental and community impacts;
- 4- Engagement with fossil fuel companies (monitoring and negotiation to achieve movement toward zero emissions) has <u>not</u> worked;
- 5- Investor funds are frozen in private funds in 10-12 year contracts. Their illiquidity makes it hard to respond to climate risks or geopolitical shifts;
- 6- Asset class names are often changed. For example, "alternatives" has now dropped out and "diversifying strategies" has been added. The Treasury invests more than half of OPERF in private investments, in multiple asset classes (private equity, alternatives, opportunity portfolio, real estate, real assets, etc.);

- 7- Private equity returns are no better than stock market investments, given private equity's high fees; Our pension fund lost 1.55% in value in 2022. Private equity returns were flat, whereas smaller investments were OK and publicly traded stocks and bonds were poor in 2022;
- 8- Fossil fuel investments create financial risk. Boards selectively or inaccurately disclose the climate risks their companies face, or leave their climate-related goals in the form of aspirational targets and commitments will be <u>exposed to regulatory action</u> and potentially significant fines and other penalties. (Emmas Marris);
- 9- Companies with high emissions are already a potential problem for investors: They are likely to be <u>hit with taxes</u>, <u>duties</u>, <u>fines</u>, <u>lawsuits</u>, reputational problems, activist investors, industry-transforming regulatory shifts, and, eventually, the <u>costs</u> of switching over to new ways of doing business;

## 10- Private equity investment:

We are 12 out of 15, where 15 is the largest size; LA County ERS Fund is 13, and Pennsylvania School Employees Fund is 15. Our 6/30/2021 - 5 year investment return was 10.5%; 10-yr. Investment return was 8.8%; private equity was 26.4% of the public portfolio; private equity target was 17.5% of the public portfolio. Ohio Teachers' Fund was 12.2% of their 6/30/2021 - 5 year investment return; 10.0% of their 10-yr. Investment return; and 0% for private equity in both categories. Their achievements are noteworthy.

## 11- Private equity

- a) transfers responsibility for debt they created to buy a company, to the company bought;
- b) transfers the money to themselves by charging multiple high fees (as "management"/"consulting" fees);
- c) hides them in various aspects of a complicated deal;
- d) issues generous dividends; and
- e) sells company assets like real estate for short-term gain.

My Goal for the Oregon Investment Council:

1- You end NEW investments in fossil fuel;

- 2- Phase out all CURRENT fossil fuel investments while protecting returns;
- 3- Use a <u>Just Transition framework</u> to reduce climate risk to frontline communities: Adopt an <u>environmental justice framework/plan</u>, taking into account the disproportionate impact of climate and of fossil fuel infrastructure on frontline communities;
- 4- Release annually to the public a list of ALL portfolio holdings; define the emissions for each holding; publish the emissions of current investments; and provide progress reports about any climate-related targets or goals each investment has set.
- 5- Set <u>aggressive timelines</u>, consistent with fiduciary responsibility for: 1-your <u>climate crisis response</u> and 2- our unfunded liability currently projected to be <u>\$28 billion</u> in pension obligations of contributors (schools, libraries, local governments, unions...) in actual numbers: \$.72 in assets per \$1 liabilities.
- 6- Require each investment to <u>release details</u> about their climate risks; <u>disclose information</u> about their greenhouse-gas emissions and exactly <u>how</u> they plan to hit the targets they keep announcing; disclose information about how climate change could affect their businesses, starting in January 2024 to the Environmental Protection Agency.

NOTE: The SEC announced its intention to add climate disclosures for 2024: companies to disclose emissions for the entire supply chain and for the life of any products they may sell – thus affecting the environment and society. This says corporations have ethical responsibilities to entities who are not shareholders.

7- Require fact-checking any green claims made by publicly traded companies to be straightforward: metrics should be similar to what is done around the world/across jurisdictions - to easily compare, say, a German company with a Brazilian one. Companies which operate in many countries will have one set of figures to assemble.

Sincerely,

Carolynn Kohout

SEIU 503/99 Member

One of Many Hats

From: Kristin Edmark

To: OIC Public Comments

**Subject:** Public comment to the OIC meeting 10/25/2023 **Date:** Friday, September 29, 2023 2:48:05 PM

## This email is from a party external to Treasury. Use care with links and attachments.

Comment to the October 25<sup>th</sup>, 2023 Oregon Investment Council Submitted by Kristin Edmark, my son and Daughter-in-law are PERS members, I have 3 grandchildren in Portland

At 3 am August 25, 2023, my sister in Kings Valley, Oregon outside Corvallis, got the call to be ready to evacuate; she could see the fire approaching down the hillside. While she loaded things of value into her sedan and woke the others living there, she worried about how her much-loved 6 horses would make it if she ran them out of the pasture onto Kings Valley Highway where they would have the best chance of running to safety. Thankfully, with helicopters and a large crew, the fire was stopped before daybreak. The warming climate is affecting people in the northwest even in neighborhoods in and near cities.

August 17, 2023, the Jenny Creek fire evacuated many of my neighbors and put half the town of La Canter, WA, on notice to be ready to evacuate. We live on the La Center border. In 2020, my daughter-in-law's family lost a much-loved home to the Oregon fires.

Funders of fossil fuel expansion like Oregon Treasury should be held accountable. The increased cost of climate-related disasters should not be borne by cities, counties, states but rather by those who are fueling/increasing the problem. Those losing their crops and livelihoods deserve reparations from those actively, knowingly increasing the problem like Oregon Treasury.

**Oregon legislation** continues to make real progress toward combating global warming as do new policies by Oregon cities and counties. The conflict between Oregon investments and increasing climate legislation could soon leave some Oregon investments stranded or displaced.

#### Evidence is clear that large pensions earn less when invested in fossil fuels.

Fossil fuels have always been a volatile investment, but economic risks have skyrocketed in the past decade. The energy sector, which dominated the S&P 500 in the 1980's with 29% of the market, is only 5% today. The MSCI All World Index (ACWI) did better when excluding fossil fuels than when including them over the past 12 years <a href="https://ieefa.org/resources/two-economies-collide-competition-conflict-and-financial-case-fossil-fuel-divestment">https://ieefa.org/resources/two-economies-collide-competition-conflict-and-financial-case-fossil-fuel-divestment</a>

Recent studies showing decreased earnings by retaining fossil fuel investments: **2023** A University of Waterloo study shows 6 large pension public equity portfolios, including Oregon, averaged 13% lower profits over 10 years than they would have had they not retained fossil fuel investments.

https://uwaterloo.ca/school-environment-enterprise-

development/sites/default/files/uploads/documents/the-impact-of-energy-investments-on-the-financial-value-and-the-carbon-footprint-of-pension-funds pdf final-version.pdf

**2021** Maryland State Retirement and Pension System (SRPS), would have made 15% more in last 10 years if they had not had their investments in the Carbon Underground 200. Investments are similar to Oregon.

https://chesapeakeclimate.org/wp-content/uploads/2022/02/FFI\_Solutions\_Backtest\_MD-MSRPS-2021.pdf

**2021** Finance Climate Maps show much lower returns in the Failed Transition Pathway. Ortec suggests "integrating climate into your investment process". <a href="https://irp.cdn-">https://irp.cdn-</a>

website.com/21c0cb7e/files/uploaded/Climate MAPS OPERF Report Oct2021 Redacted.pdf 2021 BlackRock report for New York City's Comptroller and pension funds found that divestment "outperforms all other options." And that fossil fuel stocks "consistently underperformed the broader market over the past five years." According to Blackrock the costs to divest were negligible and can be done within normal activities. https://ieefa.org/articles/new-vork-city-comptroller-urges-blackrock-drop-fossil-holdings

https://ieefa.org/articles/new-york-city-comptroller-urges-blackrock-drop-fossil-holdings 2019 CalSTRS would have gained \$11.9 billion and CalPERS would have gained \$5.5 billion had they been invested in other than oil/gas production in the 10 years between 2009 and 2019.

https://fossilfreeca.org/calpers-corporate-knight-report/

#### Fossil-free investments fees

Dropping fossil fuels from an investment portfolio is no longer prohibitively expensive. Investment indexes are changing as more pensions and endowments are divesting. According to the Global Fossil Fuel Divestment Commitment Database, 1593 Institutions have made commitments to divest representing \$40.5 Trillion. Another example: The Net Zero Asset Owner Alliance, which was formed in September 2019 during the UN Secretary-General's Climate Action Summit, had 273 signatories as of 5/2023 representing over USD \$61.3 trillion of assets with the goal to mobilize private capital in support of the Paris Agreement. By setting clear milestones, the alliance aims to foster transparency and accountability in its journey towards carbon neutrality. https://greenly.earth/en-us/blog/company-guide/what-is-the-net-zero-asset-owner-alliance-nzaoa. Demand for transparency and investments without fossil fuels is creating more choice and normalizing of fees.

## Fossil Fuel Performance and Risk as summarized by Tom Sanzillo of the IEEFA

The following quotes are from a report on the IEEFA website

(https://ieefa.org/resources/financial-case-pensions-dump-fossil-fuels-california-strong-despite-resistance) written by Tom Sanzillo, Director of the Institute for Energy Economics and Financial Analysis. He has 17 years of experience with the City and the State of New York in senior financial and policy management positions. As the first deputy comptroller for the State of New York, Tom oversaw the finances of 1,300 units of local government, the annual management of 44,000 government contracts, over \$200 billion in state and local municipal bond programs as well as a \$156 billion global pension fund and administration of a one-million-member retirement system.

The report reads, "The oil and gas industry has been experiencing a long-term downward trend. Fossil fuels made up 29% of the Standard & Poor's 500-stock index in 1980. Today, they account for 5%, after falling to 2% in 2020. Although Russia's invasion of Ukraine drove up oil prices, the disruption provides no prudent basis for long-term investment in the fossil fuel industry. Despite an unprecedented rise in oil prices and banner industry profits in 2022, the industry fell back to last place in the stock market after annual earnings were announced in early February.

Meanwhile, fossil-free versions of stock indexes, like the MSCI All Country World Index, have <u>outperformed</u> the all-in index over the last decade. Facts like these have led more than 1,500 investment funds worth \$40 trillion—including global investors such as BlackRock, Harvard University, New York State's pension funds, and insurance giants Zurich and MetLife—to adopt fossil fuel exclusion policies. Excluding fossil fuels has become so mainstream that the <u>international standard setting body</u> for insurance company regulation sees it as an essential piece of any effective strategy to manage climate risk...

Meanwhile, the energy transition is generating competition in key fossil fuel market segments. Gasoline and diesel comprise the market for 65% of every barrel of oil drilled, but ExxonMobil CEO Darren Woods now expects all new passenger vehicles to be <u>electric</u> by 2040. The electric utility industry is investing <u>six times</u> more in wind and solar than in gas or coal power plants over the next five years. Petrochemicals are seen as a growth market for oil and gas, but single-use plastic bans proliferate. Countries from Asia to Europe have adopted decarbonization plans to reduce the use of fossil fuels in petrochemicals."

Thankfully, the morally right course of action aligns with fiduciary responsibility. Please decrease fossil fuel investments in all asset classes, commit to no new investments with fossil fuels or with entities with large investments in fossil fuels. Please demand transparency and provide transparency to OPERS members.

From: Rory Cowal

To: <u>OIC Public Comments</u>

**Subject:** Public statement for the upcoming OIC meeting **Date:** Wednesday, October 18, 2023 9:54:01 AM

## This email is from a party external to Treasury. Use care with links and attachments.

Dear Chairperson Samples and Council Members,

I urge the OIC to ensure that the Treasurer's decarbonization plan sets aggressive timelines. The level of greenhouse gas reductions in the next 6 years will largely determine whether or not we exceed 1.5° C this century and experience the worst of climate devastation. This is the conclusion reached by the UN's Intergovernmental Panel on Climate Change. Its 2023 Assessment Report communicated a dire warning: a liveable future can only happen with "deep, rapid and sustained greenhouse gas emissions reductions in all sectors." The OIC has the ability to act on this warning: it can ensure that the Treasurer's decarbonization plan meets the urgency of the climate crisis.

UN Secretary General Antonio Guterres said: the IPCC report "is a clarion call to massively fast-track climate efforts by every country and every sector and on every timeframe. In short, our world needs climate action on all fronts -- everything, everywhere, all at once." I urge the Treasury and the OIC to do its part by taking bold action now.

Sincerely, Rory Cowal