5

Environmental Policies to Save the Planet

Richard Lewney

1 Introduction

Neoliberal economics has generally opposed or rolled back policy measures designed to protect the environment. In June 2017, President Trump[1] announced the decision for the United States to withdraw from the Paris Agreement, and in November 2019, Secretary of State confirmed that the United States had initiated the process of withdrawal (to be completed a year later). Burke, Hagen, Höhne, Nascimento, and Bals (2019) ranked the United States as bottom of its Climate Change Performance Index league table of 61 countries on a variety of indicators,

---

[1] It is debatable whether President Trump and politicians with similar convictions can be classified as 'neoliberal' given their predilection for protectionism in trade policy. But they do share and draw support from the neoliberal suspicion of strong government intervention when it comes to environmental policy.

R. Lewney (✉)
Cambridge Econometrics and Cambridge Trust for New Thinking in Economics, Cambridge, UK
e-mail: rl@camecon.com

P. Arestis, M. Sawyer (eds.), *Economic Policies for a Post-Neoliberal World*, International Papers in Political Economy, https://doi.org/10.1007/978-3-030-56735-4_5

including a 20% weighting for policy. Australia remains a signatory to the Paris Agreement, but ranked 56 out of 61 in Burke et al. (op. cit.); in November 2019, the Swedish central bank announced[2] that it had divested from bonds issued by the states of Queensland and Western Australia, also the Canadian province of Alberta, because of sustainability concerns. Brazil's President Bolsonaro threatened withdrawal from the Paris Agreement when running for office in 2018, but has so far decided not to carry out the threat. However, he has been openly critical of Greta Thunberg and vowed to reduce tribal rights to land and allow commercial exploitation of protected reservations.[3]

Neoliberal economics typically draws on neoclassical economics for intellectual support, although the two are far from coterminous. Neoclassical economics does not necessarily prescribe neoliberal policies, but its benchmark of perfectly competitive markets is consistent with neoliberal ideals. Neoclassical economics recognises environmental degradation as a classic example of an externality and frames its response in terms of correcting that market failure, but the limitations of its marginal cost-benefit approach have been exposed in the climate change debate. This chapter explores the role that the key insights of post-Keynesian and Schumpeterian economics (such as path dependence, radical uncertainty, the presence of heterogeneous actors, the role of money and finance, and the representation of endogenous technical change) are playing in forming an analysis of environmental policy that is better adapted to the challenge of tackling global warming.[4]

The chapter initially presents an introduction to environmental pressures, concluding that, among the various threats, climate change poses the biggest challenge. The relationship between neoliberal politics and mainstream (neoclassical) economics is then discussed and the response of the latter to the climate change challenge is critically reviewed. A subsequent section discusses possible technological pathways to reach

---

[2] Available at: https://www.riksbank.se/en-gb/press-and-published/speeches-and-presentations/2019/floden-riksbank-selling-bonds-for-climate-reasons/

[3] Available at: https://uk.reuters.com/article/uk-climate-change-greta-bolsonaro/brazils-bolsonaro-calls-activist-thunberg-a-brat-idUKKBN1YE27U

[4] See Pollitt (2019) for a modeller's perspective on the opportunity for post-Keynesian analysis to meet the needs of policymakers seeking to confront the climate crisis.

net-zero greenhouse gas (GHG) emissions by 2050. The next section discusses key obstacles to be overcome and policies to address those. The final section summarises and concludes.

2 Economic Development and Environmental Degradation

2.1 The Concept of Natural Capital

The concept of *natural capital* provides a framework within which to understand how environmental degradation affects *human* well-being.[5] The UK Department for Environment, Food, and Rural Affairs (2018) draws on the Natural Capital Committee (2013) to provide a succinct definition of natural capital as

> the elements of nature that directly and indirectly produce value or benefits to people (now or in the future), including ecosystems, species, freshwater, land, minerals, the air and oceans, as well as natural processes and functions. (Department for Environment, Food and Rural Affairs, 2018, p. 6)

Natural capital is therefore understood as one of four types of capital that provide services to individuals and society, the other three being:

- manufactured or produced capital (e.g. buildings, roads or machinery),
- human capital (e.g. knowledge and skills) and
- social capital (e.g. trust, behavioural norms and institutions).[6]

Natural capital provides *ecosystem services*, categorised in the European Environment Agency's Common International Classification of Ecosystem Services[7] into three broad sections. Table 5.1, taken from

---

[5] The concept of natural capital embodies an anthropocentric approach to the question of why we should take care of the environment. See Williams (1995) for a discussion of this ethical stance.

[6] Natural Capital Committee (2013, p. 10).

[7] Haines-Young and Potschin (2018).

Table 5.1 Sources of economic value from ecosystem services

Category	Example	Source of economic value	Direct implication of depletion/ degradation
Provisioning	Crops and livestock Fisheries Water supply Timber	Inputs to production/ direct consumption	Lower/costlier production
Regulation and maintenance	Air quality regulation Flood regulation Global climate regulation	Maintenance/ protection of human and physical assets	Impaired productive capacity Costs of defence/ repair Costs of alternatives
Cultural	Recreation	Intrinsic (amenity) value	Lost welfare/ well-being Costs of maintenance/ repair

Source: White et al. (2017)

White et al. (2017), shows the three sections and gives key examples of particular services that support human well-being, including economic activity. It also indicates the direct economic implications that might be expected to arise from the loss of each type of ecosystem service, as a result of environmental degradation.

To give some idea of the scale of ecosystem services (Costanza et al., 2014), and as IPCC (2019, chapter 1) reports,

> [t]he annual value of the world's total terrestrial ecosystem services has been estimated [in 2011] to be … approximately equivalent to the annual global Gross Domestic Product. (p. 81)

The stresses placed by human activity upon natural capital, and hence upon the ecosystem services it provides, come about through unsustainable use of resources (overfishing, overuse of ground and surface water resources, repurposing of natural habitats, forestland and flood plains for agricultural use or building, etc.), and through the unsustainable use of environmental sinks (disposal of waste pollutants at a higher rate than the capacity of the environment to process, absorb and render harmless the pollutants).

2.2 The Key Threats to Ecosystem Services

The latest in the European Environment Agency's (2019, p. 35 and following) five-yearly assessments of the state of the environment and prospective changes makes the following key points:

- Population and economic activity have put huge pressure on our planet's life support systems, reflected in climate change, loss of biodiversity and changes in the chemical composition of atmosphere, oceans and soil.
- More species are now facing the threat of extinction than at any time in human history.
- The period since the 1950s has seen an unprecedented acceleration in global temperature change due to anthropogenic greenhouse gas emissions, the result in turn of fossil fuel combustion, agricultural practices and deforestation.
- The plans submitted by countries under the Paris Agreement are consistent with an increase in global temperatures of about 3 °C compared with pre-industrial levels by 2100.
- There is great uncertainty over what change in temperature would trigger tipping points leading to self-reinforcing feedback loops, but some estimates are in the range of 2–3 °C.
- Europe's consumption of goods and services depends on the extraction of resources outside of the continent and so Europe is responsible for environmental impacts felt in other parts of the world.

Thus, while some improvements to environmental quality have been made in some countries, because of more stringent environmental standards (e.g. reduction in certain local air pollutants in cities in the West), the threats associated particularly with declining biodiversity and global warming are very high.

2.3 The Response of Neoliberal Economics

The 'neoliberal' label is used in a variety of ways. Here we adopt the definition offered by Castree (2010) for 'neoliberalism as policy discourse' and summarise it as the following agenda for government (Castree, 2010, p. 10):

- privatisation, including the assignment of clear, legally enforceable private property rights to environmental assets;
- marketisation: introducing market exchange, for that might not previously have been subject to a market logic;
- state roll-back or deregulation, including the contracting-out of delivery of some state services;
- market-friendly reregulation and tax policies;
- use of market proxies in the residual (non-privatised) state sector;
- strong encouragement of 'flanking mechanisms' in civil society to provide social support mechanisms that the state no longer provides; and
- creation of 'free', 'self-sufficient', and self-governing individuals and communities with a strong ethic of individual responsibility.

In principle, this agenda does not preclude the adoption of policies intended to meet ambitious targets to prevent and reverse environmental degradation, but it does circumscribe tightly the permissible policy tools used to pursue those targets (limited essentially to market-based instruments). However, there are two reasons why, in practice, neoliberal economics ends up with at best a very limited policy intervention for environmental goals.

Firstly, its philosophical standpoint gives primacy to the individual as the arbiter of value. If someone chooses to drive a diesel car in the city even in the face of a substantial hike in the tax on fuel designed to reflect the environmental externality, that shows that the cost (in terms of lost welfare) of a policy that leads or forces them to switch to a zero-emissions vehicle is very high. It makes no difference if the saving in their total cost of driving over time, suitably discounted, is greater than the additional purchase cost of the vehicle: the fact that they could have realised that saving but choose not to do so is proof that they prefer not to make the change. If they persist in driving the diesel car when the fuel price has been raised to reflect the cost that their behaviour imposes as an externality on others, that is a more desirable outcome than one in which policy leads or forces them to curb their emissions (say, by regulating the maximum emissions permissible from cars). The consequence is that, in a cost-benefit calculation, a high value is placed on *behavioural inertia*, interpreting it as a freely made, informed choice. If, in contrast, the behaviour has a more complex explanation that does not allow such a straightforward interpretation of welfare to be made, the neoliberal approach to welfare has an inherent bias towards the status quo rather than action to improve the environment. In addition, if a completely different ethical yardstick is adopted, the choice to pay a fine and continue to pollute may not be regarded as socially acceptable.

Secondly, it places a very high priority on individual freedom as against state action that limits such freedom, even if the action itself uses a market-based instrument rather than, say, regulation as the tool. Raising the price of carbon constrains the freedom of individuals to drive internal combustion engine cars, to travel by aeroplane and to turn up the heat instead of insulating their home. Raising the price of goods whose production is intensive in methane emissions constrains the freedom to eat beef and consume milk. The scale of state intervention required to implement widespread greenhouse gas taxes goes well beyond the minimalist state envisaged in neoliberal political philosophy. For the neoliberal, the individual freedom that has to be sacrificed is so precious that there is almost no prospective benefit that could make it a price worth paying.

In trying to reconcile an unwillingness to countenance the loss of that freedom with the prospect of an existential threat to human life, one solution is to deny the validity of the climate science. Hornsey, Harris, Bain, and Fielding (2016) undertake a meta-analysis of earlier studies testing for an association between individuals' characteristics and acceptance of or scepticism about climate change. and conclude:

> [T]he data suggest that 'evidence' around climate change is searched, remembered, and assimilated in a way that dovetails with people's own political loyalties and their worldviews. For some, this may lead to a disre-

gard for (or misunderstanding of) the scientific consensus around climate change. (Reported in 'Implications' of Hornsey et al., 2016)

2.4 The Response of Mainstream Economics

The best-known economist working on climate change economics from the mainstream neoclassical tradition is William Nordhaus, who shared the 2018 Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel.

Nordhaus developed the influential DICE (Dynamic Integrated model of Climate and the Economy) integrated assessment model (IAM),[8] which combines an economic growth model with a calculation of emissions of carbon dioxide (CO_2) (which respond to a carbon price and the cost of abatement technology) and a reduced-form model of the consequent global warming and damages suffered. Society has a choice whether or not to abate emissions in any given time period, trading off the cost of doing so with the discounted cost of damages from global warming in the future. The model can determine the 'optimal' (within its own terms) rate of trade-off and hence the time profile for the carbon price required to prompt the necessary expenditure on abatement in each period.

DICE has a single-good neoclassical economic growth function, with population-driven assumptions for labour-supply growth and an assumption for total factor-productivity growth. Gross investment (and hence changes in the capital stock once depreciation is deducted) is determined by saving, where the saving rate is optimised over time (reflecting a choice made by consumers between consuming today or investing to consume more tomorrow). Hence, output is either consumed (providing utility now) or invested (to provide utility tomorrow). Assumptions are included for the time profile of carbon emissions produced per unit of GDP, and then an endogenous abatement factor is applied to determine the emissions that go into the atmosphere. The abatement factor is determined by a decision whether to pay a carbon price or invest in a zero-emissions 'backstop' technology which has an assumed (initially high but declining

---

[8] The first version of DICE was published in Nordhaus (1992). The current version of DICE is documented in Nordhaus (2018a).

over time) cost per tonne of CO_2 abated. Assumptions for land-use CO_2 emissions are added to give total emissions. A set of geophysical equations link emissions to temperature change. Finally, a damage function, with a quadratic form to represent a non-linear impact of temperature on damages, determines the reduction in GDP associated with global warming.

Critics of DICE, from the environmental side, regard its conclusions for mitigation action as insufficiently radical. Nordhaus (2018a, Table 4, p. 353) reports a 'no-policy' projection of a 4.1 °C temperature increase above pre-industrial levels by 2100 under 'best-guess' parameters, which is within the 3.7 °C–4.8 °C range for median estimates of temperature increase reported in the IPCC's (2014, p. 20) 5th Assessment Report. But the 'optimal' scenario in Nordhaus' (2018a) work has only modest mitigation measures producing a temperature increase of 3.5 °C, much higher than the Paris Agreement's objectives (well below 2 °C and towards 1.5 °C). In his own qualitative conclusions, Nordhaus (op. cit.) regards the implications of his work as supporting a call for coordinated global mitigation action in the form of a global carbon price, not a justification for inaction. However, he positions his analysis between the relatively weak action taken by governments so far and excessively ambitious (i.e. too much cost in the near future for too little gain in the long term) objectives such as those recommended by Stern (2007).[9]

Why might the conclusions from DICE understate the urgency for substantial mitigation action and the speed with which it should be carried out? The answers relate to: (i) the choice of discount rate used to weight losses of future consumption (due to damages) against losses of present consumption (due to mitigation); (ii) the estimates of the relationship between the scale of greenhouse gas emissions and damages; (iii) estimates of the cost of abatement/mitigation; and (iv) the treatment of uncertainty in the cost-benefit calculation.

---

[9] See also Nordhaus (2007, pp. 26–27) and Nordhaus (2018a, Table 2, p. 349).

2.5 The Choice of the Discount Rate

When Stern (2007) was published, an element that proved controversial was its choice of a lower discount rate than was used conventionally by economists. Since a lower discount rate gives more weight to the well-being of future generations compared to the present, it results in policy prescriptions with a greater emphasis on mitigation action.

Nordhaus (2007) argues for the 'descriptive'[10] approach in the choice of interest rate, which is to use the estimated real market rate of return on capital. The justification is that this approach captures the way people today behave when comparing the weight given to consumption now compared with consumption in the future. In contrast, 'normative' approaches like that of the Stern Review take an ethical stance that, according to descriptivists, governments impose on society's choices vis-à-vis future generations. The suspicion of government typical of neoliberal economics can be clearly seen in Nordhaus' (2007) characterisation:

> The *Review* takes the lofty vantage point of the world social planner, perhaps stoking the dying embers of the British Empire, in determining the way the world should combat the dangers of global warming. The world, according to Government House utilitarianism,[11] should use the combination of time discounting and consumption elasticity that the *Review's* authors find persuasive from their ethical vantage point. (pp. 148–149)

The Stern Review is therefore characterised not as a contribution to debate in a democratic society, but as the imposition of the views of an imperial elite.

Apparently reluctant to rest his argument about the appropriate choice of discount rate on political philosophy, Nordhaus (2007) does not proceed to the logical next step of making the argument that governments should respect the preferences revealed by the individuals who make up society collectively to value present consumption substantially more than future consumption. Rather, he seeks to distinguish his approach as one

---

[10] Following the terminology of Arrow et al. (1996).

[11] A term coined by Sen and Williams (1982).

of empirical realism in contrast to moralising that is irrelevant to the way the world actually works, hence the term 'descriptive'. Nevertheless, there is no escaping the need for additional justification for moving from 'is' to 'ought'. If DICE is intended as a model of how people actually behave, the 'optimal' path that it derives must be interpreted not as 'desirable' but merely as capturing the choice that actors would *actually* make to adjust consumption over time. Together with the associated social cost of carbon, this can only become a policy recommendation if we accept that the discount rate implied by the observed rate of return on capital is an *acceptable* rate by which society should trade off the consumption of future generations against consumption now.

Consider a mitigation opportunity that involves a consumption sacrifice of €1bn today to prevent damages worth €100m per year in perpetuity. The descriptivist's logic is that if the rate of return for that opportunity is less than the market rate, future generations will be worse off if society invests in the mitigation opportunity than in the alternative opportunity available on the market. Hence, the market rate becomes the benchmark by which any investment, including mitigation, should be judged. Society, the argument goes, should undertake mitigation up to the point where the rate of return falls below the market rate and then stop. On this argument, the discount rate applied to mitigation is not to determine the trade-off between consumption today and consumption tomorrow: that trade-off has already been decided by choice of how much to save. Rather, the discount rate is used to allocate scarce investment resources between mitigation and other kinds of investment. Future generations are going to receive income from the saving (=investment) undertaken by today's generation: it is just a question of whether they receive it in the form of reduced damages or higher GDP (arising from the alternative, non-mitigation investment).

However, can the market rate of return on capital be interpreted as representing society's preferences about the value of consumption today versus the consumption of future generations? As far as individuals are concerned, the long tradition in the literature on myopia in economic behaviour[12] casts doubt on whether the observed tendency to choose earlier over later rewards should be interpreted as a pure time preference (i.e. that individuals actually care less about tomorrow's consumption than today's). Gabaix and Laibson (2017) develop a model in which *imperfect information* leads a 'perfectly patient' (i.e. with zero pure time preference) Bayesian decision-maker to act as if they have time preferences, and that agents who are better informed in various ways exhibit less 'as if' discounting.

When behaviour is aggregated, there is clearly a problem with regard to who is represented in the financial market transactions that determine the market rate. For the generation alive today, wealth is very highly concentrated both within and across countries, and so the observed choices made in financial markets are not representative of the general population. Even if they were, future generations are not represented at all. The calculation based on the rate of return in capital markets of any trade-off between consumption today and consumption tomorrow is, at best, lifetime consumption smoothing for relatively wealthy individuals who are not infinitely lived (but may, if they are wealthy enough, make some allowance to provide an inheritance for children and grandchildren).

Thirdly, if we abandon the notion that the rate of return in capital markets is the price that clears the market for saving (sacrificed consumption) and investment in favour of one in which the supply of investible funds depends upon the creation of money by private banking institutions, the observed rate of return can no longer be interpreted as a measure of society's willingness to trade off consumption today against consumption tomorrow. Rather, it is a measure of the extent to which expected returns exceed banks' cost of capital, in which the rate of interest that has to be paid to depositors (the price that could influence consumption/saving decisions) plays only a small part.

The choice by neoclassical economists of the market rate of return as the discount rate to use in assessment of environmental policy, therefore, builds in a bias towards today's consumption versus tomorrow's, and

---

[12] See, for example, Kahneman and Lovallo (1993), Larson, List, and Metcalfe (2016), and Thaler, Tversky, Kahneman, and Schwartz (1997).

against mitigation action, consistent with the limited 'optimal' scenario recommended by Nordhaus (2007).

2.6 The Damages That Will Arise from GHG Emissions

Even if a zero pure time preference rate is accepted, the discount rate used in cost-benefit analysis (CBA) also incorporates[13] a factor that captures diminishing marginal returns to additional consumption, or, equivalent in the mathematics but more relevant for environmental policy, the idea that an additional unit of consumption is worth more to the poor than to the rich (and that social welfare is treated as an aggregation of individuals' utility). If economic growth permits per capita consumption to be higher in the future than today, and if mitigation action imposes costs on today's generation (see below on each of these assumptions), the impact of the policy is to transfer consumption from this generation (including the population of poor countries) to its richer descendants. Unabated carbon emissions may increase the number of very hot days in what are currently temperate climates, but (so the argument goes) those who suffer the consequences will be better able to afford air conditioning than their parents and grandparents were able to afford abatement measures.

An external critique of that argument is that it accepts the premise built into IAMs like DICE that we value climate damages on the same scale as consumption so that they can be traded off against each other, rather than treating them as incommensurable.[14] An alternative approach, and the one effectively adopted by the governments that have committed to the most ambitious targets for climate change mitigation, is to set an objective for the time profile of net emissions and to rank alternative pathways to achieve that objective according to the each pathway's economic and social impacts.

---

[13] In the formula developed by Ramsey (1928).

[14] One way of extending CBA under these circumstances is to use multi-criteria decision analysis, an approach now included in the UK government's economist's toolkit. Available at: https://www.gov.uk/government/publications/green-book-supplementary-guidance-multi-criteria-decision-analysis

Within its own terms, the argument assumes that mitigation undertaken in the present period imposes a cost on consumers in the present period. Even if mitigation comes at a cost (see discussion below), the measures could, of course, be funded by borrowing so that the cost is spread at least partly over future generations. An obvious example is the cost of investment in a power generation plant based on renewable sources, for which future electricity consumers will pay the debt servicing costs in their electricity bills over the life of the plant. IAMs like DICE do not represent the role of finance in spreading repayments explicitly; if saving determines investment in the present period, then there is no need to take account of borrowing: those who are funding the loans must cut their consumption to effectively support the consumption of those for whom the cost burden is deferred.

The argument also depends on the assumption of continued growth in per capita consumption under business-as-usual (so that future generations are richer) and on the scale of damages that mitigation would avoid. The DICE quadratic damage function is quadratic in temperature increase, meaning that there is a non-linear (accelerating) impact on GDP as temperature rises. However, the scale of impact is relatively modest: 2.1% of global income at a 3 °C warming, and 8.5% of income at a 6 °C warming (Nordhaus, 2017).

Strikingly, even analysis that yields a damage function with similar modest impacts at a national level can comprise much larger impacts at the regional or local level. Hsiang et al. (2017) report a negative correlation between county-level damage impacts and per capita incomes, with damages in 2100 in the range 2%–20% of county income for what are currently the poorest third of counties under business-as-usual emissions.

Weitzman (2009) notes that any extrapolation to high-temperature outcomes of a damage function that fits low-temperature conditions, including the quadratic form assumed in DICE and other IAMs, is highly uncertain:

> High-temperature damages extrapolated from a low-temperature damages function are remarkably sensitive to assumed functional forms and parameter combinations because almost anything can be made to fit the low temperature damages assumed by the modeler. Most IAM damages func-

> tions reduce welfare-equivalent consumption by a quadratic-polynomial multiplier equivalent to $1/[1 + \gamma(\Delta T)^2]$, with γ calibrated to some postulated loss for $\Delta T \approx 2^{\circ}C - 3^{\circ}C$. There was never any more compelling rationale for this particular loss function than the comfort that economists feel from having worked with it before. (p. 16)

Burke, Hsiang, and Miguel (2015) use the World Bank country-level panel data for 166 countries over 1960–2010 and find that

> the slope of the damage function is large even for slight warming, generating expected costs of climate change 2.5–100 times larger than prior estimates for 2°C warming, and at least 2.5 times larger for higher temperatures. (p. 239)

Burke et al. (2019) follow this up with a panel data study of 11,000 districts across 37 countries, arguing that a more granular geographical approach allows for more precise estimates than using country averages (in which within-country variations are lost). The implications for the relationship between GDP and temperature change are similar to those in the earlier relevant study.

Burke et al. (2015) note that the estimates are conservative in the sense that these kinds of damage function equations, estimated over historical data (as is the case also for the IAMs), yield estimates that

> are based only on temperature effects (or effects for which historical temperature has been a proxy), and so do not include other potential sources of economic loss associated with climate change, such as tropical cyclones or sea-level rise. (p. 239)

Keen (2019) argues that the exclusion of these kinds of system effects is the critical weakness in the Nordhaus approach. Even wide variations in temperature across places during a period in which global temperatures are less than 1 °C higher than pre-industrial levels do not provide a representative evidence base for the kind of damages that could occur when global temperatures are, say, 4 °C higher than pre-industrial levels: the geophysical consequences are different when there is so much more energy stored up in the system. However, Nordhaus (2007) recognises that the form of the damage function used in DICE (and other IAMs) does not include sharp thresholds or tipping points, and justifies this on the basis of a reference to a literature survey which Keen (2019) identifies as Lenton et al. (2008). Keen (2019) cites text from Lenton et al. (2008) to show that the reference actually warns *against* smooth projections of climate change and explores various potential tipping points. Keen (2019) concludes:

> So the very reference that Nordhaus uses to justify **not** having a tipping point in his Damage Function establishes that *his Damage Function should have a tipping point*. (Emphasis in the original)

Nordhaus (2007) himself acknowledges that the optimal policy conclusions from DICE would change radically if damage impacts were higher/non-linear for temperature increases above 2 °C, although he does not regard current damages studies as supporting either of these (IRENA, 2019). Dietz and Stern (2015) provide a demonstration that, indeed, the implied optimal policy recommendation from DICE is for much stronger action if DICE is amended to include a stronger non-linear response of GDP to warming, a mechanism for endogenous technical change/growth and an explicit treatment of uncertainty over climate sensitivity to emissions.

2.7 The Costs of Abatement/Mitigation

Reflecting the underlying assumptions of neoclassical economics, DICE assumes that mitigation must be costly: if a choice were available that could provide the same of higher level of welfare at a lower cost, agents would already have chosen it. The question then arises as to how to interpret the existence of ‘no regrets’ opportunities, the classical example of which is roof insulation, which typically has a very short payback period for owner-occupiers. Conventionally, the failure of some consumers to undertake such opportunities is interpreted as showing that the welfare loss associated with the inconvenience outweighs the value of the cost savings available or that the consumer's rate of time preference is very high (so that future energy bill savings count for little). Hence, *by assumption*, mitigation measures must be welfare-reducing (before taking account of the environmental benefits of reduced emissions).

Inertia in take-up of mitigation options combines with endogeneity in technological change to produce pathways for mitigation in which costs are strongly path-dependent. The outstanding example in renewable energy is the dramatic fall in the costs of solar photovoltaic technology (PV) over the last two decades, as a direct result of greater sales. The idea that solar PV would already be competitive with fossil fuel generation in many situations (IRENA, 2019) would have seemed ridiculously optimistic even a decade ago.

However, even relying on conventional IAMs, IPCC (2014, p. 24) reported mitigation costs that are small in the context of expectations of long-term income and consumption growth (a median estimate of 4.8% of 'business-as-usual' (BAU) consumption in 2100).

2.8 The Treatment of Uncertainty

Nordhaus (2007) places considerable emphasis on uncertainty in his analysis, but not the consequences of uncertainty for the behaviour of agents in the economy and society. Rather, his treatment of uncertainty relates to *parameter uncertainty*, and he examines the consequences for the key outputs of his model (such as the social cost of carbon) of different draws from probability distributions assumed for parameter estimates. As far as it goes, this is clearly a commendable approach, acknowledging the uncertainty that the modeller faces in trying to predict the future. However, if the modeller faces uncertainty about the future, so do the agents whose behaviour the modeller is seeking to capture, and so it is inconsistent not to incorporate that uncertainty into the representation of behaviour and the interpretation of elasticities.

Weitzman (2007) shows how the motivation for mitigation is affected by a recognition that the scale of impact of future warming is uncertain:

> The basic issue here is that spending money to slow global warming should perhaps not be conceptualized primarily as being about consumption smoothing as much as being about how much insurance to buy to offset the small chance of a ruinous catastrophe that is difficult to compensate by ordinary savings. (p. 703)

Daniel et al. (2019) pursue this idea, drawing on the financial economics literature for decision-making under risk and uncertainty. In contrast to the implications of DICE, their analysis suggests a profile for the carbon price that begins high and then is likely to decline over time as the insurance value of mitigation falls (we know, increasingly over time, the extent and impact of global warming) and technological change makes emissions cuts cheaper.

Nevertheless, uncertainty in the behaviour of economic agents extends much further, into decisions to take up and to commit finance to new (and therefore unfamiliar) technology. If there is an uncertainty penalty for new, clean technologies, we can no longer interpret low responses to carbon price signals as indicating the preferences of fully informed, rational individuals. In other words, what looks like a high mitigation cost in a world of perfect information (agents will not act unless the price signal is very high) becomes a case of herding behaviour (agents will not act until they see other agents doing so).

2.9 Is Raising the Carbon Price an Adequate Policy Response?

The policy recommendation of the neoclassical tradition emphasises 'correcting' prices as the way to address externalities such as carbon emissions. Nordhaus (2007) argues strongly for action to raise the carbon price, concluding:

> To a first approximation, raising the price of carbon is a necessary and sufficient step for tackling global warming. The rest is largely fluff. (p. 28)

Nordhaus is urging policymakers to grasp the painful nettle of raising the price of carbon rather than produce call-for-action soundbites that fail to include this essential step for fear of political unpopularity. Similarly Weitzman (2007), applauding the Stern Review's unequivocal call for a higher carbon price, argues:

> [S]teady pressure from the predictable presence of a high carbon price reflecting social costs (whether imposed directly through taxes or indirectly via tradable permits) would do more to unleash the decentralized power of capitalistic American inventive genius on the problem of researching, developing, and finally investing in economically efficient carbon-avoiding alternative technologies than all of the piecemeal command-and-control standards and patchwork subsidies making the rounds in Washington these days. (p. 723)

So, raising the carbon price is indeed a necessary step for tackling global warming, but it is far from sufficient, for reasons that neoclassical analysis typically ignores.[15] Reliance on this single policy assumes that agents are certain that the policy will be maintained, and even strengthened as necessary, in the future, so that they will be willing to commit to investment in long-lived assets. Imperfect information, uncertainty and institutional obstacles (where privately rented tenure is important, separating the dwelling owner from the household that would benefit from an investment in energy efficiency) act to make households less responsive to energy price signals, making a much higher carbon price necessary to squeeze out consumption. But the distributional impact of a very high carbon price will be severe, with a substantial increase in energy poverty, unless action is also taken to ensure a large improvement in the thermal efficiency of the homes that poor households inhabit. Some of the key green technological advances such as the dramatic cost reduction in solar PV, improvements in the energy efficiency of cars and the development of battery electric vehicles (BEVs) have come about not because of a commitment to a high carbon price but through a mixture of initial R&D support, regulation and a growing general shift in the public policy stance. To insist on reliance on the carbon price instrument alone is to misunderstand key features of the world we actually live in.

---

[15] See Grubb et al. (2014, Section 8.8, pp. 302–305) for a fuller discussion.

3 What Would Getting to Net-Zero Greenhouse Gas Emissions by 2050 Look Like?

3.1 Possible Futures

A number of different pathways to achieve net-zero greenhouse gas (GHG) emissions by 2050 can be envisaged, depending on the rate of change in candidate, and sometimes competing, clean technologies, and on the extent of changes that might occur in personal and social behaviour. The scale of the challenge also depends on what is assumed for economic and demographic growth over the period, since that increases the scale of pressure on energy and other resources that needs to be curbed.

The EU's long-term climate strategy (European Commission (2018)) presented five different scenarios for the EU that would achieve an 80% reduction in net GHG emissions by 2050 (hence falling short of net zero). All five scenarios involve almost complete decarbonisation of electricity generation, on the assumption that there is not sufficient progress in bringing down the cost and improving the efficacy of carbon capture and storage (CCS) technology for this to be applied to fossil fuel power generation on a large scale. Renewable technologies expand their share of generation dramatically and nuclear continues to play a role. However, the scenarios differ in the way that final energy demand is met. One scenario focuses on electrification of most energy applications, for example, with heat pumps and electric vehicles. Another focuses on the production of 'green' (by electrolysis) or 'blue' (by steam reforming of natural gas coupled with CCS) hydrogen by electrolysis and its use as a feedstock in industry, in space heating and in hydrogen fuel-cell vehicles. A third assumes that synthetic hydrocarbons in the form of both liquid fuels and methane are produced using electricity and CO_2 (sourced from biomass or direct air capture), and then used in the same way that their fossil fuel-derived counterparts are today. A fourth scenario assumes deep energy efficiency improvements across all sectors, including deep renovation of buildings and modal shift in transport towards more sustainable modes.

The fifth focuses on the contribution that circular economy measures could make via increased resource efficiency and recycling.

In order to make the further cuts in emissions required to go from an 80% reduction by 2050 to net zero, two further scenarios are produced. In one, a technology-driven solution is followed, with the most cost-efficient options from the first four scenarios combined with 'bio-energy with carbon capture and storage' (BECCS) plants to remove carbon from the atmosphere. In the other, the emphasis is on lifestyle changes, extending the circular economy measures to include changes in diet and transport choices, while natural carbon sinks are also enhanced.

In analysis carried out for the European Climate Foundation's Net Zero 2050 series, Cambridge Econometrics and Element Energy (2019) also developed a number of alternative pathways for the EU with the same distinction scenarios with high electrification of final demand and those with more of a role for hydrogen. The study emphasised the impact that demand-side choices have on the costs of the energy system, particularly a system dominated by renewable energy in electricity generation. Power generation is then subject to intermittency and seasonal variations in supply and lacks the flexibility to meet demand peaks provided currently by fossil fuel-based dispatchable capacity. The use of smart technology to smooth electricity demand peaks reduces the need for extra generation capacity to ensure adequate supply, particularly in countries with a cold winter that face a large power deficit on a cold evening. Battery storage, including vehicle-to-grid technology, can be used to achieve short-term load shifting. Investment in energy-efficient buildings both reduces peak demand and reduces the capacity required of heat pumps to achieve the required ambient temperature. The study also considered the need for seasonal storage of energy, to make use of surplus renewables capacity to produce hydrogen in summer and use it in power generation or direct final demand applications in winter.

On present assumptions, both the European Commission (2018) and Cambridge Econometrics and Element Energy (2019) find that scenarios with substantial behaviour change including deep energy efficiency, dietary changes and enhanced circular economy measures permit a lower-cost energy system than do scenarios that put most of the weight on technological solutions. The question, therefore, is the extent to which we are willing to adopt the behaviour changes or, instead, to pay higher energy costs.

In its global analysis, IEA (2019) has a Sustainable Development Scenario which achieves net zero by 2070 rather than 2050 with similar features to those already discussed for the EU. Electricity generation is largely decarbonised, but there is some CCS with fossil fuel plants in a few countries. Energy efficiency measures keep the scale of final energy use broadly stable despite economic and population growth. There is substantial electrification of final demand, substitution of hydrogen for methane and some CCS to capture industrial emissions. To go further, to stabilise the global temperature increase at 1.5 °C (50% chance), either a scaling-up of negative emissions solutions or shutting-down/retrofitting with CCS of existing fossil fuel power plants would be required.

IPCC (2018) reviews a range of model-based scenarios that keep temperature increase to 1.5 °C. It notes that scenarios that include a temporary overshoot in emissions (to permit a slower and, perhaps, less costly transition) rely on the future deployment of carbon dioxide removal (CDR) technologies, typically either BECCS or afforestation, to make up for the overshoot, and the availability of such technologies is far from certain. In summarising the findings of its review, IPCC (2018) notes the need for action in both energy and non-energy sources of emissions of all the greenhouse gases:

> Limiting warming to 1.5°C implies reaching net zero CO2 emissions globally around 2050 and concurrent deep reductions in emissions of non-CO2 forcers, particularly methane (high confidence). Such mitigation pathways are characterized by energy-demand reductions, decarbonization of electricity and other fuels, electrification of energy end use, deep reductions in agricultural emissions, and some form of CDR with carbon storage on land or sequestration in geological reservoirs. Low energy demand and low demand for land- and GHG-intensive consumption goods facilitate limiting warming to as close as possible to 1.5°C. (p. 95)

4 Obstacles and Policies

4.1 The Macroeconomic Impact

One of the key political obstacles to the transition to net zero is the fear that it entails a significant economic cost, experienced in constrained choices, higher prices, lower returns on investment, lower incomes and fewer jobs. The capacity of governments to protect or compensate losers would be reduced if the transition entailed a macroeconomic cost: it is harder to redistribute pieces of the pie if the overall pie is smaller.

Paroussos, Fragkiadakis, and Fragkos (2019) provide a review of recent studies that use integrated assessment models (IAMs) to assess the macroeconomic impacts of the transition. They categorise the studies into two broad groups according to the modelling methodology adopted:

> The first group includes IAMs that assume optimising behaviour agents that operate in a closed resource system (where capital and labour resources are sscarce (Type I–IAMs) … The second group includes IAMs that consider an open resource system with no capacity constraints (Type II–IAMs). (Section 1)

And their review finds:

> For green growth to take place, it requires that GHG emission reduction takes place at such rate that allows clean energy technologies to become market competitive, while at the same time sufficient financial resources at a low cost exist. The studies that find negative impacts from reducing GHG emissions attribute this either to the factor that clean energy technologies do not achieve price parity with fossil-fuel technologies or because there is no sufficient financing available that eventually puts a stress in the capital markets and reduces financing for alternate investment projects. (Section 2)

Hence, the answer to the question whether the transition would have a positive or negative impact on indicators of national economic performance such as GDP, or consumer spending, depends critically on what is assumed about the way that the economy works. Suppose that agents make choices that maximise their intertemporal welfare, and that their collective behaviour has no impact on the rate of technological advance in clean technologies. In that case, action by government to price the externality of GHG emissions into product prices or to regulate to prevent certain choices being made must result in a sub-optimal outcome (i.e. with lower welfare before the benefits of curbing emissions are counted in). And if investment is determined by an interest rate that equilibrates the supply of and demand for saving, then an alternative future with much higher investment in decarbonisation technologies must drive up the interest rate and crowd out consumption or other kinds of (and more productive) investment.

In the European Commission (EC)'s Long-Term Strategy, the estimates of impact on the level of EU GDP in 2050 in decarbonisation scenarios that meet 2 °C and 1.5 °C targets by that date range from −1.3% to +2.2% (European Commission, 2018, Table 12, p. 219). The small negative impacts are found using GEM-E3,[16] a hybrid global Computable General Equilibrium (CGE) macro-sectoral model, while the small positive impacts are found using E3ME,[17] a macroeconometric macro-sectoral model in the post-Keynesian tradition.

In its discussion of alternative pathways to achieving 1.5 °C target, IPCC (2018) does not present macro GDP impacts. Instead, it highlights qualitatively the potential synergies and trade-offs between the whole set of UN Sustainable Development Goals (SDGs),[18] an approach that has the clear merit of highlighting fundamental objectives (e.g. eliminating poverty, promoting decent work and living standards) rather than the means to an end represented by the GDP measure. It also forces attention on the extent to which raising GDP is likely to achieve those fundamental objectives, taking account of distributional considerations and impacts on the full range of ecosystem services. Of course, the impacts on SDGs depend critically on how mitigation is achieved. IPCC (2018) expresses the view that the synergies between action to curb

---

[16] Available at: www.e3mlab.eu/e3mlab/index.php?option=com_content&view=category&id=36%3Agem-e3&Itemid=71&layout=default&lang=en

[17] Available at: www.e3me.com

[18] Available at: https://sustainabledevelopment.un.org/?menu=1300

warming and the promotion of many of the SDGs outweigh the trade-offs (IPCC, 2018, p. 20), in part no doubt because global warming damages are estimated to fall more heavily on poor countries/communities.[19]

4.2 Winners and Losers and Higher Costs for Those Unable to Mitigate the Impact of Carbon Taxes

Unsurprisingly, there is general agreement that the transition involves substantial restructuring of economies. In the absence of economically viable technological solutions that capture, use and store carbon at the time of fossil fuel combustion or which extract and store carbon dioxide from the atmosphere, the economic activities that depend on the extraction, processing and distribution of fossil fuels must be phased out. Similarly, there are very significant challenges for energy-intensive industries that currently depend heavily on fossil fuels and for industries that emit carbon dioxide or other GHGs in process emissions: they must find alternative energy sources and ways to capture process emissions or we must reduce our use of their products. At the same time, the economic activities that depend on the development and production of the green technologies and products needed to take the place of GHG-intensive activities would flourish.

Even models in the neoclassical tradition that find a negative impact of the transition on GDP can report net positive employment impacts[20] because their production functions include a substitution of labour (as well as capital) for energy, while models that find a positive impact on GDP also find a positive net impact on jobs. European Commission (2018, p. 226) reports net positive impacts on jobs for the EU from both GEM-E3 and E3ME. Models such as these that distinguish sectoral detail also capture the feature that output and job losses are mostly in sectors with low labour intensity (fossil fuel extraction, oil refining), while some of the sectors that gain have higher labour intensity,

---

[19] See the discussion of Hsiang et al. (2017) above in this chapter.

[20] Unless they assume full employment in the 'business as usual' scenario against which the transition scenario is compared.

particularly refurbishment to make buildings more energy efficient. However, there are counter-examples. The shift from internal combustion engine to battery electric vehicles (BEVs) involves a shift in the location of value added in the supply chain from engine to capital-intensive battery manufacture; BEV engines last longer and need less maintenance, and refuelling does not require petrol stations and fuel delivery. ILO (2018) provides global estimates that in a 2 °C scenario there would be an additional 24 million jobs in the sectors that benefit from the transition against some 6 million lost in fossil fuel extraction processing and power generation.

The transition would therefore create both losers and winners. The restructuring impact is made more severe by the fact that the activities that would be phased out tend to be geographically concentrated (regionally and internationally) either as a consequence of geology or because they are subject to economies of scale and so tend to have large plants that are major local employers.

The European Commission's Long-Term Strategy notes that there are three NUTS 2 (i.e. level 2 of the Nomenclature of Territorial Units for Statistics) regions in the EU in which the extraction of fossil fuels and the associated support activities account for more than 1% of the region's total employment. The area around Aberdeen in Scotland is particularly vulnerable, with over 11% of jobs directly related to the oil and gas industry. Silesia in Poland and SudVest Oltenia in Romania have a dependence on coal and lignite production, accounting for 5% and nearly 2% of each region's jobs respectively (and, obviously, larger shares in the particular communities where the mines are located). While fossil fuel sectors face job losses, energy-intensive industries, such as metals and chemicals, and motor vehicle manufacturers will need to transform their processes and products. The Strategy reports that there are 24 NUTS 2 regions in which these sectors account for more than 1% of employment, and the higher shares are in less prosperous Member States. In Strední Cechy in the Czech Republic, Közép-Dunántúl in Hungary and Vest in Romania, these industries account for about 10% of each region's jobs (European Commission, 2018, p. 232). The prospect of these kinds of job losses can be expected to lead to a strong political reaction in favour of political parties opposed to green policies: the success of the Alternative für

Deutschland party in state elections in eastern Germany has been attributed in part to reaction to the closure of coalmines.[21]

What these findings highlight is the critical need for policies to support reskilling of workers so that they can adapt to the change in the jobs market and to support the development of alternative employment in the localities whose economies are specialised in the vulnerable sectors.

Cedefop (2019) reported a review of policies to support green skills and employment in six EU countries. It found that all the countries covered had some sort of sector-based skills anticipation mechanisms, within which the particular needs associated with the transition could be included. Similarly, programmes for skills development for the unemployed or those in work existed, but most did not have a specific focus on green skills (Cedefop, op. cit., p. 14).[22] It remains to be seen whether, without that focus, these mechanisms would identify skill mismatches that arise during the transition quickly enough and steer funding into the training programmes that can meet those needs.

Examples of local communities whose social and economic life has been torn apart by the closure of a major industrial employer are not hard to find, with legacy effects that span more than one generation. Beatty, Fothergill, and Gore (2019) describe the continuing evidence of deprivation in the former coal fields of Great Britain, encompassing a population of 5.7 million (9% of the UK total), where major job losses in coal mining mostly occurred more than 30 years ago. There remains a large jobs deficit, with just 55 employee jobs per 100 residents of working age (the national average is 73) and low wage rates for those in work.

The biggest policy shift intended to anticipate job losses due to the transition came in August 2019 when the German federal government announced a €40bn plan to support coal mining regions over the coming two decades during which coal-fired power generation is due to be phased out. Elements of the plan include improved broadband access and transport infrastructure and locating research institutes and federal authorities

---

[21] Available at: www.bbc.co.uk/news/world-europe-49544781

[22] Exceptions to this general rule were reported for the French public employment service and charitable/not-for-profit organisations, for example, in the United Kingdom.

in the areas losing jobs.[23] In January 2020 the European Commission launched its Just Transition Mechanism designed to mobilise at least €100b over the period 2021–27 to be targeted at the most affected regions, including €30–50bn of grants to support reskilling of workers, promotion of new employment opportunities and energy efficiency investments.[24]

The question is whether governments have the will and capacity to bring about the transformation of opportunities in these regions. The Long-Term Strategy (European Commission, 2018, p. 235) notes that there are other prospective long-term trends, unrelated to climate change mitigation, that present significant labour market challenges. Illustrating this, Lewney, Alexandri, and Storrie (2019) undertake scenarios using the E3ME macro-sectoral global model to assess the potential impact of a radical acceleration in job automation and find much larger potential job shifts and losses than in climate transition scenarios. Job losses in industries vulnerable to the transition will likely be happening at the same time as widespread labour market restructuring, the social implications of which could prove to be a major challenge, perhaps *the* major challenge, to sustained political commitment to decarbonisation.

The restructuring will also require households and individuals to change the way that they use energy. There are technological solutions that would involve less behavioural change, namely to produce synthetic versions of refined oil and methane in a way that is carbon neutral (extracting the carbon from the atmosphere), but these currently look to be very expensive. The lower-cost alternatives involve a combination of heavy investment in buildings to improve their thermal efficiency and a switch to greater use of electricity or hydrogen in transport and heat applications. In some cases technological advances are likely to reduce the cost of the zero-carbon alternative to the point where it is competitive with fossil fuels so that users will be no worse-off as a result of the transition. However, this will be true only if energy users are in a position to make the change. Policy would have to ensure that the price of fossil fuel

---

[23] 'Germany to spend up to $44 billion to cushion coal exit', as reported in: apnews.com/f3e79e70c2e547428db34a9f1b073f42

[24] Available at: https://ec.europa.eu/commission/presscorner/detail/en/ip_20_17

energy products rises; anyone who continues to rely on those products for transport and heating and who cannot make their home more energy efficient would face higher energy bills. This threatens to penalise those in privately rented accommodation and those who cannot afford to pay (or arrange to borrow to finance) the higher upfront investment cost for zero-carbon heating and transport solutions even if the saving in running costs would ultimately pay back that investment. The *gilets jaunes* movement in France remains a powerful reminder of what can happen when a government seeks to raise the price of fossil fuels.

To tackle the threat of increased fuel poverty as energy prices rise, very substantial investment in housing is needed to raise the standard of thermal efficiency of homes (to reduce the need for both heating and cooling). This is clearly a case where market signals are not strong enough to promote change. In England, for example, less than 2% of homes are in one of the top two energy efficiency rating bands and the owner-occupied or privately rented homes tend to be in the lower bands (Ministry of Housing, Communities,, & Local Government, 2019). More worryingly, only 1% of new homes in 2018 were built to the highest Energy Performance Certificate rating (Band A), in part because policies to support low-carbon measures had been weakened (Committee on Climate Change, 2019, p. 11). The UK Committee on Climate Change (CCC) has recommended that retrofitting energy efficiency measures in existing homes be undertaken as a national infrastructure priority with substantial public funding. It has also called for new homes to be required to meet ultra-high efficiency standards and that, from 2025 at the latest, no new homes should be connected to the gas grid. Local authorities (the planning authorities charged with ensuring compliance with regulations) need to be adequately resourced to act vigorously to promote energy efficiency.

4.3 The Take-Up and Cost of Clean Technologies

The pace of decarbonisation clearly depends on the speed of take-up of clean technologies.

Take-up is complicated by the fact that many of the key physical assets have a long life: motor vehicles can remain in the stock for ten years or more, while the useful life of power generation plant, industrial plant and buildings is measured in decades. Decisions made now can lock us into carbon-intensive technologies just when the pace of decarbonisation needs to be stepped up. Shearer, Yu, and Nace (2019) report that while the rest of the world outside of China collectively reduced its coal-fired power generation capacity over January 2018–June 2019, this reduction is more than offset by the scale of new build in China:

> China's recent growth is due to a brief but massive spree of project permitting that occurred from September 2014 to March 2016, a period when the central government delegated permitting to provincial authorities who had strong incentives to approve and build coal plants to hit province-level economic targets … Today, 147.7 GW of coal plants are either under active construction or under suspension and likely to be revived – an amount nearly equal to the existing coal power capacity of the European Union (150 GW). (Shearer et al., op. cit., p. 3)

Shearer et al. (2019, p. 13) estimate China will only be able to achieve Paris-compatible reductions in CO_2 emissions from power generation if its coal-fired plant is retired after operating for just half of the normal lifetime. Similar issues arise for other fossil fuel assets. Mercure et al. (2018) estimate that the adoption of Paris-compliant policies worldwide could result in a discounted global wealth loss of $1–4 tn. The greater the scale of such prospective losses, the greater is the incentive for those whose wealth is at risk to commit resources to persuade governments to delay action.

The path dependence implied by technological lock-in is strengthened by the endogenous nature of technological change and the role played by radical uncertainty in decisions to invest in innovation and to adopt new technologies.

Heuberger, Rubin, Staffell, Shah, and Dowell (2017) provide a short discussion of the tradition of technology cost reduction and the cost learning curves that are included in empirical models in which technology costs are endogenised. They note a range of technology cost-reduction drivers, including: market push (competition driving investment in R&D), demand pull (the stimulus to technological development given by a step increase in demand, for example, through government R&D policy or subsidy) and process advancement (e.g. through the exploitation of economies of scale). All can support the general principle of a virtuous circle in which increased deployment and production of a technology stimulate further cost reductions and hence greater deployment and so on. The relationship between deployment and cost reductions may be non-linear and typically varies with the maturity of the technology. The case of photovoltaic modules has been extensively studied. Kavlaka, McNerneya, and Trancikab (2018) note a variety of factors that drove the 97% reduction in module costs over 1980–2012, with government-funded and private R&D the most important driver, while economies of scale became increasingly important after 2001.

Drawing on Grubb et al. (2014), Mercure et al. (2016) review the barriers at various stages in the development of a new technology following a Schumpeterian approach. They note that the costs of investment in the innovation stage are often considerably greater than in the basic research stage and so uncertainty over prospective returns is a key obstacle. They cite the analysis of the innovation chain for power generation technologies of Murphy and Edwards (2003), who identify a 'technology valley of death' for technologies that receive early-stage public finance but fail to attract subsequent private finance for the commercialisation stage.

Mercure et al. (2016) also review barriers to take-up of new technologies: the diffusion stage. Here, again, uncertainty is key, in that take-up is low and slow even when technologies are cost-effective ('no regrets' opportunities). A critical factor informing potential policies on how to accelerate take-up is recognition of the importance of heterogeneity among potential users of a technology. The standard S-curve of market penetration over time, in which adoption rates are initially slow, then accelerate sharply, then level off again, is understood to reflect the different attitudes to risk of different market segments ('innovators', 'early adopters', 'early majority', 'late majority' and 'laggards').

The lessons for policy from this application of innovation and diffusion theory to the case of power generation and energy using technologies are therefore as follows. The risk of lock-in is high because the technology assets have a long life. The players in the industry sector are typically large because of the economies of scale that are present in fossil fuel extraction and processing, power generation and energy-intensive manufacturing. Once technology lock-in occurs, these players have a very strong incentive to lobby governments to delay decarbonisation policy action and even to fund 'spoiler' research to make the scientific consensus on climate change appear to be less coherent. Hence, the technology lock-in leads to political lock-in: the time is never right for strong action. Because of the dependence of future technology cost reductions on the scale of investment and deployment, there is a potential virtuous circle to be triggered once deployment passes a certain threshold. However, firms and households are wary of adopting new technology until market penetration reaches a level that gives confidence, even it appears cost-effective. Similarly, financial investors require a higher risk premium for 'unproven' technologies (those with a lower market share).

All of this points to the need for decisive early policy action to head off lock-in, promote take-up of new clean technologies past the early adopter stage and trigger the virtuous circle of greater deployment, innovation and cost reductions. Once the barriers to a new technology have been overcome, government support can be redirected to less mature technologies. A policy approach that is limited to incorporating the climate warming externality in the price of fossil fuels would prove inadequate because it is not adapted to the dynamics of economics and technological innovation. While commitment to raise the cost of fossil fuels through a carbon tax is important to ensure that price and cost incentives are aligned with the decarbonisation goal, those incentives would fall short in a world in which people operate with bounded rationality in a context of radical uncertainty.

4.4 The Mobilisation of Finance

Most of the changes required to decarbonise the energy system involve the substitution of capital equipment for the burning of fossil fuels. In power generation, renewable energy sources such as solar photovoltaic panels and wind turbines have a high capital cost and low running cost (including a zero cost for the energy captured from the sun and wind). The same is true in road transport, where zero-carbon vehicles (battery electric or fuel cell vehicles) have a higher purchase cost but lower running costs, and for heat pumps in buildings. Heavy investment will be needed in energy efficiency, particularly to renovate existing buildings. Furthermore, the energy system will require substantial investment in electricity transmission and distribution networks to meet the much higher demand and investment in smart technology and in short-term and seasonal storage solutions to balance demand with renewable supply.

Some of this investment will take the place of what would be needed in a fossil fuel future. However, because the net-zero technologies are more capital intensive, the overall scale of investment in the energy system would be higher, especially in the period up to 2050 when the entire new system needs to be put in place. Estimates of what that level of investment would be vary quite widely, depending on the pathway by which emissions reductions are achieved. For example, 'reduce' measures (changes in consumer lifestyles and energy efficiency investments) permit lower investment requirements than 'pure technology' solutions.

For a 1.5 °C pathway, IPCC (2018) draws on existing studies to present an average estimate that annual global investment in the energy system amounting to $2.4tn (at 2010 prices) would be needed between 2016 and 2035, equivalent to 2.5% of world GDP. This is a gross figure, meaning that the energy system would in any case require substantial investment in a 'current policies' baseline case (about 1.8% of global GDP) (IPCC, op. cit., p. 373), but the additional investment is still substantial. The figure is for the energy system (supply-side and demand-side) only. IPCC (2018) cites analysis by OECD (2017) suggesting that when investment in transport and in other infrastructures is included, the gross figure could be nearly three times the figure for the energy system alone. However, because cars have a shorter asset life than energy system equipment, much of that investment could take the form of substitution of the purchase of zero-carbon instead of fossil fuel vehicles and so the additional cost, relative to a fossil fuel future, would be much lower.

IEA (2019) presents an estimate of global annual investment needed in the energy system under its Sustainable Development Scenario, which achieves net-zero carbon emissions by 2070, consistent with limiting global warming to 1.65 °C (50% chance)–1.8 °C (66% chance). Over 2019–40, average annual investment of \$3.2tn (at 2018 prices) is needed, including some \$0.75tn in energy efficiency (IEA, op. cit., Table 7, p. 50).

Broadly, comparable figures to those of IPCC (2018) are estimated for the EU. In the analysis carried out for the EU's long-term climate strategy, European Commission (2018) presented an estimate for the EU that suggested averaged annual investment in the energy system of €550bn (2013 prices) would be needed in the period 2031–50 for a 1.5 °C, equivalent to 2.8% of GDP. This compares with investment amounting to 1.9% of GDP in a baseline that already includes some decarbonisation actions.[25] When transport investment is included, the annual investment figure rises to €1.4tn (2013 prices), some 20% higher than in a 'current policies' baseline (European Commission, 2018, pp. 201–202). EU Technical Expert Group on Sustainable Finance (2019, Table 17, p. 95) presents an analysis of the difference between estimated annual investment required under a business-as-usual scenario and various scenarios of greater ambition prepared for the EC.[26] By far the largest increase over business-as-usual, both in absolute and in percentage terms, is reported for buildings; 95% of that increase is expected to be funded by loans.

What are the economic implications of a finance requirement on this scale? In a traditional neoclassical model, investment must be 'financed' by saving in the same period, where 'saving' here is the national accounts concept: disposable income less final consumption. The rate of interest is determined as the price of saving that equilibrates demand (for investment) and supply. There is no role for banks (except, conceivably, as an intermediary between savers and investors, in the same way that a market stallholder acts as an intermediary between farmers and households).

Paroussos et al. (2019) cite the comment by Flaherty, Gevorkyan, Radpour, and Semmler (2017) that,

---

[25] The Long-Term Strategy baseline is a 'current policies' scenario, sufficient to achieve a cut in EU CO2 emissions by 65% compared with the 1990 level, rather than the reductions of between 80% and 100% in net emissions required to meet the Paris Agreement's objectives (well below 2 °C and towards 1.5 °C).

[26] The business-as-usual scenario is the Commission's REF2016 projection for energy use, and the scenarios with greater ambition are the various EUCO scenarios.

> [i]n most current models, the burden of enacting mitigation and adaptation policies falls on current generations. (p. 468)

which motivates a theoretical model designed to show that intertemporal borrowing through a vehicle such as green bonds would result in a Pareto improvement for both current and future generations.

In effect Flaherty et al. (2017) provide the motivation for modelling to represent a role for banking to allow agents in the present period to borrow on the expectation of repayment out of future income. Paroussos et al. (2019, Section 6) report the application of a hybrid applied CGE model that implements the possibility of intertemporal borrowing. That model allows three alternative macroeconomic closures for the treatment of the money supply: (1) money supplied by agents within the same period, (2) money supplied by agents across periods (implying a bank that creates money at the time of borrowing and then destroys it as the loan is repaid) and (3) 'unlimited money supply at exogenously defined interest rates' (in which all investments that are viable at the exogenous interest rate are funded). The latter two modifications, therefore, relax the constraint that would otherwise require that additional investment for decarbonisation must crowd out other investment or consumption in the current period.

A post-Keynesian approach to finance rejects entirely the notion that bank lending is constrained by the decisions of savers to supply deposits, which is why models like E3ME do not impose a trade-off between consumption and investment. For an individual bank, the deposit it creates for the borrower would, when the borrower spends the proceeds, become deposits held throughout the banking system, and so the bank needs to raise finance to replace its lost deposits on its balance sheet. However, for the banking system as a whole, the deposits that banks create at the time of initiation of loans collectively match the value of the new loans on their balance sheets.

Rather than channel saving to investors, banks bear liquidity and credit risk: they convert the risk attitudes of those from whom they raise finance (depositors, bondholders, shareholders) into terms that match the risk profile of those to whom they lend. For example, a bank chooses to offer loan finance to a customer to build a wind farm. The loan has a long term and there is some credit risk (moderated by the presence of equity investors in the same project). The deposit created by the bank is drawn on by the project developer to pay contractors, who in turn pay workers, who deposit the proceeds in (for simplicity[27]) the same bank. The workers are holding their additional wealth in the form of a demand bank deposit, highly liquid and very low credit risk (and very low or zero interest payable). The loan has created the deposit needed to finance the bank's loan asset. The bank bears some liquidity risk (because it has lent long-term but raised short-term finance) and also bears a particular form of credit risk (through exposure to the wind farm operation), neither of which is borne by households (except indirectly).

The critical issue is, therefore, not the availability of current saving to 'finance' current investment but rather, on the one hand, the willingness/capacity of financial institutions, and especially banks, to bear risk and, on the other, the risk profile of probable returns to investment.

The lessons for policy from this understanding of the role of finance is therefore to focus on: (i) derisking investments for which uncertainty is the key obstacle, notably policy risk, R&D risk and various aspects of technology risk; and (ii) improving the information flow to financial investors seeking to align their portfolio to a net-zero emissions objective.

Policy risk reflects uncertainty over the commitment of governments to decarbonisation. The United Kingdom has taken a strong lead in this respect and the Climate Change Act 2008 established a legal framework that probably sustained the policy commitment at times during the last decade when short-term priorities were focused elsewhere. Similarly, the EU's commitment to successively more ambitious decarbonisation targets provided important leadership in the 2015 Paris Agreement negotiations. Policy also has a key role in promoting the development of supporting infrastructure where it is needed to promote take-up (e.g. of BEVs).

---

[27] In practice, as already noted, an individual bank will not receive back all the deposits it creates from any loan it makes. However, collectively, the banking system holds the deposits that match all the new loans. If agents decide to repay loans rather than hold deposits, the deposits are destroyed and the banking system's loan assets fall by a matching amount. In an open economy; a country undertaking additional investment may see a deterioration in its balance-of-payments current account. To that extent, the initial deposits created by the loan come under the ownership of foreign banks who create matching foreign-currency deposits for the foreign residents who supplied the imported investment goods.

A whole-innovation chain approach to technology policy is needed. This includes R&D support for new technologies that are far from the market and which will be essential for long-term mitigation, recognising that some technologies will fail along the way. Nevertheless, the approach also includes incentives for early take-up of new technologies in the early phase of diffusion so that investors gain familiarity and confidence and risk perceptions are reduced.

There are signs that policy action is already shifting the market. Growing confidence in the prospect of sustained policies to promote the transition was reflected in Mark Carney's, 2015 speech (Carney, 2015) to Lloyd's of London when he was the then Governor of the Bank of England. This represented a turning point for the commitment of regulators towards the integration of climate-related risks into their financial stability monitoring and micro-supervision, a programme taken forward by the grouping of central banks and regulatory authorities, the Network for Greening the Financial System.[28]

With regard to improving information for financial investors, the European Commission has taken the lead in establishing a taxonomy[29] that is intended to ensure that investment products labelled as 'sustainable' genuinely contribute to achieving a climate-neutral economy. Outside of public authorities, the Task Force on Climate-related Financial Disclosures[30] has developed recommendations for voluntary climate-related financial risk disclosures for use by companies in providing information to the financial community, covering physical, liability and transition risks. In his annual letter to CEOs in January 2020, BlackRock's CEO Larry Fink wrote:

> Climate change is almost invariably the top issue that clients around the world raise with BlackRock. From Europe to Australia, South America to China, Florida to Oregon, investors are asking how they should modify their portfolios… And because capital markets pull future risk forward, we

---

[28] Available at: https://www.ngfs.net

[29] Available at: https://ec.europa.eu/commission/presscorner/detail/en/IP_19_3034

[30] Available at: https://www.fsb-tcfd.org

> will see changes in capital allocation more quickly than we see changes to the climate itself. In the near future – and sooner than most anticipate – there will be a significant reallocation of capital.[31]

4.5 A Green New Deal

Many of the features of policy argued for here have been included in the various versions of Green New Deal proposals that have been advanced since the phrase was coined as a response to the 2007–08 financial crisis. All have had the goals of promoting the decarbonisation transition, achieving a just transition and creating high-quality jobs. In the United States, the Green New Deal resolution, proposed to Congress in February 2019[32] by Senator Edward Markey and Representative Alexandria Ocasio-Cortez, called for a ten-year mobilisation plan covering a wide range of environmental, economic and social projects. Senate Republicans blocked it in March 2019. In the United Kingdom, Green New Deal proposals were incorporated in the Labour Party's November 2019 election manifesto,[33] including a specific commitment to bring almost all of the United Kingdom's 27 million homes up to the highest energy efficiency standards and eliminate energy poverty. Labour lost the election, but campaigners such as the New Economics Foundation continue to promote it.[34]

A version that is going ahead is the European Green Deal[35] launched in January 2020, incorporating the European Green Deal Investment Plan, the Just Transition Mechanism and proposals for a carbon border tax to limit carbon leakage. This represents a significant policy development, but the European Commission has limited funds and powers to bring about many of the Plan's goals and much will depend on the enthusiasm with which Member States take it up and supplement it.

---

[31] Available at: https://www.blackrock.com/hk/en/larry-fink-ceo-letter

[32] Available at: https://www.congress.gov/bill/116th-congress/house-resolution/109/text

[33] Available at: https://labour.org.uk/manifesto/a-green-industrial-revolution/

[34] Available at: https://neweconomics.org/campaigns/green-new-deal

[35] Available at: https://ec.europa.eu/info/sites/info/files/european-green-deal-communication_en.pdf

4.6 Making Space for Conservative Environmentalism?

At the same time as pressure from the Left has mounted for a Green New Deal in the United States, the Climate Leadership Council (2017) launched a 'conservative case' for an escalating carbon 'dividend' (i.e. a tax in all but name) levied on fossil fuels to be recycled in equal shares to individuals, accompanied by a 'border carbon adjustment' import tariff. The plan has garnered significant support from former senior Republican politicians, business leaders and mainstream economists. Its proposals formed the Energy Innovation and Carbon Dividend Act of 2019 introduced into Congress as a bipartisan initiative by Representative Ted Deutch, a Florida Democrat, in January 2019. The prospects for the bill improved in early 2020 when Jamie Dimon, CEO of JP Morgan, embraced the initiative, now supported by Goldman Sachs, MetLife and ten energy companies, including BP.[36] The focus on carbon pricing alone makes the initiative more palatable to small-government conservatives, while the border carbon adjustment can appeal to the populist trade agenda ('We will call it a Trump tariff if this helps'.[37]). It remains to be seen whether Republican politicians and voters will coalesce behind the plan and whether it will be implemented at a level of tax that makes a real difference, given the prospective impact on gasoline prices and the fossil fuel energy industry.

5 Summary and Conclusions

The response of mainstream economics to the climate crisis has been weak, reflecting key inadequacies in its understanding of human behaviour, the consequences of imperfect information and radical uncertainty, the nature of finance and the contribution policy can make to reduce risk perceptions and the critical importance of just transition considerations in determining the social acceptability and hence longevity of

---

[36] Reported in Tett (2020).

[37] Tett (2020).

commitment to decarbonisation targets. Mainstream economics focuses on the carbon price as a sufficient policy instrument and this is misleading and uninformative to policymakers.

Mainstream economics assumes that the impact of environmental degradation can be measured in terms of lost human consumption and compensated for by higher economic growth. It treats the rate of return in capital markets as the measure of societal preferences with regard to consumption now or in the future, when most of the human population now and in the future play little or no part in the functioning of capital markets. It is far too sanguine about the scale of potential damages from global warming and is willing to stake the planet's future on the assumption that tipping point thresholds will not be crossed. In this it makes the dangerous mistake of treating large uncertainty (we do not know how close we are to the tipping points) as 'no evidence'. It assumes that mitigation opportunities necessarily represent a more costly path. It places a high value on inertia, interpreting it as the preference of an informed individual who takes account not only of their own welfare but that of future generations, instead of the heuristic response of an imperfectly informed individual faced with an uncertain future.

A serious response to the climate crisis necessarily involves substantial policy action, which, in turn, would accelerate the shift in financial markets that is already happening. It requires a focus on derisking key investment decisions. It requires a major commitment to mitigate policy impacts on energy poverty and to provide alternative, decent work opportunities for those dependent on fossil fuel-related jobs, or else social divisions will ultimately undermine political commitment. The challenge we all face is whether our political and economic system can find the way.

References

Arrow, K. J., Cline, W., Maler, K. G., Munasinghe, M., Squitieri, R., & Stiglitz, J. (1996). Intertemporal Equity, Discounting and Economic Efficiency. In J. Bruce, H. Lee, & E. Haites (Eds.), *Climate Change 1995: Economic and Social Dimensions of Climate Change* (pp. 125–144). Cambridge, UK: Cambridge University Press.

Beatty, C., Fothergill, S., & Gore, T. (2019). *The State of the Coalfields 2019*. Coalfields Regeneration Trust. https://www4.shu.ac.uk/research/cresr/sites/shu.ac.uk/files/state-of-the-coalfields-2019.pdf

Burke, J., Hagen, U., Höhne, N., Nascimento, L., & Bals, C. (2019). *Climate Change Performance Index Results 2020*. Bonn, Germany: Germanwatch, NewClimate Institute and Climate Action Network.

Burke, M., Hsiang, S. M., & Miguel, E. (2015). Global Non-linear Effect of Temperature on Economic Production. *Nature, 527*, 235–239.

Cambridge Econometrics and Element Energy. (2019). *Towards Fossil-Free Energy in 2050*. Brussels: European Climate Foundation. https://european-climate.org/wp-content/uploads/2019/03/Towards-Fossil-Free-Energy-in-2050.pdf

Carney, M. (2015). *Breaking the Tragedy of the Horizon – Climate Change and Financial Stability*. Speech Given to Lloyd's of London. London: Bank of England. https://www.bankofengland.co.uk/-/media/boe/files/speech/2015/breaking-the-tragedy-of-the-horizon-climate-change-and-financial-stability.pdf?la=en&hash=7C67E785651862457D99511147C7424FF5EA0C1A,29.9

Castree, N. (2010). Neoliberalism and the Biophysical Environment: A Synthesis and Evaluation of the Research. *Environment and Society: Advances in Research, 1*, 5–45.

Cedefop. (2019). *Skills for Green Jobs 2018 Update European Synthesis Report* (Cedefop Reference Series; No 109). Luxembourg: Cedefop. https://www.cedefop.europa.eu/files/3078_en.pdf

Committee on Climate Change. (2019). *UK Housing: Fit for the Future?* London: Committee on Climate Change. https://www.theccc.org.uk/wp-content/uploads/2019/02/UK-housing-Fit-for-the-future-CCC-2019.pdf

Costanza, R., Groot, R., Sutton, P., Van der Ploeg, S., Anderson, S., Kubiszewski, I., et al. (2014). Changes in the Global Value of Ecosystem Services. *Global Environmental Change, 26*, 152–158.

Daniel, K.D., Littermanc, R.B., & Wagnerd, G. (2019). Declining CO2 price paths. Proceedings of the National Academy of Sciences October 15, 2019 116 (42) 20886-20891; https://doi.org/10.1073/pnas.1817444116

Department for Environment, Food & Rural Affairs. (2018). *A Green Future: Our 25 Year Plan to Improve the Environment, Annex I Supplementary Evidence Report*. H M Government. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/673492/25-year-environment-plan-annex.1.pdf

Dietz, S., & Stern, N. (2015). Endogenous Growth, Convexity of Damages. *Economic Journal, 125*, 574–620.

EU Technical Expert Group on Sustainable Finance. (2019). *Taxonomy Technical Report*. Brussels: European Commission. https://ec.europa.eu/info/sites/info/files/business_economy_euro/banking_and_finance/documents/190618-sustainable-finance-teg-report-taxonomy_en.pdf

European Commission. (2018). *In-Depth Analysis in Support of the Commission Communication COM(2018) 773 ('The Long-Term Strategy')*. Brussels: European Commission. Available at https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf

European Environment Agency. (2019). *The European Environment – State and Outlook 2020*. Brussels, Belgium: European Environment Agency. https://www.eea.europa.eu/publications/soer-2020

Flaherty, M., Gevorkyan, A., Radpour, S., & Semmler, W. (2017). Financing Climate Policies Through Climate Bonds – A Three Stage Model and Empirics. *Research in International Business and Finance, 42*(December), 468–479. https://doi.org/10.1016/j.ribaf.2016.06.001.

Gabaix, X., & Laibson, D. (2017). *Myopia and Discounting* (NBER Working Paper No. 23254). https://www.nber.org/papers/w23254

Grubb, M., Hourcade, J-C. & Neuhoff, K.(2014). Planetary Economics: energy, climate change and the three domains of sustainable development. Routledge.

Haines-Young, R., & Potschin, M. B. (2018). *Common International Classification of Ecosystem Services (CICES) V5.1 and Guidance on the Application of the Revised Structure*. Nottingham, UK: Fabis Consulting Ltd. Available at www.cices.eu

Heuberger, C. F., Rubin, E. S., Staffell, I., Shah, N., & Dowell, N. M. (2017). Power Capacity Expansion Planning Considering Endogenous Technology Cost Learning. *Applied Energy, 204*, 831–845. https://doi.org/10.1016/j.apenergy.2017.07.075.

Hornsey, M. J., Harris, E. A., Bain, P. J., & Fielding, K. S. (2016). Meta-Analyses of the Determinants and Outcomes of Belief in Climate Change. *Nature Climate Change, 6*, 622–626.

Hsiang, S., Kopp, R., Jina, A., Rising, J., Delgado, M., Mohan, S., et al. (2017). Estimating Economic Damage from Climate Change in the United States. *Science, 356*, 1362–1369.

IEA. (2019). *World Energy Outlook*. Paris: International Energy Agency.

ILO. (2018). *Greening with Jobs: World Employment Social Outlook 2018*. ILO. https://www.ilo.org/weso-greening/documents/WESO_Greening_EN_web2.pdf

IPCC. (2013). *Climate Change 2013: The Physical Science Basis: Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge University Press.

IPCC. (2014). *AR5 Synthesis Report: Climate Change 2014*. IPCC. https://www.ipcc.ch/site/assets/uploads/2018/02/SYR_AR5_FINAL_full.pdf

IPCC. (2018). *Global Warming of 1.5°C. an IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change*. Intergovernmental Panel on Climate Change.

IPCC. (2019). *Climate Change and Land*. IPCC. https://www.ipcc.ch/srccl/

IRENA. (2019). *Renewable Power Generation Costs in 2018*. IRENA. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/May/IRENA_Renewable-Power-Generations-Costs-in-2018.pdf

Kahneman, D., & Lovallo, D. (1993). Timid Choices and Bold Forecasts: A Cognitive Perspective on Risk Taking. *Management Science, 39*, 17–31.

Kavlaka, G., McNerneya, J., & Trancikab, J. E. (2018). Evaluating the Causes of Cost Reduction in Photovoltaic Modules. *Energy Policy, 123*, 700–710. https://doi.org/10.1016/j.enpol.2018.08.015.

Keen, S. (2019). *Playing DICE with Life on Earth: Nordhaus's Damage Function*. https://www.patreon.com/posts/26781733

Larson, F., List, J. A., & Metcalfe, R. D. (2016). *Can Myopic Loss Aversion Explain the Equity Premium Puzzle? Evidence from a Natural Field Experiment with Professional Traders* (NBER Working Paper No. 22605). https://www.nber.org/papers/w22605

Lenton, T. M., Held, H., Kriegler, E., Hall, J. W., Lucht, W., Rahmstorf, S., & Schellnhuber, H. J. (2008). *Tipping Elements in the Earth's Climate System*. https://www.pnas.org/content/105/6/1786. Accessed 14 Jan 2020.

Lewney, R., Alexandri, E., & Storrie, D. (2019). *Technology Scenario: Employment Implications of Radical Automation*. Eurofound. https://www.eurofound.europa.eu/sites/default/files/ef_publication/field_ef_document/fomeef18009en.pdf

Mercure, J.-F., Knobloch, F., Pollitt, H., Lewney, R., Rademakers, K., Eichler, L., van der Laan, J., & Paroussos, L. (2016). *Policy-Induced Energy Technological Innovation and Finance for Low-Carbon Economic Growth*. Research Prepared for Study on the Macroeconomics of Energy and Climate Policies. European Commission. https://ec.europa.eu/energy/sites/ener/files/documents/ENER%20Macro-Energy_Innovation_D2%20Final%20%28Ares%20registered%29.pdf

Mercure, J.-F., Pollitt, H., Viñuales, J. E., Edwards, N. R., Holden, P. B., Chewpreecha, U., et al. (2018). Macroeconomic Impact of Stranded Fossil Fuel Assets. *Nature Climate Change*, 588–593. https://doi.org/10.1038/s41558-018-0182-1.

Ministry of Housing, Communities & Local Government. (2019). *English Housing Survey, Headline Report, 2017–18*. Ministry of Housing, Communities & Local Government. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/834603/2017-18_EHS_Headline_Report.pdf

Murphy, L. M., & Edwards, P. L. (2003). *Bridging the Valley of Death: Transitioning from Public to Private Sector Financing*. Golden, CO: National Renewable Energy Laboratory.

Natural Capital Committee. (2013). *The State of Natural Capital: Towards a Framework for Measurement and Valuation*. https://www.gov.uk/government/publications/natural-capital-committees-first-state-of-natural-capital-report; https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/516707/ncc-state-natural-capital-first-report.pdf

Nordhaus, W. D. (1992). An Optimal Transition Path for Controlling Greenhouse Gases. *Science, 258*, 1315–1319.

Nordhaus, W. D. (2007). *The Challenge of Global Warming: Economic Models and Environmental Policy*. http://www.econ.yale.edu/~nordhaus/homepage/OldWebFiles/DICEGAMS/dice_mss_072407_all.pdf

Nordhaus, W. D. (2017). *Revisiting the Social Cost of Carbon*. https://www.pnas.org/content/114/7/1518. Accessed 14 Jan 2020.

Nordhaus, W. D. (2018a). Projections and Uncertainties about Climate Change in an Era of Minimal Climate Policies. *American Economic Journal: Economic Policy, 10*, 333–360.

OECD. (2017). *Investing in Climate, Investing in Growth*. Paris: Organisation for Economic Co-operation and Development Publishing. https://doi.org/10.1787/9789264273528-1-en

Paroussos, L., Fragkiadakis, K., & Fragkos, P. (2019). Macro-Economic Analysis of Green Growth Policies: The Role of Finance and Technical Progress in Italian Green Growth. *Climatic Change*. https://doi.org/10.1007/s10584-019-02543-1.

Pollitt, H. (2019, May). *The Contribution of Post-Keynesian Economics to Climate Policy and Meeting Global Decarbonisation Targets*. Paper Presented to the 29th Annual Workshop of the Post-Keynesian Economics Society, University of London. http://www.perc.org.uk/project_posts/29th-pkes-annual-workshop-29th-may/

Ramsey, F. P. (1928). A Mathematical Theory of Savings. *Economic Journal, 38*, 543–559.

Sen, A., & Williams, B. (1982). *Utilitarianism and Beyond*. New York: Cambridge University Press.

Shearer, C., Yu, A., & Nace, T. (2019). *Out of Step – China Is Driving the Continued Growth of the Global Coal Flee*t. Global Energy Monitor. https://endcoal.org/wp-content/uploads/2019/11/Out-of-Step-English-final.pdf

Stern, N. (2007). *The Economics of Climate Change: The Stern Review*. Cambridge, UK: Cambridge University Press.

Tett, G. (2020) Wall Street is trying to catch up on climate change, Financial Times, 14 February 2020.

Thaler, R. H., Tversky, A., Kahneman, D., & Schwartz, A. (1997). The Effect of Myopia and Loss Aversion on Risk Taking: An Experimental Test. *Quarterly Journal of Economics, 112*, 647–661.

Weitzman, M. L. (2007). A Review of the Stern Review on the Economics of Climate Change. *Journal of Economic Literature, 45*, 703–724.

Weitzman, M. L. (2009). On Modeling and Interpreting the Economics of Catastrophic Climate Change. *Review of Economics and Statistics, 91*, 1–19.

White, C., Thoung, C. Rowcroft, P., Heaver, M., Lewney, R., & Smith, S. (2017). *Developing and Piloting a UK Natural Capital Stress Test*. Prepared by AECOM and Cambridge Econometrics, WWF-UK. https://www.wwf.org.uk/sites/default/files/2017-09/Developing%20%26%20Piloting%20a%20Natural%20Capital%20Stress%20Test_AECOM-WWF%20Sept2017.pdf

Williams, B. (1995). Must a Concern for the Environment Be Centred on Human Beings? In B. Williams (Ed.), *Making Sense of Humanity and Other Philosophical Papers 1982–93* (pp. 233–240). Cambridge, UK: Cambridge University Press.