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Climate Change, Development, Poverty and Economics

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1. Introduction

The past three decades have seen an unprecedented increase in world living standards and a fall in poverty across many fundamental dimensions. For example, life expectancy has risen from 45 years in 1950 to 71 years in 2013[1] and global adult literacy from 36 per cent to 84 per cent.[2] The number of people living on less than $1.90 a day has been reduced by over a billion.[3] Whilst these remarkable changes occurred as the result of decisions and actions by many private and public actors, they were in large measure driven by an improvement in decision-making in public institutions and in governance.

Increased confidence in what was possible together with greater acceptance of moral responsibilities led to the adoption of the Millennium Development Goals (MDGs) at the turn of the century. They provided a real basis for international cooperation and development. However environment, climate and sustainability issues were not prominent in the MDGs. With hindsight we can now see that this was a mistake. The world has been slow in recognising the crucial importance of these issues in shaping future living standards and indeed for survival. Our activities in the next two or three decades will determine whether our successes will be sustained or advanced, or whether they will be undermined or reversed.

In the Sustainable Development Goals (SDGs), agreed in September 2015, there is now a common platform for the next phase of the fight against poverty. The SDGs build on the MDGs on income, education and health, but they are stronger and broader in terms of environment, climate and sustainability. The SDGs make it clear that we are entering a new phase in economic development, one where poverty reduction, development and the environment are at the forefront and increasingly intertwined. Thirteen of the 17 SDGs are directly concerned with the natural environment, climate or sustainability.

A key factor in all this is climate change. Climate change is not the only environmental problem we face. Nor is it the only threat to global prosperity. But climate change is unique in its magnitude and the vast risks it poses. It is a potent threat-multiplier for other urgent concerns, such as habitat loss, disease and global security (IPCC 2014) and puts at risk the development achievements of the past decades (World Bank 2016). If unchecked, climate change could fundamentally redraw the map of the planet, and where and how humans and other species can live. It could create global living conditions way outside the ranges that human beings have experienced in their history.

For climate change, too, there is now an international platform through which global action can be advanced and coordinated. The Paris Agreement was negotiated at the end of 2015 (at COP21 of the UN Framework Convention on Climate Change) and signed by 175 nations in the spring of 2016. It sets out a process through which the rise in global mean temperatures may be curtailed to

[1] http://www.who.int/gho/mortality_burden_disease/life_tables/situation_trends/en/ and Riley (2005).

[2] http://www.uis.unesco.org/Education/Documents/fs26-2013-literacy-en.pdf, and van Zanden, J.L., et al. (2014).

[3] http://wdi.worldbank.org/tables, accessed 21 April 2016.

"*well below*" 2^{o}C above pre-industrial levels and perhaps as low as 1.5^{o}C. These are the central long-term objectives of the agreement.

Meeting the Paris objectives requires sustained action from developed and developing countries over many decades. It demands a reshaping of the global economy towards cleaner forms of production, not just in energy, but also in industry, transport and land-use. And it requires the reorientation of investment. At least US$ 100 trillion will be invested over the next two or three decades into buildings and urban infrastructure, roads, railways, ports and into new energy systems. It is imperative that these decisions are taken with climate change in mind. Otherwise we will lock in polluting capital exactly at the time when we are exhausting our global carbon budget. The chance of holding climate change to 2^{o}C would be lost and we would be walking into dangerous territory.

This paper sets out the implications of climate change for development economics and development policy. It emphasises both the role and nature of the necessary change and its implications. We start with an examination of what economics has had to say about the link between economic prosperity and the environment. We then explain why climate change is a different kind of problem and why it requires a new approach to both analysis and policy. The final two sections explore how this new approach to climate change economics and its contribution to development policy might look.

2. Prosperity and the environment

Environmental concerns entered development policy relatively late. The World Bank created the Office of the Environmental Advisor in 1970, but in the early years this was very much an advisory function. Over time the role of the office evolved and the environment grew in importance, culminating in the creation of the Environmentally Sustainable Development Vice Presidency in 1993.[4] In parallel, environmental economics began to emerge as a new field of academic study. The origins of environmental economics are usually traced back to the 1960s, when the term began to appear on book titles and in academic publications (see Pearce 2002).

Ever since, development practitioners and academic writers have grappled with the interactions between economic growth and environmental protection. Understanding of, and action on, these interactions is crucial to development in all countries, but especially in poor ones. Careful environmental management is a critical ingredient of any viable path to poverty reduction and prosperity. Bad environmental management results in environmental degradation, poor health and lost economic output. Poor people are the primary victims of these trends, though we should recognize that poverty also contributes to them (Dasgupta and Mäler 1994; Pearce and Warford 1993).

[4] https://archivesholdings.worldbank.org/

Environment and growth

Knowledge about, and concerns for, the link between economic development and the environment goes of course back much further than the 1960s. The economics pioneers of the 18th and 19th century were well aware of environmental resources as an essential source of wealth, and indeed as a potential constraint to economic growth. For David Ricardo differences in land quality were the main source of rent for land owners. Thomas Malthus, more pessimistically, predicted widespread poverty as a consequence of population growth and decreasing returns in agriculture (Niehans 1990). The early focus was on resource endowments. Climate factors rarely featured. Montesquieu speculated at length about the influence of the climate on society and the "*temper of the mind*" (Montesquieu 1748, Book XIV), but the link to economic performance was cursory.

Unlike Montesquieu's theories on the climate, Malthus' concern about natural resource constraints has remained a constant feature of the growth debate. In the 1860s William Stanley Jevons worried about the future of industrial England when its coal reserves would run out. In the 1970s the Club of Rome made headlines with *The Limits to Growth* (Meadows et al. 1972). Inspired by Kenneth Boulding's (1966) notion of "*spaceship Earth*", the interdisciplinary field of ecological economics has continued to probe the natural boundaries, which the laws of science impose on economic processes (e.g., Rockström et al. 2009).

So far, Malthus and the resource pessimists have generally appeared to be wrong, including in a famous 1980 wager between ecologist Paul Ehrlich and economist Julian Simon. The two men had bet on the scarcity and long-term price of five important metals, copper, chromium, nickel, tin and tungsten. Simon, the resource optimist, won on all five. Human ingenuity, it seems, has so far managed to outpace natural resource constraints (although Simon would have lost over a longer time frame and a broader selection of minerals, Grantham 2011).

This does not mean environmental resources are not overexploited. They are, including not least in developing countries. Excessive water abstraction, deforestation, overfishing and habitat loss are widespread. However, in almost all cases they appear, in large measure, to be the result of policy mismanagement and market failure, rather than resource scarcity *per se*.

The management of natural resources

From the outset, economists have devoted considerable attention to the effective management of natural resources. In the 19th century Knut Wicksell and Martin Faustmann were among the first to study the optimal harvesting cycle for slow-maturing resources like forests (Hedlund-Nyström et al. 2006; Niehans, 1990). However, it was Harold Hotelling (1931) who produced the defining treatise on natural resource management. According to his Hotelling rule, the value of natural resources, if optimally used, must rise at the rate of interest. If the value were to rise more quickly at the margin we should postpone use. This insight has formed the basis of natural resource economics to this day. It also informs the analysis of stock pollution problems like climate change.

The Hotelling rule was revisited in the 1970s, when it became apparent that it may not be consistent with an emerging development concept, that of sustainable development. The notion of sustainable development was popularized by the Brundtland Commission on Environment and Development, which defined it as "*development which meets the needs of current generations without compromising the ability of future generations to meet their own needs*" (Brundtland et al. 1987). For economists, this meant consumption (or utility) could not be allowed to decrease over time. Robert Solow and John Hartwick worked out what non-decreasing utility meant for resource depletion. The rents from natural resource extraction had to be re-invested into other forms of capital, so that the total stock of environmental, physical and human capital remained constant (Solow 1974; Hartwick 1977).

The Hartwick-Solow rule has obvious implications for development policy and the World Bank has been at the forefront of translating it into practical policy advice, including through the promotion of resource funds for future generations, enhanced green accounting systems and macroeconomic performance metrics like adjusted (or "genuine") savings (World Bank 2011).

Environmental management and public policy

If Harold Hotelling is the forefather of natural resource economics, Arthur Cecil Pigou deserves the credit for incorporating environmental concerns into welfare economics. Drawing on his teacher Alfred Marshall, Pigou introduced into economics the notion of externalities, that is, costs or benefits that are not captured in the market price of goods. Later writers added nuance and extensions – such as open access problems, common property resources and public goods – that refine our understanding of environment-related market failures, but the core concept of externalities remains central to modern environmental economics.

Pigou's observations on the environment were prescient. He discussed at length the negative effects of pollution, which "*inflicts a heavy uncharged loss on the community*" (Pigou 1920, as cited in Sandmo 2015). The concern remains valid to this day. Urban air pollution, linked to particulate matter and other pollutants, remains a major issue in most countries (New Climate Economy 2014). In another perceptive comment, Pigou praised the external value of forests, whose "*beneficial effect on climate often extends beyond the borders of the estates owned by the person responsible for the forest*", though he probably had the local climate in mind (ibid).

Pigou also identified the requisite remedy to address these market failures: a corrective tax levied in proportion to the externality. This was later complemented by the work of Ronald Coase, who showed that problems of externalities could also be managed via clearer (and perhaps tradable) property rights (Coase 1960). Both writers were drawing on John Stuart Mill, who already in 1848 had called for government intervention to ensure the "*common enjoyment*" of the world's natural riches (Sandmo 2015).

Today, variants of Pigovian taxes and Coasean trading schemes are in use throughout the world (for an overview, see Sterner 2003; Freeman and Kolstad 2007). Though they are not without problems, schemes like Payment for Ecosystem Services and the Clean Development Mechanism have helped to mobilize billions of dollars for environmental protection in developing countries (Fankhauser and Pearce 2014).

Following in Pigou's footsteps, John Hicks and Nicolas Kaldor developed the theory for a systematic comparison of the costs and benefits of policy intervention (see Drèze and Stern 1987). It was James Meade (1955) who provided the defining general equilibrium approach and analysis in his seminal book *Trade and Welfare* (see particularly the mathematical appendix). For a formal discussion of this theory of reform where there are multiple market features, see Drèze and Stern (1987, 1990) and Guesnerie (2004). Cost-benefit analysis soon became the standard tool for project appraisal, including in development organizations like the World Bank (e.g., Little and Mirrlees 1974 and Squire and van der Tak 1975). In environmental economics, the extensive body of work on welfare economics gave rise to the field of environmental valuation – the use of techniques that monetize the external value of the environment, so it can be appropriately reflected in cost-benefit analysis (for an overview, see Hanley and Barbier 2009).

The models and analyses in the tradition of Pigou and Meade generally see the environment as affecting utility or welfare through services or damages that enter utility functions directly. The mismanagement of the natural environment is a concern only in as far as it affects human welfare. However, nature's contribution to human welfare goes well beyond direct use through the provision of food and materials, which had exercised Malthus and the Club of Rome or the direct externalities of Pigou and Meade.

The modern theory of ecosystem services (e.g., TEEB 2010) distinguishes between provisioning services (food, water, materials), cultural services (spiritual value, recreation, mental and physical health), regulating services (air quality, water treatment, carbon sequestration) and support services (genetic diversity, habitats). The full extent of this rich range of services is not yet fully understood or indeed always appreciated by policy makers. It remains an active and important area of interdisciplinary research in environmental economics and the natural sciences. But progress is being made in incorporating ecosystem services into policy decisions and national accounting frameworks (World Bank 2012).

A central test for any economic prescriptions on environmental management is the health of the natural environment. Against this yardstick the economics of Hotelling, Pigou, Meade and their successors does perhaps not rate as well as it should, or would in a less complex world. There have been some notable successes, but on the whole the *realpolitik* of environmental protection has been much harder than embodied in simple theory (e.g. Burgess et al. 2011). The political economics of poverty and the environment is particularly complex and needs to account for factors like power, exclusion, land rights, market access and gender relations.

Unfortunately, the environment - development nexus is about to become more complex still. The environmental problems of the 21st century could be of a different order of magnitude and generality than those of the past, and none more so than climate change.

3. Why climate change is different

Climate change is different from the environmental problems we have encountered until now. It is different in terms of its scale, the magnitude of risks and the urgency of action. We are all involved both in the generation of the problems and in our vulnerability to its impacts. Climate change is also different in terms of its complexity and the difficulty of identifying a "solution". To appreciate the scale of the challenge it is necessary to set out some basic science about climate change.

The risks

The science around climate change is based on almost two centuries of theory and evidence. The basic physics of the greenhouse effect – that there are heat-trapping gases in the atmosphere, which allow the Earth to retain heat – were established by Jean-Baptiste Fourier and John Tyndall in the second half of the 19th century. Studying the Earth's heat balance, the former showed that something was preventing the escape of energy, and the latter identified the key gases at work. At the start of the 20th century Svante Arrhenius made the link to fossil fuel-based emissions by showing that they intensified the magnitude of the natural greenhouse effect and provided some calculations of the potential scale of the effect. In the first half of the 20th century, with the rise of quantum theory, it was established that the mechanism at work was the frequency of oscillation of greenhouse gases (GHGs), which interfered with that of infrared energy. The systematic monitoring of atmospheric CO_2 concentrations began in 1958.

Thanks to these efforts we today have a good understanding of the physics and chemistry of the atmosphere. Important uncertainties remain, but we increasingly understand the main driving forces within the inherently complex and chaotic system that is the Earth's climate. From all this evidence, which continues to be published and presented, it is clear that the current, unprecedented climate change starts and ends with people.

Human activity, through the extraction and combustion of fossil fuels, removal of forests, or agricultural activities contributes to the emissions (or "flow") of greenhouse gases. The increased flows lead to increased quantities (or "stocks") of greenhouse gases in the atmosphere and with it an increase in the amount of heat energy trapped by the atmosphere. As the heat energy increases so to do the average global land and sea temperatures. With higher temperatures and more energy there is increased intensity and variability within the global climate system, leading to fluctuations or changes in local and regional weather patterns.

The full implications of this complex causal chain are difficult to comprehend and the specifics cannot be predicted with certainty. However, it is clear that the effects in terms of human lives and livelihoods are potentially severe. The key issue is change. Our settlements and practices have been built around current climate and weather systems, rivers and coasts. If these change dramatically the conditions shaping lives and livelihoods could change radically, including where people can live.

To understand the scale of the risks it is useful to illustrate climate change through a simple risk assessment framework: the magnitude of the potential losses and, where possible, some indication of the probabilities that these losses will occur.

The starting point is the flows and stocks of greenhouse gases outlined above. The benchmark is usually the beginnings of the Industrial Revolution in the mid-1800s. Since then the atmospheric concentration of the six main gases[5] (the stock) has increased from around 285 parts per million (ppm) of carbon dioxide equivalent (CO_2e) to over 450 ppm of CO_2e today, of which 400 ppm is CO_2.[6] Around 70 years ago we were adding approximately 0.5ppm of CO_2e per year and now we are adding around 2.5ppm of CO_2e per year. That rate of addition continues to rise. If this continues the overall concentration could be in the region of 750ppm of CO_2e by the end of the century. An atmospheric concentration of 750ppm is associated with a median temperature increase over the next one or two centuries in the region of 4°C, with a substantial probability of well over 4°C (IPCC, 2013).

To put these numbers into context, our civilization has developed during the climatically benign Holocene period, following the last ice-age around 9,000 or 10,000 years ago. The Holocene has had relatively stable temperatures that fluctuated in a range of ± 1°C to 1.5°C relative to the late 19th century benchmark. We are now on the edge of that range. The current increase in atmospheric concentration has resulted in a global temperature increase across the Earth's surface of around 1°C above the long-term average (Met Office, 2016). Fifteen of the 16 warmest years on record have occurred since 2001. If the temperature increase reaches 3°C or 4°C we would be way outside the range of experience of Homo sapiens. The planet has not seen 3°C for around 3 million years (when the sea level was around 20 meters higher than today, IPCC 2013), and 4°C for tens of millions of years. Homo sapiens as a species are only around 250,000 years old, and our current civilization in terms of cultivation and villages is only 9,000 or 10,000 years old.

Along with the physical science, the natural and social sciences are rapidly developing and investigating the risks of rising temperatures for economies, ecosystems, cultures, movement and social structures. The specifics cannot be known with certainty, but the World Bank (2012), for example, anticipates a significant risk of "unprecedented heat waves, severe drought, and major floods in many regions, with serious impacts on human systems, ecosystems, and associated services", exacerbating and compounding other threats like habitat loss, stability and disease (IPCC 2014).

Poor countries and poor people would be hit particularly hard. They rely more heavily on climate sensitive economic activities like agriculture and have weaker capacity to adapt effectively. Poor people are also more likely to live in hazard zones, such as flood plains, and their assets are more likely to be damaged in extreme weather events. They are also more susceptible to the pests and

[5] Carbon dioxide (CO_2), methane (CH_4); nitrous oxide (N_2O), hydrofluorocarbons (HFCs); perfluorocarbons (PFCs); and sulphur hexafluoride (SF_6).

[6] The other GHGs are usually aggregated together with CO_2 to form CO_2 equivalent or CO2e. The aggregation is done via the radiative forcing effect of the gas.

diseases that follow heat waves, floods and drought (World Bank 2016). Climate change could undermine development and growth, increase vulnerability, threaten health and push people back into poverty.

The risks will increase as temperatures rise and we breach potential environmental tipping points, such as the thawing of the permafrost and release of methane, or the loss of winter sea ice in the Arctic. These tipping points (or abrupt shifts) are more likely for temperature increases above 2-3°C, but some are forecast to occur within the 1.5°C to 2°C range set in the Paris Agreement (Drijfhout et al. 2015). Even 1.5°C to 2°C should not therefore be seen as a “safe” limit. It is degrees of danger at stake, particularly those of tipping points and irreversible outcomes.

The urgency

Limiting temperature rises to any level will require the eventual stabilization of greenhouse gas concentrations in the atmosphere. To achieve stabilization total annual emissions will eventually have to reach “net-zero”, that is, a balance has to be reached between the release of greenhouse gases into the atmosphere and their removal (for example through reforestation). The lower the temperature target, the sooner emissions have to peak and the earlier “net zero” will have to be achieved.

As illustrated in Table 1, for a realistic chance to stabilize temperatures around 2°C we would need to stabilize greenhouse gas concentrations of around 350 ppm – 400 ppm. However, as of February 2016, CO_2 concentrations in the atmosphere breached the 400 ppm (NOAA, 2016). This reality has contributed to the current focus on a new target of 450 ppm, the concentration target with which 2°C is often associated. However, this level only provides a likely (66 – 100 percent) chance of remaining below 2°C by 2100, while remaining below 1.5°C is “more unlikely than likely” (IPCC 2013). Already at current concentration levels and rates of emissions the probabilities of exceeding 2°C by 2100 are considerable. They increase further at higher stabilized concentrations, when temperature increases in the range of 3°C or 4°C become the most likely outcome (IPCC 2013).

Table 1: Stabilisation of GHG concentrations and associated potential temperature increases

Stabilised GHG Concentrations (ppm CO_2)	Global mean temperature increase above pre-industrial at equilibrium, using “best estimate” [7] climate sensitivity (^oC)	Latest possible peaking year for CO_2 emissions [8]
350 – 400	2.0 – 2.4	2015
400 – 440	2.4 – 2.8	2020
440 - 485	2.8 – 3.2	2030
485 – 570	3.2 – 4.0	2060

[7] Note: that global mean temperature at equilibrium is different from expected global mean temperatures in 2100 due to the inertia of the climate system.
[8] Ranges correspond to the 15th to 85th percentile of the Post-Third Assessment Report (TAR) scenario distribution. CO_2emissions are shown, so multi-gas scenarios can be compared with CO_2-only scenarios.

570 – 660	4.0 – 4.9	2080
660 – 790	4.9 – 6.1	2090

Source: IPCC (2007)

To have the greatest chance of meeting the lower concentration levels required by science and restrain temperature increases, global greenhouse gas emissions will have to peak in the very near future (around 2020), and start to decline in absolute terms from then on. Each stabilized atmospheric concentration level is associated with a cumulative CO_2 emissions budget available for all anthropogenic sources. The idea of a "budget" underlines the insight that, if we want to hold below a given temperature with some given probability then if there is a delay in reducing emissions we will have to increase the rate of decrease in subsequent years.

The IPCC (2013) has calculated that for a roughly 66 percent chance of keeping below 2°C, cumulative emissions (since 1880) need to remain below 2,900 billion tonnes of CO_2 ($GtCO_2$). For a 50 per cent chance of less than 2°C the cumulative emissions the budget is 3,010 $GtCO_2$. This budget is currently being exhausted and by 2011 around 1,900 $GtCO_2$ of this budget had already been utilized, leaving about 1,000 $GtCO_2$ remaining for the rest of the century. If we are to meet the temperature target this budget will have to be distributed between countries and it is here that many of the disagreements have occurred around sharing the burden.

While developed countries are responsible for the majority of greenhouse gas emissions since the 1900s (particularly the USA and the EU countries), the balance has shifted in recent years and in 2005 developing countries (led by China) emitted more than developed countries. Rapid growth in the developing world means that developing and emerging market countries now account for around 60 per cent of global emissions (New Climate Economy, 2014). Six of the top 10 emitting countries are developing countries (WRI, 2014).

The importance of the reducing emissions from all countries can be seen in the example of China and India. If both countries were to stabilize their greenhouse gas emissions in 2050 at roughly half the current OECD country levels (around 5 tCO_2e per person) they would at this stage use up around 75 percent of the available annual global carbon budget available in 2050 (of around 15Gt CO_2e), leaving only 25 per cent for the 4.5 billion people in all other developing countries, (i.e. 5Gt CO_2e or around 1 tonne per capita), even if by this stage all developed countries would be at net-zero emissions.

Ethics

The magnitude of the risks and the lasting impact of climate change and policy choices on lives and livelihoods, both today and in the future, inherently raise issues of equity and justice. Judgments have to be made that involve much more severe and difficult ethical questions than we usually encounter in policy analysis.

Different ethical approaches embody different perspectives and foundations to guide the actions of individuals and communities. But they all offer consistent and clear normative support for strong action (Stern, 2007, 2015; Dietz et al. 2008). In the consequentialist framework usually adopted by economists, actions are chosen in terms of the "goodness" or "badness" of their outcome. In relation to climate change the "goodness" or "badness" of actions is in turn usually assessed through two related lenses: an inter-generational lens, which stresses the welfare impact of climate change on future generations, and an intra-generational lens, which is concerned not least with the implications of actions (or non-actions) for poor people. In a non-consequentialist framework actions are judged on their intrinsic merit, as with Kant and his categorical imperative or Aristotle on virtue (Stern 2015).

Moral guidance is also offered in the teachings of major religions. Deep respect for the environment, concern around future generations, and the need for strong action to protect these are consistent themes in many religions with large numbers of followers, including Christianity, Islam, Hinduism and Buddhism. This engagement around the role of nature and our impact on it, and attempt to provide moral guidance can be seen from the encyclical *Laudato Si: On Care for Our Common Home,*[9] the Islamic Declaration on Global Climate Change,[10] the *Bhumi Devi Ki Jai!* (A Hindu Declaration on Climate Change),[11] and the Buddhist Climate Change Statement to World Leaders.[12]

While all these perspectives come from their differing viewpoints they are consistent in their call for swift and unified global action to halt environmental degradation, and tackle climate change. At a number of points they emphasize that current generations are stewards of the earth with a duty to provide a healthy, clean environment for future human generations and other species.

Cooperation

As demonstrated addressing climate change requires concerted efforts from all countries and strong international cooperation. The human contribution to rising greenhouse gas concentrations depends only on the sum total and not on the (cumulative) emissions of any one country alone.

Game theory tells us that such cooperation can be hard to secure, and indeed international cooperation on climate change has historically been difficult. The benefits that accrue from reduced climate risks are a global public good. Countries cannot be excluded from profiting and have incentives to free-ride if they perceive reducing emissions to be very costly to themselves and disregard the benefits to others. It is implausible to envisage effective supranational authority that could hold countries accountable or enforce an outcome that would appropriately serve present and future generations. Moreover, the group that would benefit is large and diverse and the impacts of accelerated climate change affect countries unevenly. These are strong reasons

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[9] http://w2.vatican.va/content/francesco/en/encyclicals/documents/papa-francesco_20150524_enciclica-laudato-si.html
[10] http://islamicclimatedeclaration.org/islamic-declaration-on-global-climate-change/
[11] http://www.hinduclimatedeclaration2015.org/english
[12] https://gbccc.org/

why reaching an agreement is difficult, but they are also the reasons why international cooperation is needed (Barrett 2003, 2007; Carraro 1999).

Against this backdrop, the Paris Agreement is a remarkable breakthrough in international climate cooperation. In order to illustrate this, it is worthwhile to compare Paris to another agreement that seemed almost impossible at the time. The Bretton Woods Agreement brought together 44 countries, in an attempt to rebuild the international economic and financial system in a more cooperative form. Keynes (1944, cited in Braithwaite and Drahos, 2001, p.98) described it as "*forty-four nations … actually able to work together at a constructive task in amity and unbroken concord. Few believed it possible. If we can continue in a larger task as we have begun in this limited task, there is hope for the world*."

While the Bretton Woods agreement should be regarded as a crucial achievement, it is important to recognize the urge for collaboration in the post-war era and the call for international coordination were almost omnipresent. The grave experience of two world wars and a great depression in 30 years taught some clear and strong lessons. The consequences of the failure to work together were demonstrated to be catastrophic; the evidence was hard and real. The USA was in a dominant position. In contrast, the Paris Agreement brings together 175 countries in *anticipation* of future harm, which makes it all the more remarkable. And no one country was dominant.

That an agreement was formed lies not only in the increased understanding of the gravity of the risks but also, and crucially, in an understanding of the attractiveness of alternative pathways towards sustainable development. This has changed the game-theoretic calculus of self-interested action. The agreement also includes features that enhance the willingness to cooperate, by increasing the benefits of cooperation and realizing them more quickly, such as international collaboration on low-carbon research and development (Keohane and Victor, forthcoming). Moreover, transfers between country coalitions (in the form of funds, commitments etc.) helped make the agreement more profitable to participants. However, we should also not under-estimate a shared sense of responsibility. Much of the motivation appeared to be beyond narrow self-interest and was about responsibility to future generations.

Yet, however remarkable, the deal struck in Paris must be seen as only the beginning of a long process of international cooperation. The effectiveness of the agreement is yet to be tested. The building blocks that have led to the agreement will need to be expanded and deepened. The pledge-and-review process contained within the agreement should help to take stock and provide transparency about the efforts of different countries, which in turn can create trust and encourage reciprocity (Keohane and Victor, forthcoming).

The pledges submitted ahead of Paris, if fully implemented, still put the world on an emissions path that is closer to 3°C warming than the Paris objective of "well below" 2°C (UNEP, 2015). The urgency of cooperation and action from all countries over the next 10 to 15 years is therefore essential and without it the chances of exceeding 2°C will become close to inevitable, and in turn increase the exposure of all countries to the potentially devastating consequences of unmitigated climate change. Action needs to be taken now if we are to have any chance of avoiding or limiting these consequences.

4. The analytical challenge: beyond the marginalist approach

As a key discipline in guiding and informing climate and development policy, economics has to recognize and embody the scale, severe risks, long lags, and publicness of causes of the phenomenon at hand. These are integral to the science. But they make the analysis of policy more difficult and the generation of political will to act more problematic. Economists are only now beginning to recognize the destiny and multiple dimensions of that challenge.

The first articles on the economics of climate change date from the 1980s and early 1990s (Nordhaus 1982; 1991a, b; Edmonds and Reilly 1983; Cline 1992; Manne and Richels 1992; Schelling 1992). The authors of those pioneering papers applied the tools of their trade. The groundbreaking work of William Nordhaus and the integrated assessment models it gave rise to were inspired by the growth theory of Ramsey and Solow. The accumulation of greenhouse gases in the atmosphere was understood as an exhaustible resource problem in the spirit of Hotelling. The likely impacts of climate change were enumerated, monetized and aggregated in the tradition of Pigou and Meade. To correct the externality, economists advocated Pigovian carbon taxes or Coasean emissions trading schemes (see Fankhauser 1995 for an overview of early climate economics).

Much of this is helpful. However, by placing a strong focus on the marginalist tools of welfare economics, economists have often failed to lift their eyes to the bigger picture and tended to underestimate both the potential impacts of climate change and the wider benefits of a transition to low-carbon growth, to the point where their models were increasingly at odds with the science. They have focused on fairly marginal perturbations to long-term growth when the question at hand is the management of immense risk and the longer term. There will always be a margin to be investigated but we must not lose sight of the fundamental question of where that margin might be located. That insight is basic and longstanding in economics, for example, in the theory of planning, but in this context it is critical.

The precautionary economics of climate change risks

Initial estimates of the economic costs of climate change began to emerge in the 1990s. They were both derived from and provided input into integrated assessment models (IAMs). These models attempt to combine the key elements of biophysical and economic systems and represent the full cycle from socio-economic activity to emissions, temperature change and impacts that then feed back into the socio-economics. It was a valiant endeavor, but the early models suffered from a poor evidence base. Many important impacts, such as the potential of large-scale human migration, either had to be omitted or were extrapolated from single data points (Tol and Fankhauser 1998). This had the effect of marginalizing or ignoring some of the most worrying risks associated with the science.

Today, our evidence base is much better (IPCC 2014). Empirical evidence is beginning to emerge on the impacts of moderate climate change, for example as regards agricultural impacts (e.g., Schlenker et al. 2005; Schlenker and Lobell 2010) and labor productivity (e.g., Burke et al. 2015; Heal and Park 2013). There is also case study evidence on the link between climate and conflict (Kelley et al. 2015). However, there are inherent limits to the empirical investigation of more severe climate change. The nature of the problem is precisely that it will take us outside the range of the empirically observed in the history of Homo sapiens (see section 3 above). But there is important evidence from the history of the earth, if we go back longer in time, for example on sea levels. This is the kind of evidence we need to incorporate to understand the consequences of the large temperature changes we might risk.

In its review of IAMs, the IPCC admitted that their results depended on a large number of "disputable" assumptions. Yet it is these hard-to-predict impacts that are the most troubling potential consequences of delayed action. The current generation of economic models has been useful in building the argument for action, but the models have been profoundly misleading in their quantification. In the most common specification, a temperature increase of 5^{o}C is associated with damages equivalent to just 5–10 per cent of GDP. Temperatures at that level have not been seen for tens of millions of years. The transformation would likely be traumatic. An 18°C temperature increase, which would render the planet all but uninhabitable, is associated with a GDP-equivalent loss of 50 per cent.

IAMs are highly sensitive to these assumptions. With only small changes in parameter values it is possible to construct optimal emission reduction paths that range from continued emissions growth to the complete phase out of greenhouse gases. The social cost of carbon, which measures the incremental damage of an additional tonne of emissions, range from a few dollars per tonne to several hundred dollars per tonne (IPCC 2014). It is a range that is much too wide to be of prescriptive value to policy makers. Dasgupta (2008) similarly concludes that the vast scale of possible losses renders narrow cost-benefit analysis, such as embodied in the use of IAMs, of very limited value to policy makers.

However, IAMs are useful in a different way. They help researchers to identify the parameter values on which their results most depend. This is important information to guide risk management and shape future research. The value of IAMs thus lies less in the damage numbers they produce than in the levels of sensitivity they reveal.

Multiple model runs and some understanding of the omitted risks show that the balance of uncertainty is heavily tilted toward the downside. Negative surprises are much more likely than positive ones. Economic tools can be used to translate these uncertainties into prescriptions for risk management. It is an important strand of research, pioneered by Martin Weitzman, who highlighted the importance of looking not just at the most likely outcomes, but also at the tail of the distribution (Weitzman 2012).

While Weitzman's focus on the tails is wise and welcome, the central estimates of potential change are themselves deeply worrying and offer sufficient grounds for strong and timely action.

There is an urgent need for a new generation of economic models that give a more useful picture of the full risks of climate change (Stern 2016). As noted above, this might require a closer look at the evidence from paleo-climatology on how the world looked at much higher temperatures than now.

The dynamic economics of a low-carbon transition

A wide array of economic approaches is available to study development paths which embody strong emission reductions. They include engineering-based least-cost models, general equilibrium models, macroeconomic models and many others. They often predate the debate on climate change and have their origin in energy sector planning. At the core of many models are estimates of marginal abatement costs (MAC), that is, the incremental cost of reducing emissions by an additional tonne.

MAC-based models have been useful in informing the low-carbon strategies of many countries, sectors and companies. A prominent example is the deep decarbonization pathways produced by the Sustainable Development Solutions Network, which offer concrete and credible emission reduction strategies for the world's largest emitters (DDPP 2015). However, by focusing on emission reduction efforts at the margin, MAC-based models often ignore the inherently systemic nature and dynamic force of transformative change. We need to focus much more on the dynamics of development. Thus we need a public economics which is about fostering system-wide change (e.g. New Climate Economy 2014).

Some system-wide effects can make carbon abatement more expensive. One key concern is structural rigidities in the labor market, both in terms of labor mobility and wages, which could lead to short-term unemployment (Bowen and Kuralbayeva 2015). There are also rigidities in the capital stock. Carbon-intensive capital is often long-lived and assets might get stranded unless investment decisions are sufficiently forward-looking. According to one estimate, under a 2°C scenario all fossil fuel investments after 2017 will have to be written off prematurely or retrofitted with carbon capture technology (Pfeiffer et al. 2016). Finally there is inertia associated with innovation, which appears to be heavily path-dependent (Aghion et al. 2014; 2016). Few of these effects are properly modelled as yet, but there are beginnings. They point clearly and strongly to the dangers of locking in high-carbon infrastructure and the potential gains from future innovation around cheaper and sustainable paths.

There challenges offer the real potential to harness the large dynamic benefits of low-carbon innovation – unlocking the process of "creative destruction" which Joseph Schumpeter described back in the 1940s. The economic literature to date has failed, in general, to capture the learning processes and economies of scale involved in radical structural change, which includes not just technological innovation but also changes in business practices and social behavior (Stern 2016). As engineers learn how to install, connect and repair technology cheaply, unit costs fall faster for many new technologies than for existing ones. This has already allowed solar-photovoltaic and onshore-wind technologies to become competitive with natural gas and coal in several locations, even without emissions or pollution taxation. Also influential will be the emergence of new networks, such as the integration of electric-vehicle-energy storage into smart grids, as well as rapid technical progress.

The low-carbon transition also has environmental "co-benefits" that could range from reducing fossil-fuel pollution (air and water), protecting biodiversity and supporting the preservation of the world's forests. Economic models generally omit these rewards, many of which, like reducing air pollution, fall disproportionately on the poor. The rewards of using cleaner fuels are potentially huge. In China and India, probably close to two million people die each year as a result of poor air quality. Expressed in monetary terms, the damages are equivalent to at least 5.5 per cent of GDP in India and probably in excess of 10 per cent of GDP in China (New Climate Economy 2014).[13] The language of "side or co-benefits" seems inadequate to capture effects of such importance.

The ethics of intervention

The ethics discourse in economics has focused heavily on intergenerational equity and in particular on the technical issues surrounding discounting. It has made little accommodation or room for the wider philosophical, legal, ethical and sociological perspectives that are relevant to policy formulation (Rayner and Malone, 2001).

Discounting is of course a central issue and requires rigorous, analytical scrutiny from economic, philosophical and political perspectives (see Stern 2007, 2014, 2015 for detailed discussions). Within the consequentialist mode of most economies we should distinguish discounting of goods and discounting of lives. If future generations are likely to be better off than those today, we may on the basis of value judgments (which can and should be morally explicit), place lower values on increments of output or consumption at a later date. But we have to remember that within the climate possibilities under consideration future generations may be worse off, perhaps much worse off. Incremental output to them might then be valued higher than now. Discounting in this central, and critical, sense is endogenous. Thus to speak of "the discount rate" as if it was something given and introduced entirely from outside is a serious conceptual mistake. The language of discounting is where we should start (see Stern 2015 for an elaboration) and we must recognize that discount factors and discount rates, like other prices and values, depend on where we turn out to be and that depends on our decisions. They are endogenous to our decision-making.

[13] The monetary cost of air pollution can be demonstrated with some simple algebra and assumptions. Take a fictional country with a population of N and a GDP per capita of x. Assume that in this country one in a thousand people die each year because of exposure to air pollution (or in algebraic terms represented by k). Whilst this figure has been assumed for demonstration purposes, it could be a plausible rough estimate for many developing countries including both India and China (Rhode and Muller, 2015). It is also assumed for statistical evaluation that the estimated cost of a life (averaged over those that are killed) is 100 times the GDP per capita within this country (this is a fairly standard approach that is used cost-benefit studies of health or transport policy, e.g. see WHO 2005) and is represented by m. The potential costs of air pollution can therefore be estimated by the equation $kN.mx/Nx$, or simplified to $k.m$. When this is equation is applied, we find that the percentage loss of GDP from air pollution in this scenario could be in the region of 10% of GDP per year.

Discounting lives is a very different philosophical issue. A particular and important case is "pure-time discounting". This involves placing a lower value on life simply because it starts at a later date. In many models this involves discounting total utility in a utility integral, often at a constant exponential rate. Thus a pure-time discount rate of 2 per cent values life A which starts 35 years later than life B, at one half of life B even though the two lives are otherwise identical. This "discrimination by date of birth" is very hard to defend with convincing ethical arguments. We would find it unacceptable, for example, in criminal courts, voting and human rights. All too few economists have spent time thinking carefully about these issues.

For development policy intra-generational equity is also very important. A main intra-generational concern is the allocation of the remaining carbon space (as discussed in section 3). In particular the questions surrounding who should reduce emissions by how much and when? A key aspect of this argument is the historical responsibility of developed countries for past emissions. That history is a fact, although its implications are much contested. Developed countries have obtained their current status through high-carbon growth and are responsible for around half of the CO_2 emissions since the mid-eighteenth century (Stern 2015). Some would argue that rich countries therefore have a moral obligation, from their history, their wealth and their technology, to take a strong lead in cutting emissions. Thus the ethics of dividing up the remaining carbon space has become a major issue of contention in international discussions.

To overcome the impasse we need to shift our sights to the dynamics of sustainable development. At the Cancun climate summit in 2010 a very helpful notion was introduced, initially by India. This is the idea of "equitable access to sustainable development". The current arguments around equity have tended to see rights and allocations only in terms of a single dimension, greenhouse gas emissions. The focus on this one dimension of climate change ignores a multitude of other relevant influencing factors and the dynamics and co-benefits of the alternative low-carbon transition.

There are no basic requirements and links that suggest that greenhouse gas emissions are necessary for development. They may be necessary in the early stages of transformation but not indefinitely. While energy is a basic requirement for development it does not necessarily, at least in a technical sense, have to be associated with greenhouse gas emissions, since it is possible to source energy with low or zero emissions. Therefore it can be argued that each country or individual has a right to development, a right to energy and a right to basic human needs, but they neither separately nor together imply a right to emit, to degrade the environment or to pollute and endanger the lives and rights of others. It is economically possible and attractive on multiple fronts (innovation, co-benefits and new markets) to move towards a low-carbon growth path.

The increasing recognition of intra-generational equity as a right to development, rather than a right to carbon space, was instrumental in paving the way to the 2015 Paris Agreement, where it was finally agreed to act collectively on climate change. The details of this agreement and the mechanisms to spur pathways for action are still to be further negotiated, but there is a common starting point and vision. However, acceleration of action, as Paris firmly requires, is crucial for the temperature targets to be reached. The public policy that can deliver this acceleration needs to be informed by better, more thoughtful economics, indeed a more "dynamic public economics".

5. The policy challenge: beyond incremental action

The development community is increasingly aware of the risks of climate change, including in and via the World Bank, which has spearheaded important initiatives on climate resilience, carbon pricing and climate finance (see for example World Bank 2010, 2012, 2016). The Global Environment Facility has served as a financing mechanism specifically dedicated to climate change since 1991. Similar new facilities are now proliferating (Buchner et al. 2015). However, the development community has yet to respond to the threat of climate change with sufficient purpose and scale.

Climate policy is not about incremental initiatives that can be attached to existing development plans. The management of climate change requires deep structural and systemic change, implemented over many decades. It needs policies that support, rather than stifle, the economic dynamism of developing countries. At the same time, the route matters as much as the destination. It is the sum total of emissions over time that matters to climate change. Delay is dangerous.

Climate-resilient development

The case for climate-resilient development is uncontroversial. It is well recognized that even moderate amounts of climate change pose risks to development. We are already seeing these effects. What is less appreciated is the extent to which the rapid development that many developing countries are undergoing is shaping their future vulnerability to climate change (Fankhauser and McDermott 2016). The large-scale development of urban coastlines, for example, is amplifying the risks of coastal flooding (Hanson et al. 2011).

The pace and scale of development means that the greatest opportunities for achieving climate resilience lie in guiding current development trends and getting the big decisions right. It suggests an approach to climate resilience that is managed at the level of national, and indeed regional, development planning. Policy makers have to become aware of the consequences for climate vulnerability of their development choices, and incorporate climate resilience into long-term development, infrastructure and spatial planning decisions. This macro-level approach is an important departure from traditional analysis, which has tended to treat adaptation to climate change as a set of self-standing, threat-specific responses, such as coastal protection schemes. Resilient development therefore requires the integration of the macro and micro considerations.

How does climate-resilient development differ from conventional development? Thomas Schelling, one of the first economists to engage with climate change, famously claimed that economic development was the best form of adaptation, implying that conventional and climate-resilient development are one and the same (Schelling 1992, 1997). Climate resilience and economic progress are indeed heavily intertwined. Education, sanitation, good institutions and access to credit, for example, are core concerns of economic development. They are also important determinants of people's ability to deal with environmental risk (e.g., Kahn, 2005; Fankhauser and McDermott 2014).

Yet not all forms of development have the same effect on climate resilience (Bowen et al. 2012). As countries develop the structure of their economy evolves, typically away from agriculture into industry and ultimately services. Sectors become more productive and the location of economic activity may shift. This is often associated with migration into the urban centers. Income per capita rises, and with higher incomes the demand for climate protection goes up. Of these changes, only the increased demand for adaptation unequivocally reduces climate change risks. The net effect of the other trends is unclear. Although agriculture is highly sensitive to climate change, a structural shift into services and industry improves resilience only if those sectors are themselves subject to less climate risks than agriculture, which in some locations they may not be. The same holds for urbanization and other geographic shifts.

The direction and nature of economic development therefore matters, and it makes sense to tackle climate risks in lockstep with development planning and investment decisions. Development strategies typically have a time horizon of five to ten years, which is short relative to the time span over which climate risks will materialize. This raises the question around which climate-resilience measures ought to be fast-tracked. Fankhauser and McDermott (2016) distinguish three priority areas: (1) strategic decisions with a long time horizon, such as urban settlement planning, which lock in vulnerability profiles for the long-term; (2) low-regrets measures that have an immediate development impact as well as climate-resilience benefits; and (3) measures with long lead-times, such as research and development, which take time to come to fruition. A large number of current development choices fall into one of these categories, including the massive infrastructure and urban development investments expected over the coming decades.

Pursuing climate-resilient development at the macro scale has institutional consequences. The responsibility for adaptation shifts from environment departments and hydro-meteorological offices to planning and economic ministries. These tend to be more powerful and better able to instigate the necessary reforms. It is an important and sometimes overlooked side-effect of moving from project-level adaptation to climate-resilient development.

The low-carbon transition

The core of climate science, in its demonstration of the potential risks, is no longer up for debate. However the policy prescriptions and pathways best suited to tackle the problem are. This includes crucially the role of developing countries in reducing global greenhouse gas emissions. Fossil-fuel sources of energy have been such a powerful force driving growth and reducing poverty that it seems reasonable to ask whether the dual goal of poverty reduction and climate change mitigation is in fact achievable, or, in the words of Dercon (2012), whether "green growth is good for the poor".

In many conventional approaches, economic growth is driven by energy derived from fossil fuels to support the mechanization of agriculture, the expansion of industry and ultimately a shift towards the tertiary sector. A move to a low-carbon growth path could, in those approaches, bring higher costs, slower growth and less poverty reduction. This idea is, in large measure, reflected in the original text of the UN Framework Convention on Climate Change,[14] which deals extensively with the question of “who bears the incremental costs?” In other words, there was an implicit, indeed fairly explicit, tension or “horse race” between growth and achieving environmental responsibility written into international discussion and development policy.

However, we can now see that the “horse race” represents a false dichotomy. The New Climate Economy (2014) has argued powerfully that the perceived incompatibility of poverty reduction and climate action is based on a fundamental misunderstanding of the today’s development possibilities and the structure of the global economy. Future economic growth and prosperity is not reliant on the high-carbon, unevenly distributed model of the past. These can be seen in the discussions around the dynamic benefits of an innovation-driven growth model, where learning processes and economies of scale create investment and employment opportunities. We have also outlined the immense environmental benefits of such a course of action, for example in terms of air quality, and the great scope to improve energy efficiency, and efficiency more generally.

The challenge for development policy is to guide economic decisions in this new direction. The choice is between pathways for growth that exacerbate climate risks and pathways that reduce climate risk and foster “better growth”. The pursuit of “better growth” in turn requires policies to guide the process of structural transformation, incentivize new investment and manage social disruptions during the transition, while still aiming to increase inclusion and reduce poverty and inequality.

Policy has to tackle fundamental market failures not just in relation to greenhouse gases, but also in networks, capital markets, clean innovation, the provision of information and with respect to the local, regional and global environment. Decarbonization would also be aided by the removal of existing policy distortions, including not least the subsidization of fossil fuels and the underpricing of energy. The OECD (2015) estimates that energy subsidies within member states amounted to US$ 160 - 200 billion annually over the period 2010 – 2014, and export credits provided for the extraction of fossil fuels were US$ 89 billion in 2013. Using a broader definition of energy subsidies, one that includes the costs of externalities (e.g. air pollution), the IMF (Coady et al. 2015) puts global post-tax subsidies for fossil fuels at US$ 5.3 trillion (around 6.5 per cent of global GDP).

The choice of policies will be important. Carbon pricing has proven an effective tool to incentivize emission reductions with very limited effects, so far, on competitiveness (Dechezleprêtre and Sato 2014). The break-through of low-carbon technology can be facilitated by deployment support schemes like feed-in tariffs for renewable energy. Thoughtful regulation (and its enforcement) also has a role to play, for example in the form of efficiency standards,

[14] https://unfccc.int/resource/docs/convkp/conveng.pdf

planning rules and building codes. Indeed energy efficiency is a very large part of the story, perhaps around half of what we need to do to cut emissions. Structural economic change will, by its very nature, involve disruption as current economic sectors change and new ones assert themselves. An essential part of the policy mix is therefore strategies to support labour mobility and retraining, while providing social safety nets and protecting low-income households.

Spurring low-carbon growth requires the redirection of financial flows and investment in the supporting infrastructure that will form the backbone of economic development, mitigation and adaptation. Over the next 20 years the required investment in infrastructure will be in the region of US$ 100 trillion or more, an average of US$ 5 – 6 trillion per year (Bhattacharya et al. 2015). This is equivalent to the current stock of global infrastructure (Bhattacharya et al. 2015). Around 70 per cent of this investment will be in new infrastructure and primarily located in developing countries. This capital stock will be long-lasting and the choices made now on how the new infrastructure will look and function will have enduring consequences for growth, development and the climate for the next decades and generations.

Currently around 60 per cent of global annual greenhouse gas emissions can be attributed to the investment in and use of infrastructure. If new investments are made on the same patterns, our cities and economic activity will become more congested, more polluted and more wasteful, undermining the quality of life and the sustainability of growth. To avoid this nearly all investment must be clean and green, starting now.

In all work on mitigation and adaptation, it important to recognize that they are not on isolated tracks from development with their own separate strategies. They are intertwined and it would be a conceptual and practical mistake to separate them sharply. There are many examples to illustrate this point. In agriculture Systems of Root Intensification (SRI), e.g. for rice, (i) save water and energy and thus promote development (ii) give more resilience (iii) release less methane from flooded paddy fields. Examples are everywhere in construction and buildings, public transport and so on. We must take great care not to present these three things as separate.

The long time horizon over which direction has to be sustained exacerbates the problem of policy inconsistency, commonly discussed in macroeconomics (see e.g. Kydland and Prescott 1997) but of even greater importance in green investment. Government-induced policy risk is an immense disincentive across the world. The *consistency, clarity and credibility* of climate policies therefore matter hugely. Private investors are being asked to radically reallocate capital, and they will only do so if the direction of travel is clear. Policy certainty is not something current political processes always deliver, but other areas of public policy can offer important lessons. Monetary policy, in particular, goes out of its way to ensure the predictability of decisions. Indeed the ability of the market to anticipate policy decisions is the hallmark of a good policy regime. The approach monetary policy has developed to ensure this may have merit in climate policy as well. A similar approach has been pioneered in the UK, where statutory carbon targets are proposed and monitored by an independent non-political body, in an institutional framework that is enshrined in legislation.

6. Conclusions

Throughout history humankind has taken advantage of the ecosystem services that nature provides, often pushing natural systems to the limits of their resilience, and beyond. Human ingenuity has succeeded in overcoming some of the natural resource constraints, including on food production, that were once thought binding. That extraordinary progress has not been sufficient to eradicate global poverty, but along a number of important dimensions human welfare has improved markedly. What is required now is both strong policy action and a radical deepening of economic analysis.

On *policy,* we are finding, and will find, some of the environmental problems of the 21st century to be more difficult than those of the past. None more so than climate change. Climate change is a threat of a completely different magnitude. It is not a localized problem, it is planetary in scale. It is systemic, rather than marginal, and requires systemic analysis and a radical response. It interacts with and compounds other global risks, such as habitat loss, disease, food security and conflict. The risks are huge and most ethical perspectives indicate that the moral imperative to act is strong.

The response to those threats is not the cessation of economic growth, as has been suggested by some (Jackson 2011, Klein 2015). We make the case in this paper that it is possible to advance economic prosperity and combat climate change at the same time. Indeed it is the only credible way: substantial poverty reduction generally requires growth, but high-carbon growth would be compromised, and perhaps reversed, by the hostile climate it engenders. A growth model driven by clean innovation and investment can create new growth and employment opportunities by generating learning processes, economies of scale, and a new dynamic of creativity. It also offers scope to improve market efficiency and secure environmental side-benefits in the form of better air, cleaner water and healthier ecosystems. The economic opportunities of the transition to the low or zero carbon economy are real and very attractive: it is a story of sustainable growth.

However, time is short. Our planning and investment decisions over the next 20 years will decide whether we have a chance of keeping climate change to 2^{o}C. Over this time period, the emerging markets of Asia, Africa and Latin America will build their cities, infrastructure and energy systems. Developed nations will need a major renewal of theirs. What we do in the next 20 years will be decisive in determining the future prospects for the rest of the century and beyond.

Changing course will require an unprecedented level of decisions, rapid action and a sustained effort over many decades and global co-operation. This is not something our political systems have a track record of delivering. Yet, there is reason for optimism. In the Paris Agreement (December 2015) and the Sustainable Development Goals (September 2015) the international community now has a platform through which climate change, environment and development can be integrated into planning, financing and investment decisions. Attitudes are changing and with them the idea of what is in people's and nations' self-interest.

Those attitudes are shaped by arguments. This is why we call for a *radical deepening of economic analysis*, including a development economics that begins to understand and incorporate climate change. Climate change is the biggest and most important example of systemic global risk but it is not the only one and we, in economics, have to learn to think about and investigate these issues much more carefully. Standard growth theory, general equilibrium and marginal methods will, as ever, have much to contribute but they will be nowhere near sufficient. This is about immense risks and radical change where time is of the essence. We should seek a dynamic economics where we tackle directly issues involving pace and scale of change in the context of major and systemic risks.

We also call for a *departure from development business as usual*. Sustainable growth requires finance and investment, and it requires strong leadership. While many of the responses are win-win that does not mean it will be easy. Poor countries have a large pent-up demand for modern forms of energy, transport and essential consumption goods that must now be met in a low-carbon way. They will suffer most from the adverse effects of climate change and need a form of economic development that manages their climate exposure and increases their capacity to adapt. In particular, we need a strong focus on investment in sustainable infrastructure. Around 60 per cent of the problem of emissions lies in infrastructure and its use. The world now needs strong and clear policies to foster those investments and a major expansion in finance to undertake them. A main part of that finance will likely require the close involvement of multilateral and national development banks. Now is the time for them to expand their balance sheets and their investment in sustainable infrastructure: radically and quickly.

It is the role of development policy, and development assistance, to facilitate the great changes now necessary. Managing climate change and reducing poverty are the defining challenges of the 21st century. Both can be tackled. The alternative paths for the transition to the low-carbon economy can be very attractive; much more so than the old ways. We know what needs to be done and how to begin. But if we fail on one, we fail on the other.

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