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Climate change and growth

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Abstract

Contrary to much of the conventional wisdom, taking stronger actions on climate change may enhance economic growth, even as conventionally measured, but even more so, in terms of societal well-being. We identify the flaws in the models and analyses which contend that there must be a trade-off and explain the mechanisms and dynamic forces which have the potential to enhance growth. Critically, there are numerous market failures that result in suboptimal economic performance. We explain how addressing climate change reduces the bite of these failures and enhances the incentives and political will to address them. We identify packages of policies that alleviate market failures, enhance growth, and reduce carbon emissions. Finally, we argue that the green transition is coming at a time when, both because of persistent deficiencies of aggregate demand and advances in technology, including artificial intelligence and robotization, the macroeconomic opportunity costs of strong climate actions may be especially low and the benefits particularly high.

JEL Classification: O40, O44, O49, Q58

1. Introduction

Climate change is already having a major global impact. This includes rising sea levels and an increased frequency of extreme weather events—hurricanes, floods, storm surges, heat waves, wildfires, and droughts—with disastrous effects on lives, livelihoods, property, and biodiversity. If climate change and the increase in atmospheric concentrations of carbon continue apace, it is likely that the total human population the planet can support will be greatly diminished. It is also likely that hundreds of millions, perhaps billions, of people would have to move, with a serious risk of extended conflict and those who could not move might suffer even greater risk. At least in many countries, growth would inevitably be negative. Furthermore, we may be dangerously near tipping points, which could unleash unstable feedback loops and very rapid and destructive change. Clearly, there are substantial risks that unmanaged or weakly managed climate change could destroy growth and reverse development. This conclusion emerges clearly from the science. Our paper is, however, about the relation between climate *action* and growth.

There is a "conventional wisdom" that suggests that tackling climate change will extract a high price from the economy—that paying too much attention to climate will hurt growth and long-run well-being. There is even an implicit argument that undermining growth in this way might be as damaging as not paying enough attention would be. It is a view held by some on the political right in rich countries, but also appears elsewhere, including in developing countries.

We show first that such arguments usually depend on simplistic standard growth models, embedding assumptions on the functioning of markets that are profoundly misleading in this context. We then present arguments that the innovation, investment, and systemic change brought about by a strong and purposive tackling of climate change can create a new, attractive, and sustainable growth story.

Standard economic modeling of action on climate change usually entails a balancing of the (marginal) costs today versus the (marginal) benefits tomorrow, discounting those future benefits in a specified way. The cumulative result of an assortment of modeling decisions embedded in the standard approach leads to the conclusion that it would be "optimal" to have policies where the central scenario entails a temperature increase of 3.5°C– 4°C (Nordhaus, 2018), far greater than the international consensus of 1.5°C to (at most) 2°C.[1] As we explained in an earlier paper (Stern *et al.*, 2022), we believe strongly that the international scientific consensus is right; analyses such as Nordhaus's have made a large number of indefensible assumptions that lead to these flawed and dangerous conclusions.

Some conservatives go further and argue that acting on climate change necessitates cutting back on other government expenditures. These policies, the argument goes, involve a reduction in growth, lower future tax revenues, and larger investments to mitigate climate change—in other words, the growth rate, g, will be lower and the interest rate, r, higher, making debt sustainability more precarious. The current situation (in this view) is especially problematic: the pandemic forced governments around the world to undertake high levels of debt, thus undermining public finances and necessitating cutbacks in expenditures across the board. Hence, it is argued that there is a macroeconomic case for delaying or reducing climate action and for a big dose of austerity in other arenas of public expenditure.

The objective of this paper is not only to expose the multiple fallacies and hidden assumptions in this reasoning in favor of weak or no action to tackle climate change but also to explain that tackling climate change can unleash higher growth, at least for a period in the coming two or three decades. The analysis by the critics of strong climate action not only misrepresents the science but also misreads critical aspects of markets, missing the central concerns of risk and societal well-being. Shifting our focus to these concerns points to stronger action on climate, both raising private investment and requiring higher government expenditures. In turn, the investment, innovation, and system change required to respond to climate change are growth-enhancing; increasing returns to scale and research and development (R&D) are crucial drivers of growth.

The paper is divided into three parts. In the first, we outline the key flaws in the standard arguments. It focuses on macro and growth issues and the associated models used to analyze them. In the second, we explain why we believe that the green transition shows every promise of moving us away from today's relatively stagnant equilibrium to a place of more dynamic growth and development. It is more structural, focusing on necessary systemic changes, and the investments and policies that can foster them.

Finally, we argue that the green transition is coming at a time when the macroeconomic opportunity costs may be especially low and the benefits particularly high.

Severe risk and multiple serious market failures are central to our argument, as are rapidly changing technology and economic structures and a broad view of well-being and concerns over distributive effects. The potential severity of risk throws doubt on standard optimization approaches based on expected utility. The centrality of market failures implies that ignoring them in standard models (or assuming they cannot be tackled at least in part, even though climate change may provide the momentum for doing so) means ignoring key routes to growth.

2. Part I: key flaws in the standard argument

In Part I, we explain the key flaws in the standard arguments put forward for limiting climate action. In the first section, we describe six analytic flaws, before turning in the second to the policy conclusion that climate change necessitates greater austerity. In the final section, we show how this analysis leads to a rejection of the two polar views: one arguing that there must be trade-offs and doing more about climate inevitably leads to lower growth and the other saying that we need to stop growth totally if we are to prevent a climate disaster.

1 Temperature change is measured here by the average global surface temperature relative to the second half of the 19th century.

2.1 Key analytic flaws in modeling climate and growth

What we refer to here as the "standard argument" that stronger climate action necessitates a sacrifice in growth has been developed using a class of models that bring together the interaction between the environment (climate) and economic activity (integrated assessment models [IAMs]) that implicitly or explicitly pursue intertemporal optimization in a world where there is no, or very limited, risk,[2] no market failures other than the environmental externality upon which they focus, unsound approaches to discounting which lead to very high discount rates, and no distributive concerns (that have not been optimally managed by government through lump-sum redistributions). Each of these four assumptions in the modeling is crucial. In each case, the assumption leads to greater pessimism than is warranted over the effects of dealing with climate change on growth. Furthermore, and this is where we start, there are problems both with the specification of the question in terms of the counterfactuals and the formulation of objectives. Taken together, "correcting" for these analytic flaws makes one far more optimistic about the likelihood that addressing climate change can be a positive-growth story.

We summarize later the key flaws in the reasoning that have led to the view that addressing climate change necessarily slows growth.

2.1.1 Getting the counterfactual wrong

What will happen to growth in the absence of climate action? The evidence is already here: climate change is causing increasing destruction to property and an increasing threat to lives. Repairing the damage and maintaining health will require increased expenditures, which will detract from standards of living and economic growth *in any case*. Spending money today to avoid these unnecessary expenditures—which, for example, have amounted to 1.5%–2% of gross domestic product (GDP) in the United States in some recent years—enables more money in the future to be spent on productive investments. If society is successful enough in mitigating climate change over the long run, growth can thus be enhanced. It is crucial to recognize that severe damage is occurring at a temperature increase of 1.1°C while, on current plans, the world could be headed for 2.5°C or 3°C or more over the next 100 years (UNEP [United Nations Environment Programme], 2022).[3] It is likely, based on the Intergovernmental Panel on Climate Change (IPCC) reports, that each extra 0.1°C causes increasing damage *at an increasing rate*. Thus, there is a failure in the standard models to recognize the scale of potential damages and the costs of handling that damage from failure to act. Without stronger climate action, current growth rates cannot be sustained; the assumption that they could is a misleading counterfactual.

2.1.2 Focusing on GDP at the expense of other consequences

The international Commission on the Measurement of Economic Performance and Social Progress (Stiglitz *et al.*, 2009), as well as the Organisation for Economic Co-operation and Development (OECD) High-Level Expert Group on the Measurement of Economic Performance and Social Progress (Stiglitz *et al.*, 2018), concluded that GDP was not a good measure of economic well-being. This is especially so given the issues at hand: GDP goes up when we have to spend more simply to repair the damage done by climate change. GDP is *gross* domestic product, not *net* domestic consumption. It also takes no account of health[4] and of how it may be adversely

2 The negative impacts from climate change are typically reduced to an aggregate "damage function." In reality, of course, the magnitude of the damage is uncertain; the damage function is presumably the expected value. Some, such are Chris Hope, have developed models where the objective function is the expectation of utility summoned over time (see, e.g., Stern (2007) for references and an example of use). Stern *et al.* (2022) have explained the limitations of this approach to incorporating risk. Needless to say, the greater the aversion to risk, and the greater one's perception of risk, the stronger the desired climate action. One can think of the international community's decision concerning limiting climate change as an expression of views about the magnitudes of the risks, how those risks change with increases in greenhouse gas (GHG) concentrations, and a willingness to accept risk.

3 While IAMs do make some effort to account for damage, typically these aggregate "damage functions" underestimate the consequences based on the most recent scientific evidence. When more realistic damage functions are used, action more in line with the international consensus emerges as optimal. Moreover, how damage is incorporated is typically flawed, as we noted earlier. Furthermore, in a world of endogenous growth (discussed later), increased expenditures on repair may be reflected in decreased expenditures on research, lowering growth rates. In assessing impacts on the average growth rates, ignoring risks (also discussed later) may be even more consequential.

4 As in the case of climate-induced property damage leading to more repair expenditures that stimulate GDP, adverse health effects of burning fossil fuels lead to more medical expenditures, which can also stimulate GDP.

affected by climate change (a topic we revisit in Part II).[5] In short, what is relevant is not growth in GDP but growth in a multidimensional measure of well-being, and with climate change increasing apace, it should be clear that there may be marked differences between the two.

This brings us back to the first flaw: the choice of counterfactual. The current trajectory, with its admittedly current low growth rate in GDP, has an even lower rate of growth in an alternative and more meaningful well-being measure.[6] Even if climate mitigation led to a somewhat lower rate of growth in GDP, it may still lead to a higher rate of growth in this more relevant measure.

2.1.3 Ignoring risk

The international community, led by the science (see IPCC reports[7]), has rightly recognized the enormous risk associated with allowing further increases in atmospheric concentrations of GHGs. Outcomes are simply unknown—and the extreme scenarios are clearly very worrisome. It is not as if the world gets just a little warmer. There will be significant increases in extreme events, as we are already witnessing, and these extreme weather events are associated with extreme and often long-lasting costs. The devastation of a flood, a hurricane, a heat wave, or an extended drought can be enormous. Rising sea levels and increased sea acidification will also impose large costs of uncertain magnitude. And we may be heading for or close to tipping points, such as the collapse of the Amazon rainforest, thawing of permafrost that would release methane, and the disappearance of ice sheets that could cause runaway damaging effects. Parts of the world may become essentially uninhabitable.

Critiques of the benefits of climate action denigrate the importance of risk and argue that markets can handle it well, and so risk presents no special problem. But that assumes that individuals are accurate in their assessment of climate risk—reflected in market prices. But the evidence is overwhelming that markets are poor at making risk assessments of complex and unknown factors—as the global financial crisis bears witness. More generally, Shiller (2015) has provided overwhelming evidence of the markets' irrational exuberance. In this context, irrational exuberance takes the form of irrational optimism that the adverse effects of climate change will be small and manageable. A wealth of recent evidence on climate risk and property values is consistent with the perspective that, at least in many cases, markets are underestimating climate risk (e.g., Dietz *et al.*, 2016; Battiston *et al.*, 2017; Monasterolo and De Angelis, 2020).

Climate risk is a *systemic risk*, and the 2008 crisis showed that the market does not do well in assessing systemic risk.[8] In a networked economy, determining systemic risk involves an overwhelming number of calculations and, at least currently, the requisite data are not available (Ranger *et al.*, 2021). These systemic effects are in part related, too, to the market failures discussed later. There are large externalities, beyond climate change, associated with actions taken by one party which affect others, including their financial position. Similarly, there are large *macroeconomic* externalities.[9]

Once one recognizes the uncertainty about the path and consequences of climate change, one must recognize that *even if the standard model were right in its central scenarios*, and the value of the parameters assumed accurately reflected mean or median values, *there is a high variance in outcomes*. In half of the feasible outcomes, inaction would lead to far greater costs, or doing more would have led to higher growth. But the losses from doing too little may be particularly large, indeed potentially catastrophic. Thus, *on average*, doing more to address climate change than these models suggest may well be growth-enhancing.[10]

5 Including the immediate health gains from reducing the air pollution associated with the burning of fossil fuels.

6 This is even more so once one takes into account the adverse distributive effects of climate change.

7 The IPCC assessment reports are prepared by panels of scientists and agreed by more than 190 governments on a lengthy process of examination. This process via its negotiations is likely to result in a cautious view of risks as governments averse to action can "negotiate down."

8 Partly, this is because the information required for an assessment of systemic risk is not available.

9 See Jeanne and Korinek (2019). Macroeconomic externalities are the macroeconomic manifestations of the pervasive externalities (including pecuniary externalities that matter) that arise whenever there is imperfect and asymmetric information and/or incomplete markets (including incomplete risk markets).See Greenwald and Stiglitz (1986).

10 This is the implication of standard results in the theory of optimal behavior in the presence of uncertainty, analyzing the effects of a mean-preserving increase in risk. See Rothschild and Stiglitz (1970, 1971) and Diamond and Stiglitz (1974).

Risk from badly managed climate change has multiple further consequences. First, and most importantly, it lowers individual and societal well-being. Humans are risk-averse—they are willing to pay a lot to avoid risk and willing to pay an enormous amount to avoid extreme risks such as those associated with climate change, reinforcing the conclusion that the presence of risk implies that stronger climate action is desirable. And taking these stronger actions will result in a higher growth in risk-adjusted expected GDP (viewed from an *ex ante* perspective.)[11]

Indeed, with these extreme risks, the standard welfare criterion (the integral of discounted expected utility) may not be well defined (Weitzman, 2009). Taking this into account alongside the deep uncertainty associated with climate risk (which even prevents forming a good sense of the probability distribution of future events), alternative decision-theoretic frameworks are required (Stern *et al*., 2022). These frameworks, such as the use of "guardrails" to set reasonable targets that help to avoid extreme damages, also imply taking stronger actions than would be implied if we ignored risk and simply focused on the "expected" outcome. In short, these risks are of first-order importance.

Second, the risk faced by private investors also increases with unmanaged or weakly managed climate change, and this itself discourages investment. Firms will have to spend more resources mitigating and managing these risks, as will households. As more private resources are directed at efforts to mitigate the risks posed by climate change, less will be available for promoting growth through other means. The greater underlying risk reduces firms' ability and willingness to undertake investment, either through capital accumulation or investments in growth-enhancing R&D.

Developing countries especially will be adversely affected, both because they will be directly affected more significantly by climate change and because increased risk exacerbates the already high-risk premia they face. Even in developed countries, this increased risk burden will have adverse effects, and especially so because risk markets are imperfect. Imperfect risk markets exacerbate other capital market constraints: more firms will face more stringent credit rationing, again impairing growth-enhancing investments.

In short, the reduction of climate risk makes entrepreneurs more able and willing to take on and focus on other aspects of risk and thus launch projects with higher expected returns than they would have otherwise. Economic growth is enhanced. This would be true even if there were perfect risk markets,[12] because the variability in output (consumption) associated with climate risk gives rise to an increase in (marginal) risk aversion, but it is even more the case in the real world, marked as it is by imperfect risk markets. Again, this in turn implies that strong policies to reduce climate change (and consequent climate risks) can be growth-enhancing.

2.1.4 Overlooking other market failures

Just as the adverse effects of climate risk may be amplified by the absence of good risk markets and other capital market imperfections, so too for other market failures. There are multiple other market failures that reduce efficiency, damage investment, innovation, and growth and can create inequalities and unemployment. Markets are not, in general, even (constrained) Pareto efficient (Greenwald and Stiglitz, 1986). (We expand on these market failures in Part II.) The policies and actions to tackle climate change discussed later in this paper may not only limit the growth-reducing impact of these market failures but also induce actions that directly impact their adverse effects.

There are interactions among market failures, with the increased risk of insufficiently addressed climate change exacerbating other market failures.

Analyses of "optimal" responses to climate change that ignore these pervasive market failures provide little helpful or sensible guidance. Even the narrow intertemporal trade-offs on which they focus are greatly affected.

11 From an *ex ante* perspective, as atmospheric concentrations increase, there is not only increasing uncertainty, but the magnitude of the uncertainty increases over time, so the certainty equivalent GDP grows at a rate that is slower than the rate of growth of (mean) GDP.

12 Recall that perfect risk markets do not eliminate risk; they only distribute/share it efficiently.

There is one crucial market failure to which we turn in greater detail in Part III: economies often operate at far below full employment. IAMs assume full employment. In that case, more money spent on mitigating climate change means less money for other forms of either investment or consumption. But for much of the time, capitalist economies have operated with significant under-utilization of labor and capital. This has been especially so in the years following the 2008 crisis, so much so that some economists spoke of *structural stagnation*—arguing that even at a zero nominal interest rate (the zero lower-bound of monetary policy), there was a deficiency of aggregate demand. Of course, there was nothing *inherent* in the situation. Even advocates of this perspective agreed that if only government undertook a more expansive fiscal policy, the economy would be restored to full employment. In other words, because in the absence of adequate climate investment, planned savings (at full employment) exceed planned investment, increasing the latter fosters employment and output while also reaping the returns from the additional investment.

Furthermore, as in the standard Keynesian and Schumpeterian models (Dosi *et al.* 2010), stronger macroeconomics (higher GDP and lower unemployment) creates a context for stronger induced innovation and, more broadly, growth (see also Stiglitz and Greenwald (2014), who provide a broader discussion of endogenous innovation). Thus, not only does the standard model overestimate the opportunity cost of stronger climate change actions by assuming technological change is exogenous (or, in any case, if endogenous, already optimally set), it misses out on an important set of growth benefits that may emanate from stronger climate action.[13]

Proponents of a "minimalist" response to climate change sometimes counter by arguing that if there are significant market failures, government should address them with or without climate change, and that it simply muddies the waters to confound these different problems. But that response is flawed. As we argue further later, the economic and political incentives and will to address these market failures may be enhanced by a commitment to address climate. While some market failures are unavoidable and inherent—for instance, there are inherent asymmetries of information—even then, how they play out can be affected by policy, including the policies designed to respond to climate change.

2.1.5 Using inappropriate approaches to discounting

Because markets typically discount the future at too high a rate—the standard criticism that markets are excessively short-term—they underinvest, including in growth-enhancing R&D. Putting too much emphasis on the present—on current consumption—relative to the future is exactly what gives rise to low growth, from too low investment in human and physical capital, too little investment in R&D, and too much damage to the environment. Many of the stronger climate actions entail increases in efficiency in energy and other key economic systems—and this itself will entail enhanced growth.

It is often assumed that there is no discrepancy between how firms discount the future and how the government should because markets are efficient. As has long been recognized (Stiglitz, 1982), in the presence of multiple market failures and tax distortions, there will, of course, be a wedge between the two. (The fundamental concept here is the discount factor, the relative value of a good now relative to a good at time t in the future. The discount rate is the proportional rate of fall of this factor.) But there may be a wedge even in the absence of market failures.

Discounting future consumption flows for an individual is not the same thing as discounting the welfare of future individuals. The latter refers to a lower social weight on an individual born later even if that individual has consumption identical to that of an individual alive now. The latter, concerning the valuation of future generations, is often termed "pure-time discounting." Ramsey (1928) convincingly argued that future generations' welfare should not be discounted—there is no ethical justification for doing so. We share that view. Pure-time discounting is essentially discrimination by date of birth. If one accepts that perspective (and, as we have shown elsewhere, the case for doing so is very powerful)—see Stern (2014a, b) and Stern *et al.* (2022)—then the extent to which a dollar today is worth more (or less) than a dollar in the future (whether the discount factor is below or above 1) depends on whether consumption (broadly understood, including the environment) is higher in the future than today. Whether and to what

13 These growth benefits are explored further in Part II.

extent future generations will be better or worse off than the current depends on policy—most importantly, what is done about climate change. One cannot simply *assume* the answer. Ironically, models which assume that they inevitably will be better off lead to an endorsement of climate policies which would result in their being worse off, invalidating the underlying assumption of the model. In other words, discounting is endogenous to the decisions we take and cannot be "read-off" from markets or something outside the analysis.

Risk introduces another complexity to the analysis of discounting. Risk and time discounting are often confounded.[14] In Stern *et al.* (2022), we discuss more extensively the appropriate way of handling risk. Because climate mitigation can be viewed as *insurance* against very bad outcomes, the appropriate risk adjustment is negative, that is, the effective discount rate for evaluating investments in climate mitigation is less than the safe rate of interest (normally around 1%–1.5%) markedly below the 4%–6% embodied in many IAMs[15] Intuitively, this reasoning around risk gives the sensible result: with greater risk, insurance becomes more important. Heightened climate risk should give rise to *more* investment, not less (Arrow *et al.*, 1996).

On the other hand, firms, in evaluating, for instance, investments in energy efficiency, typically use their cost of capital, including a risk premium reflecting cyclical risk and sometimes even own risk,[16] a number that is significantly greater than the safe rate of interest, leading them to underinvest, for instance, in energy efficiency increasing R&D. Thus, stronger public climate actions in these areas can be growth-enhancing.

2.1.6 Ignoring distributional effects (intergenerational or across generations) to focus on efficiency

This flaw is much akin to the previous: while the standard model wrongly evaluated the impacts of climate change and actions to avert it on the intertemporal distribution of income—putting too little weight on future generations—it paid essentially no attention to the distribution of income within each generation,[17] just as it ignores market failures. Climate change hits poor people and poor countries earliest and hardest. Thus, values that place greater weight on benefits for poorer people point to stronger action on climate change and implicitly using a lower discount rate.

Interestingly, models that put more emphasis on inequality say it is desirable to take stronger climate action (more in accord with the 1.5°C or 2°C target than the 3.5°C–4°C target)—*even without taking into account risk* (Stern *et al.*, 2022).[18]

A key argument for ignoring these distributional effects is that if they are important, the government should have already "corrected" these problems—and would have and will continue to do so as climate change unfolds. But there is a big difference between "should" and "would." There are costs of redistribution—most importantly political impediments. But these impediments may be influenced by climate change and public discussion of action on climate. Tackling climate change effectively requires recognizing both the inequitable impacts of climate change, both intra-temporally and intertemporally, and the imperative of a just transition and the management of dislocation.

Because climate change has a disproportionate effect on the poor, it increases inequality and increases the marginal social benefit of redistribution. If there are, for instance, fixed costs associated with redistribution, it might not have been desirable to redistribute in the absence of climate change, but in its presence it becomes desirable to do so. Thus, bringing climate change into the discussion shifts the economic and political calculus.

Moreover, economic logic and political logic are not always aligned. Political leaders often have short-term horizons and see impediments to redistribution—the opposition of the elites who would bear higher taxes. But changes in the economic logic, here bringing in climate change, can

14 The only plausible qualification to this statement would be to introduce an external probability of the total vanishing of the world—see, for example, Stern *et al.* (2022).

15 Under the Trump presidency in the United States, the number used in this context was 7%.

16 See Stiglitz (1972).

17 Some models deal with different countries or regions, but they are few in number and pay little attention to distribution within communities. These models provide support for stronger climate action. See Stern *et al.* (2022).

18 The same is true for models which correct for the other market failures and model limitations noted, for example, those using a lower discount rate.

shift the political logic. Climate is already changing politics in many countries, and as climate change proceeds, almost surely will do so even more in the future.

2.2 Implications for budgetary stances

Fiscal conservatives might argue that with tax revenues dependent on GDP, *if* climate change decreases growth, the negative prognosis of countries' fiscal position in the future is an increasingly relevant constraint on climate action. Moreover, the lower GDP and the higher investment required for mitigation and adaptation, it is argued, will lead to higher interest rates. With (real) interest rates higher and growth lower, debt sustainability becomes more problematic. A central argument of this paper, however, is that taking stronger action on climate change may enhance growth (relative to the relevant counterfactual), even measured narrowly via GDP, and may accordingly increase the tax base and improve countries' fiscal position.

Moreover, there are scant grounds for confidence in our ability to predict the evolution of interest rates, as Orszag *et al*. (2022) point out. There has, for instance, been a slight secular decrease in real interest rates, even as population growth has slowed (which led some to argue to the contrary that real interest rates would increase[19]). Before the 2008 financial crisis, there was much discussion of a savings glut (e.g., Bernanke, 2005). In some quarters, there were worries about negative real interest rates—a zero nominal rate combined with slight inflation.

One source of uncertainty about the effects of greater climate investments on the savings glut/shortage is that there is uncertainty about the effects of changes in risk on savings behavior. Individuals may save more to protect themselves against the doomsday, but they may save less because of a sense of hopelessness about the future.[20] In the latter case, climate investment may enhance savings, leading to a reduced real interest rate.

2.2.1 Multiple ways of responding to a shortage of savings—including raising taxes

If real interest rates were to increase because of a shortage of savings, with fiscal sustainability being threatened, there are multiple ways by which the government could respond. Increased progressive taxation would increase government revenue and reduce the need for borrowing.[21]

Responding to climate change in part by the imposition of a carbon tax (or the auctioning of emission permits) would yield substantial revenues, at least in the next few decades. These revenues would go a substantial way to providing the funds necessary for climate investment—and address any putative "savings shortage."

There are still other taxes that might simultaneously improve economic performance or enhance social justice: other environmental taxes, various forms of financial taxes, real estate taxes, and inheritance taxes. In the United States, for instance, an array of such taxes could increase tax collections by several percentage points of GDP. Furthermore, stronger tax administration can yield strong revenue increases in all countries. So too could international agreements to close the routes available to rich individuals and corporations to avoid and evade taxes, including tax havens and profit-shifting.[22]

In short, there are a variety of ways that government can raise revenues and in ways that enhance efficiency, reduce emissions, and/or reduce inequality. Responding to climate change does not necessitate austerity in other areas of public expenditure, and even a pessimistic prognosis on future public finances is not an excuse for climate inaction.

There are other reasons for a more optimistic prognosis of growth and budgetary positions, some related to a more careful assessment of the right counterfactual. Many countries are already spending large amounts on *repairing* the damage from climate change. Governments inevitably

19 Such analyses focus on the short run, noting that the increase of retirees dissaving relative to workers saving will decrease the aggregate supply of savings. In standard life cycle models, a decrease in the growth rate of population has an ambiguous effect on real interest rates, depending on the elasticity of substitution.

20 Standard theoretical models often generate ambiguous results, based on the value of the third derivative of the utility function. See, for example, Rothschild and Stiglitz (1971).

21 There is considerable evidence of an intertemporal elasticity of substitution of less than 1 so that in the standard life cycle model, interest income taxes, which are on average progressive, induce more savings.

22 The Independent Commission on the Reform of International Corporate Taxation has proposed a number of concrete reforms that go well beyond the weak measures currently being proposed within the OECD framework (ICRICT [Independent Commission for the Reform of International Corporate Taxation], 2018).

absorb a large fraction of the costs of extreme weather events, via assistance at the time of the event and via restoration (rebuilding and reconstruction). Moreover, the costs of repair are (at least for firms) tax deductible, eroding the tax base. Furthermore, there are large health costs associated with pollution, and these too are disproportionately absorbed by the public. A more thoroughgoing assessment of the uncertainty and risks involved in climate change, as outlined earlier, shows that it is at least plausible that a less environmentally fragile economy is in a far better position to cope with fiscal challenges.

Furthermore, if we think of destruction of the environment as a liability we pass onto future generations, then we face an unpleasant choice: financial debt versus environmental debt, with the latter far worse than the former. The financial debt we pass on to future generations is simply money owed by one part of society to other parts. In short, it is money owed by society to itself. We can make this debt go away, through debt restructuring. Debt restructuring does not lead directly to less physical, human, or natural capital, although it might impair governments' ability to borrow in the future, necessitating raising taxes to finance expenditures (i.e., limiting the ability to postpone taxes into the future). And some people might be very unhappy at the writing down of their assets.

The most important debt burden left to future generations is the deterioration of the environment. We cannot rid ourselves of this burden as easily as we can the debt burden. We can rid the atmosphere of its GHGs only by very large *real* expenditures.[23]

Of course, as countries assess their fiscal position, they have to make judgments about future growth and future interest rates. They should aim for debt sustainability—there are often large costs associated with debt restructurings, which often plunge countries into a crisis. However, the (dynamic stochastic general) equilibrium framework that has dominated macroeconomics does not provide the appropriate framework for thinking about the issues, precisely because crises reflect disequilibrium, macroeconomic inconsistencies, and situations where plans are not met. There are huge costs to acting in such an extreme way as to ensure that plans will always, under all contingencies, be fulfilled (Guzman and Stiglitz, 2020). It makes little sense to cut back today either on public investments in education, infrastructure, R&D, or the environment simply because in the future, if things turn out badly, debt *might* not be sustainable. Decision-makers might want to raise taxes now or to raise taxes in the future (as we get more information either about growth or real interest rates). As we have already discussed, there are a variety of ways by which revenues can be enhanced in an efficient way.

2.3 Rejecting two opposing arguments: "lukewarmers" and "no-growthers"

To conclude Part I, there are two sets of extreme arguments that we reject. The first, often from the far right in politics, is that markets function well and allocate resources efficiently, and therefore there must be a trade-off in terms of output if we pursue climate objectives. That is clearly wrong: we have already set out relevant market failures, which are returned to in Part II.

The purist versions of market fundamentalism, combined with science skepticism, have mutated somewhat in the face of evidence. Some versions would now recognize the existence of market failures, and that both stronger growth and reduced climate change could flow from addressing them. However, market fundamentalists still claim that we have already done everything that is economically beneficial or politically acceptable to overcome them. Hence, once again, in this perspective, there must be a growth-environment trade-off.

This conclusion is wrong. First, we have explained how climate change increases the *economic* returns to overcoming these market failures, including because reducing underlying climate risk may reduce the force with which these market failures bite, for example, if the market failures limit the management of risk. Because the returns to addressing the market failures most relevant to climate change have increased, there should be a greater willingness to address them and to mitigate their impacts, especially in the context of climate change. This is evident, for instance, in the increasing number of green development banks and the expansion of industrial policies. There were strong arguments for creating development banks and pursuing industrial policies

23 The current cost of direct air capture of CO_2 is around $500 per ton (McQueen *et al.*, 2021). While it is falling, it is likely to remain well above $200 for some time.

before climate change moved center stage; but at least in the United States, these arguments never overcame the political opposition. Today's focus on climate change has thus achieved a political victory that long seemed out of reach, and these policies and institutions will have benefits that have a far broader reach than just climate.

Second, even apart from this, the salience of climate change may overcome political impediments to tackling these failures, at least in this context.[24]

'Lukewarmers' say that while there may be some modest climate effects, these are not of sufficient significance to incur very much in the way of costs of climate action, particularly once one recognizes the costs of overcoming market failures, the centerpiece of the new "weak" market fundamentalism. Again, that argument is especially unconvincing given overwhelming scientific evidence on the potential scale of damage and destruction to lives and livelihoods from climate change and the potential to reduce emissions in the context of rapidly falling costs of alternatives to fossil fuels and save lives from reduced air pollution that comes from climate action.

Indeed, the lower cost of energy, in part because of innovation induced by concerns about climate change, illustrates one of the central points at issue: accelerating the move to cheaper renewables can itself be the basis not only of reduced climate change but also of faster growth.

Moreover, the fact that renewable energy resources are more widely distributed than fossil fuels means that a move toward the green transition will help create greater global equity and security, although this requires minimizing the negative impacts of the new resource extraction necessary in a renewable energy system.

2.3.1 The no-growthers

At the other extreme to those arguing to do next to nothing are those saying that growth should stop immediately. This claim too we think is wrong. Doing so is neither necessary nor sufficient for achieving net-zero carbon emissions. Moreover, such a policy is politically unacceptable and for good reason. The political reaction to insisting on stopping growth may undermine the acceptance of climate policies in general.

Emissions cannot be reduced from their very high levels of close to 60 $GtCO_2e$ per year *simply* by stopping growth. Halting growth just freezes emissions, here at very high levels. Stabilizing temperature leaves stabilizing concentrations and that means achieving net-zero emissions.

To put the issue in stark form, we surely do not want to get to net-zero emissions by having zero consumption. The "no growth" argument diverts attention from the key issue of breaking the relation between consumption and production on the one hand and destruction of the environment on the other. That will be achieved by consuming and producing in different ways, and many of the technologies needed to do so exist already. We can also change our patterns of consumption toward goods and services that are "greener"—and this too is already happening. The societal welfare costs of these changes in patterns of consumption, while hard to evaluate within economists' standard normative framework,[25] may be low: the younger generation consuming a vegetarian or vegan diet seems to get as much pleasure out of cooking and eating as the older generation did consuming meat—and are likely to have longer and healthier lives. Thus, a new form of growth can be created, as we argue in Part III.

Furthermore, investment and growth will be needed to overcome poverty across the world and make progress toward the Sustainable Development Goals and an increase in well-being across all its dimensions, particularly in poor countries.

To say that investment and growth are essential in the coming two or three decades, it is not, however, a statement that growth should go on forever. Planetary boundaries do impose constraints (Rockström *et al.*, 2009). In the next two or three decades, climate action is likely to help in addressing these problems. In the later part of the century and moving into the next, the boundaries may well constrain growth (both in GDP and population) and should already be prominent in thinking about public policy.

24 See also the discussion earlier on the political economy consequences of climate change's distributional impacts.

25 That framework requires fixed, exogenously specified preferences. With endogenous and/or changing preferences, the question is, which preferences does one use to evaluate alternative trajectories? On endogeneity of preferences, see Hoff and Stiglitz (2016). For a brief discussion of the implications for climate policy, see Stern *et al*. (2022).

3. Part II: from sluggish and destructive growth to dynamic and sustainable development

The analysis of Part I showed why the assertion that there must be a trade-off between climate action and economic growth has little or no foundation. It looked in detail at standard aggregate growth and macro models and arguments that had concluded that that was so and showed their built-in biases against strong action. In this section, we examine the potential forces, policies, and actions that can drive the change from the dirty and destructive paths of the past toward more resilient and benevolent forms of growth and development. In large measure, these arguments and directions for action flow from a recognition of the nature of the flaws in the opposing views described in Part I. They also build on lessons from the experience of climate action to date and emerging possibilities of even stronger actions in the future. This section is therefore more positive in terms of thinking about and formulating viable actions and policies. In so doing, it has a less aggregative approach and is somewhat more sectoral and structural. It points to a new growth story, employing the technologies of the 21st century rather than those of earlier centuries, one that is clean and constructive on multiple dimensions of well-being.

In thinking about the new growth story, we need to reflect on how this plays out in the short, medium, and longer runs. In the short run, there are already many investment opportunities around newer technologies. Good policy can create confidence that the economy is transitioning purposefully and durably and thereby incentivize investment in modern, clean, and efficient activities. In the medium run, there will be a Schumpeterian process of innovation and discovery, as entrepreneurs and inventors develop new techniques and methods; this is already underway in some sectors and beginning in others. In the medium to longer run, there is no high-carbon growth story: the effects of unmanaged climate change are so severe that they will very likely derail any (misguided) attempt at high-carbon growth. The only long-run growth trajectory is a green trajectory.

The first section below begins with some specific driving forces generating green growth. The second examines focuses on market failures and how they can be addressed and systemic change and how it can be promoted. If market failures and systemic change are tackled effectively, these driving forces will be unleashed. The third examines path dependence and the history of technologies, including the role of non-convexity and multiple equilibria, and the fourth sets out some quantification of the necessary scale of investment.

3.1 Driving forces

Broadly speaking, eight complementary and interacting driving forces can generate a new growth story, operating individually and together. The first four refer to an increase in productivity via change in design, technologies, and systems. The next two refer to global cooperation around investment, finance, and standards. The final two concern health and behaviors. On all of these and their interactions, artificial intelligence (AI) and digitization can have powerful, enabling, and reinforcing effects. It is fortunate that the extraordinary advances in AI and the profound need for sustainability and new technologies are occurring simultaneously. Some recent further analyses examining and demonstrating these growth effects were published in January 2023: the Skidmore report for the UK government (Skidmore, 2023) and the Stern and Romani report for the World Economic Forum (Stern and Romani, 2023).

3.1.1 Improved resource efficiency

More efficient use of the same quantity of resources means higher productivity. There is great scope for improved energy efficiency (Lovins, 2018; IEA, 2022). There are real potential resource savings in the circular economy, in which what would previously have been treated as waste becomes an input into production (Ellen MacArthur Foundation, 2019; Pauliuk *et al.*, 2021). The work of the Rocky Mountain Institute has demonstrated high returns from investments in "integrative design" (e.g., Lovins, 2018), where a whole house, process, or system is designed for efficiency, including heating, water flows, lighting, construction, and so on.

It is not true, as essentially assumed in simplistic neoclassical models, that all available efficiencies have been realized already. Unnecessary waste can be immense across food, raw materials, energy, and beyond . Indeed, as Stiglitz and Greenwald (2014) point out (supported by a large literature), most firms are far from the production frontier, and there is an enormous scope for increasing overall efficiency simply by moving firms that are below the frontier to the frontier.

3.1.2 Increasing returns to scale

There are powerful increasing returns to scale in both production and discovery for new technologies arising from scale technologies, learning by doing, and induced innovation. This means that as we shift more to the green economy, costs may fall—and growth will increase. These are reflected in part in the rapidly falling costs of production of solar panels, wind turbines, and batteries. There are further returns to scale embodied in critical networks—for example, electricity grids, broadband, public transport, or recycling and reuse facilities. Scaling up green activities will enable our economy to take advantage of these returns to scale.

3.1.3 Stronger system productivity

Energy, cities, land, and transport systems can all become more productive through improvements to how each operates as a system and how these systems interact.[26] Climate action and the drive to net-zero emissions require cities that are designed to accommodate more cycling and walking, integrate public and private transport in a more deliberate way, and have much cleaner air through vehicles without internal combustion engines, integrated heat and power systems, and cleaner homes and industries. They would be more compact, but even so, less congested as a result of more extensive public transportation and biking. Cities where you can move more easily and breath more healthily will be more productive. Similarly, sustainable approaches to land use do not poison rivers, degrade land, and destroy forests. In each case, acting on negative externalities and recognizing how systems function can improve efficiency and productivity, including delivering ecosystems that are robust, fruitful, and more productive across whole areas of human activity and well-being.

3.1.4 Moving the frontiers of knowledge quickly and in ways consistent with social priorities

When societies set urgent priorities and intensify focus, such as the production of aeroplanes and training of pilots in wartime or the creation of vaccines and their delivery during a pandemic, action can be rapid and lower costs and greater scale can be realized quickly. However, these processes require a shared sense of purpose and recognition of the necessity of pace. Prices typically do not, by themselves, provide an adequate signal of urgency, and markets do not respond with the necessary effectiveness or speed: that is why few countries rely primarily on markets in wartime (Stiglitz, 1989) to deliver the pace and scale of change that is necessary. Even the United States, the bastion of "free market economics", passed the War Production Act, which it invoked in the urgency of the pandemic, giving government powers to commandeer resources, if necessary, when markets fail to respond adequately. Other countries (such as Australia) acted similarly during the pandemic.

The climate crisis is an example of crucial importance where there is real urgency. Costs are already being driven down rapidly in key areas where the social and economic focus is concentrated. The rates of progress on clean energy are far faster than old technologies (Way *et al.*, 2022). The pace of these changes is remarkable and largely unanticipated and comes on the back of relatively modest government support, suggesting that more robust government support might generate substantially faster innovation.

3.1.5 Higher investment globally

There is, or should be, a shared understanding, across policymakers and investors, that climate action requires substantial investment across all countries and sectors. Estimates for the scale of these investment needs are presented in Section 3.4. Mutual reinforcement from simultaneous

26 There are multiple reasons why there is no presumption that the market outcomes in these complex systems will be efficient, including pervasive externalities and non-convexities within the system, and a complexity necessarily results in there being incomplete pricing and markets. In most of these systems, some governmental body plays a regulatory or coordinating role.

action in multiple countries and sectors can stimulate investment and innovation in all countries. If many or most countries recognize the importance of the new path and the necessary scale and pace of investment to achieve it and reflect that in their strategies, policies, commitments, and actions, then those who produce investment goods and those who engage in R&D will have confidence in their markets, and investors will be confident that policies conducive to the profitability of their investment are likely to be in place. Confidence can be built and sustained through strategic plans and policies (packages that we have discussed elsewhere, including standards and regulation, taxes and subsidies, public investments, and approaches to procurement—see Stern, 2021). For instance, a sound and credible carbon price will lead to faster replacement of old capital goods by new, more energy-efficient, and less carbon-intensive capital goods. New standards and regulations will have similar effects.

The new investment will have demand- and supply-side effects. If there is a shortage of aggregate demand, as there was for a decade after the global financial crisis, growth will be strengthened through that channel.

Second, new, more productive technologies are embodied in new capital goods, so that an increase in the pace of investment, as old capital goods of the old economy are replaced by new capital goods of the new economy, will increase the rate of growth.

Thus, the investments that are part of the green transition will have a powerful effect on growth, at least in the short run, especially if the economy is constrained by aggregate demand, but even if it is not. As we elaborate more fully in Part III, investment was low and productivity growth slow across the world throughout the 2010s. Commitment to a sustainable form of growth and development could fire up both investment and growth in a mutually reinforcing way across the world.

3.1.6 Global cooperation and coordination

As the world has come to recognize the necessity of a green transition, they have also realized that climate change is a global public good (bad) and that it can only be tackled globally. Even if the advanced countries bring down their carbon emissions to (net) zero quickly, climate change will proceed apace, unless developing countries and emerging markets also make the green transition. They are unlikely to be able to do this on their own; given that so much of the current atmospheric concentration of GHGs is due to the actions of the advanced countries, they are unlikely to be willing to either. Thus, the resolve embodied in the Paris Agreement (but not fully acted upon) to help developing countries and emerging markets such as through financial assistance and transfer of technologies. See Songwe *et al*. (2022) for an analysis of necessary financial action to support the investment which is necessary for the Paris Agreement.

If the Paris commitments are honored, global growth will be strengthened, as both investment and technology transfer will increase productivity in developing countries and emerging markets. Because of the greater scarcity of capital in developing countries and emerging markets, the transfer of capital will itself improve the efficiency of global allocation of capital and thus enhance global growth, so too for the transfer of technology.

There is another important dimension to this cooperation and coordination: actions to prevent a race to the bottom where countries might attempt to seek competitive advantage by *not* going green. Increasingly, countries are recognizing that cleaner production methods are cheaper, at least in many sectors, but even when it is true, it is not always recognized, and some countries may not have access to the relevant technologies. Incentive structures to avoid such a race to the bottom (such as cross-border adjustments) will likely be necessary. There are signs that the world is moving toward cross-border taxes to promote compliance with global agreements (such as the EU's "carbon border adjustment mechanism"; European Parliament, 2022). If enough of the world adopts such provisions (or if their possibility is reflected in international agreements), then incentives to make investments green are enhanced.

Global cooperation weakens incentives to behave badly, but it also strengthens incentives for innovation and investment, such cooperation helps create a larger global market for green products, including green capital goods. The major economies can set standards (e.g., not allowing the sale of internal combustion vehicles after a certain date) which will shape technologies across the world. Even setting standards for government procurement can have large effects.

3.1.7 Improved health

Air pollution is associated with 10%–20% of annual global deaths (between 5 and 10 million deaths per annum; IHME [Institute for Health Metrics and Evaluation], 2020; Vohra *et al.*, 2021). On top of that, there is great and widespread damage to health, including cardiovascular disease, respiratory illness, and cancer. Reducing emissions from fossil-fuel combustion will reduce these impacts and alleviate the associated burden on the economy, fostering growth through multiple channels, including greater labor productivity and lower health-care costs. Some of the actions to cut emissions, such as greater cycling and walking, can themselves also improve health and productivity (Woodcock *et al.*, 2009).

3.1.8 New norms

As society moves toward a green transition, there will be changes in social norms. For example, if we see others being much less wasteful or destructive, we may be more likely to change our own behavior, as for example in littering or smoking. Diets and lifestyles will change, and that will unleash many of the dynamics described earlier through "social tipping points" (Winkelmann *et al.*, 2022): firms will seek to satisfy these new desires, leading to a burst of innovation in new products, with new enterprises often leading the way. And there will be opportunities for taking advantage of economies of scale in these new preference patterns. Good information on products and companies will be an important part of this process, including independent scrutiny to expose "greenwashing."

3.2 Translating drivers into growth: overcoming market failures and promoting systems change

The drivers make it clear that addressing climate change can indeed increase growth. In the remainder of this part, we describe how policy responses to foster action on climate change, including those that tackle some of the key problems noted in Part I, can promote growth through the promotion of these key drivers. We focus in this section on overcoming market failures and promoting systemic change.

3.2.1 Market failures

In Part I, we argued that the failure to take into account the multiple other market failures besides climate change—but which interact with it—made the analyses of most of the early work from the IAMs unreliable as a guide to policy. By contrast, by recognizing and focusing on them, we can identify actions to overcome them and in doing so simultaneously obtain reduced emissions and "better" and higher growth.

Overall, we note at least six key market failures of direct importance to climate change and development (not including the macroeconomic consequence of these, the shortfall versus full employment, raised in Part I and discussed further in Part III). The market failures are of a scale and importance that they lead to major inefficiencies, static and dynamic, which, if they can be overcome (even partially), can help tackle climate change and generate extra output, growth, and well-being across its multiple dimensions. They are set out in Table 1, which also includes examples of policy approaches to overcoming each. As we comment on further later, the list is not meant to be exhaustive.[27] There are many actions available that can make major progress in tackling these failures even if government policy cannot entirely remove the underlying problems.[28]

27 Moreover, some of the identified market failures are largely or totally a result of *other* market failures: the market failure in R&D can be attributed to externalities (imperfect appropriability of returns), imperfect competition, incomplete risk markets, and imperfect capital markets; imperfect competition, in turn, can be partially attributed to non-convexities associated with returns to scale in discovery and learning. Similarly, earlier we noted that the market failure in systems is related to externalities and other more "primitive" market failures. Co-benefits, of course, are just another example of externalities.

28 In the presence of these market failures, shadow prices and market prices will differ markedly, so project appraisals and cost–benefit analyses, for example, of regulation will have to check shadow prices against market prices with some care.

Table 1. Key types of market failures associated with climate and environmental change and impacts and possible policy responses

Market Failure	Description	Policy Option
GHGs	Negative externality because of the damage that emissions inflict on others. Actions to reduce emissions are contributions to a public good and without policy, there will be underinvestment in that public good.	Carbon tax/cap-and-trade/ regulation of GHG emissions (standards)/public investment.
Research, development, and deployment	Knowledge as a public good: underinvestment and restrictions on usage. Direction of innovation is not socially optimal (too little green research).	Tax breaks and other subsidies for green research, support for demonstration/deployment, and publicly funded research/dissemination.
Imperfection in risk/capital markets	Resulting from imperfect and asymmetries of information, costs of creating markets, results in credit rationing and incomplete risk sharing, and highly risk-averse behavior.	Disclosure requirements for securities, analyses of systemic risk associated with climate change and climate risk confronting various locations, and green development banks.
Networks and systems	Problems in the coordination within a network and of multiple supporting networks and systems network externalities.	Investment in infrastructure to support the integration of new technologies in electricity grids, public transport, broadband, and recycling; planning of cities; and, more broadly, economic and social coordination.
Information	Lack of awareness of technologies, actions, or support. Failure to integrate relevant information into behavior and behavioral interdependencies.	Labeling and information requirements on cars, domestic appliances, products, and, more generally, awareness of options; facilitating creating new norms and disclosure requirements for securities; and analyses of systemic risk associated with climate change and related environmental processes (e.g., biodiversity loss).
Co-benefits	Consideration of benefits beyond market rewards.	Valuing ecosystems and biodiversity, recognizing impacts on health; regulations to limit negative impacts.

There are important interactions across these market failures. And further failures arise from the absence of key markets, including around risks, technologies, long-run carbon prices.

As Part I outlined, the market failures we have identified interact with each other and are various manifestations of externalities, the inability to appropriate the full benefits of one's actions and the failure to bear the full costs, free rider problems associated with public goods, and the problems arising from the absence of markets. Inefficiencies/inadequacies in R&D are partly linked to imperfections in risk and capital markets and, especially for innovation to reduce GHGs, to the lack of an adequate pricing/regulatory framework. The magnitude and pervasiveness of these market failures means that there is no presumption that market outcomes are optimal in any sense—including in relation to output and growth, however measured. And this in turn means that (as the last column of Table 1 illustrates) there are many public interventions that could be welfare and growth-enhancing. The central message is simple: by tackling these market failures, we can reduce climate change and enhance growth.

A simple example demonstrates this. Solar panels to provide electricity for electric water heaters are very cost-effective, *if individuals could borrow money at a low interest rate*. Private financial markets charge poor borrowers 30% or more. The government could lend, through the tax system, for the purchase of a solar panel, at a rate just slightly higher than that it borrows (in recent years, near zero) with no impact on its overall budget constraint. Such a program would have lowered the cost of living for these citizens, reduced carbon emissions, and helped stimulate the economy, important in the post-2008 era when the economy was consistently operating significantly below potential.

Governments have undertaken a variety of programs to address other instances where credit availability is limited—for example, in small business lending (Emran and Stiglitz, 2009). Development banks have been created to address the lack of productive capital for poor countries and emerging markets. But the shortage of green finance has provided additional impetus—social benefits exceed private benefits because of *both* the environmental externality and the capital market failure. This *combined* impetus has led to the creation of green banks and a host of efforts at the national and international scales to de-risk green investments in the poorest countries—to reduce the level of risk faced by private investors so that greater capital can flow to projects with high social returns. Furthermore, the benefits of such programs (in contrast to their costs) may increase with climate change, making them more likely to be undertaken.[29]

Achieving greater resource efficiency (the first of the drivers above) requires, *inter alia*, overcoming market failures in information, transaction costs, finance, and networks. For example, improving building efficiency requires understanding options in materials and energy sources and finding ways for systems and networks of construction companies, energy generating and distributing companies, financial institutions, and local authorities to work in concert. It will, for instance, be much easier for households to better insulate their homes and replace gas boilers with electric heat pumps if those institutions and authorities work together to make those investments less complicated and lower cost.

Realizing increasing returns in production and discovery requires in many cases overcoming market failures in capital markets affecting both risk and credit availability (and the terms at which it is available). These may particularly affect R&D and nascent industries. These market failures have traditionally provided part of the rationale for industrial policies and development banks, but again, adding on the necessity of the green transition has provided the additional impetus, reflected, for instance, in the willingness of those in the United States who previously had opposed such policies now to support them.[30] The purpose of industrial policy is not to "pick winners" but to correct for market failures—here, excessive short-termism, inadequate attention to climate change, and insufficient finance for long-term and risky investments.

Scale can further be increased, and uncertainty reduced by standards and regulations. Setting a date beyond which internal combustion engines cannot be sold is an important example. Standards and regulations reduce uncertainty (compared to, for instance, trying to incentivize similar behavior through the price mechanism) and rule out activities that are destructive and toxic, thereby creating confidence in markets that there will be demand for alternatives.[31]

Although it will not be possible to overcome *all* market failures relevant to the absence of risk markets, great improvements can be made in terms of managing, reducing, and sharing risk, and climate change is providing enormous impetus to do this.[32]

There are also *market* failures beyond those discussed so far. There is no way for those today to engage in trade with their great-grandchildren. Thus, it is not possible for economic agents to exchange rights to carbon emissions in a century's time, even though such trades would be supportive of efficient investment decisions. Similarly, although many new technologies will be very important, agents cannot transact in them, buying insurance, for instance, against the changes

29 The magnitude of the investment required (discussed in Section 3.4) is such that even if existing development banks put climate at the center, there would be insufficient funds at existing capitalizations. The extent to which additional capital should be allocated to new versus existing institutions is a question beyond the scope of this paper.

The importance and scale of the required investment (see Section 3.4) imply that all development banks should place sustainability at center stage.

Reducing risk is especially important because of the absence of good risk markets.

30 Although geopolitics may have provided an even more important role.

31 Neither the government nor those in the private sector can be sure about responses to the price signal; they can have greater confidence that a regulation that there will be no new fossil-fuel generating plants will increase demand for alternatives.

32 As outlined in Part I, most IAMs assume *no* market failures beyond that for GHGs. Some more recent versions have attempted to embrace one or another market failure or limitation, such as limited redistribution (Dennig *et al*., 2015). Our point here is that the extent to which there are societal efforts to overcome market failures is *endogenous*, and the green transition is providing incentives to do so.

in prices that they might induce, since many have not yet even been conceived. If key markets for the future are absent, public investment may be required (as may other forms of collective action of the kind we have briefly described). So too, shaping expectations becomes very important for private investment, and this necessitates establishing a clear, strategic direction for both the world economy and individual economies, shaping the terms and parameters of markets, including setting clear standards around future pollution and emissions.

We should emphasize again, as we set out in Part I earlier, that the political readiness to tackle these market failures can be enhanced by the recognition of the urgency and importance of action on climate.

3.2.2 Systemic and structural change

As outlined in the third driving force earlier, action on climate will involve radical changes in key systems, including cities, land, transport, and energy. These systems interact and fit together to form larger and even more complex systems, increasingly with newer, cleaner technologies at their core. For example, reforming interwoven city, energy, and transport systems means harnessing battery storage (including at static, utility-scale, and housed in vehicles) while also drawing on spatial planning to make public spaces more friendly toward cyclists and pedestrians. In addition, these choices interact with health systems, including via pollution, heat stress, and exercise from cycling and walking. These interactions defy straightforward modeling with conventional economic approaches involving fixed technologies, exhibiting constant or diminishing returns to scale. The kind of marginal analysis that is central to traditional economics does not suffice to ensure that the market equilibria that may emerge in these complex interacting systems marked by large non-convexities are efficient.[33] Indeed, a general characteristic of economies marked by such non-convexities is that there may be multiple equilibria,[34] and the economy can get trapped in a bad equilibrium. Government intervention can help move the economy to a better equilibrium.

Moreover, the scale and rapidity of the requisite transitions put us beyond the economists' standard equilibrium analysis. Economic modeling focuses on the efficiency of the *equilibrium* (under the highly restrictive conditions entailing an absence of market failures); it says nothing about how that equilibrium is attained. But at the center of what is being discussed is the green transition. There is little doubt that there will be a green transition; the only question is how fast. *There is no presumption concerning the efficiency of the market in making this structural transformation.* Quite the contrary, as we discuss in Part III.

The implication of this analysis is that major changes in the productivity of people and resources can come from a radical new approach to systemic design driven by a desire for a cleaner, less-polluted, more environmentally friendly, and healthier society and promoted by government actions.

Examples of the potential of overall system design lie in the circular economy, which depends strongly on changing systems from "end-to-end," high material throughput forms of production to those that foster reusing, reducing waste, and recycling.

Redesigning systems and running them effectively and efficiently can be greatly facilitated by AI. Indeed, recreating and managing some of the interactions, whether in the circular economy, electricity grid systems with more flexibility in demand and supply, transport interactions, or city design, are likely to be very intensive in the strategic deployment of AI tools, which can identify more productive patterns and anticipate challenges much more effectively than human design alone.

Prices alone, in the presence of many market failures, will not deliver the major systemic and structural changes that will be necessary. More connected and coordination action, for example

33 This is not the place to review the central role that convexity assumptions play in standard neoclassical analysis, for example, in establishing the first and second fundamental welfare theorems and in the proof of the existence of a competitive equilibrium. We note that markets where non-convexities are important are not likely to be competitive. We further note the fundamental linkage between externalities and non-convexities observed by Starrett (1972). In all of the cases discussed in the discussion earlier, government has, in fact, played an important role: one cannot approach the analysis of these systems without taking the public sector into account.

34 An example of which is illustrated in the next section.

around grids, networks, cities, and lands, can deliver these changes more successfully, and both drive growth and reduce climate change.

3.3 Path dependence and the history of technologies

In this section, we explore further how increasing returns and other non-convexities[35] and information imperfections can lead to low-level equilibrium traps and path dependence. If, for example, there is little investment in R&D, the economy will be small, and given that much of R&D expenditures are fixed costs, it does not pay to invest much in R&D. But if the economy is expected to be large in the future, the benefits of R&D are large (see Stiglitz, 1994). Low-level traps can occur where mutually reinforcing market failures frustrate the achievement of increasing returns to scale and from mutually reinforcing expectations around the status quo. Multiplicity of equilibria, outside the simplistic models upon which economists have focused in recent decades, is now recognized to be pervasive (see Vines and Wills, 2020; Hirano and Stiglitz, 2022a, b). In these contexts, the initial equilibrium can be improved upon, and often not just marginally. In particular, the potential presence of low-level equilibrium traps indicates that a sufficiently strong set of public actions could unleash a dynamic move away from the low-level equilibrium to a different, better equilibrium. Growth in the new equilibrium may be higher, and/or growth in the transition to the new equilibrium may be stronger.

Such economies also exhibit path dependencies, in which history matters. Path dependence will arise in particular from learning by doing, economies of scale in discovery, and search processes which are influenced by expectations of the future based on past experience and by local conditions and experiences (Aghion and Howitt, 1992; Atkinson and Stiglitz, 1969). Economic agents also "learn how to learn," increasing the pace of knowledge uptake and productivity gains (Stiglitz, 1987). But learning to learn also may be localized, exhibiting path dependence.

Localized learning just means that firms know more about the technologies that they have been using than alternative possible technologies; they similarly may know more about how to improve technologies than they do about alternative technologies, giving existing technologies a path-dependent advantage. But this advantage runs against the counterforce of diminishing returns: research focuses on low-hanging fruit; further advances may be increasingly difficult.

The pattern of advances in new technologies illustrates this kind of path dependence. Many theories of the advance and diffusion of new technologies point to movement along logistics curves. As new ideas get underway, they are only a small part of processes and systems and will not have a major effect immediately. One discovery leads to others, as ways of thinking change and new avenues, previously unthought of, are opened up. As their potential is understood, increasing returns to scale are realized, experience builds, more related discoveries are made, and their impact, productivity, and output all accelerate. Eventually, ideas expand their potential: new ideas become old ideas, the gains from further diffusion are mostly exhausted, and new discoveries in those areas decline.

It is likely that this story of the slowing down of improvement has run its course for the internal combustion engine to note a crucial example. On the other hand, for newer, cleaner methods of transportation, technical advance and deployment are taking place very rapidly. It means that if somehow the economy could be moved toward these newer technologies, the pace of innovation and growth might actually increase: precisely what we have seen in the case of renewables.

As we noted in Part I, those who believe that a green transition *must* entail slower growth might reply that *if* these alternative technologies are so productive, the market would undertake them—and indeed would have already done so. We also responded to this claim in Part I: there are a host of market failures that may result in the economy not making the socially efficient choice. If any firm could fully appropriate the benefits of the learning as it switches to the newer technology, it would make the switch, but it cannot, given that the economy remains trapped in the older technology—unless the government gives it a shove.[36]

35 The market failures we have already discussed can give rise to non-convexities. We discussed earlier the non-convexity associated with externalities. Radner and Stiglitz (1984) and Arnott and Stiglitz (1988) discuss non-convexities associated with imperfections/asymmetries of information. See also Stiglitz and Greenwald (2014).

36 The central role of knowledge spillovers/imperfect appropriability of the benefits of improved learning is emphasized by Greenwald and Stigltiz (2006).

Similarly, private actors do not take into account the environmental benefits of a green transition, health benefits, or other public goods from R&D; they face credit constraints and cannot adequately share risks; and the economy may be trapped in a low-level equilibrium trap—there are coordination failures, not adequately resolved by simply relying on prices.

Not only may the market fail to make the choices that maximize societal welfare, taking into account the environment, but there are also a variety of policies that can advance the creation and adoption of new technologies which enhance growth and reduce carbon emissions.

There is a substantial and long-standing literature study on how changes in economy-wide technology can be associated with long-term cycles (Kondratieff, [1925] 1979) and "creative destruction" (Schumpeter, 1942). Freeman and Perez (1988), writing in the Schumpeterian tradition, identify six major disruptions from the steam engine and mechanization in the 18th century to the computer and digital revolution of the 20th century. Classifying disruptions in a different way, Schwab (2016) writes of a "fourth industrial revolution." All these approaches to the economic history of technologies associate disruption with creative growth. These ideas have been developed theoretically and empirically in the recent literature by Aghion and collaborators (e.g., Acemoglu *et al.*, 2012; Aghion *et al.*, 2021).[37]

The combination of new green technologies with digital and AI is already beginning to drive the next disruption. Entrepreneurs, financiers, and investors describe these with phrases such as "the biggest investment opportunity since the industrial revolution" (e.g., Fink, 2021). Grandiose terms aside, the central point is that the green transition can be part of a major economic transformation which can be growth-enhancing. A central challenge of economic policy is to accelerate these processes because of the danger arising from the rapid increases in atmospheric GHGs. The variety of actions described here and in the previous section can accelerate technological change and that can enhance growth.

3.4 Scale, nature, and urgency of investment

The potential of and requirements for the new growth story are embodied in the analysis of the scale and nature of investment it will require.

This is not the place to set out the investment numbers in detail, but some appreciation of the necessary scale and pace of investment is crucial to the understanding of the new growth story. Tables 2–4 summarize a set of estimates of necessary investments in the coming years for developed and Emerging Markets and Developing Economies (EMDE) countries for physical, natural, and human capital. China is separated from other EMDEs here because it is *sui generis*, and its challenges are mainly in changing forms of investment rather than the overall level of investment. The estimates are based on sectoral and geographical analyses of investments necessary if production and consumption are to move toward those consistent with a path to net-zero emissions by 2050 and consistent with the Paris–Glasgow temperature targets of well below 2°C and keeping 1.5°C within reach. They cover adaptation, as well as mitigation, and natural capital. They are not incremental investments, but overall necessary investment flows. They include human capital, physical capital, and natural capital.

They do, however, involve a major increase in investment and changing the nature of the investments. Such investments will generally provide high returns for the economy and society beyond simply emission reductions and can deliver major advances toward the Sustainable Development Goals, which embody a broad set of dimensions of well-being. The numbers (see Table 2, 3 and 4 for references) are drawn from the work of Amar Bhattacharya, Homi Kharas, SYSTEMIQ, and their collaborators. They are largely consistent with other analyses, such as those from the International Energy Agency, OECD, and the Energy Transition Commission, although in drawing comparisons care is needed as to the scope of objectives, geographical coverage, and any counterfactuals at play.

37 There is some controversy about the relative importance of these disruptions as compared to the steady, year-over-year improvements in technology. The distinction is blurred: even a major innovation like electricity took years to be put into place, and doing so required a series of small innovations. Major innovations, too, stand on the shoulders of innumerable and often seemingly less important innovations. See Stiglitz and Greenwald (2014).

Table 2. Investments and development spending targets for high-income countries

	Gross spending 2019		Spending target 2025		Spending target 2030	
	US$bn	% GDP	US$bn	% GDP	US$bn	% GDP
Human capital	6608	13	7531	13	8278	13
Sustainable infrastructure	1112	2.1	1883	3.2	2410	3.7
Natural capital	182	0.3	416	0.7	718	1.1
Adaptation and resilience	52	0.1	237	0.4	327	0.5
Total	7954	15	10 067	17	11, 733	18

Table 3. Investments and development spending targets for EMDEs (excluding China)

	Gross spending 2019		Spending target 2025		Spending target 2030	
	US$bn	% GDP	US$bn	% GDP	US$bn	% GDP
Human capital	1470	7.0	2000	8.2	3065	9.5
Sustainable infrastructure	730	3.5	1160	4.8	1840	5.7
Natural capital	150	0.7	355	1.4	650	2.0
Adaptation and resilience	35	0.2	180	0.7	325	1.0
Total	2385	11.3	3695	15.1	5880	18.2

Source: Bhattacharya et al. (2022).

Table 4. Investments and development spending targets for China

	Gross spending 2019		Spending target 2025		Spending target 2030	
	US$bn	% GDP	US$bn	% GDP	US$bn	% GDP
Human capital	1022	7.1	1427	7.1	2346	7.1
Sustainable infrastructure	1377	9.6	1603	8	2108	6.4
Natural capital	350	2.4	530	2.6	937	2.8
Adaptation and resilience	1	0	6	0	16	0
Total	2750	19.2	3567	17.8	5408	16.4

In Tables 2, 3 and 4, the estimates for human capital investment are based on analysis by Kharas and McArthur (2019). The estimates for sustainable infrastructure investment build on analysis by Bhattacharya *et al.* (2016), incorporating the additional investment required for the energy transition, as discussed earlier. The estimates for Agriculture, Forestry and Other Land Use investment combine an analysis of agricultural spending by Kharas and McArthur (2019) and an analysis of investments to protect and restore nature by Systemiq (2021). The estimates for adaptation and resilience investment are based on analysis by Systemiq (2021).

As a percentage of GDP, the overall investment will have to increase by 2–3 percentage points in advanced countries. Around 7 percentage points would be necessary for developing countries and emerging markets, with about 3 percentage points for physical capital, 2.5 percentage points for human capital, and 1.3 percentage points for natural capital. Aggregate increases are unlikely to be necessary for China. However, in all countries, the form of the overall investment needs to change dramatically from that of earlier years.

The investment figures are not intended as part of a rigid planning model but are estimates of what would be required for a green transition to achieve the internationally agreed climate goals as described in the Paris Conference of the Parties 21 and Glasgow COP26.

Most of them will be executed and financed by the private sector and shaped by their entrepreneurship. But such investments cannot be made at the necessary scale or directed in the right direction without clear policy frameworks. As we emphasize in Part III, the policy frameworks guiding these investments will need to include not only price signals but also regulations and public investments. Substantial public investments, including sustainable and resilient infrastructure, will also be required. Such frameworks from public decision-makers must be coherent in relation to energy demand and supply, the functioning of cities and transport, allocation of land, and so on.

There has been much discussion of the precise division of responsibility between the public and private sectors. The division of roles between the private and public investment may differ from country to country depending for instance on the development of their capital market institutions. But in all cases, the formulation of the guiding frameworks requires strong collaboration between public and private sectors, including the active participation of civil society, and, in many cases, the involvement of relevant international institutions.

Many, observing that high country risk premia have been an impediment to private investments in developing countries, would like public “de-risking,” with the international financial institutions playing a key role. Others note that a key reason that the financial sector is awash with funds is liquidity provided by the (public) central banks. There is something peculiar about the public sector providing money to the private sector (often at very favorable terms)—a private sector that has demonstrated short-sightedness combined with a poor ability to manage risk—who are now asking public institutions to “de-risk” their lending so they can invest more in climate change; it might be preferable to more directly have the funds go to specialized green development banks, focused on the long term, and centered around the public good of climate change.

What is clear, though, is that there are multiple ways of financing the required investment. This expansion of investment not only is feasible but also will be a driving force for the transition to not only a new form of growth but also stronger growth. This is especially so in the short run for two reasons noted earlier. First, more productive technologies will be embodied in these new capital goods. Second, this investment is especially stimulative in a world economy where planned saving has exceeded planned investment and where real interest rates and productivity growth have been low for many years. We expand on this in Part III.

4. Part III: a world economy in malaise—an opportune moment for the green investment and the realization of the new growth story

The past decade and a half have been marked in many countries by anemic growth and growing inequality. Some have claimed that there is a “savings glut.” Weak aggregate demand and low growth have led to limited demand for labor, contributing to a world economy consistently operating below full employment and increasing economic inequality. Some have claimed further that the world economy faces secular stagnation, in other words, a long period marked by slow growth with an insufficiency of aggregate demand even at zero interest rates.[38]

Weakness in investment has arisen in part from the market failures described earlier. This is an opportune moment for green investment both to revive the world economy and to set it on a new path of green growth.

Some problems of demand for labor may be exacerbated by robotization and AI, which are overall labor-saving innovations. There is a real likelihood that the demand for labor at existing wages will diminish, implying that (real) wages will fall and/or unemployment will increase. Declining real wages will contribute to weakening aggregate demand, leading to still further macroeconomic weaknesses, as it did in the run-up to the Great Recession (see, e.g., Stiglitz, 2010; Stiglitz *et al.*, 2009). The resulting shortfall in output below potential GDP could, in turn, lead to decreased investment in R&D, diminishing growth rates. On the other hand, if investment demand of the right kind is fostered, then as outlined in Part II, AI, robotization, and related technological advances can be a powerful force for accelerating discovery, reducing waste, increasing efficiency, and managing systemic change. But investment demand is critical.

With excess supplies of both capital and labor, there are resources available for the green transition. Even better, finding institutional ways of deploying more resources to the green transition would improve welfare, and not just because unemployment would be reduced. Higher levels of

38 We put aside the post-pandemic issues associated with seeming labor shortages. The rebound of participation rates in the United States and the differences in labor market dynamics between the United States and other countries suggest that the shortage, to the extent that it exists, may have much to do with the peculiar policies pursued in that country, which resulted in very high levels of unemployment during the pandemic, and that post-pandemic labor market behavior will return to pre-pandemic patterns. It seems unlikely that the global economy suddenly shifted out of an era where there were persistent deficiencies in global aggregate demand.

output will *induce* more innovation (investments in R&D are fixed costs, and the optimal level of investment thus increases with the level of expected output (Stiglitz and Greenwald, 2014)).

Excess supplies of both capital and labor suggest that something is wrong with the functioning of the economy. The problem is not an insufficiency of high *social* return investments. If our analysis is correct, with the risks of climate change being so large and the significant investments required for adaptation and mitigation, there are ample investments with high social returns that could easily eliminate the "savings glut" and restore the economy to full employment. They can carry the substantial benefits outlined in Part II.

As this paper has argued, the economic problems at issue here arise from a combination of market failures that result in large disparities between private and social returns. First, financial markets focus on the short term, when the needed investments are long term. Second, climate investments are often risky, and there is an incomplete set of markets for risk.

These market failures take on heightened importance in the context of a structural transformation such as that associated with the green transition, and even more so because of the rapidity with which this transition needs to be made. For instance, a large fraction of investment is financed through the retained earnings of successful firms, but the structural transformation will require the creation of new innovative firms, and given capital market imperfections, these may not be able to obtain the requisite funds. Indeed, even successful, established firms may find their retained earnings insufficient, given the need to expand rapidly into green technologies.

More generally, markets on their own do not manage large structural transformations well. Resources must move out of old sectors into new sectors. The redeployment of labor necessitates upfront expenditures on training and often relocation, beyond the resources available to many individuals. The social barriers to relocation compound the economic barriers. The Great Depression, with the economy moving from a rural, agrarian economy to an urban, manufacturing economy, illustrates the difficulties—and the consequences of the transition not being managed well. So too for the more recent structural transformation from a manufacturing economy to a service, knowledge-based economy, the problems of deindustrialization are at the center of much of today's political and economic travails (see Battiston *et al.*, 2012; Stiglitz, 2015).

We can expect the green transition to be just as difficult. It will not be easy to redeploy coal miners or oil and gas sector workers. The usual rhetoric emphasizes that there are more solar panel installers than coal miners and that more jobs will be created than lost. Even if that is true in the long run, redeployment requires substantial investment in people and in the places where dislocation is concentrated. Some cities have been able to recover from such structural "shocks" and redefine themselves, such as Glasgow and Newcastle in the United Kingdom, but the process has often been too slow and costly in human and societal terms.

Over the medium term, the labor required to build and maintain electric cars may be of an order of magnitude smaller than for combustible engine cars. Train transport may require less labor than air. These are increases in efficiency and should be socially beneficial. But those benefits cannot be realized without policy fostering investment and innovation in new activities, and helping reallocate displaced resources, particularly adversely affected workers.[39]

Thus, while the green transition is potentially a powerful and attractive growth story, as we have outlined above, it requires an array of policies to ensure that most of society benefits and that it accordingly receives widespread political support. Because of the presence of a host of market failures, simply relying on a carbon price will not suffice.[40] There needs to be a package of policies, aimed at inducing the green transition and protecting workers who would otherwise be adversely affected.

Standards and regulations are needed to quickly move the economy along in the green transition. Some of these can be quite simple and markedly can reduce the uncertainties associated with relying on firm responses to price incentives: for instance, no coal-fired electric power plants or no sale of combustible engine cars after clearly defined dates. Much of the global economy is

39 As Stiglitz pointed out in *Globalization and Its Discontents* (Stiglitz, 2002), moving many workers from low-productivity jobs to zero-productivity unemployment does not increase overall productivity, even if a few workers' productivity increases.

40 See Stiglitz (2019) and Stern *et al.* (2017).

already regulated, as it must be. There are zoning, environmental regulations and building regulations in cities; without these cities, they could not function. There are environmental and water regulations in agriculture. What is required now is simply that they be more focused on making a rapid green transition. Well structured and shaped together with the private sector, standards can boost confidence and investment and accelerate change. They can induce a race to the top; without them, there can be a descent to the bottom.

There are an array of other policies, to which our earlier discussion has called attention: there need to be industrial policies to develop the new industries and to ensure that even small businesses and ordinary households are apprised of the appropriate new technologies (like the agricultural extension services that were instrumental in promoting growth in 19th century America). Part II emphasized how a successful green transition will require large changes in the major systems that comprise the economy, requiring, at least in some cases, high levels of coordinated action among all the market participants. And public investments are needed in, for instance, public transportation.

Active labor market policies help individuals move from the old jobs and places to the new.

There must be development banks that foster sustainable investment; short-sighted private financial markets cannot raise the necessary investment alone, since they face little incentive to fully reflect the social cost of carbon and other benefits of a green transition in their decisions and typically, they operate with too short of a time horizon.

A green R&D strategy is needed, combining public R&D, patents, and prizes. Public institutions and publicly provided resources will inevitably have to play a large role.

The analysis of this paper should have made clear that an appropriate package of policies can enhance growth in standards of living—in growth *appropriately defined* and even in growth inappropriately defined (focused narrowly on GDP).

4.1 Concluding remarks

Economists think of the world through the lens of trade-offs. When economists began to think about inequality, they first argued that inequality could be reduced only by giving up on growth. Okun ([1975] 2015), Chairman of President Johnson's Council of Economic Advisers, wrote about "the big trade-off." Almost a half-century on, as the understanding of market failures increased, it became clear that growth and equality could be complementary: more equal societies could grow faster (Stiglitz, 2012).

It was natural that, some 40 years ago, as economists first confronted the problem of climate change, they used the lens of an environment-growth trade-off. One could have a "cleaner" environment only by sacrificing growth. In this paper, we have attempted to explain why that reasoning is also flawed. In a world with many market imperfections, we have profound and pervasive inefficiencies. Climate change is an example. The global economy is not on its production frontier (either in a static or dynamic sense). Thus, we have shown that while there must be strategies and choices, this does not necessarily involve a trade-off between environment and growth.

The implication of the absence of a trade-off (or, if there were a trade-off, the magnitude of the loss in growth being far smaller than assumed in the standard model) means that the optimal response to climate change entails stronger climate actions.[41]

We have outlined several reasons that stronger climate action, entailing a package of policies and commitments, including public investments, regulations, and carbon prices, may enhance growth. First, stronger climate action reduces risk—including the risk faced by the private sector, risk-bearing for climate can "crowd out" other forms of risk-bearing. Reducing climate risk enables firms to undertake higher-return but risker projects; as they do that, growth increases. Second, stronger climate action reduces unproductive expenditures required to replace destroyed property from climate events and the defensive expenditures required to protect against such destruction, leaving more scope and greater demand for more productive growth-enhancing investments. Third, the systems changes and innovation that are part and parcel of stronger

41 We have also shown that the presence of uncertainty about the magnitude of the trade-off itself entails taking stronger climate actions. The policy implications are elaborated in Stern *et al*. (2022).

climate action are themselves growth-enhancing, and more so as we take stronger climate action, as we take advantage of the economies of scale in the new green economy and the inherent benefits of learning (learning by doing and learning by investment). Moreover, the pervasive non-convexities mean that the economy can be trapped in a "bad" (low growth) equilibrium, and climate action can shock the economy into a better equilibrium, marked by not only lower emissions but also faster growth. Fourth, the salience of climate change has political economy effects, enabling us to address certain market failures (such as those associated with imperfections in capital markets), which have impeded growth. Fifth, the salience of climate change may have other behavioral effects, which translate into stronger growth. Climate change is forcing us to think in the longer term, and one of the impediments to strong, long-term growth is the short-sightedness of market participants. There will be institutional and behavioral spillovers from the individual and societal responses to climate change that will support stronger growth. Sixth, especially in an era marked by deficient aggregate demand, stronger climate action will lead to a fuller utilization of our economy's resources. Seventh, stronger climate action will be associated with greater health—and this too will increase productivity growth. And eighth, climate change undermines biodiversity, on which we depend in multiple ways.

Some of the effects we have described (and others) will be "one-time" increases in productivity, leading to increased growth *rates* over the period in which they are realized, although they yield long-term increases in standards of living. For instance, the replacement of dirty capital with green capital will be associated with an improvement in the capital goods in other ways leading to increased productivity. This will provide a temporary boost to growth rates.

To the extent that there are growth benefits, they will be reinforced through public finances: the extra tax revenue generated can be spent to strengthen further public investments and the higher green GDP will induce still more (endogenous) innovation.

At a minimum, what this paper should have convinced the reader is that it is not inevitable that addressing climate change will lower growth, even as we standardly measure it. The market economy does not maximize growth and, given the multiple market failures, does not even maximize growth taking into account the costs of growth-inducing investments (including in R&D).

We are optimistic that it will increase growth, at least in the short to medium term—growth measured relative to the relevant counterfactual, growth with the current insufficient climate action.

Even if it turns out that GDP as conventionally measured grows more slowly, the green economy can be an economy in which standards of living, appropriately measured across multiple dimensions of well-being, can increase rapidly. But it will not happen on its own. It will require the kinds of strong public policies that we have outlined in this paper.

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