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A CRITIQUE OF TECHNO-OPTIMISM

Efficiency without sufficiency is lost

> *The solution to the unintended consequences of modernity is, and has always been, more modernity – just as the solution to the unintended consequences of our technologies has always been more technology.*
>
> – Ted Nordhaus and Michael Shellenberger

1. Introduction

As the human species evolved, one of our most significant evolutionary advantages proved to be our opposable thumbs, which made it easier for us to make fire and other basic tools, like knives and spears. These early 'technological' advances, primitive though they seem to us today, nevertheless shaped the course of human history. They helped solve some of our problems, such as staying warm and gaining advantage over other species, as well as securing a more reliable source of food, especially protein, which contributed to the development of our brains. With larger brains, we came to understand the world better and were able to manipulate it to our apparent advantage. Thus the conscious development of technology is arguably what defines us as humans and separates us from all other forms of life.

Science and technology have continued to play a central role in the development of civilisation. Through their advancement human beings have been able to produce electricity, cure diseases, split the atom, travel into space, invent computers and the internet, and map the human genome, among an unending list of things that often seem like miracles. Notably, these scientific and technological advancements have also assisted in the unprecedented expansion of our productive capacities, primarily through harnessing the energy in fossil fuels and developing machines to augment human labour. This has allowed many people, primarily in the developed nations, to achieve lifestyles of material comfort that would have been unimaginable even a few generations ago. Increasingly all seven billion people on the planet seem set on achieving these high consumption lifestyles for themselves, and at first consideration the universalisation of affluence indeed seems a coherent and plausible path of progress.

But, however awesome the advancement of science and technology has been as a means of raising material living standards, there are also well known social and environmental dark sides that flow from this mode of development. Economic activity depends on nature for resources, and as economies and populations have expanded, especially since the industrial revolution, more pressure has been placed on those natural resources, ecosystems, and waste sinks. Today, we face a series of overlapping crises owing to the heavy burden our economies are placing on the planet (Meadows *et al.*, 2004; Ehrlich and Ehrlich, 2013). According to the best available evidence, the global economy now exceeds the sustainable carrying capacity of the planet by 50% (Global Footprint Network, 2013), with deforestation, ocean depletion, soil erosion, biodiversity loss, pollution, water shortages, and climate change being just a sample of these acute, unfolding problems (Rockstrom, *et al.*, 2009; Brown, 2011). The latest publication from the IPCC (2013) reiterates the immense challenge of climate change in particular, with the necessity of rapid emissions reductions becoming ever more pressing as carbon budgets continue to shrink through lack of committed action. At the same time, great multitudes of people around the planet still live in material destitution, and global population continues to grow (UNDSEA, 2012), suggesting the environmental burden is only going to be exacerbated as the global development agenda – the goal of promoting growth in global economic output – is pursued into the future (Turner, 2012).

Technological optimists believe, however, that just as the application of technology has been a primary cause of environmental problems, so too does it provide the primary solution (Lovins, 1998; Lovins, 2011; Lomborg, 2001). From this view, humanity will be able to solve environmental problems primarily through technological advancement, while continuing to focus attention on economic growth (see, e.g., Grantham Institute, 2013). By implementing this approach it is widely believed we will be able to eliminate global poverty and raise living standards for all, without destroying the necessary ecosystem services that sustain life as we know it. There can be no doubt that this promise of technology is seductive – material abundance for all, while solving environmental problems. But is this promise credible? If not, what are the implications?

This chapter presents an evidence-based critique of such techno-optimism, arguing that the vision of progress it promotes is unrealisable due to the limits of technology and the inherent structure of growth economics. The focus of this critique, however, is not on the techno-wizardry that holds up desalination plants as the solution to water shortages, genetically modified foods as the solution to global hunger, or geo-engineering as the solution to climate change, etc., important though those critiques are (see Huesemann and Huesemann, 2011; Hamilton, 2013). Rather, the present focus is on the subtler faith that many people place in 'efficiency' as the environmental saviour. Techno-optimism, in this sense, can be broadly defined as the belief that science and technology will be able to solve the major social and environmental problems of our times, without fundamentally rethinking the structure or goals of our growth-based economies or the nature of Western-style, affluent lifestyles. In other words, techno-optimism is the belief that the problems caused by economic growth can be solved by more economic growth (as measured by GDP), provided we learn how to produce and consume more efficiently through the application of science and technology. Proponents of this view argue that advancements in knowledge and design, in conjunction with market mechanisms, will mean that we will be able to decouple our economic activity from environmental impact, thus avoiding the implication that economic growth has biophysical limits. Should any resource become scarce, it is assumed that 'free markets' and high prices will incentivise more exploration or the development of substitute resources (see, e.g., Simon and Kahn, 1984; Beckerman, 2002). Rather than questioning growth economics, then, this dominant school of thought advocates 'green growth' or 'sustainable development' (see Purdey, 2010). This general perspective defines the present era more than any other, but the evidence reviewed below shows that the vision is profoundly flawed.

The critical analysis begins in Section 2 by placing techno-optimism in theoretical context. It is important to understand the structure of techno-optimism and see why it forms a central part of the ideology of growth. In Section 3, the notion of an Environmental Kuznets's Curve (EKC) is outlined and considered. This hypothesis holds that environmental harm tends to increase in early stages of industrialisation, but as economies get richer and their technologies develop, environmental impact tends to decrease. The evidence for this position is reviewed and analysed, and it is shown that the EKC hypothesis is generally without substance. At least, the EKC has to be qualified so heavily that it essentially disappears. In sections 4 and 5 the notion of 'decoupling' is examined, and this analysis is used to explain why efficiency improvements have not produced sustainable economies despite extraordinary technological advancements in recent decades. It turns out efficiency improvements have not often been able to keep up with continued economic and population growth – largely due to 'rebound effects' – meaning that overall environmental impact continues to grow, despite efficiency improvements. Section 6 unpacks the arithmetic of growth to expose how unrealistic techno-optimism really is. In the concluding sections the implications of the analysis are discussed. The central conclusion of this critique is that technology cannot and will not solve environmental problems so long as it is applied within a growth-based economic model. In order to take advantage of efficiency gains, which are without doubt an essential part of the transition to a just and sustainable world (von Weizsacker *et al.*, 2009), it is argued that a value-shift is required to move cultures and structures away from growth-orientated consumerism toward a 'post-growth' or 'steady state' economy based on material sufficiency. The nature of this alternative is briefly outlined, although the purpose of this chapter is primarily diagnostic rather than prescriptive.

2. Techno-Optimism and the Ideology of Growth

In 1971, Paul Ehrlich and John Holdren published an article that greatly advanced the understanding and communication of environmental problems and their potential solutions (Ehrlich and Holdren, 1971). In this article they developed what has become known as the IPAT equation. This equation holds that environmental impact (I) equals, or is a function of, Population (P), Affluence (A), and Technology (T). While this equation is not without its limitations and drawbacks – some of which will be discussed below – it nevertheless made it easy for environmentalists to talk about the nature of the unfolding environmental crisis (Meadows *et al.*, 1972). With the IPAT equation, it could be shown in clear terms that environmental impact could be mitigated by the various means of reducing population, reducing per capita income, and increasing productive or energy efficiencies through technological development. Put otherwise, the equation showed that continuous population and consumption growth would exacerbate environmental problems, unless technological advancement could outweigh those impacts through efficiency gains.

One of the attractions of the IPAT equation was the way in which it highlighted the fact that individuals and policy-makers had various options for tackling environmental problems. People who cared about the environment could try to lessen impact either by trying to reduce population, by trying to consume as little as possible, or by trying to produce and consume as efficiently as possible. However, the fact that there were options turned out to be a mixed blessing. It suggested that if people or nations were unable or unwilling to tackle certain parts of the IPAT equation, they could still reduce impacts by addressing one or more of the other variables. As it turned out, the IPAT equation ended up marginalising population and consumption as sites of environmental action, and privileging technological fixes (see Huesemann and Huesemann, 2011).

In one sense, this was quite understandable. Population control is obviously a thorny issue, in that procreation seems like a very intimate issue that governments should not try to regulate. With some justification, how many children people have is widely considered a private matter. For this reason, population has been, and to a large part remains, one of the great taboo subjects of the environmental debate. We know that population is a multiplier of everything (Alcott, 2010), but so challenging and controversial is it to reduce or regulate population that governments have generally looked elsewhere to respond to environmental problems (Ehrlich and Ehrlich, 1990).

A similar dynamic could explain the marginalisation of consumption (Simms *et al.*, 2009). Since a higher income is almost universally considered better than a lower income, governments and individuals have looked for other ways to lessen environmental impact. Voluntarily reducing consumption was, and is, a hard sell, and it certainly does not suggest itself as a vote-winning basis of a political campaign in consumer-orientated societies (or anywhere). To borrow a phrase from George Monbiot (2006), people do not 'riot for austerity'.

The IPAT equation, however, had within it the win/win solution that people seemed to be seeking: efficiency improvements. Even if a nation was unable to reduce population, and even if it was unwilling to reduce its income, the equation provided a theoretical framework that showed that it was nevertheless possible to reduce environmental impact through technological advancement (Simon and Kahn, 1984). This 'techno-fix' approach was a much more politically, economically, and socially palatable way to address environmental problems – leaving to one side, for the moment, the issue of whether the strategy was likely to succeed. It provided governments and individuals with a means of responding to environmental problems (or being seen to respond to environmental problems), without rethinking population growth or questioning affluent lifestyles. In theory, at least, it seemed like a coherent and politically appropriate strategy, and for this reason it came to define, and remains, the mainstream position on environmental matters. At the Rio+20 conference in 2012, for example, the international declaration repeatedly called for 'sustained economic growth' (UN, 2012; Monbiot, 2012) as an essential ingredient in 'sustainable development'.

In much the same way, and according to the same logic, the IPAT equation also opened up a strategy for the corporate world to try to respond to environmental problems, in ways that would not interfere with the interests of capital expansion (Lovins, 2011). Increases in population means there are more consumers and more labourers, so businesses have an economic incentive to consider population growth as a good thing. Similarly, and even more obviously, businesses are in favour of increased consumption, not decreased consumption. As a means of responding to environmental problems, therefore, the corporate world has a clear incentive to privilege techno-fixes. Not only does this strategy avoid having to confront the non-profitable terrains of population or consumption reduction, but it also opens up a huge market for 'green products' which could be sold to a growing demographic of environmentally aware consumers and governments (Pearse, 2012).

As noted, this 'green growth' approach, based on a profound faith in technological solutions, has come to define our times. Reducing overall population and consumption are notoriously difficult and unpopular policies, so the world shies away from them no matter how necessary they may be. But technology is there to save the day, at least in theory (Trainer, 2012a). While lip service is occasionally paid to the challenge of population, and while occasional comments are made regarding the importance of not over-consuming, the reality is that mainstream environmental discourse, especially in the political realm, has placed its faith, explicitly or implicitly, almost entirely in techno-fixes. That is, it is widely assumed that reducing environmental impact – reducing emissions, in particular – will be achieved not by reducing population or consumption, but by producing and consuming goods more efficiently. In this way, economies can still grow in terms of GDP, and affluence can be universalised, while environmental impact reduces. This, in essence, is the vision encapsulated within notions of 'sustainable development', 'green growth', and 'ecological modernisation'. It is so convenient that governments and businesses tend to believe in it, irrespective of whether it has much empirical support. As the next sections show, that empirical support is lacking, which is a most inconvenient truth for those consciously or unconsciously committed to the ideology of growth (Hamilton, 2003).

3. Is There an Environmental Kuznets Curve?

In 1955, the economist Simon Kuznets published a paper arguing that the relationship between GDP and income inequality showed an inverted U-shape when graphed (Kuznets, 1955). That is, he argued that income inequality first increases as a nation develops, but eventually, as a nation's economy continues to grow, inequality levels off and begins to decline, leading to a broader distribution of wealth. Leaving to one side the validity of that socio-economic thesis, a similar idea was later proposed with respect to environmental degradation instead of income inequality (Grossman and Kruger, 1991). This became known as the Environmental Kuznets curve (EKC).

The EKC hypothesis holds that an economy's environmental impact tends to increase during the early phases of industrialisation, but as a nation becomes richer its environmental impact levels off and eventually begins to decline. The essential reasoning beneath this hypothesis can be summarised as follows: (1) as GDP grows, nations can dedicate more of their attention and resources toward environmental protection (a so-called 'post-materialist' need), whereas the poorest nations must focus solely on meeting their basic material needs, irrespective of environmental impact (Carson *et al.*, 1997; McConnell, K., 1997; cf., Martinez-Alier, 1995); (2) richer nations will be able to develop and afford better technologies, which will make production cleaner and less resource-intensive (Lovins, 1998; Grossman and Kruger, 1995); and (3) as nations get richer their economies tend to shift from 'industrial' economies to 'post-industrial' or 'information' or 'service' economies, which it is claimed rely on lower material and energy flows (Janicke *et al.*, 1997; Lomborg, 2001).

Based on these somewhat overlapping lines of reasoning, the EKC hypothesis is used to argue that there are no environmental limits to growth (c.f. Meadows *et al.*, 2004; Trainer, 2010; Heinberg, 2011) – that growth is ultimately good for the environment, even if at first it seems bad. As Wilfred Beckerman (1992: 482) puts it, 'although economic growth usually leads to environmental degradation in the early stages of the process, in the end the best – and probably the only – way to attain a decent environment in most countries is to become rich'. It should come as little surprise that the EKC hypothesis – at least, its essential message – was enthusiastically embraced by mainstream politicians and businesses (Purdey, 2010). After all, it suggested that economies should remain focused on growth in GDP, not in contradiction of environmental concerns but in support of them. This approach was the path of least resistance, as the win/win message it entailed was that there was no inconsistency with promoting limitless economic growth *and* caring for the environment. In terms of responding to environmental problems, therefore, the EKC propped up the status quo and gave apparent legitimacy to 'business as usual'. The logic, such that it is, becomes: 'Grow now, clean up later' (Van Alstine and Neumayer, 2010). We can have the cake and eat it too – or so the argument goes.

The EKC hypothesis might have some initial theoretical plausibility based on the three lines of argument listed above, but the hypothesis should only shape policy, of course, if it can be empirically substantiated. The empirical foundations of the hypothesis, however, are dubious, at best. A comprehensive review of the literature on EKC hypothesis is beyond the scope of this chapter (see Stern, 2004; Bradshaw, Giam, and Sodhi, 2010), but in broad terms the empirical status of the EKC can be expressed as follows. Some studies have shown that where certain types of environmental damage are generated and suffered locally (or within adjacent cooperating nations) an EKC can indeed be seen (Dinda, 2004; Bo, 2011). These limited circumstances include wastewater discharge, sulphur dioxide emissions, and carbon monoxide emissions. On the other hand, when the environmental problems cross national boundaries or have longer-term impacts, studies conclude that the EKC does not hold (Stern, 2010). Most importantly, an EKC exists neither for carbon dioxide (Luzzati and Orsini, 2009) nor biodiversity loss (Mills and Waite, 2009; Asafu-Adjaye, 2003), two of the most significant environmental crises. It is hard to defend a growth model of progress based on the limited cases of environmental improvement, if sustained growth in GDP fails to address (and indeed exacerbates) problems such as climate change or biodiversity loss. As Brian Czech (2013: 200) puts it, the EKC represents 'a grain of truth embedded in a fallacy'. The environmental costs of growth also tend to impact most on the poorest parts of the world (Woodward and Simms, 2006), at least at first, providing further grounds for questioning whether growth is really the path of progress.

Furthermore, a study by Holm and Englund (2009) has done much to debunk the widely held belief that a movement toward a 'service', 'information', or 'post-industrial' economy leads to reduced environmental impacts. In a review of the evidence on this matter, they show that despite growth of the service sector during the last decades in the world's wealthier countries, overall resource consumption has increased (see also, Fourcroy *et al.*, 2012; Henriques and Kander, 2010). Moreover, to the limited extent that some 'service' economies do seem to be decoupling growth from impact per capita (an issue considered in more detail below), it is arguably due to the outsourcing of manufacturing to developing nations, especially China. Accordingly, any apparent decoupling can often be attributed to dubious or at least incomplete accounting. For example, it is no good claiming a reduction in national deforestation, say, if a nation is simply importing more wood from abroad rather than cutting down its own trees (Asici, 2013); and it is no good claiming a reduced carbon footprint per capita if it simply means China or other industrialising nations are serving as a 'pollution haven' (Cole, 2004) for carbon-intensive manufacturing (see Wiedmann *et al.*, 2013). That would be not so much 'decoupling' as 'recoupling'.

This accounting issue is slowly being recognised even by mainstream institutions like the United Nations, which recently noted, albeit in an understated way, that 'a certain amount of material burden and the associated environmental impacts are being "externalized" from importing countries… Countries may improve their decoupling performance most easily by outsourcing material-intensive extraction and processing to other countries and by importing concentrated products instead' (UNEP, 2011: 60-61). While it may be possible to 'externalise' impacts from any particular nation, the planet as a whole, of course, is a closed system. Accordingly, when 'externalised' manufacturing is 'internalised' from an accounting perspective, much of the perceived dematerialisation of rich nations disappears (Wiedmann *et al.*, 2013).

In one of the most comprehensive reviews of the data and methodologies used to estimate the EKC hypothesis, David Stern (2004: 1435) concludes that 'the statistical analysis on which the EKC is based is not robust. There is little evidence for a common inverted U-shaped pathway that countries follow as their income rises.' This general conclusion finds much evidential support (see Wang *et al.*, 2013; Wiedmann *et al.*, 2013).

Even in those limited cases where the EKC can be shown to exist, it is far too simplistic to suggest that this is solely or primarily because a nation has become rich. Often it can be shown that environmental improvements are associated with new laws, policies, or institutions (see Magnani, 2001). This raises the question of whether such improvements were due to increases in GDP, as the EKC hypothesis holds, or simply due to better regulations. It could not credibly be argued that getting rich is the only relevant variable. Reductions in harm do not happen automatically when nations become rich. Policies are usually needed – such as regulations about factory pollution, land use, the fuel efficiency of cars, or the treatment of rivers – and it is at least arguable that the regulations could have been produced at much lower levels of income and achieved the same or even more positive environmental outcomes.

Perhaps the most damming criticism of the EKC hypothesis, however, comes from the ecological footprint analysis (White, 2007; Caviglia-Harris *et al.*, 2009; Wang *et al.*, 2013; Global Footprint Network, 2013). The EKC, if valid, would suggest that nations should seek growth in GDP if they want to reduce their environmental impact. But when this extraordinary claim is considered in the context of ecological footprint analysis, the hypothesis is simply and obviously wrong. The US is the richest nation on the planet, but if the US way of life were globalised we would need more than four times the biocapacity of Earth (Global Footprint Network, 2013). On that basis, who could possibly argue that environmental degradation decreases as wealth grows? For a further example, take Australia – another of the richest nations – which has the highest per capita carbon footprint in the OECD and one of the highest in the world (Garnaut, 2008: Ch. 7). This strongly suggests that the EKC hypothesis is embraced for political reasons, not scientific foundation.

Even the somewhat less resource-intensive Western European nations – the so-called 'green' economies like Germany, Norway, Denmark, and Sweden – are grossly exceeding their 'fair share' of the planet's biocapacity (Vale and Vale, 2013). We would need approximately three planets if the Western European way of life were globalised, and that is assuming no population growth (Global Footprint Network, 2013). So even if there were an EKC, the turning point in the curve would be occurring much too late in the process of development to validate anything like the conventional development path. Accordingly, the argument that sustainability will arrive when the entire world gets rich or 'developed' is patently wrong, and it is intellectually irresponsible to pretend otherwise (White, 2007). It is a view that simply lacks any evidential foundation.

In sum, one must not get caught up in the smoke and mirrors of isolated studies that show certain aspects of environmental damage or pollution have declined as a nation has gotten richer. Such analyses totally miss the bigger picture, which is that it would be ecologically catastrophic if the entire world tried to become affluent as a means of environmental protection (Turner, 2012; Smith and Positano, 2010). If the EKC hypothesis sounds too good to be true, that is because, on the whole, it is false.

4. Are Economies Decoupling Growth from Impact?

Given that the richest nations demonstrably have the largest ecological footprints, it is surprising, or at least disappointing, that mainstream environmental discourse still tends to assume that sustained growth in GDP, across the globe, will solve the ecological predicament; or at least, that sustained growth is not incompatible with sustainability (UN, 2012). There seems to be an implicit acceptance of the EKC hypothesis, driven by techno-optimism, even though it lacks empirical foundation. This can be explained primarily in terms of political convenience. Politicians seem very reluctant to accept any incompatibility between growth and environmental protection, because that would involve choosing between those goals. Instead of making tough choices, politicians just pretend that there is no incompatibility, which is what people and businesses seem to want to hear. All the while, the biocapacity of the planet continues to decline (Lawn and Clarke, 2010).

There is, however, the *theoretical possibility* that in the future our economies will be able to achieve sustainability by decoupling their economic activity from environmental impact, through efficiency gains (UNEP, 2011). It is this seductive line of reasoning that now deserves deeper consideration. After all, the fact that technology and growth have not been able to produce a sustainable economy does not mean that it is not possible to do so in the future. As Nordhaus and Shellenberger (2011) argue: 'The solution to the unintended consequences of modernity is, and has always been, more modernity – just as the solution to the unintended consequences of our technologies has always been more technology.' While this can be accepted as a theoretical possibility, there are dynamics at play – including the laws of physics – that suggest that decoupling through efficiency gains will not reduce the overall ecological impacts of economic activity if global growth remains the primary economic goal.

In assessing the prospects of efficiency gains as a means of reducing environmental impact, it is imperative to distinguish between 'relative' and 'absolute' decoupling (Jackson, 2009). Relative decoupling refers to a decline in the ecological impact *per unit* of economic output. Absolute decoupling refers to a decline in the *overall* ecological impact of total economic output. While relative decoupling may occur, making each commodity less materially intensive, if the total consumption of commodities increases then there may be no absolute decoupling; indeed, the absolute ecological impact of total economic activity may increase.

Given that the global economy already exceeds the planet's sustainable carrying capacity (Global Footprint Network, 2013), it is clear that absolute decoupling is what is needed. As shown below, however, it is just as clear that absolute decoupling is not occurring. Overall (or absolute) energy use and resource extraction continues to rise, even if in places the energy or resource intensity per capita is in decline (Wiedmann *et al.*, 2013).

Consider, for example, the energy intensity per unit of global economic output, where the evidence of relative decoupling is quite clear. Tim Jackson (2009: 69) reports that the amount of energy needed to produce each unit of the world's economic output has fallen more or less continuously in recent decades, with the global energy intensity per unit now 33 per cent lower on average than it was in 1970. Unsurprisingly, this improved energy efficiency is also leading to relative decoupling in terms of carbon emission intensities. The global carbon intensity per unit of economic output declined by almost one quarter from just over 1 kilogramme of CO2 per US dollar in 1980 to 770 grams of CO2 per US dollar in 2006.

However, despite declining energy and carbon intensities, Jackson shows that total CO2 emissions have increased 80% since 1970. 'Emissions today,' he adds, 'are almost 40% higher than they were in 1990 – the Kyoto base year – and since the year 2000 they have been growing at 3% per year' (Jackson, 2009: 71). This shows that despite significant relative decoupling of energy intensities, absolute levels of carbon emissions are rising significantly. Efficiency gains are not fulfilling their promise to reduce overall impact.

Peter Victor (2008) arrived at essentially the same conclusion when he reviewed studies of decoupling with respect to the total material resource requirements of Germany, the Netherlands, US, and Japan – some of the most technologically advanced nations on the planet. He reports that although a degree of relative decoupling has occurred in recent decades, the decoupling was insufficient to prevent the total use of resources increasing. He explains that '[t]his is because the rate of increase in GDP in each of the four countries was greater than the rate of decrease in material intensity' (Victor, 2008: 55). This suggests that even if these technologically advanced nations were able to fully decarbonise their economies in response to climate change, the material intensity of their economies (in terms of resource consumption) would remain unsustainably high. This points to the important but often forgotten fact that acute environmental crises would remain (e.g., deforestation, ocean depletion, biodiversity loss, soil erosion, etc.) even if the issue of climate change were somehow resolved. Globally the message is essentially the same:

> Comparing 2002 with 1980 about 25 per cent less natural resources (measured in physical units) were used to produce one dollar of GDP. This relative decoupling of economic growth and resource use was insufficient to prevent the total quantity of resource extraction increasing, which it did by 36 per cent (Victor, 2008: 55-6).

The message of this analysis is not that decoupling through techno-efficiency improvements is unnecessary – far from it. Decoupling has an absolutely vital role to play in the attainment of a sustainable society (von Weizsacker *et al.*, 2009). But the evidence shows that despite many examples of relative decoupling, growth in overall economic output has meant that absolute impacts on the environment are still increasing. Every year more carbon emissions are sent into the atmosphere and more renewable and non-renewable resources are extracted from our finite Earth. In short, decades of extraordinary technological development have resulted in increased, not reduced, environmental impacts. It is not clear, therefore, whether the 'optimism' in 'techno-optimism' has any rational basis at all.

5. Efficiency, Rebound Effects, and Jevons' Paradox

The evidence reviewed clearly indicates that there has been significant relative decoupling in recent decades, but little or no absolute decoupling – certainly not at the global level. This is somewhat counter-intuitive, perhaps, because one might ordinarily think that efficiency gains (which produce relative decoupling) would lead to absolute decoupling. In other words, it is plausible to think that as the world gets better at producing commodities more efficiently, the absolute impacts of our economic activity would naturally decline. But this assumption has not played out in reality. As will now be explained, one of critical reasons it has not played out is because of what are known as 'rebound effects', or the Jevons paradox (Alcott, 2005; Polimeni *et al.,* 2009; Owen, 2012).

The Jevons paradox acquires its name from the classical economist William Stanley Jevons, who was the first to formalise the idea that efficiency gains would not necessarily lead to a reduction in resource consumption, and could even lead to increased consumption. Writing at a time when there was increasing concern over England's diminishing coal reserves, Jevons (1865) noted that the more efficient steam engines were not reducing but actually increasing the consumption of coal. This was because the new technologies being developed made the engines more accessible and affordable to more people, thus increasing the demand on coal resources even as engines became more efficient. He formalised his view by stating: 'It is a confusion of ideas to suppose that the economical use of fuel is equivalent to diminished consumption. The very contrary is the truth' (Jevons, 1865: 103). What are the dynamics of this paradox and to what extent does it exist?

The Jevons paradox is generally discussed in the scholarly literature with reference to the notion of 'rebound effects' (Herring and Sorrell, 2009; Alcott and Madlener, 2009). A rebound effect is said to have occurred when the benefits of efficiency improvements are partially or wholly negated by consumption growth that was made possible by the efficiency improvements. For example, a 5% increase in energy efficiency may only reduce energy consumption by 2% if the efficiency improvements incentivise people to act in more energy-intensive ways (meaning 60% of anticipated savings are lost or 'taken back'). In other words, efficiency improvements can provoke behavioural or economic responses ('rebounds') that end up reducing some of the anticipated benefits of the efficiency improvements. When those rebounds are significant enough they can even lead to *increased* resource or energy consumption, which is sometimes called 'back-fire' – or the Jevons paradox. As will now be explained, there are three main categories of rebound effects – direct rebounds, indirect rebounds, and a macroeconomic or economy-wide rebound.

A direct rebound occurs when an efficiency gain in production results in increased consumption of the same resource (Khazzoom, 1980; Frondel *et al.*, 2012). For example, a more fuel-efficient car can lead people to drive more often, or further, since the costs of fuel per kilometre have gone down; a more efficient heater can lead people to warm their houses for longer periods or to hotter temperatures, since the relative costs of heating have gone down; energy efficient lighting can lead people to leave the lights on for longer, etc. (Sorrell, 2009). Because efficiency generally reduces the price of a commodity (since it makes production less resource-intensive or time-intensive), this incentivises increased consumption, meaning that some or all of the ecological benefits that flow from efficiency gains are often lost to increased consumption.

An indirect rebound occurs when efficiency gains lead to increased consumption of some other resource. For example, insulating one's home might reduce the annual consumption of energy for electricity, but the money saved from reduced energy costs is often spent on other commodities that require energy (e.g., a plane flight or a new television). This can mean that some or all of the energy saved from insulating one's house is actually consumed elsewhere, meaning overall energy dependence can stay the same or even increase.

A macroeconomic or economy-wide rebound is the aggregate of direct and indirect rebounds. New technologies can create new production possibilities, or make existing production possibilities accessible to more people, thus stimulating economic growth. The result is that efficiency-promoting technologies often facilitate the consumption of more energy and resources even as energy and resource intensities reduce, as Jevons observed long ago.

While the basic mechanism of rebound effects is widely acknowledged, and, indeed, beyond dispute, there is an ongoing debate over the magnitude of the various rebound phenomena. Some argue that the macroeconomic rebound actually exceeds the energy or resource savings (Polimeni *et al.*, 2009; Hanley *et al.*, 2009; Owen, 2012), suggesting that efficiency improvements, designed to reduce overall consumption, sometimes actually back-fire and lead to increased consumption. This would cast into grave doubt the presumed value of efficiency improvements, at least in some circumstances. Other theorists are more circumspect (Herring and Sorrell, 2009), suggesting at the very least that the case for back-fire is unclear. It is also the case that rebounds generally differ according to context and type of rebound, and assessing the degree of rebound also depends on the methodological assumptions used when studying them.

Direct rebounds are estimated to range generally in the vicinity of 10-30% (Sorrell, 2009: 33), meaning that typically 10-30% of the expected environmental benefits of efficiency gains are lost to increased consumption of the same resource. In some circumstances, direct rebounds can be 75% or higher (Chakravarty *et al.*, 2013). Indirect rebounds are somewhat harder to measure, but are generally thought to be higher than direct rebounds, and estimates of macroeconomic rebound range from 15%-350% (Dimitropoulos, 2007). The huge range here again points to differences in methodological assumptions. Without entering into the intricacies of the complex empirical and theoretical debates, it is fair to say that despite the uncertainties, there is broad agreement that rebound effects exist and that they are significant. The benefits of technology are almost always less than presumed, and, in fact, at times efficiency improvements can lead to more, not fewer, resources being consumed overall.

What seems to be far less widely appreciated, however, is that when efficiency gains occur within a paradigm of growth economics, there is little to no chance of absolute decoupling occurring (Herring, 2009; Huesemann and Huesemann, 2011; Trainer, 2012). This is partly due to rebound effects, and partly due to the inherent structure of growth economics. It will now be shown that in order to achieve the absolute decoupling required for sustainability, efficiency gains must be governed, not by an imperative to grow, but by an economics of sufficiency.

6. The 'Growth Model' Has No Techno-Fix

Perhaps the limits of technology can be most easily understood when clarifying exactly what is expected of technology in terms of achieving sustainability. The global development agenda, as expressed in the Rio+20 declaration, is that all nations should seek 'sustained growth' (UN, 2012) in GDP as a path to sustainable development. But what degree of efficiency improvements would be required to make sustained global growth 'sustainable'? When one does the math on this question, it becomes perfectly clear that technology can never make the growth model 'green'. Consider the following basic arithmetic:

Throughout much of the 20th century, developed economies achieved around 3% growth in GDP per annum, meaning that they doubled in size roughly every 23 years (Purdey, 2010). This has become something of a reference point for signifying politico-economic 'success' (Hamilton, 2003), so let us assume that when the United Nations talks of 'growth' it means continuing levels of growth that have been experienced in recent decades. Furthermore, for social justice reasons, let us assume that the aim of 'development' is ultimately to bring the poorest parts of the world up to the living standards enjoyed by the developed world. After all, from a moral perspective, it is difficult to argue that one section of the global population is entitled to a certain income per capita while denying a similar level to others. If, however, this global development agenda were to be achieved over the next 70 years, how big would the global economy be relative to the existing economy?

The figures are confronting, to say the least. Over 70 years, at 3% growth, the economies of the developed world (populated by roughly 1 billion people) would have doubled in size three times, meaning they would be eight times larger, in terms of GDP, than they are now. If we also assume that by 2080 the world population is going to be around 10 billion (UNDSEA, 2012), and that this population has caught up to the living standards of the developed world by this stage, then the global economy would be around 80 times larger, in terms of GDP, than the size of the developed world's aggregate economy today.

Needless to say, ecosystems are trembling under the pressure of one 'developed world' at the existing size. Who, then, could seriously think our planet could withstand the equivalent of an 80-fold increase? The very suggestion is absurd, and yet this very absurdity defines the vision of the global development agenda. It is the elephant in the room. If we make the rough estimation that the developed world, on its own, currently consumes the earth's entire sustainable biocapacity (Vale and Vale, 2013), then an 80-fold increase would imply that in 70 years we would need 80 planets in order to sustain the global economy. We only have one planet, of course, and its biocapacity is already in decline.

At this stage the techno-optimist may wish to interject and insist that in this scenario, which forecasts GDP growth into the future, we can expect that there would be efficiency improvements, such that the impact of global growth would be less than projected above. There would be efficiency improvements, indeed, meaning that the impact could be significantly less than projected above. For example, a recent study (Wiedmann *et al.*, 2013) shows that with every 10% increase in GDP, the material footprint of economies 'only' increase by 6%. But based on that estimate of decoupling, we would still need 48 planets' worth of biocapacity. Accordingly, even if these figures are overstated by an order of magnitude, the point would remain that efficiency gains could not possibly be expected to make the projected amount of GDP growth sustainable. The levels of decoupling required would simply be too much (Huesemann and Huesemann, 2011; Trainer, 2012). To think otherwise is not being optimistic but delusional.

Even based on more conservative numbers, the decoupling required would be unattainable. For example, Tim Jackson (2009) has done the arithmetic with respect to carbon emissions, envisioning a scenario in which current Western European incomes grow at 2% and by 2050 nine billion people share that same income level. In this more moderate scenario, the global economy still grows 15 times. Jackson shows that in order to meet the IPCC's carbon goal of 450ppm, the carbon intensity of each dollar of GDP must be 130 times lower than the average carbon intensity today. This means carbon intensities must fall 11% every year between now and 2050. By way of context, carbon intensities have declined merely 0.7% per year since 1990 (Jackson, 2009: 79). When these numbers are understood, one can only conclude that techno-optimism is not a scientifically credible position but is instead a 'faith' without foundation.

According to the latest IPCC report (2013), if the world is to have a 50% chance of keeping warming to less than two degrees (the so-called 'safe' level), no more than 820-1445 billion tones of carbon dioxide and other greenhouse gases can be emitted during the rest of this century. Based on existing yearly emissions, and aiming for a 66% chance of success, this carbon budget is going to be used up by

2045. If existing trends of growth in emissions continue or accelerate, or if we demand a higher chance of success than 66%, that budget will be used up even sooner (see also, Moriarty and Honnery, 2011).

The question, therefore, must not be: 'How can we make the growth model sustainable?' The question should be: 'What economic model is sustainable?' And the answer, it seems, must be: 'Something other than the growth model.'

7. Efficiency Without Sufficiency is Lost

The central message of the analysis so far is that efficiency gains that take place within a growth-orientated economy tend to be negated by further growth, resulting in an overall increase in resource and energy consumption, or at least no reduction. Technologies that increase labour productivity, for example, are rarely converted into less labour input; instead of allowing for less work, productivity gains tend to 'rebound' as more overall production (Norgard, 2009). Similarly, developments in the design of commodities that allow for less material or energy inputs end up reducing the cost of production, but cheaper production reduces the price of the commodity, generally resulting in increased consumption. Furthermore, capital investments in technology (R&D) are generally driven by the need for a 'return on investment', meaning that the technologies that are developed are generally the ones that maximise profits (Huesemann and Huesemann, 2011). These are the types of dynamics by which the potential ecological benefits of efficiency gains are lost.

In order to take advantage of efficiency gains – that is, in order for efficiency gains to actually *reduce* resource and energy consumption to sustainable levels – what is needed is an economics of sufficiency; an economics that directs efficiency gains into reducing ecological impacts rather than increasing material growth. Sufficiency is a concept that is entirely absent from the paradigm of conventional growth economics, but once the limits of technology (and thus the limits to growth) are recognised, it becomes clear that embracing an economics of sufficiency is absolutely necessary if we are to create an economic model that is ecologically sustainable (Alexander, 2012a; Goodman, 2010; Herring, 2009).

Space does not permit a detailed outline of what an economics of sufficiency would look like, but some general comments are in order. In the poorest parts of the world, of course, economic development *of some form* is still required in order for basic material needs to be sufficiently met. In such contexts, an economics of sufficiency might still imply a phase of economic growth, for using efficiency gains to help eliminate poverty is certainly a part of what 'development' should mean (for a discussion of 'appropriate development', see Trainer, 2010: Ch. 5). But in the most highly developed regions of the world – where the main focus of this analysis is directed – an economics of sufficiency would involve moving away from a focus on continuous economic growth toward a 'post-growth' or 'steady state' economy that operated within the sustainable carrying capacity of the planet (Daly, 1996; Norgard, 2009). Given that those highly developed nations currently all have unsustainably high ecological footprints, any transition to a steady state economy presumably means not simply moving away from continuous economic expansion (in terms of resource and energy use), but actually entering a phase of planned contraction of resource and energy use – a process known as degrowth (Alexander, 2012b). Technology provides no escape from this logic, which is the main point of this chapter.[2]

The broad vision implied by an economics of sufficiency involves the richest nations initiating a degrowth process while the poorest nations grow in order to meet basic needs. If sustainability is to be achieved over coming decades the rich and poor economies will need to converge to produce a global economy that meets the basic needs for all while operating within the sustainable carrying capacity of the planet (Lawn and Clarke, 2010). This may not seem very likely at all – and the necessary policies or mechanisms of change cannot be explored presently – but the vision is presented here as a far more coherent conception of sustainability than the dominant notions of 'sustainable development' based on continuous global growth. Note that this alternative vision does not entail globalising Western-style affluence but rather globalising less-consumption orientated lifestyles of material sufficiency (Princen,

[2] The term 'degrowth' obviously has huge public relations challenges and for that reason it is highly unlikely to ever become the basis of a popular campaign. Nevertheless, in an era where growth is widely considered the solution to most societal problems (Hamilton, 2003), the value of the degrowth literature lies in its provocative suggestion that contraction, not growth, of material and energy consumption may be required in overdeveloped areas of the world in order to transition to a just and sustainable world. That is the provocation entirely absent from notions of 'sustainable development' within mainstream environmental discourse (see Goodman, 2010). Whether 'degrowth' is the best way of framing the necessity of contraction is an important issue, but one that must be left for consideration on another occasion.

2005; Trainer, 2010). In short, sustainability in the developed nations does not just meaning producing and consuming more *efficiently*; it also means producing and consuming *less*. This follows from the critique of techno-optimism detailed above.

In order for this admittedly radical vision to be realised – or, at least, to begin moving toward it – what is needed, at a minimum, is for rich nations to stop redirecting efficiency gains into production and consumption growth. Instead, efficiency gains must be used to reduce overall energy and resource consumption. For example, technologies that increase labour productivity should generally lead to decreased working hours, not increased production; technologies that increase energy efficiency must not be used to 'do more with the same inputs' but to 'do enough with fewer inputs'.

Reducing the ecological impacts of developed nations, however, cannot be achieved simply through the application of technology. As well as using technologies to reduce the impact of economic activity, what is also required is that typical levels of consumption and production in developed nations go down. This can be achieved partly by cultural change, through which people practice 'voluntary simplicity' by exchanging superfluous consumption for more free time (Burch, 2012; Alexander, 2012c). But such cultural change needs to be supported and facilitated by structural changes that support an economics of sufficiency (see, e.g., Alcott, 2008; Trainer, 2010; Alexander, 2011; van den Bergh, 2011).

Exactly what form those cultural and structural changes should take, and how they may be achieved, are large and complex questions that cannot be addressed presently. This includes the question of to what extent the required structural changes can arise within a 'market-based' economy (see Trainer, 2011), and whether the necessary change will need to be driven from the 'top down' or 'from below' (Trainer, 2010). There is also the critically important question of what *types* of consumption and production need to 'degrow', and whether some types may still need to 'grow'. For example, it can be fairly presumed, even within a degrowth model of progress, that any transition to a sustainable society is going to depend on a considerable expansion of the production of solar panels and wind turbines. This suggests that the dualism of growth vs. degrowth is somewhat simplistic and needs to be negotiated with some subtlety. But this chapter will have served its purpose if the need for a paradigm-shift in economics is now more clearly evident. Accurate prescription is not possible until there has been an accurate diagnosis, and the evidence-based diagnosis delivered above is that the conventional growth model of progress is cancerous and cannot be saved by technology. Any transition to a just and sustainable economy, therefore, depends on a value-shift in the direction of sufficiency. Until that occurs, sustainability will remain a will-o'-the-wisp.

8. Conclusion

This chapter has reviewed the evidence in support of techno-optimism and found it to be wanting. This is significant because it debunks a widely held view, even amongst many environmentalists, that 'green growth' is a coherent path to sustainability. Perhaps it would be nice if affluence could be globalised without damaging the planet. It would certainly be less confronting than rethinking cultural and economic fundamentals. But there are no credible grounds for thinking that technology is going to be able to protect the environment if economic growth is sustained and high consumption lifestyles continue to be globalised. The levels of decoupling required are simply too great. More efficient growth in GDP, therefore, is not so much 'green' as slightly 'less brown' (Czech, 2013: Ch. 8), which is a wholly inadequate response to the crises facing humanity.

We have seen that as nations get richer, their overall ecological footprints and carbon emissions tend to rise, from which it follows that the argument that higher GDP will produce sustainable economies entirely lacks evidential foundation. The central problem is that in a growth-orientated economy, efficiency gains are almost always reinvested into increasing production and consumption, not reducing them. These rebound effects have meant that the overall impact of economies tends to increase, even though technology has produced many efficiency gains in production. In other words, technological advancement has produced relative decoupling, but little or no absolute decoupling. The latter is obviously what is needed, however, given that the global economy is in gross ecological overshoot (Turner, 2012).

Since there are no reasons to think that more efficient growth is going to reduce humanity's ecological footprint within sustainable bounds, it follows that we must consider alternative models of economy – alternative models of progress – even if these challenge conventional economic wisdom. To draw on the Einsteinian dictum: we cannot solve our problems using the same kinds of thinking that caused them. Among other things, this implies taking population stabilisation and reduction policies much more seriously (Alcott, 2012). But even if population were to be stabilised today, the global economy would remain in gross ecological overshoot. All appropriate technologies must also be exploited – this chapter does not argue otherwise! – it only maintains that technology is not going to be able to solve environmental problems when the application of technology is governed by a growth imperative. Accordingly, this chapter has argued that what is needed for true sustainability (as opposed to 'greenwash') is a transition to a fundamentally different kind of economy – an economy that seeks sufficiency rather than limitless growth. This may not be a popular message, and it may already be too late for there to be a smooth transition beyond the growth model (Gilding, 2011). But on a finite planet, there is no alternative. The sooner the world realises this, the better it will be for both people and planet.

We must embrace life beyond growth before it embraces us.

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