RECONCEPTUALISING HUMAN NEEDS, EQUITY AND WELLBEING IN THE CONTEXT OF GLOBAL SUSTAINABILITY

A Dissertation Presented for the Degree of PhD

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The material presented in this dissertation has not been used for any other award and is entirely original except where sources have been acknowledged. No ethics clearance was required as it presents a new and original analysis of publicly available data. As well as conference abstracts, one peer-reviewed A-level paper has been published from this work so far, as follows and appended:

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Abstract

The integrity of the planet is under threat by growing populations of people living under vastly inequitable conditions. Achieving global equity based on historical notions of prosperity threatens human survival by the year 2100. This puts intergenerational equity in direct conflict with international equity, creating a paradox within the original definition of sustainability. On top of this, there is public and political resistance to the climate science.

Is any kind of balance between people and planet ever going to be possible? This work lays out the main issues and explores an approach based on human needs. Within the definition of global sustainability, it uses a simplified adaptation of established econometric and psychometric techniques to compare curves at the frontier of life expectancy as a proxy of human survival needs. The methods deliberately err on the side of empirical simplicity to remain easily understood, replicable and falsifiable - a characteristic needed to enhance multidisciplinary and public collaboration on rapidly accelerating threats to human sustainability.

Six exploratory studies are presented using publicly available data from the United Nations (UN), World Bank (WB) and New Economics Foundation (NEF), which cover up to 200 countries and 250 years of time series. The first tests the proposed methods against a basic need like food consumption, showing that the method captures an appropriate metabolic boundary that is stable across half a century and produces a bell-curve that matches results within countries.

The second uses the same methods to confirm similar boundaries for life expectancy and life satisfaction. Results match previous studies, especially with

reference to the Easterlin Paradox and Set-Point Theory. This suggests development might have reached an optimum beyond which further planetary exploitation offers little or no gain to human outputs; it might also mean the UN Human Development Index (UN-HDI) and even the NEF Happy Planet Index (NEF-HPI) could be inherently unsustainable. The third applies the methods of the NEF-HPI itself to newly available data for age and gender to show this metric is unrepresentative of children. So using the alternative methods explored in this work moves away from pursuing an all-encompassing composite index in search of a more policy-relevant dashboard of sustainable human needs.

To this end, the fourth study tests the stability and reliability of the proposed methods across many more available metrics at different times over the past decade. Whether a candidate ‘need’ consistently displays a bell-shaped curve has important implications for sustainability in the long run as it suggests redistribution might achieve global equity where nobody loses and everybody gains – a non-monetary form of Pareto efficiency. The fifth study bypasses candidate needs and directly applies the method to human life expectancy and carbon emissions over the past half-century. The results produce a stable bell-curve where the optimal target for carbon emissions is always more moderate and sustainable, identifying the first human centred target of Contraction and Convergence. The sixth and final study explores whether the methods properly predict known targets by returning to food consumption. A host of tests are made in this study to explore the limitations of the methods – issues like data density, outliers, whether targets might be inflated, variable intercepts and causality, not all of which are resolved.

The methods explored mostly produce appropriate targets for different biological, socioeconomic and psychosocial metrics, the broad trend being that some countries are ‘over-developed’. They also help explain why more sustainable countries have been tracking on high human outcomes with relatively meagre input for decades – countries like Costa Rica, Malta, Vanuatu, Vietnam and Japan. These countries offer implications for balancing international and intergenerational equity, without which global negotiations on climate change and sustainability will continue to stall.

"Treat the earth well. It was not given to you by your parents.
It was loaned to you by your children"

Kenyan Proverb

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List of Abbreviations and Acronyms

AEDI	Australian Early Development Index
BCE	Before the Common Era (Substitute for BC)
BMI	Body Mass Index
C&C	Contraction and Convergence
CE’s	Carbon Emissions (not equivalent)
CEe	Carbon Emissions (equivalent)
CFCs	Chlorofluorocarbons
CI	Confidence Interval
COP	Conference of the Parties Convention on Biological Diversity
CPI	Consumer Price Index
CSDH	Commission on Social Determinants of Health (WHO)
DALY	Disability Adjusted Life Years
DEA	Data Envelopment Analysis
DSM	Diagnostic & Statistical Manual of the American Psychiatric Association
ED	Education
EF	Ecological Footprint
FA	Factor Analysis
fMRI	Functional Magnetic Resonance Imaging
GCI	Global Commons Institute
GDP	Gross Domestic Product
GFC	Global Financial Crisis
GHG	Greenhouse Gas
GHQ	General Health Questionnaire
GNH	Gross National Happiness
GNI	Gross National Income
GNP	Gross National Product
GNU R	Statistical Program of the GNU Project
HALE	Health Adjusted Life Years

HANPP	Human Appropriation of Net Photosynthetic Product
HBSC	Health Behaviors in School-Aged Children
HDI	Human Development Index
HDR	Human Development Report (UN)
HILDA	Household Income and Labour Dynamics in Australia Survey
HIV	Human Immunodeficiency Virus
HLE	Happy Life Expectancy
HLY	Happy Life Years
HMD	Human Mortality Database
HPI	Happy Planet Index
IBM	International Business Machines
ICD	International Classification of Diseases
IEA	International Energy Agency
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change [UNEP-WMO]
IQ	Intelligence Quotient
IRA	Irish Republican Army
kCal	Kilocalories
LE	Life Expectancy
LN	Natural Logarithm
LS	Life Satisfaction
MBA	Master of Business Administration
MDG	Millennium Development Goal
MIPS	Material Input Per Unit of Service
MMPI	Minnesota Multiphasic Personality Inventory
NASA	National Aeronautics and Space Administration (US)
NEF	New Economic Foundation
NEF-HPI	New Economics Foundation Happy Planet Index
OECD	Organization for Economic Co-operation and Development [UN]
OLS	Ordinary Least Squares

PASW	Predictive Analytics SoftWare
PPP	Purchasing Power Parity
QALY	Quality Adjusted Life Years
RAS	Reticular Activating System
SD	Standard Deviation
SE	Standard Error
SWB	Subjective Wellbeing
SOEP	German Socio-Economic Panel
UN	United Nations
UNFAO	United Nations Food & Agriculture Organization
UN-HDI	United Nations Human Development Index
UNICEF	United Nations International Children's Emergency Fund
USDA	US Department of Agriculture
WVS	World Values Survey
WWF	World Wide Fund for Nature
WWII	World War Two
ζn	Frontier Subsample
$INT	International Dollar

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And for all the world's amazing kids …

Paul Read

Monash Sustainability Institute, 9 August 2013

1. Introduction

1.1 THE NATURE OF SUSTAINABILITY

This chapter will outline how the original definition of sustainability is misunderstood across different disciplines and yet always comes back to issues of human needs and their equitable satisfaction across both countries and generations. This chapter covers:

1. An introduction to the logic of the work linking human needs, equity and wellbeing in the context of sustainability
2. The implications of current climate science for human needs and equity
3. The history of sustainability and its tensions with neoliberal economics
4. Recent measures based on human development, health and 'happiness'
5. Why these recent measures should, and could, be recontextualised by human needs theory

In this chapter, the current state of the climate science is provided with its implications for children (intergenerational equity) and the need for One Planet Living (ecological footprint), tracing tensions between concepts of wealth, health and happiness from the Enlightenment, through the Industrial Revolution, to the current debate on sustainability. It then provides an explanation of how the economic discount rate (central to the Stern Report) affects intergenerational equity and how GDP mismeasures both health and happiness outcomes. The UN Human Development Index and the NEF Happy Planet Index provide an alternative model for measuring development but there are issues relating to their use of the data that are highlighted by the academic arguments between authors like Veenhoven, Easterlin, Preston and Cummins.

An attempted reconciliation of competing problems is then based on a detailed discussion of Set-Point Theory and Human Needs with implications for sustainable development. Whereas previous authors have focused on how there are planetary limits to economic growth, this thesis says there are human limits to how much economic growth people can stand (at least as economic development is currently measured and pursued). In other words, economic development in its current form is not only eroding the global ecology but also affecting human health and wellbeing. It shows how economic development lifts nations out of abject misery, but only to a replicable point where basic human needs are satisfied, beyond which higher psychosocial needs are increasingly frustrated by further economic growth and overconsumption, leading to falling life expectancies and subjective wellbeing among countries that are traditionally seen to be more developed.

A host of very contentious multidisciplinary issues swirl around this argument and are tested using a novel statistical approach that confirms many previous studies. This method, and the use of life expectancy as the main dependent variable, is used as the key to measure many divergent independent variables from disparate sources using the same method (without resorting to multivariate analysis or modelling). It uses calorie consumption as a test case and then moves onto available time series data across many different variables. The main study shows that international equity within an increasingly constrained carbon emissions budget – a major precondition for international agreement – could have (at least when written) maximised global life expectancies across all countries whilst still ensuring future generations had a decent chance of achieving the same levels of longevity. It then argues that the satisfaction of human needs is a necessary precondition for subjective wellbeing.

1.1.1 Linking Human Needs, Equity and Wellbeing

There was an acceptance from the outset that this work would have to be multidisciplinary. Because of this, basic arguments could not be outlined without explaining vastly different concepts, disciplinary languages, methods and results – hence the long introduction spanning psychology, development, health, history, economics and climate science. With reference to the title of this thesis, working backwards helps contextualise human needs, equity and wellbeing against the backdrop of global sustainability. For the purposes of this work, sustainability is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987, Chapter 2, p.1). Explicit in this original definition is the concept of needs; implicit the concept of equity – both within and across generations, including those yet to be born. The other key concept, development, is usually conflated with economic growth and stages of development ranging from agrarian, through industrialisation, to service economies. It is argued by some that this should be replaced with human wellbeing as the key output – an argument resonating with the Enlightenment, the French and American revolutions, and their origins in the Magna Carta. But this thesis argues this is a dangerous mistake, based on psychological evidence. Rather, this thesis argues that development should be reconceptualised in terms of human needs that resonate at both the personal and national level, with wellbeing emerging as an epiphenomenon of life satisfaction and life expectancy reflecting the satisfaction of needs that have evolved to match an environment more sustainable than 'developed' nations currently create. If this can be shown, it effectively reconceptualises development as the satisfaction of human needs, measured against life expectancy, and from this logically shifts the definition of development and equity from monetary to time-based metrics. They can still be mathematically interchanged within countries and economies, but only life expectancy works across countries, across disciplines and across timescales (as proxied by paleoanthropology, human height and other available measures that help test the methods; even across species proves useful in taking human culture out of the experiment).

Sustainability First, the concept of sustainability goes beyond climate science alone. It spans issues like water (UN, 2009), population (Ehrlich, 1971) and aging (Magnus, 2009), war and terrorism, peak oil (Hubbard, 1956; endocrine disruptors affecting human reproduction (Cadbury, 1997), social justice and equity, social stability and many others[1]. Notwithstanding, this thesis does focus on climate change as the main lens through which to focus on issues of sustainability and development. Second, it must be recognised that sustainability has been an issue confronting humanity for much longer than might be imagined. The clash of human needs with resource scarcity has left behind evidence of tragedy like starvation, war and even basic stupidity (see Diamond, 1991, 2005 on Easter Island; also Ponting, 1993 on other civilisations). Other populations and civilisations, either through good luck, ingenuity or travel, were able to escape or adapt. This thesis is one among many attempts to test a pathway towards human adaptation in the modern era by balancing human needs across cultures and time, recognising that most of the problems of

[1] Just in terms of environmental pollutants that are carcinogenic or teratogenic there are now 5 million contaminated sites affecting human health and sustainability worldwide, 60% of them located in urbanised areas (see GCRI, 2013); 1 trillion plastic bags discarded annually have enough embodied petroleum to drive 3 million cars around the globe every year (Nolan, 2002); the islands of garbage floating in the Pacific Ocean have increased one hundred-fold since 1972 (Goldstein et al., 2012); species loss is already at least 1000 times the natural extinction rate with the highest loss estimates reaching *up to* 100,000 species every year (WWF, 2013)

sustainability now emerge from industrialisation over the past few centuries. The first part of this introduction covers the veracity of the climate change debate, recognising that growing human populations seeking growing quality of life driven by growing carbon emissions is creating an accelerating threat to the wellbeing of future generations.

Wellbeing To this end, the work first recognises that human welfare is central to sustainability in terms of both outcomes *and motivations to act*. Governments only recently recognised that sustainability is an issue of human welfare to be incorporated in statistical measures of social progress (see the ABS MAP Project, 2011). The problem is that traditional economic conceptions of human welfare are conflated with utility theory and simply contribute to the problem by driving more consumption and production. Governments and economists began to look further afield by pursuing more 'human-centred' concepts such as subjective wellbeing (SWB). Yet this might be a mistake in the context of sustainability unless the psychometric rather than econometric properties of SWB are given greater precedence in the debate. This is because when consumption reaches a threshold beyond which human needs are satisfied, one strategy people use to increase their wellbeing is to gain more than others, in which case consumption becomes insatiable against an upwardly moving target. Psychological research on human wellbeing then provides a salutary warning for those who see it as a simple output measure that can bypass economic metrics, even among those who use it to argue for a more sustainable future (such as the New Economics Foundation).

Equity This relativistic characteristic of human wellbeing, possibly related to sexual selection (see Etcoff, 2000; Wilson, 1975), essentially demands structural inequity, which has always been a world-wide problem, both across countries and within, leading to a zero-sum game on behalf of future generations. If the developing world achieved parity with the developed world, existing ecological problems would have to be multiplied and the implications for future generations would be cataclysmic. Given current climate science, any world scenario in which international equity, here defined as unity, was achieved in the short term could devastate any chance for inter-generational equity across all countries in the longer term. The tension between these two types of equity is the second introductory theme of this work, especially as international negotiation on climate change now demands international equity as a precondition for developing countries to sign up on a treaty that might preserve equity across generations. To break the deadlock requires a profound adaptation in terms of human behaviour, politics, attitudes and values. It is argued that there might already be a solution to the problem deep within the cross-national datasets collated by transnational agencies, and that the solution can be tested using life expectancy, which so far offers the best available metric of human needs. As will be seen, relationships between material consumption and life expectancy follow the same cross-national curve as material consumption and wellbeing – curves extant for decades back to 1890. It is argued from within the psychological literature (ranging from neurobiology to modelling) that wellbeing should not be treated as the proper outcome of government (as per the Enlightenment and American Revolution) but rather should be treated as an epiphenomenon – a neurobiological signal – that human needs are being met in service of actual survival.

Needs The concept of human need has always been problematic because it is ethically untestable. But the current work argues that it can be tested across disciplines and the satisfaction of human needs - physiological, psychosocial, economic and political - tends to be much less ecologically ‘expensive’ than would be expected. The reason is that almost every human need has a threshold at which further consumption beyond threshold becomes either useless or damaging. In medicine, it is called a dose-response curve which usually follows an inverted bell-shape, the peak representing a threshold or metabolic set-point that maximises health, wellbeing, performance, etc. One important question here is whether the econometric law of diminishing marginal utility, at least when applied to different needs as input and life expectancy as output, is capturing similar processes. It is shown how curves across countries and within countries tend to suggest that both life expectancy and wellbeing can be maximised at levels that are much more sustainable than most developed countries are currently pursuing, suggesting it is only by cleaving to long-cherished notions about the pursuit of 'wealth' and 'happiness' that actual 'wealth' and 'happiness' might elude us. It suggests that some nations are working at odds to evolved human needs, usually by thinking 'more is better', when it comes to economic growth. This only applies with more human-centred metrics. Whilst the main introduction to this work covers background problems in sustainability, wellbeing and equity, the methods present a new and empirical way of testing human needs based on frontier regression and validated using other statistical methods across time and aggregation levels, as well as triangulating results from different disciplines and historical accidents. Human needs must be universal across cultures and disciplines to be equally important across generations, and issues like ecological fallacy and Simpson's Paradox must be addressed in detail, especially when crossing from studies at the intra- to inter-national levels of aggregation. The work tests itself backwards in time to make sure its conclusions will be broadly applicable forwards in time, its main concern being the wellbeing of future generations, whether conceived of as children now living or the unborn (the latter raising economic and legal issues in terms of rights).

Hypotheses The primary hypothesis is that moderation of consumption across inputs, whether biological or psychosocial, maximises output as the proxy of partial survival represented by life expectancy – a harmonised metric that allows equal comparisons across all other input metrics. The economic expression of this is that utility can be maximised in the form of life expectancy, even when resources are redistributed, achieving Pareto efficiency by putting survival in place of happiness as the end goal. A corollary to this is that countries achieving the more moderated ideal across inputs will then display more subjective wellbeing anyway, due to the evolutionary significance of 'happiness' to survival itself. In other words, we can live longer and be happier in societies that live within the means of the biosphere, which then offers some hope for balancing the conflict between international and intergenerational equity. A more human-centred rather than purely economic understanding of human metabolic limits to health and happiness would then suggest some level of balance between people and planet might be possible, even in the face of accelerating threats to human survival over the coming century.

1.1.2 The Latest Data on Climate Change

When global warming exceeds 2°C above pre-industrial temperatures, the latest models predict 25% increases in famine across Africa and West Asia, collapse of the Amazon rainforest and Greenland ice sheet, and *at least* 20% species extinction (Mendelsohn, Nordhaus & Shaw, 1994; Gleick, 1996; Leemans & Eickhout, 2004; McMichael et al., 2004; Parry et al., 2004; Bosello et al., 2006; McMichael, Woodruff & Hales, 2006). Loss of species include snakes and frogs, lions and tigers, orangutans and polar bears, butterflies and bees, flowers and fruits, as well as crops and even gut bacteria that are fundamental to human survival (Pearson & Dawson, 2003; Thomas & Cameron et al., 2004; Thomas & Williams et al., 2004; Malcolm et al., 2006; McClean et al., 2005; Pearson, Bustamante & Coloma, 2006; Pouns et al., 2006).

The word ‘when’ is chosen instead of ‘if’ because the latest studies show climate change beyond 2°C is no longer controllable by global collaborative efforts (Hansen, 2008; NASA, 2012). The results have already begun to affect human populations and the opportunity to reverse this trend could close as early as 2013 (IEA, 2012). In 2009, governments working with the International Panel on Climate Change (IPCC) in Copenhagen achieved multilateral agreement on a limit of 2°C warming, beyond which it was agreed there would be unacceptable impacts on biosocial systems affecting humanity (McGray, 2010). This then created an upper ceiling of total allowable emissions based on constraining the atmospheric concentrations of carbon dioxide at or below 400 parts per million (Hare & Meinshausen, 2006). Some of the background evidence is summarised below in Figures 1-2, where leading studies have tracked carbon emissions and temperature changes over different timescales, and Figures 3-4, where the impact on glacial melt is then shown using satellite data.

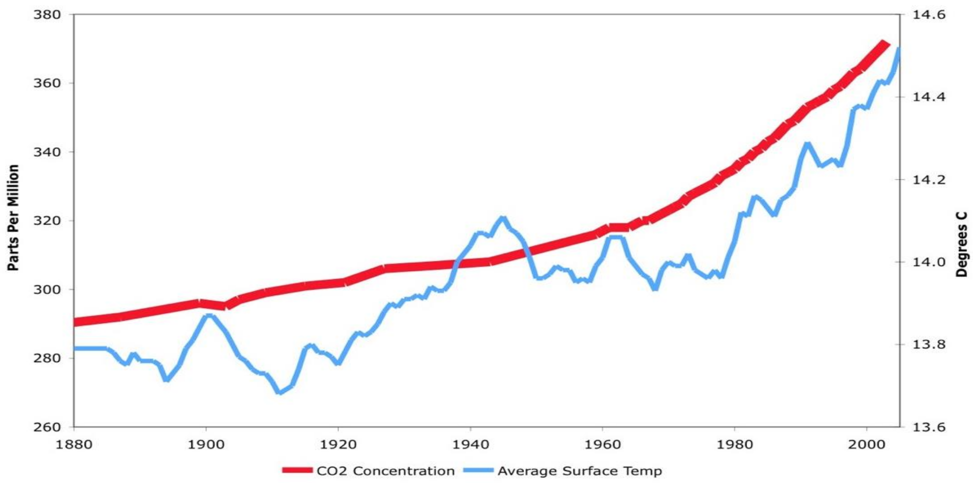
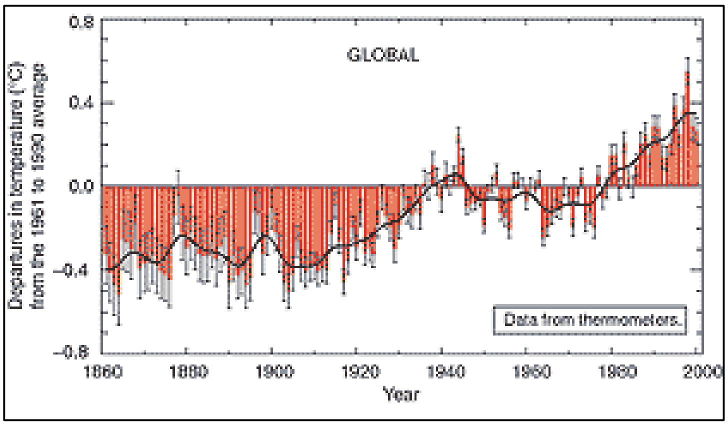


Figure 1-1 Global average temperatures since 1856 (IPCC, 2007; NOAA, 2013)

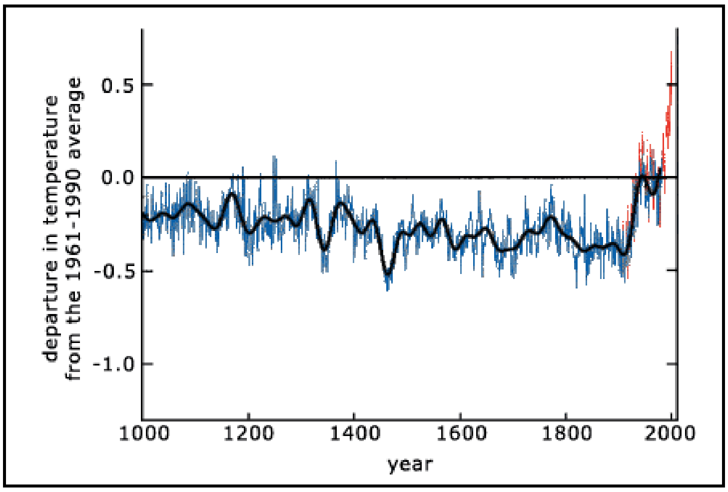
The causal link between atmospheric carbon emissions and global temperature is not contested. It is simple physics. The sun radiates in short waves, hits the Earth and then radiates back in infrared or long waves. Carbon dioxides and other Greenhouse Gases (GHGs), including water vapour itself (clouds), work like a two-way mirror that let the short waves in without letting the long waves out, so they re-radiate back to Earth. This is exactly what NASA and the Japanese Space Agencies have been confirming since 1970 using three separate satellite systems (Harries & Brindley et al., 2001; Griggs, 2004). Clouds contribute half of the background Greenhouse effect but carbon dioxide adds another 25%, even though it represents only 0.03% of the atmosphere – just like painting a thin sliver of silver on glass.

Unlike the atmosphere of planets like Mars and Venus, Earth trapped most of its carbon in plants, animals and oceans over the geological timescale. This has been drilled and re-released into the atmosphere by carbon-based fuels and gases since the Industrial Revolution. Although this trapped energy has served our needs for centuries, it is now re-accumulating in the atmosphere at dangerous levels that will increase global *average* temperatures by amounts small enough to have big effects.

a) The past 140 years (Smith & Reynolds, 2005; NOAA, 2013)



b) The past 1000 years (IPCC, 2001, 2007)



c) The past 400,000 years (Keeling & Whorf, 2005)

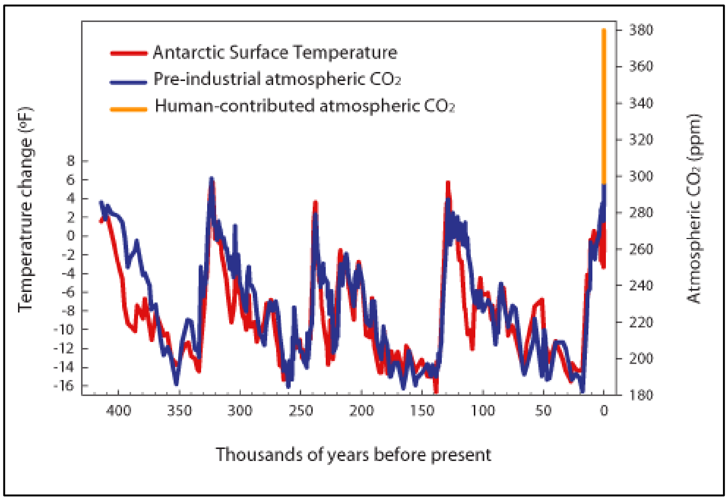


Figure 1-2 Available temperature data over different timescales

Leading up to 2050, the strongest modelling so far has been developed by Meinshausen and colleagues (2009). This seminal work demonstrated a 25% risk of exceeding 2°C with a total cumulative emissions budget of a trillion tonnes (1000 Gigatonnes, Gt) from 2000-2050. Using the same model, risk is substantially reduced with a much smaller budget of 750 Gt suggested by Hansen and colleagues (2008). The problem confronting both, however, is that the world had already used up 234 Gt by 2006 (Meinshausen et al., 2009).

As of 2011, global emissions peaked at a record high, prompting the International Energy Agency's Chief Economist Fatih Birol to warn "the door to a 2°C trajectory is about to close" (IEA, 2012, p1). The World Meteorological Organization in Geneva now reports that the past decade was the hottest on record for 94% of the world's nations (Cohen, 2013). More recently, atmospheric emissions breached 400 parts per million for more than 24 hours on 2 May, 2013, the first time for 800,000 years (Beillo, 2013).

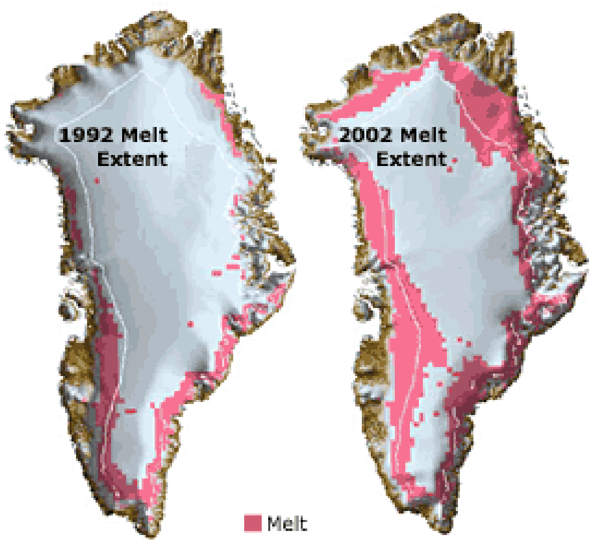


Figure 1-3 Greenland Glacial Melt (NASA, 2003)

Given current growth in carbon emissions alone - much less methane CH_4, nitrogen protoxide N_2O and halocarbons like chlorofluorocarbons (CFCs) which take 1000 years to dissipate (IEA, 2012) - most of the Meinshausen budget will have been used up by 2013, leaving smaller rations for the next four decades. Delayed international action then makes the rate of change in the future much steeper and harder to adapt to for both advanced and developing economies. This raises an ethical dilemma in terms of international and intergenerational equity because in order to satisfy the one it must undermine the other.

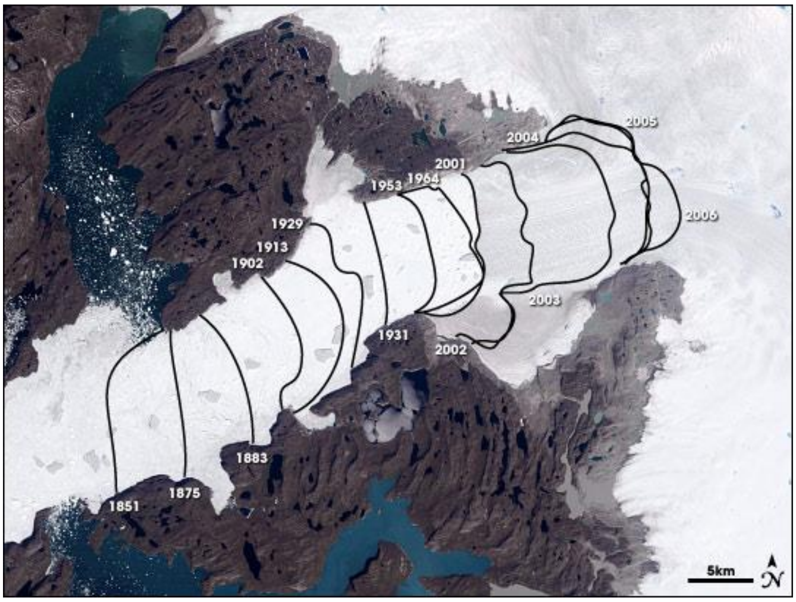


Figure 1-4 Retreat of the Jakobshavn Glacier, Greenland 1851-2007 (Haven, 2007)

To explain, the world in 2012 was close to reaching the precipice of exceeding the 2°C limit without allowing the bulk of developing nations to reach industrial parity with a minority of wealthier, carbon-intensive nations. Because global emissions (IEA, 2010) and population (UN, 2011) are both steadily growing, the yearly amount of allowable emissions compound the ethical problems yet to be confronted. Developing nations will not accept emissions cuts without equity but developed nations are already spending up to 10-times more than their fair share (based on Qatar's emissions versus the Meinshausen budget in 2009).

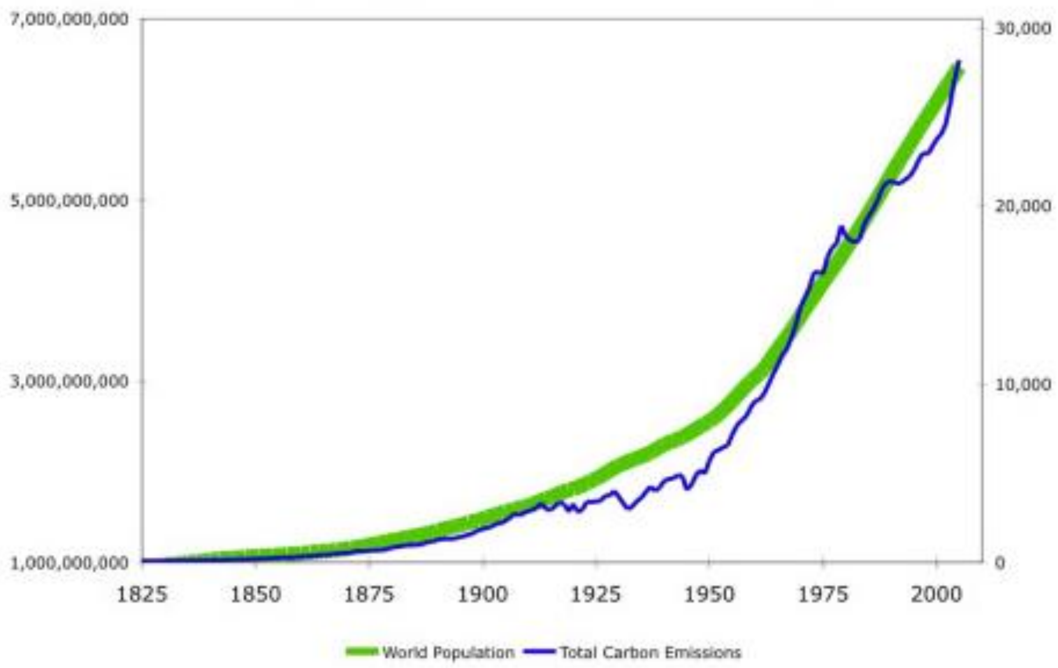


Figure 1-5 World Population and Global Carbon Emissions Since 1825

Carbon emissions have followed both population and economic growth for centuries (Figure 1-5). Population tends towards a linear trajectory of up to 13 billion people by 2100 but is expected to stabilise at 10 billion in 2062 due to falling fertility rates worldwide, partly expected because of social progress and economic growth (see Magnus, 2009). Equally conservative annual increases in carbon emissions were 4% since 1962 falling to 3% since 2000 because of rising technological efficiencies (Husler & Sornette, 2011). Yet with these forces combined, the entire Meinshausen budget should still be completely used up by late 2022 (September 2016 for the Hansen budget). One way to visualise how delayed action impacts on future generations has been calculated below in Figure 1-6 (based on data provided later in Study Five).

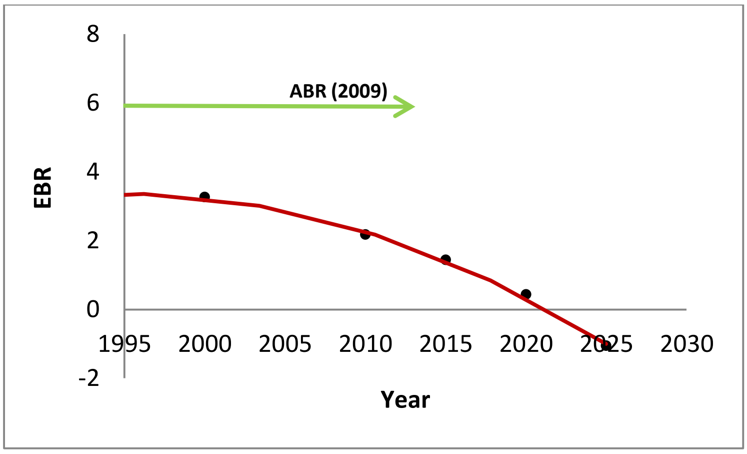


Figure 1-6 The equitable Meinshausen emissions budget remaining in key years from 2000-2025 (EBR) against the global per capita average in 2009 (ABR)

This means the original 2°C limit was already heading towards being breached before the global community agreed to act, especially among resistant countries like Australia and the United States. Even though earlier, more alarmist predictions are attenuated, the climate is still moving too fast for science, policy and technology to catch up. The latest data show the trajectory of global warming is already committed to an unavoidable increase of 4°C by 2100 (IPCC, 2013).

This exceeds conservative IPCC projections where an increase of 3°C would result in the acidification the oceans, European drought, 4 billion more people suffering water shortages, 170 million more people evacuated by coastal flooding, 500 million more people starving, half of all species made extinct, the complete collapse of the Amazon Rainforest, and the flooding of some world cities due to sea level rises (see Stern et al., 2006, Smith et al., 2009). To put it in further context, the last time world temperatures *fell* by only 5°C, New York was under a mile of ice (Hamilton, 2013).

When the trends of population growth and carbon growth are extrapolated to 2100, equity applied without any effort to curb climate change would now push the atmospheric concentrations of carbon dioxides upwards to 1251 parts per million.

The last time this occurred was 100 million years ago when the global temperature was hotter by 8°C. For most people, this variation seems quite small against seasonal and daily variations in their own parts of the world. But the global effect on habitable zones based on the human metabolic limit for similarly small *average global* temperature rises were conservatively shown by Sherwood and Huber (2010) as follows in Figure 1-7.

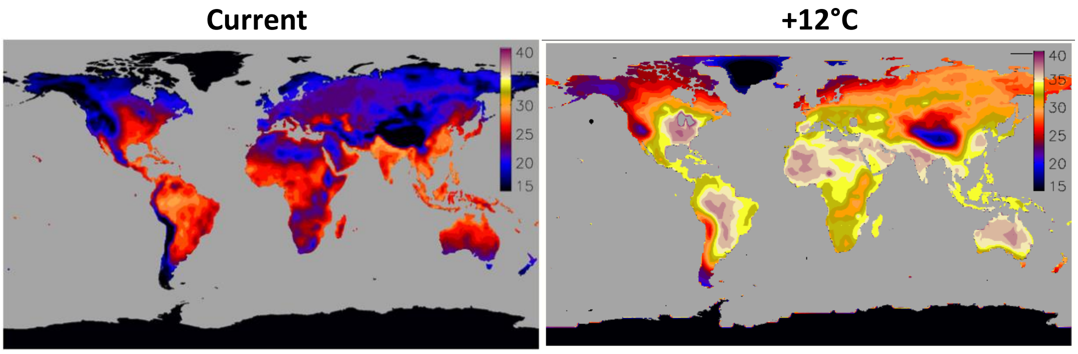


Figure 1-7 Human habitability zones (blue and red) based on human metabolic adaptability under current versus +12°C (Sherwood & Huber, 2010)

Bearing in mind that humanity barely survived at least one and possibly three climate-induced bottlenecks over a much smaller timescale of 74,000 years (Ambrose, 1998)[2], further delay on international action is simply not an option. The total impact on biosocial systems preserving human life cannot be properly estimated

[2] Apart from the Ice Age theory of human monogamy and another bottleneck about 150,000 years ago, Ambrose (1998) argued, with genetic data, that humanity fell to only 10,000 unique individuals surviving in the Horn of Africa after the Toba supervolcano eruption 74,000 years ago, which affected climate for 1000 years. Recent arhceological evidence in Pradesh, India, disputes this (for an early review of the genetic divergence evidence, see Hawks et alia, 1999)

but the World Health Organization is already counting death rates directly attributable to climate change as well as extreme weather events and pollution (WHO HELI Project, 2013, McMichael et al., 2004).

For those who have more trust in business metrics, the international reinsurance agency, Munich Re, says extreme weather events have tripled since 1980, with record rates of floods, wildfires, heat waves, cold snaps and hurricanes (see Shneider & Lane, 2006, Harmeling & Eckstein, 2012, Munich Re, 2010). Australian farmers are increasingly worried by record rates of extreme and unpredictable weather patterns (ABS, 2009). Of a sample of 150,000, 62% directly attributed falling production to climate change, especially its effects on rainfall, extreme weather and changes in pests, weeds and diseases. Fruits, vegetables and cattle were said to be the most affected.

Meanwhile, sea levels have been rising due to thermal expansion and glacial melt will add to this (Hunter & Allison, 2012). Although the rise is much slower than originally forecast, the people of low-lying Pacific islands like Kiribati are now planning mass re-location to Fiji because rising saline water tables and storm surges are causing brackish water to poison their crops and rainfall changes are restricting their access to fresh water (Tong, 2013). The rising rate of environmental refugees is becoming more salient and presents its own moral and policy dilemmas.

As for the biosphere, animal and plant species are vacating the equator and moving southwards at a rate 10 times faster than the last major extinction and extinctions have reached a rate at least 100 times faster than the normal background rate of the past 300,000 years (Flannery, 2005).

Not all of this is based on future modelling – most is hard data taken from today. Efforts towards climate change mitigation, that is reducing emissions at the global level, are now further complicated by the need for climate change adaptation, which promotes learning to live with the new paradigm as if it were inevitable. A disturbing trend in the adaptation literature has begun to emerge recently where notions of climate change ‘winners’ and ‘losers’ are discussed in an economic sense (Smith et al., 2001). For example, some industry sectors like shipping are looking forward to new and shorter trade routes through the melting Arctic. This is unhelpful to the mitigation argument as only short-term benefits accrue to the developed world based on existing economic resilience, and the focus on exploiting newly emerging comparative advantages would only deepen existing inequities.

As seen, global emissions (IEA, 2010) and population (UN, 2011) are both steadily growing, putting further strain on global adaptation and mitigation as the world reaches, very conservatively, 9.2 billion people by 2050 (UN, 2011). The implications of this growth is that the budget per person, whether wealthy or poor, would have to be cut by 95% to restrain climate change at acceptable limits defined by Copenhagen (equalling the economic cost estimated by Dasgupta, 2007 based on Stern, 2006). This is an impossible figure when about one third of emissions are devoted to basic needs like food (Vermeulen et al., 2012; Thornton et al., 2012) and 15% of the world’s people (870,000) are already in a state of permanent starvation (UNFAO, 2012). If this were the end of the story, the future would seem to be impossibly bleak.

Equity is the biggest issue confronting sustainability on a multitude of levels, both economic and political, an issue recently recognised in an emerging effort to redefine the Millennium Development Goals (MDGs) in terms of sustainability (see

Griggs and associates, 2013). Leading climate economists like Nordhaus (2007) and Stern (2006), despite their opposing views, also agree that *intergenerational* equity is the 'nub of the matter,' whereas equity across countries has been the growing issue in inter-governmental negotiations since Cancun and Copenhagen (see Meyer & O'Connell, 2010). Moreover, the emerging equity argument which links poverty and climate change is implicit within sustainability as it was originally defined - "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987, Chapter 2, p.1). Note the only concept reiterated in this definition is the problematic issue of human need and its equitable satisfaction in two forms:

1. Equity across all people now living - across all countries and all cultures
2. Equity across all generations – which means across all time periods

The preservation of a world satisfying the needs of future generations only becomes an issue if there is a real threat to the satisfaction of their needs in the first place. Although climate luminaries like James Lovelock (2012) accept that earlier predictions (including those by Al Gore and Tim Flannery) over-reached themselves and led to overly frightening conclusions, the broad trend of global warming remains. Scientific consensus on this was recently confirmed by 97% of 12,000 peer-reviewed articles (Cook, 2013). If we then accept that there is a real threat to future generations that is anthropogenic and controllable by present generations, then changes to the way we live now hinge on the legal, moral and economic values we place on the welfare of future generations versus our own, another issue beset with controversy.

If it is accepted that anthropogenic threats to future generations are caused by current levels of economic development, *and we care about the welfare of future generations*, it then raises the problem of existing international inequities, which remains a political problem

Some of the work highlighted earlier (e.g. Sherwood & Huber, 2010) suggests human extinction is possible by 2100 if all countries (much less industry sectors in a globalised free market) have the sovereign right to exploit their comparative advantage to maximise the welfare of their own populations, allowing the least developed countries to bring themselves out of poverty to the extent that they achieve parity with developed nations. So intergenerational equity comes into direct conflict with the levels of international equity that would preserve intergenerational equity in the first place. Any way you look at it, someone loses. This is why economists and politicians have described the problem of sustainability as one of the most diabolical moral dilemmas in human history (Rudd, 2007, Cairns, 2008, Garnaut, 2008)[3].

As further population growth collides with climate change, the only way to engage multilateral cooperation aimed at preserving the biosphere on behalf of future generations will be to champion international equity on behalf of present generations. Whereas the process of mitigation is more optimistic and proponents argue countries should cooperatively act to reduce the impact of climate change, adaptation is a more

[3] Garnaut said “the framework remains, as it was in 2008, a robust, logical and ethical framework within which to consider the most vexed policy question of the age, climate change” (Update 1), “the search for effective climate change policy is partly a search for effective cooperation amongst countries of a kind and dimension that has never previously been known” (Update 2), “Climate change policy must be based on thinking a way out of the biggest “prisoners’ dilemma” the world has seen, and the dilemma can only be resolved by explicit agreement, or by implicit agreement that each country on its own is contributing its share.” (Update 6) Rudd (2007) called climate change "the greatest moral, economic and social challenge of our time." Cairns (2007), whose context was the entire geological timescale said “climate change debates need an ethical dimension” and “Global warming … [and its impacts on inequitable distribution of food, [sic] … is a major ethical/moral/religious problem.”

pessimistic outlook, with the subtext that countries should adapt to maximise their own welfare.

Adaptation implies we start planning our economies and living strategies, including technologies, to accommodate climate change as if a high and dangerous temperature rise is inevitable (Schneider et al., 2007). Mitigation, on the other hand, implies we should immediately reduce our emissions to preserve survival, even if it means some countries must reduce their existing emissions by relying on greater technical efficiencies or else basic changes to consumption (Verbuggen, 2007).

It is increasingly recognised that both adaptation and mitigation are needed to achieve an ideal outcome for human habitability, such that economic strategies to mitigate climate change - a global carbon tax, an international carbon trading scheme, or a cap and trade system, a fixed price on carbon and many other complementary measures - might simultaneously reduce emissions and raise funds that can then be channelled into adaptation efforts, including green technology development and human behaviour change (Garnaut, 2008). The usual consensus is that a combination of all of these strategies is needed to avoid what Hansen (2009) describes as the 'S*torms of My Grandchildren'*.

The unspoken third alternative is to reduce human population through eugenics, war or genocide, among various other dystopian nightmares that could still, if mitigation were not pursued, become the worst case scenario in terms of adaptation, beginning with fights over water (Pachauri, 2009; Hsiang et al. 2013). A more civilised solution to climate change would require fundamental changes to public and political attitudes worldwide.

The current work tries to outline a pathway to development and growth pursued in more human-centred ways that could still incentivise novel approaches to international agreement on climate change and preserve biosocial systems (including endangered species) that maximise the chances of human survival into the future. This outcome hinges on giving attention to universal human needs that transcend cultures and timeframes – needs that are more human-centred and healthy, ranging from food and water to psychosocial needs that transcend 'manufactured values' serving economic growth.

Optimistically, there might be reason to believe that humans have their own internal metabolic limits to acting on their optimal levels of production and consumption – a notion recently described as a 'sweet pot' of health co-benefits in the climate change debate (McMichael et al., 2008). The idea resonates with decades of study on health and subjective wellbeing that is beginning to converge on the idea that human outcomes emerge at the confluence of nature and nurture, where findings from many different disciplines must be 'synthesised' to understand the broader trends towards social progress (see Cummins, 2005, Eckersley, 2005; Stiglitz, Sen & Fitoussi, 2010, Stanley, 2010). Despite political and ideological resistance, there is growing evidence from disparate sources that actual social progress must go back to basic human needs and values that have evolved over millennia, but have been mostly overlooked in the economic development literature (see Boyden, 2004).

Even without climate change and the impending mass extinction of species, there remain tragic levels of inequity at the global level and even as economic growth continues to rise among the wealthiest nations a range of negative health and psychosocial effects persist among wealthy countries themselves:

1. Cancer, obesity, heart disease, sleep disorders and diabetes (e.g. Lopez & Mathers et al., 2006)
2. Childhood depression, autism, ADHD, early female puberty and male infertility (e.g. Cadbury, 1997)
3. Divorce, domestic violence and family breakdown, drug abuse, aggressive crime and suicide since 1950 (e.g. Hordern, 1976)
4. Male stress and falling female 'happiness' since 1970 (e.g. Stevenson & Wolfers, 2009)

If nothing else, the problem of climate change puts a spotlight on where humanity is headed and what it wants for its future.

1.1.3 The Goldilocks Planet and One Planet Living

Stephen Hawking (1985), among others, suggested that the conditions of planet Earth were so extraordinarily perfect for the evolution of life that finding another equally supportive planet was almost impossible. The Rare Earth Hypothesis says a planet must be neither too close nor too far from its central star to promote survival - a circumstellar habitable zone where the distance of the planet from its star would be balanced against its mass and atmospheric pressure to ensure it could maintain liquid water on its surface (Muir, 2007).

Regardless of the pace of technological progress, the idea of relocating 10 or more billion people by 2100 to some anthropotrophic planet that exactly matches the conditions under which humanity evolved is yet another optimistic fantasy. An infinite universe argues for an infinite number of similar planets but it also suggests it might take infinite distances to reach them. In 2011, NASA tentatively suggested there might be 54 habitable worlds outside of our solar system but the closest would take about 2000 years to reach, and even then travelling at the speed of light. So, for now, there is only one planet for all to share.

One Planet Living is defined as the amount of human consumption and production in a given year that would allow the Earth to regenerate the same amount in the following year. It is profoundly influenced by the size of the human population against the integrity of the biosphere, which then relies on the ability of the Earth to provide material sources against its ability to process waste.

The idea of One Planet Living emerged with the landmark work of Wackernagel & Rees (1995) on defining Ecological Footprint (EF). Before this index was developed, there were two extant approaches to measuring human impact on the planet. The first was physical, more grounded in global climate science but rather difficult to apply at a policy level; whereas the second was economic, more applicable at a national policy level but beset with intra-nationally specific assumptions. Physical studies of human impact on the planet gained momentum in 1986 when Ehrlich and colleagues demonstrated that humanity was already consuming 40% of the world's net photosynthetic product (Vitousek, Ehrlich, Ehrlich & Matson, 1986).

Whilst Ecological Footprint owes its heritage to the physical indices, it also promised a more advanced metric of ecological externalities to economists by taking into account annual production of carbon emissions and the fraction of anthropogenic emissions sequestered by oceans and the re-uptake per hectare of forest land at world average yield.

The beauty of this index is that it can bring the global measure down to national and even household and individual levels by measuring it in hectares per person, making it one of the first policy-relevant physical measures available. By weighting itself against population, it can then measure the ratio of EF against the known limits of the biosphere, which means it also offers the first true measure of One Planet Living at the global level, defined as the amount of resources available for human consumption in one year that still allows for full regeneration of those resources for consumption in the next year, a definition resonating with the original definition of sustainability across time.

Compared to other metrics, EF has the strongest convergent validity with global satellite imagery split by country borders, one based on night-time light emissions (Sutton, 2003) and the other based on day-time aggregations of pavement (Sutton et al., 2009) . So it can be reasonably trusted.

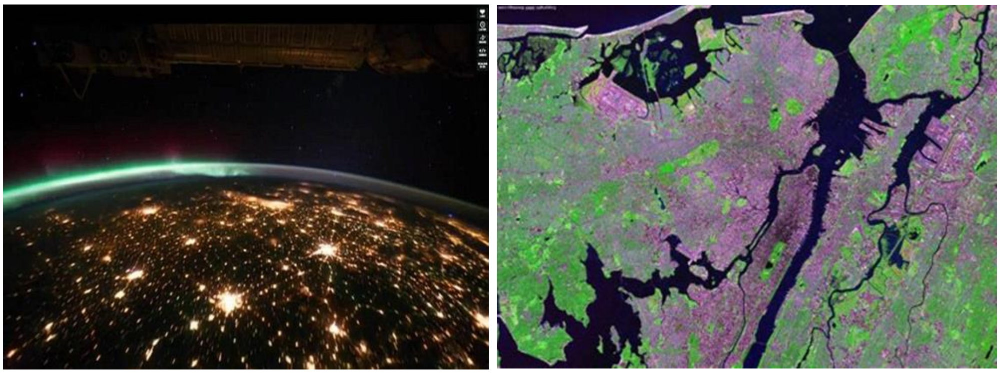


Figure 1-8 Examples of how satellite images can capture night-time light emissions and day-time pavement concentrations versus green areas (Read, 2012)

Every year, the Global Ecological Footprint Network commemorates a moving date where the world has used up its annual budget of resources and moved into future 'debt' affecting future generations. Since inaugurated on 19 December, 1987, World Overshoot Day has progressively fallen on earlier dates in the calendar year, demonstrating that growth in population and economic development is putting more strain on the ability of the Earth to regenerate resources for the following year. As of

2011, the date had moved by about three months to 27 September, even though the Global Financial Crisis (GFC) had actually softened its impact by forcing a reduction in global consumption. The last time One Planet Living was achieved was in 1987. As of 2013, the global population was using 1.5 planets per year, with countries like Australia living as if three planets were available for consumption by its people. Put another way, if all people lived like Australians, it would take three years for the Earth to regenerate before another year of consumption was allowed, at least if equity across time and generations was valued as much as equity across countries.

1.1.4 From the Enlightenment to Modern Sustainability

Since the Enlightenment, Rousseau's concept of the Noble Savage living in harmony with Nature has been mostly dismissed as a beautiful but impossible dream. By contrast, recent work on the economics of human height, drawn from three lines of evidence ranging from modern anthropometric data, back through centuries of military records, to paleo-anthropological bone measurements on ancient skeletal remains, highlight two impressive findings:

1. The Indian hunter-gatherers of the Great Plains in the 1700's were as tall as modern Danes (Diamond, 1987; Prince & Steckel, 2001)
2. But only the wealthiest kings and queens of the agrarian societies had access to enough protein in childhood to grow tall (Prince & Steckel, 2001)

Rousseau argued that a utopian society based on the fruits of Nature was not only possible but potentially limitless (an ironic resonance with modern economic growth theory), whereas the Reverend Thomas Malthus (1766-1834) said that human population, by its own greed, lust and savagery, would outstrip resources and cause famine (Malthus, 1807). This is why he described the emerging discipline of economics as the 'science of doom'.

By contrast, the father of economics, Adam Smith, wrote two noteworthy but apparently contradictory works, one in which he argued that human virtue, in this case sympathy and compassion, was the key to the good life (The Theory of Moral Sentiments, 1759) and one in which enlightened self-interest as the 'invisible hand of the market' was the key to maximising wealth at the aggregate, which he defined more broadly in the sense of modern wellbeing than monetary wealth itself (The Wealth of Nations, 1776).

Smith's work (1776) was the first to explicitly advocate the division of labour, which was one of the foundational elements of the Industrial Revolution and brought production out of the home and into the factories. This progressively removed people from Nature (agriculture) and families from their children and communities, laying the groundwork for institutionalised education, mechanised agriculture and funding for healthcare.

Yet despite Malthusian doom, the Industrial Revolution and the technological progress it embodied vastly improved agricultural food supply to a growing population and almost doubled life expectancies from its comparatively miserable baseline of 40 years (Bronowski, 1973). Moreover, economic growth was thought to promote equity because wealth 'trickled down' to the people (a concept recently attacked by Quiggan, 2010). As Bronowski (1973) said, the company Wedgwood was not built on the patronage of Catherine the Great who commissioned £2000 worth of hand-painted porcelain in 1774, but on the common earthenware sold for a shilling a piece. Growth emerged not from the patronage of the wealthy but from "the ability of manufacturers to more cheaply provide for the poor – cotton underwear and soap, a greater choice of food, glass windows, coal burnt under an iron stove and an extra bedroom to afford ladies some modesty" (Bronowski, 1973, p.279).

Before the Industrial Revolution, at least according to Bronowski (1973), "the country was a place where men worked from dawn to dark, and the labourer lived not in the sun, but in poverty and darkness" (p 260). Further in support of this post-industrial view, the pace of technology allowed humanity to more efficiently draw many more resources from the environment – a trend which has remained self-evident through the power of steam, coal, electricity, petroleum, nuclear energy, solar, wind and waves, all steadily pushing human development and population growth far beyond anything Malthus ever imagined. Rather than the kind of population collapse expected by Malthus, UN population projections to 2050 now suggest a world population of around 10 billion and up to 38 billion - such is the range of variation in the four scenarios modelled (UN Population Division, 2009, 2011). The history of human ingenuity and the pace of technology avoided all the earlier predictions of Malthusian doom.

Ironically, a return to the kind of Paradise envisioned by Rousseau would now, in the absence of modern agriculture, trade and transport, result in global starvation. This precludes the traditional 'back to nature' approach taken by, for example, the Findhorn Foundation and other utopian subcultures in the developed world (see Findhorn.org). These approaches are too land-intensive to be upscaled at a global level precisely because the fruits of industrialisation among the countries in which such communities are nested are not yet shared across cultures, generations and countries.

By contrast, the majority of families and children need further agricultural and technological development, not less. The United Nations International Children's Emergency Fund (UNICEF, 2000; cited in Shah, 2011, p.1) says more than one million children die each year due to poverty and they "die quietly in some of the poorest villages on earth, far removed from the scrutiny and the conscience of the world. Being meek and weak in life makes them even more invisible in death." For many, their lives are further cheapened by human trafficking, sex tourism, organ harvesting and slavery, all supporting economic growth in both the developing and developed world, especially when complicated by globalisation (Roby, 2005). Think, for example, *Nike*, cheap t-shirts and chocolate; even toys for export to the developed world for Christmas are manufactured using child labour - the moral dilemma being that closing down the sweat-shops put children on the streets.

Another problem is sustainability itself. As stated, the original definition was 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (Brundtland, 1987, Chapter 2, p.1). If all countries pursue the classic trajectory of industrialisation, the amount of economic growth needed to redress the balance would consign all future generations to ecological collapse long before the year 2100 (Hansen, 2010). The term 'development', since dropped in favour of the single word 'sustainability', was originally meant to focus on the needs of the developing world but was then distorted to justify further growth in the developed world (Beder, 2000).

By 2012, 15% of the world's people were still starving but 1000 wealthy individuals had capitalised on growth to such an extent that they owned 5.7% of annual global production, more than the combined wealth of 3.2 billion of the world's 7.2 billion people (Kroll, 2012). This alone challenges the idea that a free market economy ensures wealth trickles down to the majority (Quiggan, 2010).

Quite apart from international inequity affecting the developing world, it appears the developed world itself is failing to preserve human equity and human outcomes (see Eckersley, 2005). Children in the UK are less happy and healthy than poorer countries in the Organization for Economic Co-operation and Development (OECD), the wellbeing of US women has been falling relative to men since the 1970s (Stevenson & Wolfers, 2009) and one leading Australian paediatrician says today's children will be the first to suffer reversals in life expectancy (Stanley, 2008).

According to a large study by the Australian Childhood Foundation (Tucci et al., 2007) one in three Australian primary school children now believe the world will end before they have a chance to grow old (possibly related to the practice of pushing causes, whether positive or negative, by targeting school children to influence parental behaviour, see Hamilton, 2009).

Note that parental wealth in the United States now has virtually no impact on child wellbeing compared to fears about the environment, divorce and crime (Twenge, 2000; Garner, 2008). In this study, the increases were so large and linear that by the 1980s most children scored higher on the anxiety scale than did children in the 1950s who were psychiatric patients. Since becoming one of the wealthiest nations in the world, the most recent data across almost 300,000 children from the Australian Early Development Index shows one in five children are still vulnerable to poverty, family break-down, child abuse and/or neglect (AEDI, 2013; see also Stanley & Goddard, 2002). Another study of young Australian males aged 16-25 shows 20% believe 'life is hardly worth living' and 8% have enacted plans for suicide (Burns et al., 2013)

What these findings suggest is that the developed world is not yet an appropriate model of growth that serves the lived experience of its people, much less the needs of other countries, generations and cultures. It also suggests different kinds of growth and development could be pursued in such a way that a fair target – one that might even satisfy the conditions of Pareto efficiency, where nobody loses and everybody gains; if the symbolic value of money is replaced with actual human outcomes that are equally valued across countries, cultures and time – things like subjective wellbeing and life expectancy.

Drawing together much additional evidence, Eckersley (2005) argues for a Multidisciplinary Synthesis that applies systems theory to economics, public health and psychology, among others, to start balancing broader trends across disciplines and policy and move societies forward in a way that is sustainable, healthy and matched to evolutionary human needs. He says (p.2) "the central purpose of a nation should be to improve the quality of life of its people. It follows that the primary function of public policy should be to improve quality of life." Nobody would disagree with this – it only requires more effort towards providing transdisciplinary evidence for what is actually meant by 'quality of life'.

By highlighting the concept of needs within the definition of sustainability, this project makes one such attempt at a politically agnostic methodology that looks to cultures and countries over time that have more successfully balanced the regulation of human and planetary needs. For decades, such countries have perplexed authors because they seem to achieve extraordinary human outcomes – both health and happiness - despite comparatively meagre resources - and regardless of different ideologies. They range across the full spectrum of political, cultural and ethnic boundaries but are unique in the way they produce, share and distribute economic growth in support of human outcomes.

This project does not argue against growth *per se* and nor does Eckersley's Synthesis Approach (2005). Even the founder of The Club of Rome, Aurelio Peccei, was one of the first to recognise that sustainability does not argue against economic growth so much as it argues against illusory and artificial values that, ultimately, do not serve humanity. "The humanism consonant with our epoch must replace and reverse principles and norms that we have heretofore regarded as untouchable, but that have become inapplicable, or discordant with our purpose; it must encourage the rise of new value systems to redress our inner balance, and of new spiritual, ethical, philosophical, social, political, aesthetic, and artistic motivations to fill the emptiness of our life; it must be capable of restoring within us … love, friendship, understanding, solidarity, a spirit of sacrifice, conviviality; and it must make us understand that the more closely these qualities link us to other forms of life and to our brothers and sisters everywhere in the world, the more we shall gain." (Peccei, 1981, pp 184-5)

1.1.5 A Short History of the Fight for Sustainability

Over the past few centuries, industrialisation harnessed so much energy outside of the metabolism of any single individual that many in the developed world now live as if they have thousands of 'energy slaves' – many more than former kings and emperors. Economic independence at the individual level has evolved in tandem with economic inter-dependence at the social level. Yet even this kind of growing 'extra somatic' metabolism[4] still needs to process waste; and because the effect is not immediately felt by the individual, corrective feedback loops cannot operate and the waste accumulates in the biosphere outside the required 'perfect knowledge' of the free market economy. This means the cost of economic growth is also shifted across countries, generations and other species. It also means that economic growth can come at a personal, family and community cost, even without counting the planetary costs.

This is a difficult issue at the nexus of psychology and economics. Despite escalating urgency, one reason why climate negotiations continued to stall at Copenhagen and Cancun was because countries could not agree on a fair target that simultaneously preserved both international and inter-generational equity. The developed world built whole economies on 'energy slaves' in three forms other than fuel – labour productivity in its own world, labour in the developing world and borrowing against the future. This means there is psychological resistance to pulling back emissions and inequity for multiple economic reasons.

Leading climate economists, Nordhaus (2009) and Garnaut (2011), have independently said climate science is too scary for the public (in the developed world) to assimilate.

"Calls for economic sacrifice, major changes to our lifestyles, and the immorality of continuing 'business as usual' — such as going on about the business of our daily lives in the face of looming ecological catastrophe — are almost tailor-made to trigger [denial] ... Having been told that climate science demands that we

[4] Extra-somatic metabolism is the processing of energy outside of the body to sustain life – humans excel at this although it is also found in other animals.

fundamentally change our way of life, many … have, not surprisingly, concluded that the problem is not with their lifestyles but with what they've been told about the science; … the threat is distant in both time and space, it is difficult to visualize and it is difficult to identify a clearly defined enemy … Rather than galvanizing public demand for difficult and far-reaching action, apocalyptic visions of global warming disaster have led many… to question the science." (Nordhaus & Shellenberger, 2009, p 2)

As early as 1966, the Club of Rome warned of ecological collapse unless either population or consumption was modified before 1985 (Meadows et al., 1972). It's work at MIT described a balanced ecological system of renewable resources and biological sinks that re-used the by-products of those resources and sank them back into the biosphere for continued production of resources for human consumption Using the most advanced technology at the time, the group ran a series of computer models, much like those used in modern economics, to describe the projected interactions of key variables split into five main groupings: human population, food, industry, pollution and resources. They were startled to find that the standard run, which they called 'business as usual', resulted in a gradual reduction in resources when a rapid fall in food supplies was closely followed by a dramatic collapse in industry and then human population.

The model suggested there would be population overshoot by 2025, economic collapse, widespread famine, food riots in Europe and resource wars in the Middle East. They re-ran the model with all sorts of constraints on industry, population and production until they found a stable version, which they described as Scenario 10. The problem was that the model required population growth pulled back to 1975 levels, capital growth pulled back to 1990 levels, resource consumption and pollution per unit of output both at a quarter of 1970 levels, societal values to move from material goods to education and health, redistribution of wealth to food production, soil enrichment and product durability rather than planned obsolescence to maximise profit.

The work was vigorously contested by economic thinkers at the time who said it was retrograde, Malthusian, naïve and anti-growth. They argued that efficiencies gained from human labour (population) and technology, funded by economic growth, would circumvent their prophecies. Although widely accepted (even among economics textbooks), these arguments emerged in a period charged with technological optimism following NASA's successful moon landing in 1969. The post-War era was still buzzing with the successes of military victory and technological supremacy supported by the emergent soft power exercised in film and television. The extremes of Communism and Nazi Germany were staunchly resisted as an assault on human virtues shared by economics, politics and populace alike, going all the way back to the US Declaration of Independence and its self-evident truths about equality, freedom and the 'pursuit of happiness'. Only some of these issues are still problematic.

One of the most intractable arguments against sustainability is the apparent neo-liberal faith in technology. Since the Industrial Revolution, global population and technical innovation allowed the two forces to go hand-in-hand in a 'virtuous' cycle of growth and development. The problem was that over the past two centuries this cycle mostly relied on non-renewable sources that are now impacting on the ecological systems needed to house and support huge and growing populations. It is becoming a 'vicious cycle'.

By contrast, the latest data on technical efficiency, as measured by economic output weighted per unit of ecological impact, regardless of how ecological impact is measured, shows that only a small minority of mostly Nordic countries are implementing technology at a pace that might help circumvent their own impact. Meanwhile, the current rate of technical growth is much lower than increases in population and resource dependency, especially as huge countries like India and China. Although investing more in education and technology than the United States and Brazil, China and India are poised on the precipice of historically unprecedented resource usage that will likely devastate planetary 'metabolism' if they follow the same trajectories as developed nations. Whilst the rate of growth was recently confirmed across 62 technologies as exponential (Nagy et al., 2013), human population growth is also exponential in large developing countries (Magnus, 2009). This is not so at the world level where it is more linear since 1960 (UN, 2003), but its ecological impacts are becoming super-exponential, even when using macroeconomic models (Husler & Sornette, 2011). So technology, whilst necessary, is not likely to be sufficient in order to avert the worst case scenarios so far predicted.

While the Club of Rome argued that the way we value progress should be changed, another argument that arose at the same time - and was roundly criticised by ethicists - was led by Paul Ehrlich with the publication of The Population Bomb (Ehrlich, 1968). This urged population control as the solution to ecological collapse, rather than technological innovation, although this was staunchly resisted because it resonated with Nazi genocide and later Chinese eugenics.

Any assault on freedom was understandably resisted, even if it was based on absolute ecological limits rather than relative political ideologies. In 1990, Ehrlich was famously humiliated by losing a bet with economist Julian Simon, who correctly predicted that the price of five metals would fall despite growing scarcity and overconsumption in the 1980s because of growing technological efficiency (Tierney, 1990). By 1990, Simon was proved correct. One reason Simon won the bet is perhaps because his reliance on economic theory was more grounded in short-term pay-offs rather than longer term impact on the environment, which could not yet be measured and could take generations, rather than decades, to manifest.

Notwithstanding Simon's successful predictions, damage to the environment manifested despite the behaviour of the market. A year after Simon made his bet with Ehrlich (1980), NASA physicist James Hansen (1981) would publish his first paper on global warming, but the ecological costs of economic development first reached prominence with evidence from much earlier work.

Inspired by a self-funded expedition by James Lovelock to study the concentration of CFCs over the Arctic and Antarctic in 1973, Nobel laureates Frank Rowland and Mario Molina presented data in 1974 that the breakdown of CFCs in the stratosphere would release chlorine and catalyse the destruction of the ozone layer. This was the first major confirmation of negative ecological externalities from economic activity on a global scale and supported Lovelock's Gaia Theory that the biosphere itself was a metabolic unit. As ozone formed the main line of defence against ultraviolet radiation, its destruction would lead to the death of crops, reefs and marine phytoplankton, the main food-source of the world's oceans, as well as causing higher rates of human skin cancers and blindness.

Although it took another 13 years, international cooperation eventually led to the Montreal Protocol in 1987, two years after British Antarctic scientists confirmed the hole in the ozone layer was already much larger than predicted. Forging a treaty to completely eliminate CFCs by 2010, the role of international government was needed to guide the 'invisible hand' of the market.

Although CFCs will not be fully eliminated until 2050, the Montreal Treaty was signed by 197 member states of the United Nations and lauded by Kofi Anan as "the single most successful international agreement to date". The agreement stimulated industrial ingenuity and many new industries began to flourish under the sustainable practices imposed. It was later cited as a beacon of hope for climate change when the Club of Rome revisited its analysis using new data in 1995 (Beyond the Limits, 1995).

In the same year as the signing of the Montreal Protocol, the Brundtland Commission carefully defined sustainable development, which began to embrace concepts of balancing equity across and within generations based on ecological integrity (Brundtland Commission, 1987). A year earlier, the first global measures of human ecological impact began to emerge when Ehrlich and colleagues estimated photosynthetic product (Vitousek, Ehrlich, Ehrlich & Matson, 1986). So momentum for the development of an index of social progress beyond Gross Domestic Product (GDP) was growing.

An alternative to the more physical measures - one less grounded in science but more usefully applied in policy - was the monetary index developed soon after by World Bank economist Herman Daly and theologian John Cobb (1989). Daly and Cobb's Index of Sustainable Economic Welfare later evolved into the Genuine Progress Indicator (GPI) and leant some weight to the Green GDP (see Lawn, 2003). This was itself based on the more conservative Index of Economic Welfare first proposed by Yale economist William Nordhaus (Nordhaus & Tobin, 1972) whose work on the DICE model of climate change later challenged the Stern Report (Stern, 2006).

The main contribution of Daly and Cobb (1989) was twofold, first in advocating steady-state economic growth and second in suggesting that the benefits of GDP and its growth must be weighed against measures of human community and ecological costs, without which GDP represented in part what they called uneconomic growth. This can be likened to the difference between a company's turnover (GDP) and its actual profit once costs have been accounted for (GPI).

Presently, the biggest sources of pollution come from land use (9%) and burning fossil fuels (91%), while the waste generated is processed by the atmosphere (50%), the oceans (24%) and the land (26%) (Global Carbon Project, 2008). These percentages can be further broken down to sources from agriculture, transport and energy production. They can also be compared across and within countries and industries subserving human consumption. For example, 30% of global carbon emissions are presently devoted to food production, packaging and distribution (Stern, 2006). Lawn (2003) recently enumerated the costs of uneconomic growth as resource depletion (sources) and pollution (sinks), as well as human impacts like crime and family breakdown.

Despite the success of the Montreal Protocol in 1987, the US Congress was confronted only a year later with evidence of another emerging ecological problem – anthropogenic climate change (Hansen, 1988). On June 23, 1988, the Congress heard evidence from James Hansen that he was 99% certain greenhouse gases emitted from the burning of fossil fuels was contributing to long-term planetary warming. Without acting to reduce greenhouse gases, the levels in the biosphere could conceivably pass a tipping point where feedback loops would rapidly hasten emissions beyond human control (Hansen, 2008). Apart from the direct impact of a hotter planet and rising sea levels from glacial melt, Hansen also predicted that both extremes of the water cycle would become more turbulent, increasing the rate and impact of rains and floods on one hand and droughts and forest fires on the other.

Hansen's analysis (2008) was based on data from meteorological stations that showed 0.6^0C warming from 1880-1985. Because the stations were mostly sited in urban centres, it was argued that Hansen's results could be an artefact of the urban heat island effect first described by Luke Howard (1810). It was also criticised because the level of warming was much smaller than temperature variations known to have occurred during the Medieval Warm Period (IPCC, 2001). It was only later that climate scientists began to collect proxy measures of temperature much further back in time, based on ice-cores, water sediments, coral growth and tree rings, which all showed the same effects. Proxy readings over the past 1165 years were later published in the journal *Nature* in 1998 and confirmed Hansen's concerns (Mann, Bradley & Hughes, 1998; see also Brumfiel, 2006).

More recently, temperatures in 2012 were among the hottest over the past 12,000 years when atmospheric CO_2 reached 394 parts per million (ppm); on May 2, 2013, concentrations breached 400 ppm for the first time in 800,000 years (Biello, 2013). Many other criticisms were levelled at Hansen's results, including the effect of volcanic eruptions (see Wishart, 2009). However, these only contribute around 180-200 megatonnes (Schlemmer, 2013) whereas man-made emissions are 2000 times greater (36 gigatonnes). Further, biological sinks like forests and oceans now absorb only about 10% of emissions, whether man-made or not (Flannery, 2005).

Hansen's submission to the US Congress was followed four years later in 1992 with the UN Earth Summit which was convened in Rio to stabilise greenhouse gas emissions, but also highlighted growing issues of water scarcity, fossil fuel depletion and poisonous transport emissions (Brown et al., 2005). In part this recognised the ecological limits first enunciated by the Club of Rome and galvanised the idea that there were limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs.

The Earth Summit also introduced the Precautionary Principle, arguing we should exercise caution in the face of uncertainty when the outcome of an action is likely to be catastrophic (Jordan & O'Riordan, 2004). This principle evolved from German legal philosophy in the 1930s before being passed into statutory law in the European Union. In its strictest sense, it shifts the burden of proof such that any development initiative must prove its negative impacts will be small in the face of uncertain risk.

To explain, for example, stubbing your toe is almost 100% certain in your lifetime but it will affect only one person and then only for an infinitesimally small percentage of your lifetime. By contrast, the chance of complete annihilation by a meteor strike is only around 0.68% in an average human lifetime but presently needs to be multiplied by 7.2 billion people. Multiplying risk by impact changes the context to such an extent that the low-risk of a meteor strike becomes 2.4 billion times more consequential than a high-risk event with low impact like stubbing your toe.

The Precautionary Principle goes further in that action (or inaction) must not cause significant harm and, if it does, there must be compensation. In itself, the idea of compensation raises many more questions about the value of human life and is often informed by econometric studies of questionable value (Murphy et alia, 2004; Viscusi & Aldi, 2003). Suffice to say that future generations are already at a disadvantage as they can never claim compensation against earlier generations that failed to take action.

The Earth Summit further stimulated serious work on developing measures of economic growth that appropriately measured ecological externalities, all of which remained limited by the lack of cross-national metrics for ecological impacts that could be given a dollar-based value. This was the main challenge facing authors as economics and ecological science attempted to work together using different methods. Economic approaches similar to the work of Daly and Cobb (1989) included environmental accounting (Yusuf, Serafy & Lutz, 1989), 'weak sustainability' based on Capital Theory (Pearce & Atkinson, 1993) and China's Green GDP, later dropped because of its impossible implications for current growth, the same issue inciting arguments between Stern (2006), Dasgupta (2008) and Nordhaus (2006) on the discount rate. On the ecological side there emerged, inspired partly by Ehrlich's earlier work on physical indices, the Human Appropriation of Net Primary Production (HANPP), the Material Input Per Unit of Service (MIPS) and Ecological Footprint (Wackernagel & Rees, 1995). From these works emerged gradual progress on both sides leading up to the Stern Review (2006) that combined the full range of available data across disciplines.

Unfortunately, the timing of the GFC in 2008 deflected concern for the climate not long after public media began questioning Al Gore's 2006 presentation of the 'hockey stick' curve (see Figure 1-2-b). This was soon followed by media exposure of the so-called 'Climate Gate' of 2009, in which tree ring data was described as a 'trick' in a personal email between colleagues at University of East Anglia (Chameides, 2010). Although much was made of this email in the media, it was not much more than the usual 'self-deprecation' in non-formal communications between colleagues and was taken out of context. The world's leading scientific publication, *Nature*, said on two occasions that the email could not be taken seriously by anyone other than the most ardent 'denialists' (Nature, 2009; *Editorial*). It was rightly described as a manufactured and orchestrated distraction made all the more damaging as it was hacked and publicised just before the Copenhagen Summit. An independent review, much less publicised, completely exonerated the scientists in question (Adam, 2010).

As for Al Gore's 'hockey stick', there had already been solid and appropriate scientific argument about its veracity long before it became headline news. The original paper (Mann, Bradley & Hughes, 1999) traced temperature over the past 1400 years, showing temperatures were stable until about 1900, following the Industrial Revolution, when they rose dramatically. The main issue, in the first instance, was that actual thermometer measures of temperature were only available in some countries over the past 150 years, back to 1860, and carbon emissions measured in parts per million (ppm) were only available since 1959. So climatologists had to use proxy measures to go back further in time. They began by using tree rings and coral growth, later expanding the measures to carbon trapped in ice-core data going back many thousands of years. The latest work has now expanded to measuring a total of 73 proxies to reconstruct both carbon emissions and temperatures going all the way back through the Holocene period 11,300 years ago (Marshall, 2013) to the more distant past over millions of years. This new work again confirms the Hockey Stick as heading rapidly towards an unnatural peak of temperature associated with carbon emissions and impacting on human populations long before 2050 (Meinshausen et al., 2009; Read et al., 2013).

The greatest irony has been that even as climate science strengthened its case, opinion polls showed public concern started waning. In the US, the Pew Research Centre released a 2009 survey showing public ‘belief’ in global warming fell in just 18 months from 71-56% and belief in anthropogenic causes declined from almost half to one third (Nordhaus & Shellenberger, 2009). The same trends emerged in a worldwide Gallup Poll showing many more people (more than a third) began to think the threats of global warming had been exaggerated.

In the UK, an equivalent poll across similar time periods demonstrated the same trends: again from 2005-2010; complete denial of global warming rose from 4-15%. The leader of the UK survey, Nick Pidgeon, said people “have become a bit bored at hearing about climate change all the time; yet another climate story and the world hasn’t drowned yet” (Kalaugher, 2011, p.1). He argues that the fall in concern is a form of ‘compassion fatigue’ and it hasn’t helped that the debate has moved into the political sphere, where people are even more distrustful of politicians than they are of ‘so-called’ experts. Other works have tried to track the reasons for public scepticism, citing psychosocial theories ranging across compassion fatigue, systems justification theory and learned helplessness.

Compassion fatigue was first described among nurses in the 1950’s whose work constantly exposed them to human tragedy and was described as a state where people are forced to dampen their emotional responses to catastrophes affecting others. Similar effects are documented during times of war and have recently been studied in terms of people giving to charities when confronted with repeated images of starving children in other countries. Compassion fatigue is used to explain decreased giving rates, especially among countries where the government has withdrawn public funding and pushed many charities to pursue more aggressive and repetitive marketing campaigns. The fact that the wealthiest communities tend to give less than the poor, at least as a percentage of their total wealth, might also suggest that compassion itself, variously described as empathy or ‘self-centred inequity aversion’ (Fehr & Schmitt, 1999), might either be a stable trait that affects people’s accumulation of wealth in the first place, or else a problem of relative context. As a learnt and self-preserving adaptation, compassion fatigue is also relevant to climate change and the reasons proposed have ranged from habituation and desensitisation through to more psychodynamic explanations such as suppression, denial and ego justification (see discussions on *Apocalypse Fatigue*; Nordhaus & Shellenberger, 2009).

When it comes to denial, Nordhaus and Shellenberger (2009) suggest that rising public scepticism of climate change could be explained by systems justification theory, citing the social psychology work of Jost (2004) . This theory states that when people are under psychological threat they tend to default to justifying the socially accepted status quo within their own reference groups, using cognitive rationalisation to deflect the perceived threat. An example often cited to explain political differences is where people evoke stereotypes to support their own social position. Consider, for example, a rich person who stereotypes the poor as lazy and unworthy, or else a poor person who views the wealthy as selfish and uncaring. This is a motivational belief that is presumed to arise from ego-justification and the protection of self-concept. The effect can sometimes be so strong that it even undermines the wellbeing of the person who cleaves to that ideological belief. Nordhaus and Shellenberger (2009) argue that systems justification theory would explain the tendency that, as the climate science grows in strength and volume, the debate becomes more polarised and even begins to lose support as the realities become more threatening.

Another two classic psychological studies might also have implications for what is now being called ‘climate fatigue’, one based on learned helplessness and the other based on conformity. One is the original study of ‘learned helplessness’ by Seligman and Maier (1967), demonstrating that a dog confined to a cage and subjected to constant electrical shocks will eventually learn to give up any attempt at escape, leading to a learnt state resembling depression (see also Overmier & Seligman, 1967). The implications for the emergence of human (reactive) depression were later explored (Seligman, 1972; Abramson et al., 1978). The other is an equally classic study by Milgram (1963), although since challenged, showing that humans themselves will continue to submit another person to electrical shocks if they think it is supported and encouraged by other people, here resembling the conformist behaviour under regimes like Nazi Germany. The theme will not be elaborated here, but the main implication for ‘climate fatigue’ would suggest that people could resign themselves to the inevitability of an apocalypse if their individual concerns are constantly perceived to be overwhelmed by a dominant paradigm that is more concerned with preserving current economic growth.

A recent survey of attitudes towards climate change suggested people in the developed world have vastly different views based on age and gender (Maibach, Roser-Renouf & Leiserowitz, 2008). As might be expected, the broad trend suggested younger women, especially those with children, are significantly more concerned about the future of the planet than older men, especially those with investments. Older generations in the developed world might have other reasons to be sceptical. They have a much greater appreciation of history than younger generations and so tend to resist tackling scenarios that resonate with past history in which the worst, at least post-WWII, rarely eventuated. As school children themselves, they were made to run through nuclear drills by hiding under their desks and they grew up under clouds of other apocalyptic threats that never emerged. They not only survived but grew up to enjoy some of the greatest economic boom periods in human history. They saw the Domino Theory of 1954, the Cuban Missile Crisis of 1962 and the hole in the Ozone Layer of 1985, all go from headline news to silence. So yet another apocalyptic prediction might be viewed with understandable scepticism because it is counter to lived experience.

Given the most recent climate science, it suggests that this, more powerful generation – rather than children – should be the key audience at the global level. Further, Pigeon (2011) says that all climate facts should be communicated in a straightforward manner that allows people to make their own decisions based on pure, accessible and understandable science. For those who deny climate change, the Precautionary Principle at least argues that they must weigh the evidence if they want to continue to live their lives under conditions of 'Business as Usual'. Weighing the evidence is almost impossible for any public informed by a news cycle that aims for objectivity by giving equal time to polarised views. Based on a recent review of 12,000 peer-reviewed scientific papers (Cook, 2013), this policy has the effect of giving equal 'weight' to 3% of the scientific community, effectively distorting the public perception in favour of disavowing the urgency of climate change.

The urgent need for more public understanding of the science argues that science should make a greater effort to make the underlying theories and assumptions more transparent. Its ideas should be carefully simplified by analogy, jargon and peripheral technicalities avoided unless absolutely central to the dialogue, and, if ever appropriate, undertaking the greater task of building simpler, more transparent and replicable analytic methods.

1.2 INTERGENERATIONAL EQUITY AND ECONOMIC DISCOUNTING

This section explains the tensions between different forms of equity that have been tested in the context of sustainability, attempting to understand the basic economic issues underlying climate policy research whilst exploring alternative ways of measuring human outcomes – from utility to wellbeing. The discussion that follows needs to be understood in the context of Ramsey's original equation for the social discounting rate (Ramsey, 1928; cited in Arrow, 1995):

$$\mathbf{r = \rho + \eta . g}$$

Such that ***r***, the discount rate of consumption in the future (a kind of 'impatience' quotient), equals ***g*** as the growth rate (expected future increase) in per capita consumption (by future generations in this context), multiplied by ***η***, how quickly utility drops as consumption increases (the elasticity of the marginal utility of consumption), plus ***ρ***, the discount rate of utility (presumed to reflect wellbeing). In terms of climate science and intergenerational equity, a strong review of the three key mathematical components is provided by Conceição, Zhang & Romina (2007), covering the range of rates from 0-3% used by Nordhaus (1994), Cline (1992), Stern (2006) and Dasgupta (2007). All are contestable when their mathematics are drilled down to their basic ethical assumptions and/or evidence bases, hence the controversy surrounding them.

1.2.1 The Value of Future Generations

Although inter-generational equity is a natural requirement for human survival, it has 'trickled up' to policy too slowly because it is too methodologically problematic and imposes many theoretical hurdles at the confluence of law, ethics and economics. Some ethicists and legal professionals argue that future generations are, as yet, unborn non-persons and so have no rights to equity in the first place (for a review, see Thompson, 2003). Some economists, extrapolating on past decades of economic growth, argue that the wealth of future generations would be so great that "equity between generations implies a strong case for redistribution from young to old" (McDonald, 2005, p13). This argument relies on two assumptions, the first being that human wellbeing derives from economic utility and the second that climate change does not exist.

Until recently, economics has eschewed any attempt to directly measure human wellbeing, relying instead on inferring it from actual human spending on products as relative prices and income compete. Although methodologically sound, this theory is usually supported by data from within, not across, countries and cultures, much less other disciplines like health and climatology. This is one form of the normative approach to discounting the wellbeing of future generations. Another approach is that any costs we are willing to bear on behalf of our children should be discounted based on the rate of pure time preference adjusted by the possibility that future generations might not even exist (e.g. Stern, 2006; Garnaut, 2008). A third economic approach to devaluing the wellbeing of future generations avoids value judgments by simply applying observations from real-world markets such as the interest rate. All of these approaches tend to forget that money itself is a symbolic metric for the transfer of physical resources that are threatened by climate change in the first place, and would, ironically, be degraded by these self-same assumptions if intergenerational equity were devalued. Stern (2006) applies two normative discount rates, one allowing unity for intergenerational equity and the other based on the probability of Earth being hit by a meteorite, in which case the likelihood of complete human extinction is 0.01 per year. By inserting this rate into his model of climate economics (the PAGE model), Stern effectively discounts the value of current action to prevent climate change which, ironically, has the effect of increasing the likelihood of extinction by climate change itself – what is described here as a *'Double Extinction Paradox'* in the discounting debate[5].

The extinction probability used by Stern was at least balanced by his approach to the other discount rate, which then became the subject of much controversy. Stern argued that the ideal equity ratio between current and future generations should be 'unity', meaning the wellbeing of future generations should be equally valued against that of current generations. Anything greater than this, he argues, is ethically indefensible, echoing the exact words of Ramsey (1928) who originally developed the mathematical model of savings, and also following the later foundational econometric work of Cline (1992).

Using this discount rate, The Stern Review concluded that the cost of inaction would begin to compound as a loss of 5% of global GDP every year, which, it should be remembered is higher than the rate of economic growth and so leads to a deepening decline in human welfare as the years unfold. If the worst case scenario

[5] Reducing the value of future generations' wellbeing based on the likelihood of extinction by other means logically inflates the discount rate which then weakens the policy imperative for mitigation and adaptation, thereby inflating the likelihood of extinction by climate change itself – a kind of ***Extinction Paradox*** that afflicts even the more generous and ethical discounting position taken by Stern versus Nordhaus, for example, but still requiring such extreme action that current action to reduce future extinction could be strong enough to cause equally powerful collapse in the current era as per Dasgupta – hence the term 'Double Paradox'

eventuated, Stern argued this would rise to 20% of global wealth. In order to avoid the worst of climate change, the current generation would have to start investing in adaptation and mitigation strategies at a cost of only 1% per year, although Stern later modified this estimate upwards to 2% to account for new climate data showing the pace of change was actually faster than originally modelled.

Nordhaus (2007), who built the United States' competing DICE model of climate change, criticised Stern by saying his discount rate of intergenerational unity was non-standard and too low. Nordhaus puts the discount rate at 3% whereas others argue for the more future-punitive 5% based on the value of money imputed from investment (e.g. US Treasury Bills; see Taylor, 2006). These sorts of higher discount rates are more traditionally applied to short-term economic projects with more easily discernible parameters than those presented by climate change (Cline, 2004). Even though the Stern Review used standard cost-benefit analyses, its low discount rate led to starkly different conclusions about how much time and how much action might be required to ramp up a global response to climate change. At first blush, said Nordhaus (2007), discounting seems to be little more than a technicality, but it turns out to be the central nub of climate economics.

The implications of the discount rate are profound. As McDonald puts it (2005, p.11), a positive rate of time preference suggests future wellbeing is worth less than current wellbeing - 3% per year, for example, reduces the value of wellbeing 50 years hence by up to 78%, suggesting that the wellbeing of generations living then should be weighted as less worthy than those living now, which in turn encourages more current consumption and less saving. By contrast, saving is encouraged by the interest rate, the marginal product of capital, driven by economic growth. At a growth rate of only 1.5%, GDP per person would still have doubled after 50 years, suggesting that the wellbeing of generations living then can be sacrificed to offset current consumption now; that is, borrowed against. Only when the difference between time preference, *p*, and interest rate, *r*, is zero do the two competing effects cancel each other out to provide a theoretical condition where standard of living has been equalised over time and between generations. The optimal growth rate of consumption was given by Ramsey (1928) to be $(p\text{-}r)/\Theta$, where Θ is the curvature of the social welfare function.

To digress a moment, the social welfare function ranks alternative social states as if they were an economic indifference curve, a curve that balances utility against competing commodities, but here embraces the utility of the whole society. It was introduced by Bergson (1938) as an attempt to mathematically describe the 'conditions of maximum economic welfare', which theoretically improves the lot of one or more people without impacting on any others (later called Pareto efficiency when satisfying the condition that nobody is made worse off by an improvement). Once again, the idea of social welfare, or being worse off, is value-laden and could be applied to many different social objectives, ranging from wealth and health to happiness. Mostly it is applied to economic welfare, and even then complicated by Arrow's Impossibility Theorem (Arrow, 1995) which argues that anything more than two competing outcomes can never achieve Pareto efficiency.

Moreover, what can be achieved by a society against its particular levels of resource consumption is empirically limited by the Possibility Function – the maximum utility derived at different levels of consumption given current states of technology (Samuelson, 1947). There are major problems with using average wealth at the aggregate level, as used in these models. One is that the average fails to take account of existing inequities within the society itself. In contrast, Rawls (1971) argues that the criterion for optimal welfare must be achieved with reference to optimising the welfare of the poorest in society and not the average. In a similar vein, Sen (1963) argues the average should be multiplied by social inequity, as measured by the Gini coefficient, to provide an estimate of equity-weighted welfare. This brings a number of ethical and philosophical questions into the debate. For example, the utilitarian principle of Bentham (1776) argues that the proper aim of government is to pursue policy that achieves 'the greatest happiness for the greatest number'. All of this boils down to a simple maxim: governments can never satisfy all the people all of the time, they can only try to satisfy most of the people most of the time, which brings us back to the more complex task of satisfying most of the people *across* time.

Under Stern's condition of intergenerational unity (Stern, 2006), Dasgupta (2007) argues that current generations would have to virtually starve themselves by committing 97% of current global GDP to shore up the wellbeing of future generations. Given past growth rates, he argues, people living in 2080 are expected to enjoy per capita incomes of US$97,000 compared to the 2007 global average of only US$7,000, an increase in absolute wealth of such proportions that it immediately questions why current generations should sacrifice any of their own income, or utility, to support their much wealthier descendants. This and other factors, says Dasgupta, might help explain why China's Green GDP was dropped within three years of its introduction. Although it later turned out that Dasgupta made a minor error (De Long, 2006), the fact remains that intergenerational equity, at least when handled by the standard assumptions underlying econometrics, is simply impossible to achieve.

In Australia, Garnaut (2008) took a more moderate path but was still attacked for using a low discount rate of 2%, once again by authors citing Nordhaus that rising per capita incomes suggest future generations will be better off so we can more heavily discount their incomes (Porter, 2009). Garnaut based the rate of 'pure' time preference[6] on a review of the econometric literature, pointing out that the discount rate is far from settled.

The complexity is summarised as follows: Quiggin (2008) argues that unity is more common in the literature; Dasgupta (2007) argues unity undermines the tax system; Evans (2005) shows the average elasticity of marginal utility across 20 OECD countries, presumed to approximate a norm for how much society values equity, was 1.4%; Nordhaus (2007) uses 1.5% or higher based on the real rate of return on capital, arguing that climate action is nothing more than yet another investment opportunity competing for funds and that a value of 2% would provide much more equity in redistribution; Smith (2010) finds elasticity of unity implies savings rates within the range of contemporary experience; Sen (1961) argues for a zero rate of pure time preference, as does De Long (2006) who shows a rate of 3% suggests somebody born in 1995 counts for twice as much as someone born in 2020, which then flies in the face of the utilitarian principle of equal weighting to every person. This again raises issues with the Benthamite welfare function, which Sen (1963) argued would further impact on equity within countries by forcing less consumption on inefficient actors such as the aged (McDonald, 2005).

In the end, Garnaut (2008) applied both normative and positive approaches and found the final outcome was matched (at least for Australia). Garnaut took a positive

[6] Pure time preference does not include Stern's extinction probability.

approach by using the market interest rate on long-term government debt after adjusting for expected inflation, and then compared the result using two normative approaches, one that assumed unity but accounted for human extinction and the other assuming greater future wealth by arguing that income today is worth twice as much as income tomorrow, effectively taxing future generations even more than we currently tax the rich today! He did this by putting per capita income growth at 0.3%, multiplying the result by the discount rate (trialling both unity and 2%), and then adding an extinction rate of 0.05%, slightly higher than Stern's.

As with all such econometric studies, the seriousness of the issue was fully recognised by all authors but could never be fully measured, mainly because the assumptions are stretched too far and even then, the actual outcomes of climate change fall outside of the economic problem, being subject to many more sources of uncertainty. Garnaut (2011) says that climate change is a 'diabolical policy problem' that is uncertain in terms of risk, insidious rather than directly confronting, long-term in both impact and remedy, and beyond the control of any single sovereign state. He recognises from the very outset that his model, for the sake of empirical accuracy, could never capture effects outside of consumption, income and economic growth – including the care economy, insurance measures of risk and outcome, and non-market benefits like amenity, longevity, health, heritage, community lifestyle and wellbeing, most of which lie outside of the econometric remit.

A careful reading of economic evidence justifying the input figures to their mathematical models too often uncovers a disturbing lack of focus on the deeper complexities uncovered by competing disciplines. Recall that one of Garnaut's preferred choices of discount rate was taken mainly from a single paper that averaged the tax rates of 20 OECD nations, arguing that "the degree to which we tax the rich proportionately more than the poor" reflects "how much society values equality". After drilling down through the assumptions underlying econometric models, it is sometimes found that econometricians use evidence that would be more carefully approached by other disciplines, in this case psychology and its study of actual human wellbeing over and above imputed utility..

All of these arguments highlight the complexity of intergenerational equity, whether it focuses on climate change or any other of the myriad negative externalities that arise from our consumption and production habits (Hails, 2006). As stated in terms of the Extinction Paradox (see Footnote 3), if the worst scenarios were to eventuate (Parry, 2007), discounting of inter-generational equity based on human extinction might only serve to hasten our demise (Cairns, 2007). Another irony is that economic growth itself, despite being a main driver of climate change, is also used to argue that future generations will be much better off. This is much like the Asian Development Bank, itself nominally committed to sustainability, using the density of pavement to empirically measure national development (ADB, 2011). Economic growth will most likely be devastated by climate change (Stern, 2006), and even then the econometric reliance on dollar imputations for human wellbeing is so polluted by unchallenged assumptions as to be rendered almost meaningless.

Not only is economic modelling mostly impenetrable to the general public, but it risks becoming all the more dangerous when used to guide the future behaviour of governments worldwide. Even among economists, Weitzman (2009) has said that insurance against catastrophe makes an even stronger case for mitigation of risk and is possibly even more important than the discount rate itself. More recent economic studies have begun to apply important climate change work from sociology, psychology and even medicine (McMichael et al. 2008), where trans-disciplinary efforts promise to change the way social progress and sustainability is measured and pursued.

As Einstein once said, that which is measurable is not always important and that which is important is not always measurable[7].

1.2.2 The Rise and Fall of GDP

Hard-fought multidisciplinary endeavours are now bringing renewed focus on what we mean and want in the concept of social progress. One of the things we need is universal agreement which protects the rights of both living and future generations, which requires something that also transcends politics and values. This work argues the answer lies in universal human needs, which can only be studied, and maybe even measured, in the 'gaps between disciplines' (Stanley, personal communication, 2010).

The importance of multidisciplinary convergence across economics, public health, social psychology and environmental science has grown over the past decade to inform the *Beyond GDP* network (see Saltelli, Jesignhaus & Munda, 2007). Some of the world's leading economic thinkers are now revisiting the notion of human-centred outcomes in economic growth. Many have shifted their focus beyond the dollar value of utility, to embrace more probabilistic but universal concerns like human happiness, health, equity, peace and stability. Many of the concepts emerging in the 'Beyond GDP' framework can be traced to the work of people like Harvard's Nobel laureate Amartya Sen, whose major contributions span human needs (his Capability Theory), equity (using the Gini Coefficient), social progress (the United

[7] Apocryphal but relevant. Some attribute a variant of this to sociologist William Cameron (1963).

Nations Human Development Index), and the multidimensionality of human wellbeing, as the central focus of the recent Sarkozy Commission (Stiglitz, Sen & Fitoussi, 2010). This most recent work showed how GDP 'mismeasures' human outcomes and should be replaced with more focus on measures of equity in household income and consumption that embrace wealth alongside non-market dimensions of subjective wellbeing. Recognising that these should include both objective and subjective measures, the authors call for much more focus on health, education, work-life balance, political and social inclusion, ecology and security.

The challenge facing this vast effort is in finding appropriate measures for social outcomes that were previously thought to be unmeasurable, especially as governments worldwide are themselves increasingly calling for policy-relevant data to balance human and ecological outcomes. Some of these have, by necessity, started out as explorations of stylised facts and simplified mathematical summaries that stick to the broader themes. Stylised facts were first defended by economist Nicholas Kaldor in 1961, who argued that new work must have the freedom to start by examining the broad tendencies rather than getting bogged down in the finer details from the outset (Kaldor, 1961). Stylised facts tend to be dismissed as scientifically invalid because they ignore complex interactions, unintended consequences and causality, at least after the fact. But when new issues arise, they are foundational.

In fact, Eckersley (2005) goes further and suggests that unintended consequences can only be avoided by looking at the broader, multidisciplinary picture, without which the whole system can be undermined by tampering with components informed by a reductionistic and intra-disciplinary framework. Many policy examples can be seen and a few well-known examples are revisited below:

1. Removal of trade barriers to support market efficiency devalues local produce
2. Then unregulated labour overseas undermines sustainable consumption
3. But boycotting products of child labour forces those children into prostitution
4. Pursuing economic growth when it continues to erode the global ecology

Simon Kuznets, the original author of Gross National Product (GNP, later GDP) disapproved of its use as a measure of social welfare (Kuznets, 1934). When he started the work, his original vision was to create the kinds of inclusive metrics just described, but he was forced to truncate his work because of the rising threat of the Great Depression and the immediate need for a comparatively quick measure of economic performance. John Maynard Keynes agreed with Kuznets, saying the day will come when economics will take the back seat where it belongs so that our hearts and minds will be occupied by our real problems – the problems of life and human relations, of creation and behaviour (Keynes, 1932).

The original metric of GNP was based on aggregate consumption and production based on ownership of resources within a country's borders – a flow measure that was a reasonable proxy of 'overall economic output' per year. It was calculated by subtracting imports from exports and adding private consumption, government spending and total investment, whereas the conversion to a welfare metric was based on dividing the aggregate by the country's population size. Since then, GDP became the preferred metric as it was progressively harmonized across national statistical agencies since the 1990s, and is now weighted against the $US or $INT dollar, sometimes with reference to Purchasing Power Parity (PPP) (UNHDR, 2013). Unfortunately, PPP is problematic when comparing nations across long periods of time because it is weighed against the price deflator, the Consumer Price

Index (CPI), which always needs a changing base year as time periods grow and inflation outpaces itself. In an era of globalisation, GDP now offers stronger comparisons than GNP across countries but is still beset with a long history of criticism.

One of the most eminent critics of GNP/GDP was the Cambridge post-Keynesian economist Joan Robinson (1962) who pointed out that it failed to capture the household economy and what was then thought of as the 'work of women'. Feminist economist Nancy Folbre (2008) more recently elaborated on Robinson's critique by showing how modern work practices and economic metrics devalue household 'production' of children, even when viewed merely as future labour capital. Folbre also applies standard econometric arguments to demonstrate that GDP is a distorted view of actual national productivity as it fails to measure the 'care economy'. This extends to the volunteer economy and many other aspects of human altruism that are fundamental to wellbeing which are not measured by GDP because they do not involve a monetary transaction. GDP also fails to capture the barter economy which is equally large, especially among poorer countries.

Together, these observations suggest GDP cannot be meaningfully compared across nations in the first instance because each nation varies in household production, bartering, volunteerism and other unmeasured sources of utility (extending to Internet sales), much less their varied involvement in Black Market economies operating outside of government scrutiny. A recent report put the value of global organised crime alone at US$870 billion – if it were a country it would be in the G20 (see ACC, 2013). This again distorts global markets when using GDP as a measure of basic social progress.

Furthermore, if GDP is weighted by population to create GDP per capita, it cannot be taken to represent the wealth enjoyed by each member of the community, especially as it relates to wellbeing, as each nation varies in the way it distributes and values measurable income, whether public or private. Efforts to compare the equity of distribution across countries were led by Sen, who used the coefficient originally developed by the Italian statistician Gini (1912) to estimate a country's degree of divergence from perfect equity (compared to the cumulative share of population through the lowest to highest observed incomes, *viz.* the Lorenz curve). The Gini value currently sits at around 0.65 for the world population, reflecting extreme wealth inequality, given that the optimal level has been estimated at 0.25 (out of 1.00). At present, the Gini coefficient is influenced by taxation regimes as well as demographic age distributions within countries, especially among those where wealth is concentrated among older age groups (and more than would be expected by accumulation across the life course alone). The Gini coefficient has been used extensively in work supporting the development of the United Nations Human Development Index, although many studies continue to calculate simpler ratios comparing the top and bottom percentages of the wealth continuum within countries (and a few alternative indices exist such as the Theil and Atkinson indices; see Atkinson, 1970; Conceição & Ferreira, 2000; Sen & Foster, 1997; Stiglitz, 2012).

A comprehensive review of the impact of equality as it relates to public health was recently outlined by the British economist Richard Wilkinson (2009). Looking at the world's 50 richest countries, he reviews work over the past 30 years to demonstrate that higher levels of inequality, however measured, is related to eleven public health variables - physical and mental health, drug abuse, education, imprisonment, obesity, social mobility, trust, violence, teenage pregnancy and child wellbeing. Although contested by some researchers[8], this was an important work that empirically operationalised what has long been suspected by eminent health and social theorists: that extreme national wealth is no guarantee of optimal human outcomes, especially in the face of income inequality. The main finding was that societies with minimal income differentials, such as Japan and the Nordic countries, better serve the health of their citizens compared to wealthier but less equitable nations like the United States, United Kingdom and Portugal (for an independent review of Wilkinson, see Sargent, 2009).

Even if GDP per capita did successfully capture the average wealth enjoyed by each member of the community, the concept of enjoyment in economics was already questioned by Joan Robinson (1962). Robinson argued that economic utility was a tautology that sidestepped any true understanding of actual human wellbeing long before modern economists started embracing actual psychometric measures of happiness in the 'real world'. Joan Robinson collaborated with both Keynes and Kaldor, and also mentored Sen and Stiglitz. (Incidentally, Sen was also a student of the eminent Cambridge economist, Dasgupta, who moderated the discussion between Nordhaus and Stern on intergenerational equity and climate change.) As for ecological externalities, it was noted by New Zealand feminist politician and human rights campaigner Marilyn Waring that the costs of cleaning up after oil spills, nuclear accidents, floods and fires are perversely counted as an accumulation of wealth within the GNP/GDP metrics (Bjørnholt, 2010).

[8] For example, Goldthorpe (2009) said Wilkinson (2009) relied too heavily on income inequality as a proxy of social class; by contrast, the Sarkozy Commission argued for greater use of household income as a better measure of economic welfare (see Stiglitz, Sen & Fitoussi, 2010) at least compared with GDP per capita

From the 1940s, a groundswell of other work was also emerging from eminent thinkers in medicine, sociology, psychology and politics that would later drive the need for measures beyond GDP. After discussing earlier economic references to the idea of happiness as a synonym for welfare (e.g. Mishan, 1968), Easterlin (1974) asked the fundamental question of whether wealth bought happiness in the first place. Until then, utility theory in economics purposefully sidestepped an actual definition of utility, and only recently has the emergent domain of ‘happiness economics’ gained traction, with some describing subjective wellbeing as the *Holy Grail* of utility theory (Clark, Frijters & Shields, 2008).

Long before this, five streams of argument were gathering momentum through the 1950s and 1960s. Joan Robinson’s critique of utility is one, and this emerged around the same time as Abraham Maslow began examining the inputs to optimal human flourishing and human needs (Maslow, 1954). Two years later, the endocrinologist Hans Selye (1956) developed the Generalised Adaptation Theory of physiological stress, with metabolic implications for both consumption and production at the human metabolic level. All emerged following the original definition of health given by the World Health Organization in 1946, as something much more than just the absence of disease or infirmity – a state that embraces “complete physical, mental and social well-being” (WHO, 1946, 1948, p.1). This overturned the idea of a continuum from illness/depression/suicide to health/wellbeing/flourishing in favour of heath and illness being distinct states.[9]

[9] Interestingly, this distinction is gaining support from recent studies using functional Magnetic Resonance Imaging (fMRI) where positive and negative emotional states ‘light up’ functionally distinct areas of the human brain, usually centred on the valuation system, which includes the bilateral nuclear accumbens (rapid response to immediate needs) and the ventromedial prefrontal cortex (slow response to goals); a study of MRI responses to images of infants among new mothers has shown that oxytocin-enabled feelings of euphoric love reflect up to 3 points on a 10-point SWB scale, which

Until recently, authors had little idea of what to do with these concepts. Economists felt much safer with utility, the World Health Organization continued to focus on illness, and any hierarchy of human needs remained completely untestable (see Heylighen, 1992). Even psychologists mostly focused on individual differences in abnormal psychology until psychometric testing of subjective wellbeing (SWB) began laying the foundations for measuring outputs and inputs to optimal human flourishing (e.g. Cantril, 1965). The fifth stream that emerged in the 1950s was the original exploration of frontier efficiency explored by Farrell (1957), a statistical approach that, although entirely focused on optimal output under input constraints, has never been applied across all of these themes. The move towards examining wealth alongside life expectancy and life satisfaction was partly opportunistic because harmonised data across countries began to emerge from the 1960s onwards. But it was also important because it began to build a multidisciplinary framework for looking at concepts of social progress outside of wealth itself.

In 1971, Brickman and Campbell published a landmark study on what became known as the Hedonic Treadmill and laid the foundations for the set-point theory of human wellbeing. Although contested later, the idea was that human wellbeing adapts to relative environmental conditions and the implication was that no amount of greater consumption or productivity could improve the human condition once it reached a certain point.

This was followed up in 1975, when two leading authors from other disciplines independently published results demonstrating almost identical relationships with national wealth, one focused on life expectancy (LE) and the other focused on life

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offers a unique insight when judging contextual differences in SWB between countries on the same 10-point scale satisfaction (LS). For both life expectancy (Preston, 1975) and life satisfaction (Easterlin, 1975), there was a strong relationship with wealth until countries moved from poor to wealthy, at which point further increases in wealth appeared to have little or no impact on either measure.

When compared to the Preston Curve, the Easterlin Curve was almost identical, despite them being very different measures – one objective and the other subjective. Easterlin demonstrated the same curve as Preston for what he called 'happiness' and later became known as either 'life satisfaction' among psychologists, or else 'utility' among economists. When life expectancy was replaced with subjective wellbeing, the same curve emerged, suggesting there was a threshold level of 'happiness' beyond which 'wealth' had no effect (Easterlin, 1974).

Both findings have remained remarkably robust over the past three decades and are replicated here for 2005 using equivalent data from the World Bank Millennium Development Goals Report (2009) and the New Economics Foundation (NEF) 2.0 Report (Abdallah et al., 2009) matched by country (N≈176).

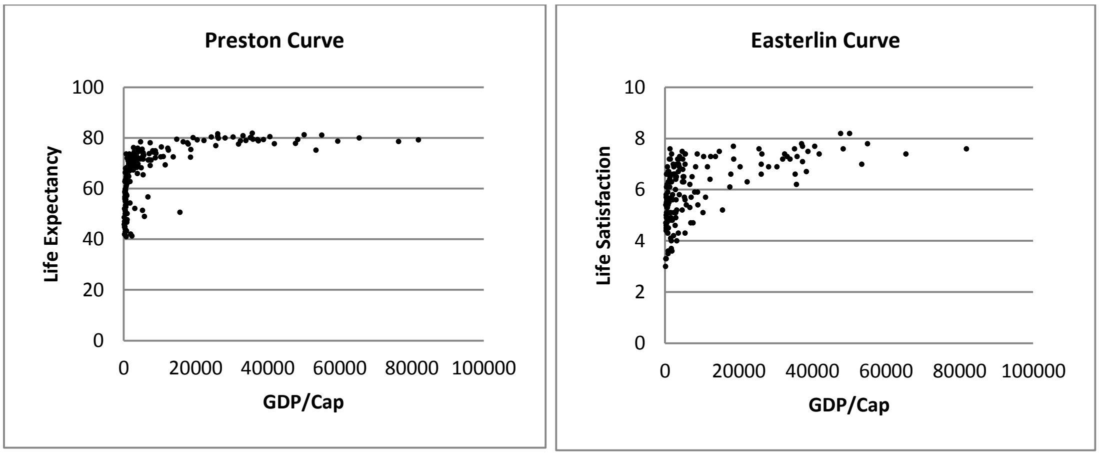

Figure 1-9 The Preston Curve and the Easterlin Curve replicated against GDP/cap

The two curves can be seen more clearly if a log 10 transformation is made to the GDP data, as below (Figure 1-15).

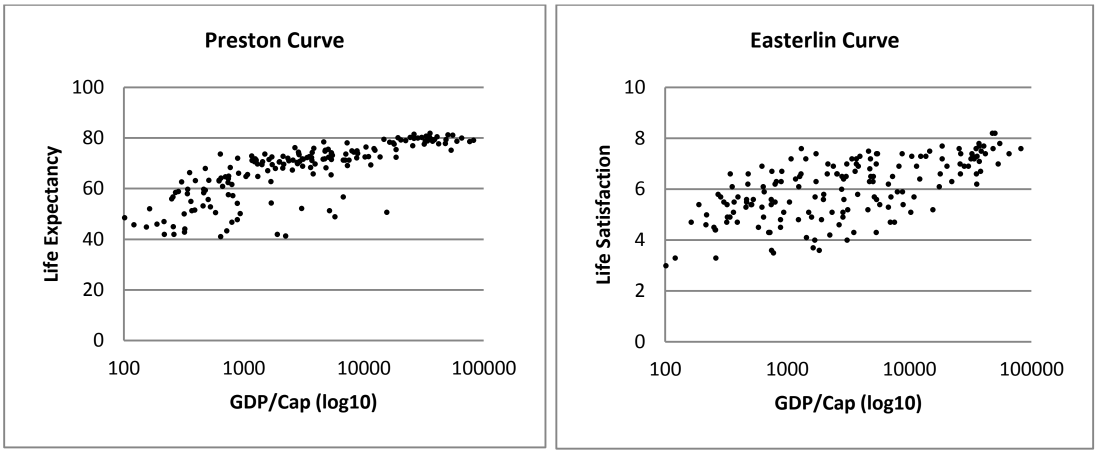

Figure 1-10 The Preston Curve and the Easterlin Curve transformed for GDP (log10)

What is most interesting about these two curves is that both challenge the idea that wealth beyond a certain threshold is actually needed to enhance human health or wellbeing. In both cases, a steep rise occurs among the poorest countries, hits a threshold and then levels off as GDP expands. The implications for sustainability become obvious given that economic expansion is the main driver of climate change (see Figure 1-16).

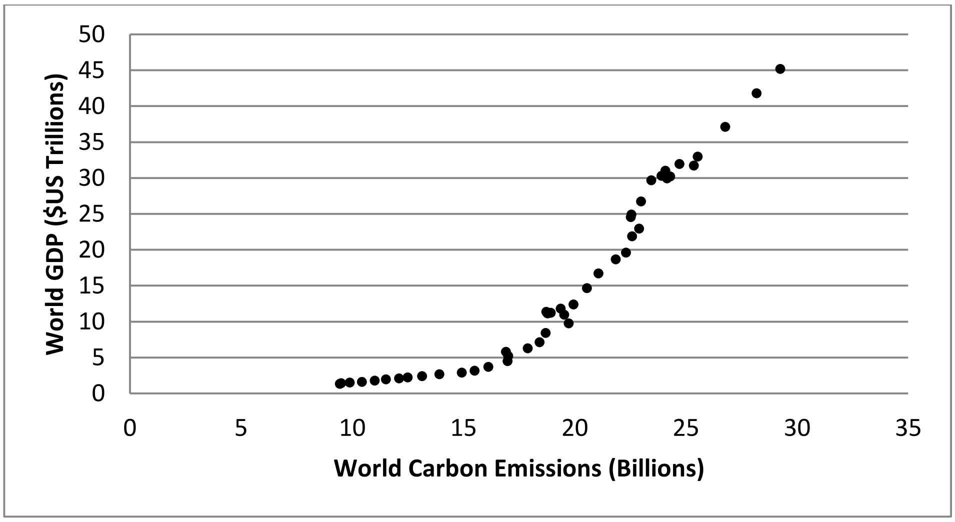

Figure 1-11 The rise in world GDP tracks with the rise in carbon emissions over the past 50 years (Sources: World Resources Institute and World Bank since 1960)

This suggests the Hedonic Treadmill operating at the individual level could be manifesting itself at the global level, achieving little more than maintaining current set-points for wellbeing – basically avoiding loss - whilst further degrading the environment at the expense of future generations and *their* wellbeing. As loss is felt more greatly than gain (see Powdthavee, 2010), the actual impact on future generations is likely to be felt as much greater, possibly even measurably greater, than the loss suffered by current generations were they to act on climate change. Such an analysis would likely reverse the predictions of utility theorists focused on the discount rates against economic growth alone.

1.2.3 Beyond GDP: The UN-HDI and the NEF-HPI

Five years after the work of Easterlin and Preston, the construction of the United Nations Human Development Index (UNHDI) in 1980 was the first great departure from using wealth as the only measure of human development. The UNHDI purposely embraced what it called more 'human-centred outcomes' that were multidisciplinary and covered both public health and education (Haq et al., 1995). Cross-sectionally, the UNHDI sought to build an output composite of GDP, education (ED) and life expectancy (LE). Education, based on Sen's Capability Theory, was thought to drive the capacity of populations to satisfy their own needs and was a composite of formal years of education and adult literacy. The basic calculation was (and mostly remains):

$$\frac{\left(\dfrac{LE_x - LE_{min}}{LE_{max} - LE_{min}}\right) + \left(\dfrac{GDP_x - GDP_{min}}{GDP_{max} - GDP_{min}}\right) + \left(\dfrac{ED_x - ED_{min}}{ED_{max} - ED_{min}}\right)}{3}$$

So any gain was weighted against the observed maximum and minimum for each index in any given year, which was empirically valid because the yearly maxima could be readily observed rather than estimated from some ideal that had, as yet, never been incontrovertibly identified. It was sensible to weight each index against its observed minimum so that the actual gain in each index was constrained within the observed range. This helped equalise the three subindices on a scale from 0-1 so that the final index could become a weighted average divided by three.

The UNHDI was supported by Sen and published by a collaborative group led by Haq and associates (1995). It was only recently that LE_{min} was changed from being weighted against its lowest observed level in each year to being weighted against a constant of 21 years, being the lowest value at which societies are thought to be reproductively feasible (Klugman, Rodriguez & Choi, 2011) – another sensible initiative that began to move towards greater comparability across larger timeframes than just the modern period. In 2012, additional changes were made to include a new high-development category, along with using the geometric rather than arithmetic mean (see Technical Notes, UNHDI, 2013).

Life expectancy itself had been calculated by the World Health Organization using a harmonized formula across a majority of countries since 1960 (CSDH, 2008). It is not a predictive measure for babies born in a particular year. Rather, it is the age at which half of the population will be dead based on the average age of death from mortality league tables for each age group, developed from national statistical agencies in the year of collection from medical death certificates. This is then weighted by the age distribution of the population. It can be viewed as the average age at death for the population in that year, given prevailing conditions. Among poorer countries with less advanced birth and death registration systems, the basic demographic calculations can be skewed, especially among older cohorts or children born during periods of extreme social upheaval. The fact that life expectancy is different from maximum longevity, currently validated at 122 years, merely reflects the way in which life expectancy captures the average for each country.

The UNHDI as a composite measure permitted researchers from different disciplines to begin collaborating on many more issues of fundamental importance over the next decades. The latest Human Development Report (along with datasets from the United Nations Food & Agriculture Organization and the World Health Organization) now covers indices as diverse as those listed in Table 1-1.

Moreover, the basic composite can be adjusted for health and equity. Having counted them in 2008, there are now at least 9832 variables measured across nations, 80% of them derived from collections by the United Nations and World Health Organization. Other metrics are collected by the World Values Survey, Gallup Poll, World Bank, International Monetary Fund and World Wide Fund for Nature, among many others.

Around the same time as the development of the UNHDI, another author was collecting and testing vast datasets on what he initially called ‘human happiness’. Ruut Veenhoven spent decades mapping life satisfaction across nations by finding ways of harmonising different intra-national surveys to build the World Database of Happiness (1986), later embracing up to 200 countries. Veenhoven (1996) argued that the UNHDI mistakenly mixed actual inputs with outputs, such that life expectancy was the only true output in the UNHDI and that both GDP and ED should be regarded as inputs. This would equally apply to many of the five hundred or so new indices now collated by the UN but not yet included in the HDI calculation.

Table 1-1 A small selection of data collected across countries by UN & WHO

HEALTH & WELLBEING	DEATH & DISEASE
Water & calories	Age & gender death rates
Protein & grains	HIV/AIDS & STDs
Fruit & vegetables	Infections & immunization
Sleep & recreation	Cancer & heart disease
Work & exercise	Tobacco, alcohol & drugs
BMI & obesity	Depression & dementia
Housing & temperature	Accidents & suicide
Sanitation & waste	Healthcare & medicine
Longevity & wellbeing	Homicide & infanticide
SOCIAL & ECONOMIC	**CORRUPTION & ECOLOGY**
GDP (PPP) & growth	Rape & prostitution
Aid, debt, tax & trade	Child labour & slavery
Equity (GINI) & wealth	Assault & extortion
Transport & communications	Bribery, fraud & theft
Urbanisation	Carbon em. & footprint
Household prod & barter	Pollution & pesticides
Education & literacy	Land & fisheries
Trust & freedom	Sea levels & species
Gender equity & equality	Energy use & electricity

Sources: see Methods Chapter for public access to WHO/UN datasets.

Life satisfaction is measured differently from ‘happiness’ but both are often conflated under the banner of SWB, which is an ongoing problem in the literature as they capture different elements of cognition and affect (see Davern, Cummins & Stokes, 2007). The idea of life satisfaction is more related to cognitive appraisals of contentment rather than hedonic affective states like happiness. In the current project, life satisfaction is the preferred metric because it resonates with needs theory and is a cognitive appraisal of overall satisfaction presumed to be more robust than transitory affective states.

Life satisfaction is simply a statistical average from a large survey of people sampled from each country, usually by the World Values Survey, Eurobarometer or World Gallup Poll, based on the question of how people feel about their life as a whole, with responses given on a 10-point scale from ‘very satisfied’ to ‘very unsatisfied’:

“All things considered, how satisfied are you with your life as a whole these days?"

As a measure it offers surprising validity and is an improvement on much earlier attempts at comparing wellbeing across countries using rates of suicide, work stress or depression as proxies. These much earlier efforts failed to capture the understanding that wellbeing is considerably different from illness – a notion recognised by the World Health Organization since 1948 and now a key precept of Positive Psychology and a broader understanding of complete mental health (see, for example, Keyes, 2002). This distinction, first alluded to by Plato and Aristotle, is now confirmed by neurological studies using functional Magnetic Resonance Imaging (to be described later).

Where Veenhoven (1996) also differed from the UNHDI was in arguing that SWB was just as important as life expectancy as an appropriate human output. He pointed out, quite rightly, that some people could have a long and miserable life whereas others might have a short and happy life. The only way to capture this tension, he argued, was to create a new composite that multiplied the two outputs. He did this by multiplying a nation’s life expectancy by its average level of 'happiness'. Having carefully examined all the many intra-national datasets on related metrics, he settled on the 10-point Likert, which is still supported as the most sensitive scale by many other authors (for reviews, see Cummins, 2010, 2013).

Where Veenhoven (1996) differed from others was in treating the 10-point scale of LS (not actual 'happiness') as if it was a percentile where a score of 10 was equal to 100% wellbeing - he simply multiplied the national average of life satisfaction by life expectancy for each country. The basic calculation for the Happy Life Year (HLY) is then LE multiplied by LS on a 10-point Likert scale divided by 100. It means, for example, that 70 years lived at an LS of 5/10 becomes equivalent to 35 years of 'perfect wellbeing' achieved within that nation. Veenhoven (1996; 2008) called this composite the Happy Life Year (HLY) – statistically shaky but still a useful alternative to the less multidisciplinary development concerns of the UNHDI.

The logic of the HLY was also resonant with another emerging argument being developed by the World Health Organization that began to weigh life expectancy by either health (Health Adjusted Life Expectancy, or HALE) or disability (the Disability Adjusted Life Year, or DALY; see Murray & Lopez, 1996). This moved beyond life expectancy alone to begin measuring the Global Burden of Disease affecting living people. The results of this work were startling because they highlighted how different diseases became more prominent, and costly, in wealthier countries - diseases like obesity, diabetes, cardiovascular disease and clinical depression over and above diseases of human needs deprivation like infant mortality and starvation. The living burden of disease was substantially increased when non-fatal disorders were included using the ICD 10 Classification of Mental and Behavioural Disorders and the Diagnostic and Statistical Manual (DSM) criteria for mental disorders. This then further encouraged collaboration between medicine and psychology on measuring Quality of Life (QOL), especially for people suffering both physical and psychological disorders, for two reasons. One was to explore inputs to human flourishing, much like the current work, and the other to assess health funding and insurance imperatives, a body of work that covered econometric studies of 'willingness to pay' that began exploring the frontier efficiency of hospitals and primary care services (e.g. Worthington, 2004)[10].

Along with these developments, Veenhoven's early work laid the foundations for a more dramatic departure from GDP when it became a key metric in the development of the Happy Planet Index (HPI). This index was developed in 2006 by the Oxford-affiliated New Economics Foundation in London as a measure of sustainable progress that purposely bypassed GDP altogether (Abdallah et al., 2009; p.1). The NEF-HPI went further than Veenhoven by weighting the derivative index of Happy Life Expectancy (Veenhoven, 1996) by Ecological Footprint (Wackernagel & Rees, 1996). In an attempt to measure cross-country sustainability, HPI bypasses all other possible inputs by adding the denominator index of Ecological Footprint to capture efficiencies in achieving HLY against ecological externalities. As such, the NEF index of sustainability is then weighted by EF, rather than GDP, as the denominator:

$$\text{Happy Planet Index} = \frac{\text{Happy Life Years}}{\text{Ecological Footprint} + \alpha} \times \beta$$

A few constants were later added but the HPI remains a composite output measure (just like the UNHDI) which is then divided by a key input measure (EF).

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[10] With further implications for the value of human life, compensation law and, by extension, the Precautionary Principle.

Effectively it is the very definition of an efficiency measure as output over input (as opposed to an intensity measure using the reciprocal). As mentioned, EF is the amount of per capita consumption in one year accounting for the material sources and pollutant sinks within a country's individual geographic space, moving towards the ideal of one-planet living required to guarantee that future generations have the same per capita resources as past generations.

Bypassing GDP altogether is a reasonable but imperfect approach in an era when countries are now actively trying to decouple their economic growth from ecological impact, which begins to weaken the traditional linearity between GDP and its ecological externalities. If the main issue is ecological impact, then mathematically, countries can do whatever they want economically as long as their EF is minimised on behalf of future generations.

The HPI ranks nations in a league table that is not always helpful. It recently nominated Costa Rica as the most sustainable country in the world (Abdullah et al., 2009). Many other countries doing well are likewise small island states like Vanuatu, the Dominican Republic, Jamaica, Cuba and the Philippines (see also Marks et al., 2006). Some of these might have comparative advantages from tourism and might also have cultural characteristics that artificially inflate Life Satisfaction (LS). Latin American and Caribbean nations as a group tend towards having the highest mean HPI score for any region. The lowest HPI scores are all suffered by sub-Saharan African countries, with Zimbabwe at the bottom (HPI score of 16.6 out of 100). Rich developed nations fall somewhere in the middle of the league table. The highest-placed Western nation is the Netherlands – 43rd out of 143. The UK ranks midway down the table (74th) behind Germany, Italy and France. It is just pipped by

Georgia and Slovakia, but beats Japan and Ireland. The USA comes a long way back in 114th place.

The main problem with this index, although a useful thermometer, is that it tries to capture too much information in one metric and the more it tries to capture the less useful it becomes. The final score is distorted differentially between the numerator and denominator. Moreover, there are also cultural differences in SWB between Japan and Latin America that also distort the final rankings (see Kitayama & Markus, 2000). The next section briefly deconstructs the main curves.

1.2.4 The Preston Curve – Health, Wealth and Mortality

Beginning with the classic Preston Curve, life expectancy reaches a peak at low to moderate levels of GDP and then levels off, such that further ‘wealth’ apparently has no great impact on ‘health’ (Preston, 1974) . Many authors have pointed out this looks like a classic economic growth curve with diminishing marginal returns, at least when wealth is conceived as an input and life expectancy treated as an output (as per Veenhoven, 1996). Moreover, Preston used available data to show that the curve retained its shape for the 1900s, 1930s and 1960s. Although countries became more long-lived with time, the curve retained its original shape and other authors later replicated the curve as early as 1890. Preston’s classic study raised three main questions for both economics and public health:

1. What is it about wealth that increases health among poorer countries?
2. What causes the increase in life expectancy for all countries across time?
3. Does more wealth offer any further benefit to wealthier countries?

The first question is focused on the strong upward slope among poor countries. It intrinsically assumes that wealth has a direct causal effect on health in the first place, which depends on private and public investment choices as well as different trade and taxation policies (e.g. Easterly, 1996). There is even evidence that causality works in the other direction, where healthier workers are more productive.

The broad trend is that wealth serves basic needs until it reaches a threshold, which prompted some authors to suggest the curve supported international wealth redistribution, especially as wealthier countries appeared to derive little benefit from additional wealth (Pritchett & Summers, 1996). For the poor, it was assumed greater wealth allowed more access to nutrition at the private level (e.g. Fogel, 2004) and more government investment in clean water, services and sanitation at the public level (Preston, 1996; Deaton 2006). This argues that some level of wealth is needed to satisfy human needs like food, water and hygiene on the upward slope.

As for the second question, the fact that life expectancy still increased across time, even among some poor countries, simply meant that some effects must have been shared. This points to technological progress at the frontier of human endeavour ranging from public health, agriculture, education and transport. Benefits from improvements in these areas can be delivered directly to poorer countries through the efforts of their governments, foreign aid and transnational NGOs, or perhaps more slowly through the activities of private corporations – the so-called ‘trickle-down’ effect from wealthier to poorer countries as private corporations bear the initial costs of opening up new markets (e.g. pharmaceuticals). Several researchers argue that technological progress is ‘the ultimate determinant of health’ even if it has decade-long lag times (Jamison et al., 2002; Cutler & Miller, 2005; Cutler & McClellan, 2001; for a complete review, see http://www.ssc.wisc.edu/~walker/wp/wp-content/uploads/2012/01/IJE2007.pdf).

Few authors offered an explanation for the third question as to why the impact of wealth consistently levelled off among richer countries. The simplest explanation offered here (and tested later) is that life expectancy had reached a metabolic ceiling based on the environmental inputs, whether nourishing or toxic, and the technological (mostly medical and public health) initiatives peculiar to the period. Only a metabolic ceiling would explain why extraordinary levels of wealth seemed to offer less and less in terms of public health as countries pursued more growth.

Three sources of evidence converge on a ceiling effect constricting life expectancy. One is the slowing growth of life expectancy across rich countries, which has now reached about 84 years in Liechtenstein and Japan (UNDHR, 2013). The second is the work of Elizabeth Blackburn (see Greider, 2009), the 2009 Nobel laureate for medicine, who demonstrated a boundary at the cellular level by showing that physiological stress progressively erodes the length of telomeres. Telomeres are likened to the tight sections of shoe laces, called aglets. With aging, or equivalent physiological stress, the telomeres progressively fall apart, leading to the 'unravelling' of DNA and the emergence of fatal diseases. Blackburn's more recent work (Epel et al., 2009; Epel et al., 2010; Jacobs et al., 2010; Humphreys et al., 2012) is of considerable importance to the current study because it shows that telomeres are significantly shortened with acute psychological stress and chronic depression (including a history of abuse among women). The third source of evidence comes from the prevalence of supercentenarians across countries, which appear to have reached a level where their numbers gently wax and wane among countries like Japan, France, Italy, the US and UK, an effect described as a relatively stable but fuzzy limit called the Calment Effect (Coles, 2013), named after the longest living person so far validated.

Frenchwoman Jeanne Calment died in 1997 aged 122 years (Coles, 2013). By interviewing supercentenarians about the way they lived their lives, a few studies have uncovered all sorts of different strategies to prolong life, some of them sparking fads like the Okinawa diet (see Coles, 2013). Jeanne herself loved dark chocolate and laughed a lot. In one of her last interviews, she said she had but one wrinkle and she was sitting on it. She took up cycling and fencing in her last 30 years and started smoking at the age of 95. She happened to be extremely wealthy. Yet despite arguments and evidence about the value of wealth, the foundational assumption of this study is probably unassailable - that human immortality is impossible and so no level of greater material input will ever display a curve other than one that is restricted to a maximum level of life expectancy. The main question, as suggested by Stanley (2008), is whether this boundary was recently breached in the past few years, and that current generations of children in the developed world will be the first in human history to suffer LE losses.

Along with the Preston Curve, the idea of a metabolic limit immediately raises a serious challenge to the sustainability of the UNHDI. If we assume that wealth beyond threshold offers little in terms of LE but continues to have a negative ecological impact, then gains in the UNHDI can only be made long after wealth ceases to have any real impact on human health. A world pursuing an improved HDI would then rely on greater ecological impact that constrains the longevity of future generations, making the UNHDI inherently unsustainable. Further, it cannot be argued that more wealth offers benefits outside of the UNHDI, such as greater human happiness, because the same effect emerges in the Easterlin Curve.

Moreover, the UNHDI has, since 1980, had to adjust its categories to account for the swelling ranks of countries at the higher levels of development. The addition of a new category called ‘very high human development’ (>0.90) (UNDP, 2010) begins to suggest the index itself is becoming increasingly obsolete.

1.2.5 The Easterlin Curve – Wealth and the Pursuit of Happiness

In his cross-country comparison, Easterlin relied on Cantril’s 1965 study of the self-reported ladder of happiness, also a 10-point scale where people rated their present circumstances against what they perceived as the best (10 points) versus worst (zero) possible scenarios (see Cantril, 1965; cited in Easterlin, 1974). By weighting the ladder against the best and worst scenarios imaginable, Cantril’s ladder was said to be subjectively anchored. The surveys were conducted across 14 countries from 1959-1962 and ranged from 480 respondents in West Germany to 2366 in India. Cantril then matched each country to their Real GNP per capita ($US) for 1961, mostly drawn from Rosenstein-Rodan’s study of international aid (1961; cited in Easterlin, 1974).

What struck Easterlin when looking at Cantril’s data was that despite a ten-fold range in income, actual happiness across ten of the 14 countries barely varied at all.

As Easterlin noted in his original paper, the fitting of curves to the data among the small subsample of wealthy countries is extremely vulnerable to outliers. Easterlin noted that a weak positive association between wealth and wellbeing relied heavily on only two outliers spanning the extremes, India being poor and comparatively unhappy versus the United States being much richer and much happier than all other nations - bar one, which was Cuba (Easterlin, 1974). Cuba sat midway between India and the United States in terms of wealth but actually matched the United States in terms of happiness, despite an almost six-fold difference in wealth.

At the time it received scant attention by Cantril (1965) who dismissed Cuba's high level of happiness as the afterglow of a successful revolution. And yet Cuba, to his methodological credit, still remains a half century later as one of world's happiest and most sustainable countries (NEF, 2009) a finding that turns out to be stable for decades by the current project. Cantril's work suggested, even then, that further growth and consumption, with its cascade of ecological externalities, might not even be necessary for human health and wellbeing.

Although technical and methodological issues arising from Cantril's approach still remain thorny issues in modern cross-national analyses of subjective wellbeing, Easterlin covered many of these in his original paper. Issues of convergent validity and test-retest reliability were addressed by Easterlin, along with linguistic translation and the related aspects of cultural equivalence and social desirability. For interest, the top three concerns identified as important to happiness across all countries were money, health and family, which varied slightly in their importance across cultures.

Easterlin (1974) noted that cultural bias was especially difficult to control for if social desirability and response bias varied with the cultural construct of happiness, an issue that has been consistently relevant because Western individualist cultures like the US tend to over-report happiness compared to collectivist cultures like Japan (see Diener & Suh, 2000). Whilst Cantril also spent much time on linguistic translation, Easterlin (1975) further reviewed evidence suggesting the self-reported ladder offered high stability (test-retest reliability) and convergent validity with other subjective and objective measures of health, depression and self-esteem. Veenhoven agreed (Ouweneel & Veenhoven, 1991). Easterlin also noticed that peer reports rarely matched self-reports, suggesting that happiness, like physical pain, is a uniquely internal construct that can only be self-reported. Diener later said that this was an especially strong aspect of subjective wellbeing because it becomes a 'uniquely democratic scalar' of social progress that transcends external metrics like wealth (Diener & Suh, 2000, p.4).

Regardless of these issues, another 30 years of research has since validated Cantril's approach and the original 10-point ladder is still used across many more countries. For the purposes of the present argument, however, the fact that both Easterlin and Preston found the same curves is the main point. These curves offer cross-validation by virtue of their different methods - wellbeing based on survey data of how people subjectively feel about their life circumstances in different countries (see Diener & Suh, 2000) and LE an objective average based on the relevant year's reported death rates weighted by population and age (CSDH, 2008).

Both have problems (LE is undermined by lack of birth registration in undeveloped countries), but their cross-validation partly obviates the need to explore these concerns in too much detail here. They suggest that no matter what the outcome metric, wealth reaches a threshold beyond which it has little or no impact on health and wellbeing across countries. The same threshold for wealth and wellbeing is also reported within countries. Regardless of wealth, Easterlin (2005), for example, recently demonstrated SWB in the USA, European Union and Japan remained mostly stagnant over the past 50 years despite up to 300-fold increases in GDP per capita. A more recent Australian study using the HILDA survey also confirms that wellbeing remained untouched during the GFC, settling at about 8 out of 10

(Wilkins, 2012). Likewise, successive waves of the Australian Unity Wellbeing Index have consistently put the average set-point at 7.5 once wealth is controlled for (see Cummins, et al., 2008). There might have been minor and insignificant increases since Cantril's work, similar to that observed for the Preston curve, but although Veenhoven (2010) continuously upgrades his estimates of optimal wellbeing (most recently suggesting 9/10), it still tends to peak at around 7.5-8 on the 10-point scale, following the same trajectory as the top-most levels of life expectancy, currently peaking at around 84 years of age (CSDH. 2008).

In other words, the Preston Curve mirrors the Easterlin curve across countries and across time. Evoking Occam 's razor, a 'fuzzy' boundary would be the simplest explanation in both cases, such that life expectancy and life satisfaction are probably limited by a pre-set point or boundary, beyond which no amount of additional wealth is likely to make much difference. As such, Easterlin's finding might be explained by modern set-point theory which argues that human happiness is genetically pre-set to a maximum of 7.5 (Gullone & Cummins, 2002).

Cummins (1995) argues there is a genetic set-point for life satisfaction that tends to settle on a stable, homeostatic maximum once human needs are met. This argument makes a lot of sense in terms of the adaptive capacity of people to balance various tensions between motivations subserving actual human survival. Set-point theory also resonates with Seligman's (1967, 1975) learned helplessness (originally using dogs), and the earlier work of Hans Selye (1955, 1956) on stress, who demonstrated (originally using mice) that optimal performance was achieved at moderate levels of stress. Low levels of challenge produce boredom and high levels exceed adaptive capacity and cause enough distress to impair performance (also see Eysenck, 1967). Only moderate levels of challenge, what Selye (1956) called eustress ('good' stress), maximises performance. In the same way, moderate levels of happiness (analogous to eustress) might also achieve optimal adaptive capacity. This idea is also illustrated in the embodiment of bipolar disorder, where both euphoria and depression manifest as maladaptive to the needs of the sufferer (DSM IV; AMA, 2000). At the social level, the latest work of Cummins (2013) covering 4000 Australians further confirms that there is a limit to human happiness that tends to peak at the aggregate. The main effects included moderate wealth (in this country's context, gross AUD$100,000 household income), at least one supportive human relationship, and a third factor that resonates with notions of motivation and existential meaning. It has long been thought that social and psychological factors are buffers for stress, whereas the level of wealth as an important factor is likely tied up in more material needs satisfaction, as will be explored below.

In summary, various streams of research suggest there is a moderated boundary of human happiness (probably subserving individual adaptability) in the same way as there is a biological limit to life expectancy (probably subserving group adaptability across time). As 'happiness', even when subjectively appraised, might still be an endocrinological epiphenomenon – a mental manifestation of physiological responses to the environment – a metabolic boundary should operate. This would explain why wealth tends to hit a ceiling for both life expectancy and life satisfaction, and further challenges the idea that more wealth (whether as production or consumption) is necessary for optimal outcomes in human health and happiness, extending further to other output measures of social progress and human development.

1.2.6 The Easterlin Paradox and Ecological Fallacy

Although additional wealth among wealthy countries seems to have little impact on happiness, even across time, the relationship is vastly different within countries. This was known to Easterlin and is consistently confirmed up to the present time (e.g. Mellor, Cummins & Loquet, 2012). Returning to the question, does wealth buy happiness, the Easterlin Paradox would answer 'yes' within nations and 'no' across nations (Easterlin, 1974). This is a strange problem that has devastating implications for sustainability, as will become clear.

In his original paper, Easterlin (1974) found that whilst vast differences in GNP across 14 countries barely had any impact on happiness, comparable measures within the United States across time suggested entirely different implications. Combining surveys from the National Opinions Research Center and the American Institute of Public Opinion from 1946-1970, results showed the highest income group was twice as likely to report being 'very happy' than the lowest income group, suggesting a positive association. In other words, happiness demonstrated the same curve as Preston found for life expectancy across countries, but still linearly increased with wealth when confined to income groups within countries, here the United States. This stark divergence between the results using comparable measures within and across countries became known as the Easterlin Paradox, highlighting the deductive dangers of ecological fallacy.

Ecological fallacy (see Schwartz, 1994; Freedman, 2002) occurs when results from an analysis at one level of aggregation, such as within a country, are falsely generalised to another level of aggregation, such as across countries. The same can occur when a small sample is taken from a subcultural community, say 4000 people, and the results then generalised to an entire nation state. In the same way that Easterlin (1974) finds different results when switching between aggregation levels for human happiness, ecological fallacy is beautifully demonstrated in the economic gradient for Type II Diabetes (and related levels of obesity, cardiovascular disease and sleep apnoea) described by the WHO's Global Burden of Disease Study (Murray & Lopez, 1996). Levels of diabetes tend to grow with wealth across countries, suggesting it is a disease of over-consumption, but when the same gradient is examined in wealthy countries, it is the poor, not the wealthy, that are most afflicted (Pearce, 2000; Gross, Ford & Liu, 2004).

So whenever ecological fallacy is suggested by irregularities in findings across different aggregation levels, it raises the spectre of ecological fallacy by suggesting more complex processes are at work. In the case of diabetes, it is explained when the same relationships are explored within poor countries as well, where the cross-national curve again re-asserts itself (perhaps partly because the endomorphic physique is valued as a sign of wealth). All this means is that the relationship between wealth and Type II diabetes is actually a bell-shaped function, where the extremes of both low and high levels of wealth tend to reduce the community incidence of Type II diabetes. Poverty prevents over-consumption of food at its most extreme levels, moderate wealth allows enough over-consumption of low-quality, high sugar foods to manifest as diabetes and then extreme wealth tends to reduce levels of diabetes because of greater access to higher quality, less processed foods (along with gym memberships, better medical treatment and the Western physical aesthetic of the mesomorph). The various curves emerge because different levels of wealth and the cultural significance of physique are superimposed over an essentially bell-shaped curve for consumption.

Likewise, when it comes to wealth and happiness, the Easterlin Paradox is much discussed in modern economics and psychology. Easterlin himself originally explained it in very simple terms with reference to the Duesenberry Hypothesis (1949). Sometimes called the *Relative Income Hypothesis,* this early idea merely states that the tensions between consumption versus savings will be less affected by an individual's absolute level of wealth than by the levels of wealth apparently enjoyed by the individual's peer reference group/s or else the individual's past levels of wealth. In other words, people have a preference for 'keeping up with the Joneses' and avoiding personal loss. This, according to Easterlin, would help explain why people within countries are quite happy to be wealthier than others, or wealthier than they were previously, but when it comes to comparing aggregate levels of happiness across countries, the effect completely disappears because the people being surveyed are comparing themselves to other people in their own country and not the exceptional wealth enjoyed in other countries. By the same token, they can be just as happy with less absolute consumption as long as they maintain relatively good levels of consumption compared to their equally poverty-stricken neighbours.

This is supported by earlier evidence in India (Sen, 1999, p.47) where some of the lowest castes of people in Kerala, as long as their basic needs are met, can be happier than would be expected from their meagre resources, perhaps because their expectations are culturally constrained within the caste system, suggesting relative perceptions can over-ride objective circumstances, especially in the presence of high social capital acting as a buffer. Another piece of supporting evidence recently emerged in the country of Bhutan. This nation enjoyed such extraordinarily high levels of subjective wellbeing that the King of Bhutan shifted government policy from Gross National Product to Gross National Happiness, which remained extremely high until television was introduced in 1999. After the arrival of 46 cable channels, Bhutan experienced its first major crime wave - murder, fraud and drug offences – possibly in part due as people shifting their focus from parochial contentment to broader, cross-cultural images of modernity (Scott-Clark & Levy, 2003).

With the Duesenberry Hypothesis in mind, Easterlin revisited the survey data originally taken by Cantril (1965) and found that this is exactly what occurred when people were asked what would make them happier under their present circumstances. Whereas people in wealthier countries said they would be happier if only they had a recreational *boat*, people in poor countries said they would be happier if only they had a *goat* (Cantril, 1965). Their desires were culturally relative even though their absolute levels of wealth were vastly different. What this meant is that people in poor countries, on average, could be just as happy as people in rich countries, on average. But whilst people in wealthy countries wanted a boat to *entertain* their families, people in poorer countries merely wanted a goat to *feed* their families.

Although the levels of happiness could be the same, the sources of happiness expressed tended to suggest that relative wealth created a ladder reminiscent of Maslow's Hierarchy of Needs (1954, 1968), such that once a lower need is satisfied and reaches optimal happiness in the short-term, another qualitative level of deprivation reaches conscious salience, motivating the individual towards achieving the next higher need, whether by comparison with others or their own past, just to preserve their previous level of happiness (much less to improve it).

Since Easterlin (1974), similar relative effects have been confirmed in almost all perception studies of psychophysiological stimuli against background noise as well as psychological studies of depression (see Patel, 1996). It is also supported by economic studies of game theory (see Oswald, 2000), where people would rather burn the money of competitors offered more than themselves, even when they were offered more than they had in the first place. This suggests people value equity against competitors much more than their own absolute wealth, which is essentially irrational but explained by the relativity hypothesis. A fascinating aspect of this work is that the *relative competitiveness* is strongest among Harvard MBA students and weakest among primary school children, who appear much more rational in terms of personal outcomes. In distributive justice experiments, the human equity preference is usually the 50:50 split, which is broadly supported as morally correct by 80% of people, a percentage that happens to match new data suggesting 70% of infants already have an instinctive preference to fairness (Geraci & Surian, 2011). In fact, 6-8 year-olds will even make personal sacrifices to maintain fair outcomes (Blake & McAuliffe, 2011; Shaw & Olson, 2012).

Whilst fairness remains important throughout the lifecourse, it appears to be relative status that becomes more salient as the child enters adolescence. Whereas most economic game studies find higher proportions of cooperation in older compared to younger children, others find less equitable and prosocial behaviour as children grow older (Harbugh et al., 2000; Sally & Hill, 2006), especially when their distributive choices are hidden from the group (Gummerum et al., 2008; Shaw, 2012). Shaw and associates (2013) cite a host of studies suggesting "adults are considerably less willing to pay costs to achieve equal outcomes when they can be unfair without appearing unfair" (p.3). In distributive justice experiments, adults also become more selfish as social distance increases (Hoffman, McCabe & Smith, 1996), but this differs across cultures, with Confucian and Japanese societies being more prosocial (Henrich et al, 2005; Kiyonari et al. [2006]), both important factors to bear in mind in the realms of inter- and intranational equity.

This suggests that either sexual maturity (and the competition arising from it) or else learnt socialisation (the pursuit of status also related to sexual competition) are driving an irrational response to the satisfaction of personal needs. It means, perhaps, that adults are far more irrational than children when it comes to equity choices that affect status. In the meantime, Maslow’s Hierarchy (to be explored in detail later) would also tend to explain the global pursuit of economic growth as people continuously climb the ladder of relative success – just to maintain, much less improve, their levels of SWB.

The Easterlin Paradox emerged at a time when data were available across a very small sample of mostly wealthy OECD countries, where the relationship between wealth and happiness was virtually non-existent. Over the decades, many more countries have now been sampled, mostly due to the early work of Easterlin’s academic nemesis, Veenhoven, who disputed the relativity hypothesis from the outset (Veenhoven, 2008). Using larger datasets, Veenhoven began to show that much poorer countries were indeed less happy than Easterlin’s original sample, to such an extent that the lower portion of the curve did operate like the curves within countries, where wealth was powerfully and linearly related to wellbeing. Veenhoven (2008) has argued since the early 90s that wealth still offers a small diminishing return in terms of happiness even among wealthy nations, which could be related in part to the satisfaction of higher psychosocial needs like self-esteem, security, status or even self-actualisation (Diener & Suh, 2000).

When expanding the datasets and revisiting Easterlin's original analyses, Veenhoven (2004) found that three key inputs explained about 80% of human happiness across countries, these being wealth, freedom and peace, and more recently argued that economic growth of about 5% should lead to an extra point of growth in happiness after about 60 years (Veenhoven, 2013). If this is true, it has grim implications for sustainability because the gain among wealthy nations, if it actually exists, is certainly subject to diminishing returns and needs vast levels of consumption to raise life satisfaction by tiny amounts.

Easterlin and Veenhoven began to fight, the former arguing there was no gain from increased wealth and the latter arguing there was a diminishing gain from increasing wealth. Based on the larger datasets embracing much poorer nations, Veenhoven (Veenhoven & Hagerty, 2006) absolutely rejected the idea of relative happiness and vociferously attacked Easterlin as "yesterday's man using yesterday's data" - at least in his first draft, which was later modified when formally published[11] (Veenhoven, 2008). The academic battle played out in the literature and reached a peak in the late 2000's with various papers published to refute each other's arguments.

Easterlin originally pointed out that no great increase in happiness occurred in the United States from 1946-1975 despite a doubling of GNP and he even made the analogy between life satisfaction and human height to demonstrate how people feel themselves to be wealthier/taller than peers at different times and in different cultures where shortness/poverty is or was the norm (citing the Middle Ages). By contrast, Veenhoven quite rightly pointed to the strong relationship between wealth and

[11] The original has now been removed from public circulation.

happiness in the increasingly available samples of poorer countries, where wealth clearly increased happiness. Easterlin (2005) responded by tracking wellbeing across a greater time period and showed that it barely shifted, as described earlier, despite 300-fold increases in wealth in the US and Japan. Veenhoven then countered by replicating Easterlin's work to show that since the 1990s, the European Union displayed significant, though very small, increases in happiness associated with wealth.

Meanwhile, an important economic study by Clark, Frijters and Shields (2008) tracked life satisfaction before and after the fall of the Berlin Wall to show that massive increases in wealth did indeed increase average happiness, as Veenhoven would predict. This was an important study because it was the first to capture an 'instrumental variable' where the direction of causality can only be traced in one direction *at the aggregate level*. To explain the logic, recall that various studies suggest that happy and healthy workers increase national productivity. This means that any correlation between wealth and wellbeing could be bi-directional (see Eckersley, 2008). But when Clark and associates (2008) demonstrated an increase in happiness in East Germany following the collapse of the Berlin Wall, it meant that the increase could only be attributed to the sudden increase in wealth outside of any impact from past levels of happiness and health pushing economic growth.

The original logic was applied *at the individual level* in the classic psychological study of lottery winners (Brickman, Coates & Janoff-Bulman, 1978) where the effect of money could be tested regardless of any personal characteristics of the winner prior to their single change in circumstances. This, along with their earlier work on the Hedonic Treadmill, found no great difference in SWB following, on one hand, a sudden increase in wealth versus, on the other, a sudden accident causing paraplegia. What's more, they found the sudden increase in wealth seemed to increase anxiety, an identical finding when their study was later replicated across time (Gardner & Oswald, 2007). This study also found that a sudden improvement in wealth caused greater stress and significantly reduced SWB in the first year, only later having a more positive impact in the third year following the win.

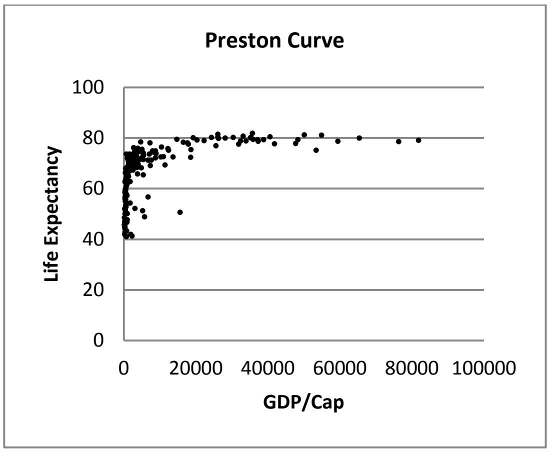
These results resonate with the original study of life expectancy in Vietnam across the years straddling trade liberalisation, or *Doi Moi*, in 1986 (Read, Minas & Klimidis, 1999, 2000). At the time, the World Bank was arguing that Vietnam's extraordinarily high levels of human development were due to trade liberalisation, but this study found that life expectancy was already high seven years before *Doi Moi*, fell significantly after, and took another seven years to recover. More recently, rapid development in Northern China has been linked to a loss of 5.5 years of life expectancy due to air pollution from coal burning alone (Dietz, 2013).

What these results suggest is that adaptation needs time. Sudden disturbances put stress on societies and individuals, whether good or bad, and although an instrumental variable might prove causality in the short-term, much greater timeframes need to be studied, even more than the three years tracked by Gardner and Oswald (2007). Mostly people and societies gradually adapt (perhaps habituate) to some changes, not all, before settling down to their original trajectories, with those trajectories influenced by many other factors influencing either life expectancy or subjective wellbeing.

So just like the earlier studies of lottery winners on SWB, more recent data on East Germany suggests the impact of sudden wealth on happiness was short-lived and mostly returned to its earlier levels, even if just slightly higher, as Veenhoven's study on the EU would predict. Even then, however, the slightly higher level across time could still be due to social changes in the background that are operating outside of the direct effects of wealth. Even an instrumental variable is only as good as the state of knowledge allows at the time of testing.

With the emergence of much larger datasets it became clearer that a relationship between wealth and life satisfaction did exist across nations, but was strongest among developing nations – a group Easterlin had no access to in 1974. Across countries, happiness rapidly increased with greater wealth until it reached a certain point of wealth – where material needs are thought to be met (Veenhoven, 1989) – and then less and less was achieved by further material wealth and consumption. Unlike the intra-national linear relationship, the international curve looks like a broken stick that mirrors the diminishing marginal return on the utility of money itself. Happiness was mostly affected among nations at much lower levels of per capita wealth, suggesting that their levels of happiness increased as their basic needs were met, but once those material needs were met, the impact of further aggregate wealth or material consumption had comparatively little impact on aggregate happiness. In other words, the relationship between wealth and happiness could still be linear within countries even though it was curvilinear across countries, probably reflecting a fuzzy boundary and metabolic set-point no matter how much more wealth was pursued.

The main problem for Veenhoven is that his original multivariate analyses (Veenhoven, 2000, 2004) on wealth, freedom and happiness performed a logarithmic transformation on GDP, which naturally makes the curve look more linear at the average and produces a stronger, more significant, statistical gain than the actual raw-data threshold would suggest. See, for example, the figure below when a *natural* logarithmic transformation is made to the Preston and Easterlin curves.



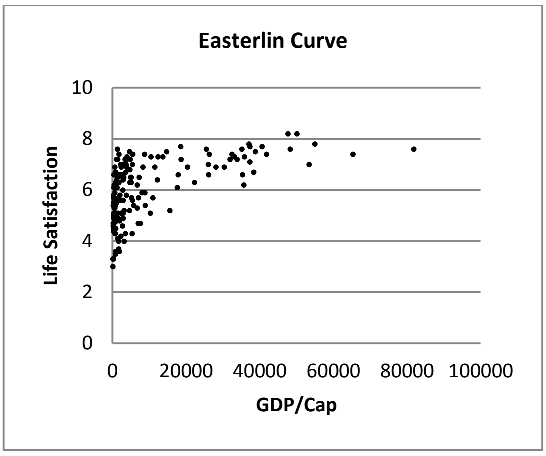


Figure 1-12 The Preston Curve and the Easterlin Curve using a natural log

These kinds of transformations are always useful when vast differences in the input metric obscure the curve at the lower ends of the abscissae where the poorest nations sit. The transformation can be made in many ways such as log 10 or the natural log preferred by the UNHDI but the choice makes no difference to the look of the resultant curves. Any of these transformations will make the overall trends easier to *see when graphed* as long as it is always remembered that the linearity of the curve does not reflect 'real world' effects. For example, the original vertical portion of the stick, the wealthiest countries, are now the small group above 10 *ln*GDP, whereas the original horizontal portion of the stick is below this point, reflecting the majority of poor countries where the subtler curve was previously obscured.

Later in this work the natural log transformation is used judiciously to interpolate human optima using life expectancy, but only when reversing the equation to reflect the proper value of the independent variable. Outside of this, the curve itself cannot be used to extrapolate back to the non-transformed dependent variable and nor should it be treated as confirmation of linearity. Any log transformation makes an essentially segmented curve look more linear than it really is, so multivariate analyses using a transformation should be carefully unpacked before making inductions and deductions. The statistical process in multivariate analyses too often obscures this basic point (often complicated by the rising practice of researchers to outsource their own statistical analyses).

Even if a stable increase in happiness is gained by greater wealth across time, as Veenhoven would attest, it is contended that the gain is miniscule compared to the possible impact on later generations affected by climate change. Although Veenhoven's work was used by the HPI, Veenhoven disavows the problem of sustainability, arguing that if Easterlin's relativity hypothesis were correct, then future generations could easily adapt. He might have thought he had Easterlin '*hoist on his own petard'* when writing this paper, but he actually undermines his own previous work on human needs, mostly because the impact on future generations would push children in the developed world to Third World levels of subsistence, below the threshold of needs satisfaction that he himself once described. By contrast, if happiness beyond needs threshold is only driven by relativity, it argues for more and more consumption to raise aggregate happiness against an upwardly moving target of winners and losers, which is entirely unsustainable and inequitable.

As Spike Milligan once said,
money won't buy you friends but you'll get a better class of enemies[12].

[12] He also cautioned that: "Money won't buy you happiness, but poverty won't buy you anything." see http://www.searchquotes.com/quotes/author/Spike_Milligan/

1.2.7 The Metabolic Set Point

Decades of work on set-point theory tend to explain these results beyond purely economic concerns by suggesting wealth is always important but only to a point (Cummins, 2011). Set-point theory argues that adult SWB returns to a heritable and homeostatically-driven level that serves the resilience and adaptability of the individual, even in the face of major life events (Cummins, 1995; Lykken & Tellegen, 1996; Cummins, Lau & Davern, 2012). It is consistent with Easterlin but not Veenhoven at the population level, especially among the more advanced nations where large-scale studies are more likely to be funded. Here, wellbeing tends to be high, probably bounded to about 7.5 and with low variation (Cummins, 1995). It is linked to wealth, freedom and peace at the population level but with personality, major life events, anxiety and stress at the individual level (Brickman & Campbell, 1971; Costa & McCrae, 1980; Headey & Waring, 1989; Cummins, 1995).

Large longitudinal panel studies can capture many other subtle impacts across the life course, including age, gender, relationships, loneliness (Cummins et al., 2011), marriage, having children, education, unemployment (Cummins et al., 2011), occupation, sexual activity and even commuting time. This argues for greater multidisciplinary collaboration to contextualise inputs.

A predominantly psychological theory that has its roots in understanding human physiology, the encroachment of econometric panel studies only sometimes challenges set-point theory and this is mostly because of inter-disciplinary misunderstanding. For example, the work of Clark, Frijters and Shields (2008) on the fall of the Berlin wall and the German panel data (SOEP) showing about 20% of the population, at least from 1985-2004, displayed permanent changes in SWB – 6%

increasing and 13% decreasing (Headey, 2007) . Though some authors might see this as a major challenge to set-point theory, it is not.

To argue that set-point is incompatible with change is an over-simplification. Just like personality and primary needs themselves, the set-point is heritable but not impervious to external impacts like extreme poverty (much like sitting in a sauna at 110C can lead to death in 16 minutes but hardly challenges the idea of a core body temperature). Panel studies like the German SOEP and Australian HILDA are statistically tight longitudinal designs that can minimise error and test instrumental variables, but their sophistication does not magically overturn decades of other evidence from, for example, identical twins brought up in different environments that still tend towards the same levels of 'happiness', much more than fraternal twins under the same conditions (see Lykken & Tellegen, 1996; Hay, 1985).

As with personality, around half the variation in the set-point also remains stable over decades (Costa & McCrae, 1980) and it is this component that appears to be 80% heritable *at the individual level* (Diener, Suh, Lucas & Smith, 1999). Population heritability is a different matter entirely and this seems to be lost on some critics like Inglehart and Klingemann (2000) who resorted to an absurd attack on set-point theory by saying a change in population wellbeing required a sudden change in the gene pool. Contrast this argument with the Evolutionary Health Principle described by Boyden (2004; Eckersley, 2005, p 11): "If an animal is removed from its natural habitat or if the environment changes…it is likely the animal will be less adapted to the new conditions and will show signs of physiological or behavioural maladjustment."

So too, a heritable set-point at the individual level can only assert itself at the maximum when the individual is placed in an optimal physical and social environment (like getting out of the sauna!). So the population averages will always rise, even permanently, when negative downward pressures are removed, even when the set-point was still just operating in the background. The tightest national gene pool worldwide is currently located in Iceland, a very happy and equitable nation by comparison with others but this does not mean that some of its population are not missing out. Although Veenhoven (1997) thinks equity is not important to SWB across countries, his work never captured these subtleties within countries.

By contrast, studies within different countries ranging from Thailand, Mexico and Australia have shown how the equitable distribution of resources can inflate or deflate the population average because sub-groups within the nation are not having their needs met to maximise the set-point. Some of these are equally strong longitudinal panel studies but more focused on the psychology, rather than the economics of SWB. Outside of traditional studies on economic equity, they provide a broader understanding of actual human outputs that are useful for governments seeking to identify disadvantaged groups (Cummins, 2007, 2008).

This is done by comparing these groups to the national average – similar in logic to the productive and technical efficiency curves later explored in this project across nations. Equity becomes even more important when the dataset is expanded across more countries and there is a recognition that some inputs to SWB have far greater immediate impacts than others. It also means that set-point theory is not incompatible with seeking social policies that promote maximum human flourishing like that pursued by Positive Psychology (Seligman & Csikszentmihalyi, 2000).

The trick is not so much to try and increase the set-point but to bring more people and nations up to its maximum. Pursuing *more* becomes less important than sharing more - equity. So the idea that set-point theory is a nihilistic non-starter for government and international interventions that aim to improve SWB for individuals is to miss the main point (see Cummins, Lau, Mellor & Stokes, 1999). The adaptive tensions between economic and non-economic sources of SWB likely resonate within the individual, through their socioeconomic context, up to national and international levels. Each level of aggregation creates its own issues that can either support or frustrate the goals of individuals (and communities), sometimes because the individual is mismatched with their culture (see Schwartz & Melech, 2000) and sometimes because the culture itself is mismatched to basic human needs (Boyden, 2004).

Governments must pursue a form of integrity that matches policy to universal and time-invariant human needs – not to more parochial concerns in the modern era alone. Universal human needs cannot be studied within a single country, whereas panel studies, whatever their cost and sophistication, are always restricted within countries so they can only point to some, not identify all, optimal conditions required for the human set-point to assert itself in the long-run. To argue otherwise would have to presume that all the relevant variables optimising human health and happiness were already known and inserted into the model, and this applies equally to instrumental variables attempting to prove causality.

Beyond aspiration and economic growth are factors like Maslow's belonging (Maslow, 1954; Baumeister & Leary, 1995; Mellow & Stokes et al., 2008), *true* freedom, tolerance, equity and community cohesion, altruism and compassion (Rilling et al., 2004; Lyubomirsky, 2005), creativity, volunteerism (Mellor et al., 2009), at least one strong personal relationship (Cummins et al., 2012; Lai & Cummins, 2013), personal meaning, resilience and wholeness (Mackay, 2013; Baumeister, 2013).

Nobody yet knows which are most important in a multidisciplinary, global, universal and time-invariant context. In terms of equity, the aspirational life goals of people in some developed countries could, under neo-liberal economic theory, strip the ability of others to satisfy their own non-economic life goals, creating an internal tension that manifests at the population level. Even among the economic 'winners' in those societies, they sometimes have to make sacrifices to non-economic domains of their lives. This can be regarded as 'neurotic' in its traditional sense because it is learnt and maladaptive, manifesting in lower immediate SWB and shorter long-term life expectancy.

This is partly why the Duesenberry hypothesis, although it helps explain the Easterlin Paradox, is only one part of the picture (see Cummins, 2011). Note that none of the broader inputs to SWB actually involve making someone else 'worse off' – they are not a zero sum game based on status, conspicuous consumption and aspiration but rather more sustainable effects based on human inter-relatedness– factors like humour, creativity and compassion that are more inherently human than gross survivalism, resource mastery and social comparison. Easterlin recently acknowledged that non-economic inputs like family and health can have a more powerful impact on SWB than wealth alone (Easterlin, 2005). Other works also suggests non-economic factors might be the last remaining drivers to improving happiness among already wealthy nations (Headey, 2007). The effect of cultural change towards these more human-centred inputs to SWB would tend towards Pareto

Efficiency both within and across countries, and enhance sustainability across generations.

1.2.8 A Possible Reconciliation Based on Human Needs

To contextualise the reconciliation at its simplest level, there can be no real happiness in the presence of starvation and slavery, there can be reasonable happiness when basic needs are met, allowing competitive status to become the next salient concern among wealthier nations – if indeed relative status represents a need of itself (as suggested by Masow, 1968). Presumably the highest levels of self-actualisation can only be achieved once all these lower needs are transcended, including relative status.

To begin with the arguments between Easterlin and Veenhoven, a reconciliation seems to be plausible but only in retrospect. It would appear that the relationship between wealth and happiness is linear for as long as basic human needs are progressively satisfied among poorer countries, and then wealth becomes more relative as higher human needs are progressively satisfied among richer countries. Higher needs like status are already inherently relative, even according to Maslow, at least until self-actualisation is achieved, usually in the mid-50s of the life course, where competition (probably sexual) is thought to be transcended by personal integrity.

Veenhoven says that “Maslow’s theory holds that deficiency needs tend to lose salience once satisfied. Diminishing satisfaction from extra gratification is the result. This view would imply that economic wealth is less relevant for the higher being needs” - such as self-actualisation and the emergence of personal integrity allowing the full enjoyment of life beyond subsistence at latter ages in the life-course. In fact, it was Veenhoven (1989), when looking at the relationship between wealth and happiness among poorer countries, who first suggested that Maslow's theory of human needs (1968) explained the curve, saying that Cantril originally hinted that happiness depends on satisfying "universal basic needs" which evolved because of their "survival value". Veenhoven said a "hierarchically ordered set of needs for physiological subsistence, safety, belonging, esteem and actualization … fits the observed pattern of differences in happiness between poor and rich nations … and is demonstrated in the … life-expectancy of their citizens."

Ironically, Veenhoven later went on to describe changes in wellbeing across periods of recession in the late 1970s that sounded similar to what Easterlin and others were suggesting in the first place. Veenhoven (1989, p 9) said that "need gratification theory can less easily explain the short-term effects of economic rise and decline on happiness in rich countries. Not only did the recession not involve any threat of subsistence, but the effects were also short-lived. Still, need theory can account for this phenomenon if one assumes that the deprivations caused by economic recession are largely symbolical … As freedom of choice is the critical variable here, the effects depend more on turns in the economic tide than on the level of affluence. This can also explain the short-livedness of the effect … Obviously, the surplus of freedom allowed by economic prosperity depends on the socio-political context." Even though Veenhoven argues that absolutism operates among poorer countries, his description among richer countries sounds a lot like relativity. The only way the theories and datasets can be reconciled is with a fuller appreciation of human needs

There are several theories of human need but the most famous is Maslow's Hierarchy (see Baumeister & Vohs, 2004). Maslow (1954, 1968) suggested that human needs could range in a hierarchy from more immediate physiological inputs like oxygen, water and food, through to more complex psychosocial inputs like security, family and status.

Although familiarity has bred contempt over the past 60 years, Maslow's hierarchy remains unique against competing theories because of its hierarchical structure, without which some have said he offers little more than a list (Reber, 1985). Major competing theories arise from Murray Alderfer (1969), Nussbaum (2005) and Max-Neef (1999). Many adapt lists echoing Maslow but tend to by-pass the issue of a fixed hierarchy. The hierarchical structure is simultaneously Maslow's greatest strength and weakness.

Alderfer challenged Maslow by suggesting, quite correctly, that there is a dynamic flux between levels of the hierarchy where individuals can suppress more basic needs to achieve higher needs. Alderfer (1969) said the satisfaction of lower survival needs are not always a prerequisite for an individual to focus on higher needs, as exemplified by the 'starving artist' who suppresses survival needs over the desire for what some call 'personal growth', much like the romantic vision of Mozart completing the Requiem on his deathbed. The most extreme form of this is altruistic suicide (Durkheim, 1897). As will be explored in the discussion, these tend to be driven by learnt 'neuroses' that conflict with the evolutionary imperative of basic survival at the individual level, but still result in early death. In other words, the suppression of basic needs in service of higher needs can only be maintained in the short term.[13]

[13] Note here the word 'neurosis' is not used in the sense of personality instability but in its traditional psychodynamic definition as learnt behaviour which is maladaptive to personal health and wellbeing.

Of relevance to this, another key contribution of Alderfer was in distinguishing primary from secondary needs. Primary needs are those that contribute to the metabolic or social health of the individual whereas secondary needs are the socioeconomic conditions that support the satisfaction of primary needs. This is a critical distinction as it puts factors like food, water and shelter as primary needs whereas wealth, education, freedom and equity might become secondary needs. It can be thought of as the difference between hard-wired biological drives and learnt adaptations that help the individual cope in their particular sociocultural context. The first group is usually measured at the individual level by medicine and psychophysiology whereas the second is usually measured at the aggregate level by sociology and economics. This might explain why a boundary operates at the ceiling across countries whereas primary needs have an intrinsically negative impact at higher levels of consumption at the individual level. The implications for sustainability become much clearer under this dichotomy because it explains why wealth hits a relatively benign ceiling that describes a threshold whereas physiological studies of metabolic needs are bell-shaped, where over-consumption is almost as dangerous as under-consumption. They are almost always driven by a metabolic set-point.

Most theories outside of physiology tend to focus on secondary needs. Economists Max-Neef (1995) and Sen (1985) both sidestep the hierarchical structure of basic needs by evoking dynamic flux in support of human freedom (like those listed in Veenhoven's multivariate analysis), which is understandable from the perspective of their discipline. For example, Sen's Capability Theory argues that the individual is always the best judge of their own immediate needs (echoing utility theory), and that society has the obligation to provide enough freedom, dignity and education (capabilities) so that the individual can satisfy their needs (Sen, 1999). This immediately preserves cultural diversity, freedom and dignity to pursue divergent values, allowing the individual to adapt to their own material and social circumstances. When working with Nussbaum, Sen argued human freedom is a universal human need and that poverty is essentially the deprivation of capabilities to satisfy other needs (Nussbaum & Sen, 1993).

Capabilities sound a lot like secondary needs and would, according to the argument mounted in the current work, tend to display a benign threshold. So it was not surprising that the economist Max-Neef (1999) argued that needs have a threshold; nor that Sen's co-author Nussbaum later argued the same thing (Nussbaum, 2006). Expanding on the freedom/capability theme, law professor Nussbaum forcefully argues that justice, at a minimum, requires the equitable satisfaction of a threshold for basic capabilities in order to achieve human dignity (Nussbaum, 2006).

Across all theories, Maslow's hierarchy is embraced in principle but remains contested because needs are actually more elastic than originally thought, especially at higher levels. If there is a split between primary and secondary needs, it would suggest that most primary needs of concern to medicine, physiology and psychology should be inelastic whereas, moving up the hierarchy, secondary needs of concern to sociology, law and economics, should be more elastic. They merely provide the socioeconomic conditions under which people can pursue more basic needs. Sometimes, the cultural strategies adopted, under the broader umbrella of more relative cultural values, might transgress other people's needs. Think, for example, the dowry culture and its link with female infanticide. At lower levels, the inelastic needs should equal values, but at higher levels, they can change by sociocultural context, whether healthy or not.

With all of these theories in mind, now consider the situation among the most advanced nations. First, the past few centuries of industrialisation has moved populations from relative subsistence to formidable wealth as the satisfaction of 'secondary' needs continuously improved the ability of individuals to satisfy their 'primary' needs. Within living generational memory, the simultaneous growth of both secondary and primary needs have so far suggested that 'more is always better'. If secondary needs are unbounded and tend towards greater consumption at the aggregate level, then a cascade of overconsumption could begin to embrace more and more primary needs, tending towards overconsumption at the individual level that also begins to express itself at the aggregate level. The problem is that overconsumption of primary needs can be toxic, both individually and at the aggregate, even when completely disregarding ecological externalities. The end result is that even secondary needs could start to display a bell-shaped curve at the aggregate level.

This is one explanation for why the most advanced nations never seem to reach the full potential of the era because their levels of wealth promote overconsumption of primary needs. It would also explain the growing but contentious literature suggesting greater wealth is not only hitting a metabolic ceiling but beginning to look more intrinsically sinister than previously thought. Secondary needs like wealth, rather than having no further impact beyond threshold, could actively start to reduce public health at extreme levels.

Moreover, if a bell-curve holds where human outcomes actually fall at higher levels of resource consumption, it could offer a more nuanced and sustainable way of defining human development, especially as it relates to the more arbitrary categories still used by the UNHDI. To illustrate, Figure 1-23 shows how the most basic logic of the production function (see Gujurati, 1995) could be used to more exactly define categories of development on behalf of the UNHDI. As is usual for the production function, two lines can be calculated and drawn using the Marginal Product of Input to show the exact points where gains from further input become negative. Combining these two lines would define categories of development and add a new category of 'over-development' if the bell-curve holds across many different measures of human output outside of GDP.

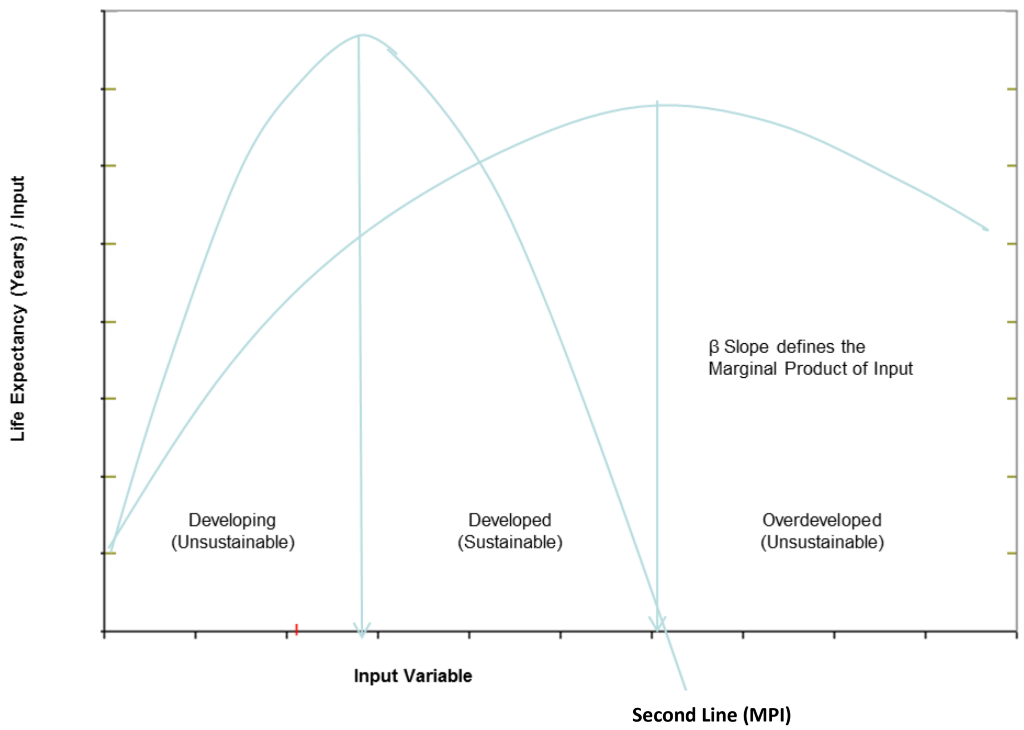


Figure 1-13 How the production function and the marginal product of input could define new categories of development for the UNHDI if human outputs like life expectancy and/or wellbeing followed the proposed bell-curve.

As yet, it's hard to know the answer because the world's wealthiest nations are so few and the emergent curves across countries are tenuous at best, allowing equally strong curve-fitting based on linear, threshold break-points or even curvilinear bell-shaped functions. For example, consider the polynomial replication of the Preston Curve fitted by Bloomberg and Aggarwala (2008) and depicted in Figure 1-24.

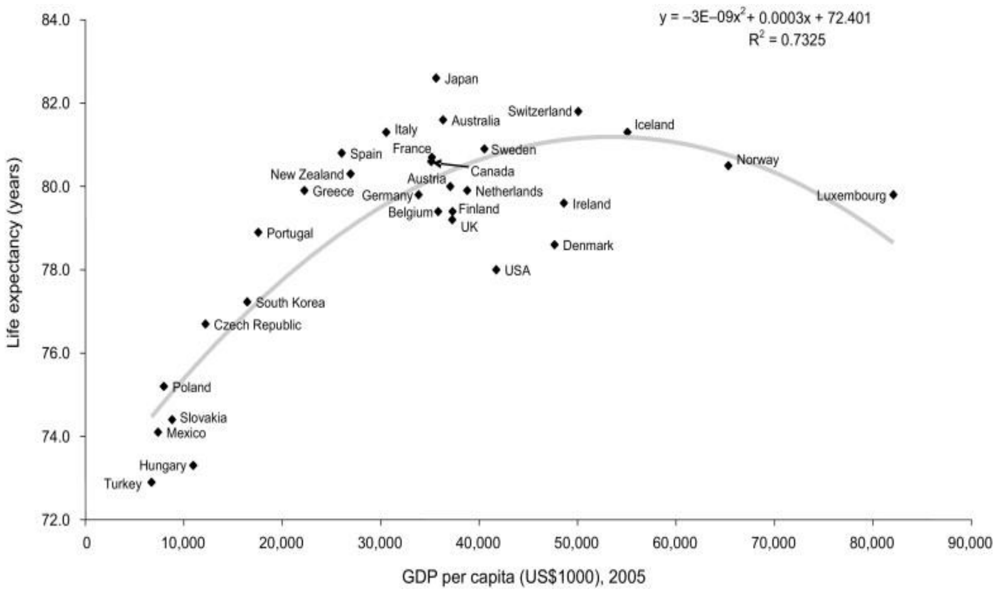


Figure 1-14 The curve for OECD countries alone (Bloomberg & Aggarwala, 2008)

Notwithstanding the small sample of wealthy nations in 2005, now consider the same curve when GDP is replaced with Ecological Footprint and life expectancy is replaced with the HDI across many more countries, as depicted in Figure 1-25. The curve does suggest an asymptotic optimum of about 7g/Ha per capita that might be more sustainable than that pursued by wealthier nations.

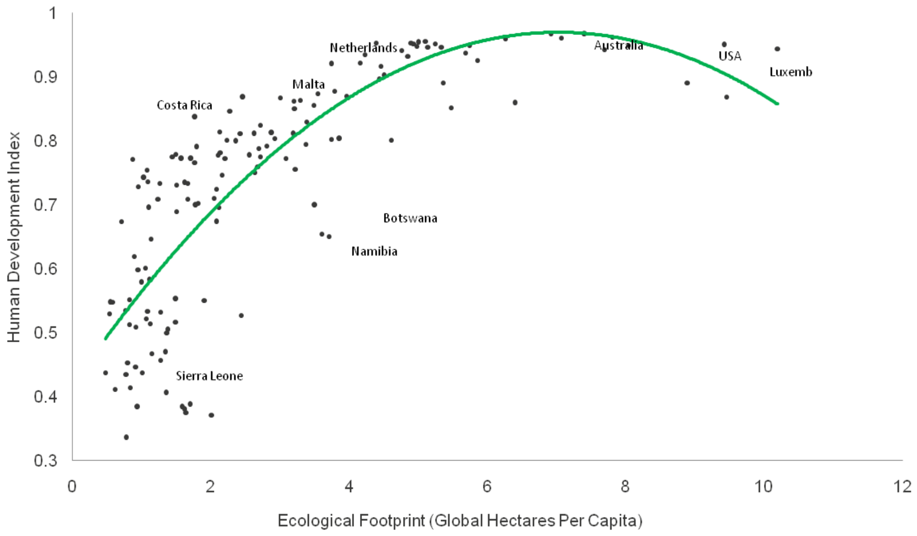


Figure 1-15 The curve for UNHDI by Ecological Footprint (2005)

Moreover, a World Bank (1993) exploration of the Preston Curve across the 20th century suggested the curve became increasingly more curved as more countries became wealthier across time. Although people still became more long-lived with time, the bell-shaped curve became more pronounced with each decade as countries collectively moved towards and beyond greater 'thresholds' of development. The wealthiest countries progressively lost more and more life expectancy as their wealth expanded, recently losing up to seven years of life expectancy compared to their more sustainable peers (Read et al, 2013). Although the sample of extremely wealthy countries was always much smaller than the number of poor, developing countries, they persistently achieved worse outcomes against what would be expected from their comparatively expansive wealth if the curve was presumed to be linear. Note, for example, the differences between Japan and Luxembourg in 2005, the latter being twice as wealthy and considerably less sustainable than the former, despite having lost about five years of life expectancy.

The growing trend towards the bell-shape identified by the World Bank (1993) suggested something more than a benign threshold began to operate at higher levels of wealth. If these technologically advanced nations continued to lose life expectancy, then technological advances could not be the only determinant of public health. Rather, there must be cultural characteristics of wealth that, beyond some point, starts to become intrinsically unhealthy. A host of multidisciplinary studies provides many clues. For now just one example will be considered and that is food.

The latest and largest study of the relationship between obesity, malnutrition and death rates in the United States (Adams et al., 2006) exactly demonstrates this type of curve, even when disaggregated by gender across about half a million US citizens. Note that death rates are treated here as a reciprocal of life expectancy. Body Mass Index (BMI) is calculated by dividing the square of height by weight and is a useful proxy of both malnutrition and obesity. For both genders, a BMI of about 25 minimises death rates, a value long known to be optimal for human health across countries (although Asian cohorts require minor adjustments).

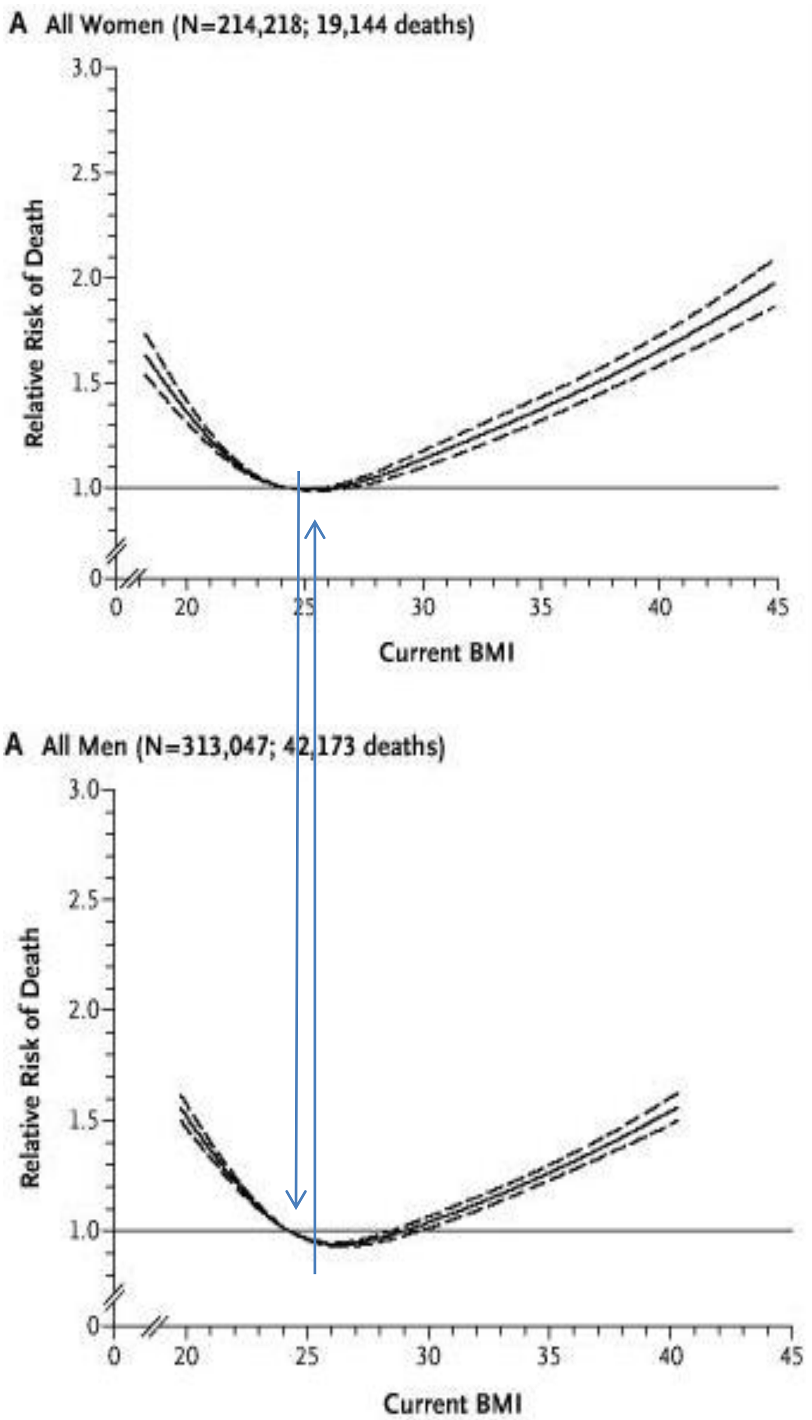


Figure 1-16 The inverted bell-curve for death rates and BMI (Adams et al. 2006)

As will be shown later, the same curve emerges across countries using calorie consumption datasets from the UN Food & Agriculture Organization (UNFAO). Moreover, reference to the WHO datasets on obesity-related deaths show that there are major differences between Japan and Luxembourg, the former consuming much less food than the latter and suffering lower rates of obesity, heart disease and cancer, sometimes attributed to high tax rates on food in Japan and sometimes attributed to dietary practices based on culture. As will be shown, genetic differences alone cannot explain the cross-country differences because the most laudable positions in life expectancy rankings have been taken up by many different Asian and Caucasian nations over the past half century.

In the meantime, the argument now introduces a key notion drawn from human physiology. Hundreds of studies of biological needs show that consumption follows the same kind of dose-response curve demonstrated for food, with survival times increasing until consumption reaches a threshold beyond which further input begins to be just as damaging as privation (see Figure 1-26). As will be shown, this type of bell-curve is demonstrated for human needs as basic as oxygen and water. These arguments are all heading towards the central point that if carbon emissions driven by consumption follows the same kind of curve, then it points towards the possibility of achieving balance between the competing needs of people and planet by moderating consumption at threshold.

There is converging support across disciplines that wealth satisfies basic human needs until it reaches a threshold beyond which returns are diminishing, zero or even negative, resembling a classic growth curve (Diener et al., 1993; Inglehart, 1997; Frey & Stutzer, 2002; Oswald, 2005). Controversies will be discussed later because they echo concerns about the environmental Kuznet's curve (for an overview, see Stern, 2004). In the meantime, we simply note that 'human needs' is a concept fundamental to the Brundtland definition of sustainability (Brundtland Commission, 1987), and if the bulk of ecological impact emerges from a minority of wealthy countries that achieve less and less in terms of human outcomes, it raises some serious questions about development and sustainability.

To reiterate, looking at many of the new metrics now available across countries, there emerges growing evidence that greater wealth is not always better for human outcomes. Wealth is important but only to a point. Of critical importance to sustainability, the apparent fall beyond threshold emerges when GDP is bypassed altogether and replaced with Ecological Footprint. Again, the plateau is replaced with an apparent fall in human welfare at levels of footprint beyond a certain threshold, regardless of whether the welfare measure is life expectancy (Bloomberg & Aggarwala, 2008), subjective wellbeing or human development (HDI).

There are two ways in which this might emerge. One is when economic growth is rapidly pursued to the detriment of human wellbeing in the short term and the other is stable levels of extreme wealth encouraging overconsumption in the long term. The first resonates with an early exploration of decadal UK census data by Sen that found life expectancy falls in decades of high economic growth (Sen, 1999), a finding also echoed in a few studies of former communist countries where life expectancy falls in the first years of trade liberalisation (Read, Minas & Klimidis, 2000; Hertzman, 1999). This might be explained at the level of lived experience because the dogged pursuit of economic growth usually requires over-work and sacrifice, the kind of process described by the Hedonic Treadmill (Brickman & Campbell, 1971),.

Add this to the Global Burden of Disease and we see a trend where the top 10 diseases measured by Disability Adjusted Life Years (DALYs) shift from diseases of malnutrition and infection among developing countries towards diseases of ‘overconsumption' in the developed world – things like diabetes, depression, heart disease and cancer (see Table 1-2; from Lopez, et al. 2006).

Table 1-2 The Economic Health Gradient for the Global Burden of Disease

DEVELOPING WORLD		**DEVELOPED WORLD**	
Cause	**% DALYs**	**Cause**	**% DALYs**
Perinatal Conditions	6.4	Ischaemic Heart Disease	8.3
Lower Respiratory Infect	6.0	Cerebrovascular Disease	6.3
Ischaemic Heart Disease	5.2	Unipolar Depression	5.6
HIV/AIDS	5.1	Alzheimer's & dementias	5.0
Cerebrovascular Disease	4.5	Respiratory cancers	3.6
Diarrhoeal Diseases	4.2	Hearing loss, adult onset	3.6
Unipolar Depressive Disorders	3.1	Chronic Obstructive Pulmonary Disease	3.5
Malaria	2.9	Diabetes mellitus	2.8
Tuberculosis	2.6	Alcohol use disorders	2.8
Chronic Obstructive Pulmonary Disease	2.4	Osteoarthritis	2.5

Along with Sen's (1999) decadal study of economic growth, the socioeconomic gradient of the DALY also suggests that the curve above threshold can fall rather than remain stable. This idea was first suggested by Zolatas (1981), popularised in the anti-growth concept of 'affluenza' (deGraaf, Wann & Naylor, 2005; Hamilton & Denniss, 2005; Oliver, 2008), and has since become an important notion in medical literature surrounding the 'health co-benefits of climate change mitigation' (Frumkin, McMichael & Hess, 2008; Frumkin & McMichael, 2008).

At its most basic level, the health co-benefits of climate change mitigation tend to emerge by multifactorial pathways that move away from cars, fast foods and passive entertainment choices towards bicycles, walking, cooking family meals and active social engagement. Just in terms of food, it moves from market-driven consumption of packaged and processed products, especially meat and out-of-season products requiring long-distance transport, towards healthier preparation of natural, seasonal products. The problem is that all of these more sustainable practices require more time, effort and cost that directly competes with the time and effort required for economic subsistence pushed by government (growth), industry (profit) and shareholders (investment). These more powerful aggregate forces are probably at odds with sustainable practices that enhance health, wellbeing and sustainability.

The overall effect is again confirmed in a recent study of carbon emissions and obesity (Edwards & Roberts, 2010), forming at least one direct link between carbon emissions, consumption and death rates. Among many other possible links is the relationship between economic development, individualism and male suicide (Read, Minas & Klimidis, 1999), or the recently highlighted fall in women's wellbeing since the 1970s (Stevenson & Wolfers, 2009). Among developed countries, some of these evoke notions of the Hedonic Treadmill (Brickman & Campbell, 1971), perhaps driven by relative status (Duesenberry, 1949). As described, the latest HPI data shows the highest levels of life expectancy and wellbeing are enjoyed by countries characterised by more moderate consumption, less development, greater levels of physical activity, stronger community cohesion, better family support and lower levels of suicide (Abdallah, Thompson, Michaelson, Marks & Steuer et al., 2009). At the international level, rates of suicide are highest in the former USSR, India and some parts of Africa whereas violence peaks among some rapidly developing economies like Brazil (*Ibid.*).

This brings us back to why evidence cited much earlier on a more stable metric like human height might help contextualise the findings, even from the modern period to prehistory. Height, like life expectancy is affected by both nature (twin studies) and nurture (twin studies where one child is relocated to a more enriched, usually developed, society and family environment). Does this support economic development?

Although there are many strong arguments for the positive impact of social development since the Industrial Revolution, convergent findings in palaeoanthropology and military history also suggest some hunter-gatherer societies were as tall and healthy as modern Danes (Prince & Steckel, 2001), partly due to equitable distribution of protein and the physical activity that enabled it. Further evidence from dentine and bone mass spectrometry supports the notion that human development has been punctuated, not linear, over the course of human evolution. These studies are valuable because modern measures of human welfare output such as life expectancy only reach as far back as 18th Century France (Human Mortality Database, 2011), whereas human wellbeing has only been measured across countries since 1960 (Cantril, 1965).

Together, the three measures of longevity, happiness and height tend to capture the WHO definition of health as something more than just the absence of disease – a state that embraces both physical and mental wellbeing (WHO, 1946). The evidence is surrounded by multiple controversies and conflicting evidence (see Zolatas, 1981; Easterlin, 2005; Veenhoven, 1991; Veenhoven & Hagerty, 2006; Oswald, 2005; Eckersley, 2006; Diener, Sandvik, Seidlitz & Diener, 1993; Frey & Stutzer, 2002; Bradshaw, Hoelscherb & Richardson, 2007; Jackson, 2009). However, these three measures all show trends that tend to suggest a more optimistic outcome for social progress against the challenge of climate change, at least if human needs can be equitably satisfied with less global consumption. They raise two possibilities.

Consumption and production beyond threshold has either no effect, or a negative effect, on key human outcomes.

In either case, consumption could, theoretically, be redistributed across countries and generations without any (or at least minimal) loss of non-economic welfare. Either way, they offer a more optimistic view of the future under conditions where a growing human population must reduce resource consumption from its current baseline. It suggests people can have more of what matters to them with less that does not.

1.2.9 The Goldilocks Curve for Human Needs

Although human needs are explicitly fundamental in defining sustainability, they turn out to be the most problematic of all sustainability concepts because they cannot be tested without crossing an ethical boundary.

By definition, a primary need is something required for survival. So testing usually takes the form of measuring time to death under conditions of complete deprivation. Most studies have resorted to animal analogues of physiological deprivations ranging across food, water, mothering, sleep, light, temperature, air pressure and many more. For obvious reasons, they cannot ethically study the same processes in humans, much less the degree to which higher needs might operate in a human culture – needs like social and family cohesion, freedom, learning, enjoyment, integrity and living a meaningful life.

For these and many further reasons, Maslow's hierarchical ranking of human needs has remained almost completely untestable for the past 60 years. Even if we could deprive human subjects of their needs in a laboratory context, we could not prove a hierarchical ranking because once deprived and tested, the subject is dead, and so unable to endure further testing to explore higher rankings. This immediately precludes testing in a causal framework using repeated measures across individuals. Third, the lists of candidate (possible) needs from different theorists could never be tested in a single discipline. They require multidisciplinary collaboration across many different needs, ranging from the most basic physiological needs to the most sophisticated cultural needs proposed. This then further precludes the use of animal analogues for higher possible ‘needs’ like education, respect or wealth.

Even when exploring the most basic of physiological needs, it turns out that evidence for humans is thin on the ground, hard to interpret and never contextualised in any form of hierarchy. But using time to death as a key to interpreting results across studies, a hierarchy might still begin to emerge.

For example, oxygen deprivation leads to death within 5-10 minutes (depending on the definition of death itself); hypothermia takes around 16 minutes and water deprivation about five days. Although these studies begin to build a hierarchy by reference to their shared survival metric, a second characteristic of human needs is equally important. In each case, too much is just as dangerous as too little. Oxygen toxicity can occur in scuba diving, hyperbaric chambers, humidicribs and space suits, usually with the collapse of the alveoli and seizures leading to death within about 48 hours. Heat stress, or hyperthermia, takes about 26 minutes to cause death, although world record attempts in sauna competitions suggest tolerance can be cultivated to high temperatures but still limited to 16 minutes. As for water, cases of toxicity can occur when hypernatremia leads to fatal disturbances in the electrolytes of the brain. It can happen after drinking about four litres within a two-hour period, depending on weight and humidity. It has occurred in marathon runners, bushwalkers, army cadets and people at dance raves, where both the primary and secondary effects of using ecstasy can further stimulate thirst. The evidence, even among extreme accidents, suggests biological needs have negative effects at both high and low levels.

This is well known in medicine, physiology and metabolism where illness or death occur at both high and low levels of consumption, even for the most basic needs like atmospheric pressure (Piantadosi, 2003), temperature (Sherwood & Huber, 2010), oxygen (Bert, 1878, 1943; Acott, 1999), water (Adrogue & Madias, 2000), food (Jore & Sharma, 2012) and, more recently, sleep (Ferrie et al., 2007).

Only blunt force trauma tends to have a non-negotiable effect, the most gruesome suggesting people decapitated during the French Revolution could still remain conscious for up to 30 seconds (Jaffe 1957); likewise EEG in decapitated rats continues for one minute although consciousness is probably – hopefully - lost in four seconds (Rijn et al., 2011). Outside of medical studies on palliative and emergency care, there is also some limited evidence from other historical events. In the case of food, the most famously documented case was the hunger strike by a group of 10 IRA prisoners led by Bobby Sands in 1981. The average time to death was 62 days, ranging from 56–73 days depending on initial weight (O'Keefe, 1984; also CAIN, 2007). They only took water.

At the other extreme, overconsumption of food is also dangerous but can take many years, not days, to cause death. This can only be measured with reference to another level of evidence coming from epidemiological studies such as the Sleep Heart Health Study (2012), the longitudinal Framingham Heart Study (2013; Giroux, 2012), the Busselton Study (Cullen, 2013) in Western Australia and the China 1

Study (Chen et al., 1990). The latest findings across 57 longitudinal studies worldwide settle on a loss of three years of life expectancy for moderate obesity and 10 years for severe obesity, equivalent to a lifetime of tobacco smoking (Whitlock & Peta et al., 2009). All suggest obesity ultimately leads to early death via multifactorial pathways associated with clusters of disease related to over-consumption such as obesity, diabetes, sleep apnoea and some forms of cancer. The risk of death is raised again if complicated by alcohol and tobacco (11 minutes of LE lost per cigarette according to Shaw & Mitchell, 2000). In a few preliminary tests for the current work, caloric intake across 22,000 people from the Framingham study was separated from tobacco use to extrapolate zero death risk, coming out at 3000 calories, a figure that will become important later as it matches cross-national recommendations from the Third World Institute and United Nations (Bissio, 1997).

In the meantime, sleep is another fundamental human need that, again, has never been testable in Maslow’s original hierarchy. More than a thousand studies of sleep deprivation have been conducted over the past century but never in humans to the extent that it caused death (Bonnett, 1989; cited in Kryger, Roth & Dement, 1994). Sleep deprivation in humans has a long and sadly recent history as a form of torture but never on the public record (e.g. Mossad and Guantanamo Bay; see Borchelt & Pross, 2005). The first study to show total sleep deprivation could be fatal was in a study of puppies in 1894. Time to death took a few days depending on initial weight, which is informative because sleep studies across species also demonstrate a strong and predictive relationship between body mass and observed sleep times. Inserting an average human weight of 75 kilograms into the allometric formula predicts that humans need around 7.5 hours of sleep. The same figure inserted into the original study on puppies suggests humans could live for about 65 days under complete deprivation, putting sleep as a basic need almost equal to food on the hierarchy.

Given the lack of extant work, this information was useful but remained unconvincing until a recent study showed the same bell-curve peaking at 7.5 hours for human sleep time and death rates (Ferrie et al., 2007). Another preliminary exploration by the current work also used the first OECD survey on average sleep times across countries to show that life expectancy was again maximised at 7.5 hours. This was two years before the Ferrie paper published the first empirical results confirming that 7.5 hours was the target optimum, citing evidence that oversleeping to around 10 hours was usually associated with higher death rates related to sleep apnoea, obesity and cardiovascular disease.

So, despite the dearth of human evidence, there still appears to be a dose-response curve for sleep where the optimum value is moderated, much like the bell-shaped curves for other metabolic needs like oxygen, food, water and heat. The same occurs for other needs that were not originally included by Maslow - air pressure, humidity, wet bulb temperature (see Sherwood & Huber, 2010)[14] and others that resonate with issues of climate change as well as the 'Goldilocks Planet' on which life evolved.

But the problem of measurement is even worse as needs climb Maslow's original hierarchy – up through shelter, safety and freedom, to self-esteem and self-actualisation. At the most basic of social levels, early studies of maternal deprivation among primates and other animals demonstrated there were critical and sensitive

[14] Regularly used to measure safety (e.g. for the Australian Open Tennis) wet-bulb temperature is used to measure temperature with humidity controlled as high levels of both humidity and temperature can be more dangerous to humans than high temperatures in low humidity; see Sherwood & Huber, 2010.

periods where maternal deprivation or privation could lead to attachment disorders, social pathology and language delay (Bowlby, 1982; Rutter, 2002). Even vision has a period sensitive to deprivation that results in partial blindness (Hubel & Weisel, 1963; Snow & Hoefnagel-Höhle, 1978). Studies of ‘feral’ children variously show that linguistic problems remain, longevity tends towards half the prevailing life expectancy but can still range, with appropriate care, from at least 38 years up to 67 years, at least among documented cases (see McCrone, 2003; Candland, 1993). So the effect on longevity, even at this most basic of social levels, seems to be more elastic than at lower metabolic levels affecting, for example, food.

Despite this rising level of elasticity among higher needs, there are many social and psychological studies that still demonstrate significant effects on life expectancy, even if they must resort to larger, more epidemiological samples to minimise error. Classic examples abound, like studies showing men live on average seven years longer if they are married, or studies showing every hour of television watching in adulthood reduces life expectancy by 22 minutes (Veerman, Healy & Cobiac et al., 2012). But these are always long-term projects that are usually confined to a single problem without contextualising it in a broader multidisciplinary hierarchy.

A recent attempt at reviewing more persistent findings was given by McNair (2008). The headline-grabbing summaries on life expectancy usually stretch the mathematics of the original studies too far, but they remain at least illustrative of how life expectancy might be expanded to capture a rough approximation of a needs hierarchy. According to McNair’s review, being ‘happy’ adds nine years of life expectancy, being married and having some spiritual faith seven years each, good sex adds four years, a healthy weight adds three years, and exercise or owning a pet both add two years. These findings come from large longitudinal studies based on intranational data sources where more careful interaction effects were given for age and gender. Note also that these findings on life expectancy, though useful for generating hypotheses, do not always match the same findings on SWB (see, for example, Cummins et al., 2013, on pet ownership).

Main factors that tend to *reduce* life expectancy, at least within developed nations, can be summarised as: poverty (-9 years), lack of sleep (-5 years), low self-esteem (-4), getting divorced or being overweight (both -3), having bad posture (-2) or even living in a cluttered home (-1) (see McNair, 2008). Thousands more studies are available along this broad theme (e.g. Christakis et alia, 2006); even the link between dental hygiene and risk of heart attack (Joshipura, Rimm & Douglass et al., 1996), but note all are based on findings from developed nations where research funding is more available and too often given to medical studies of little relevance to broader human needs. Even when their results are robust and significant based on larger cohorts across time, their actual effect size is sometimes so small as to render some issues completely irrelevant when compared to bigger socioeconomic issues at the population level.

Other approaches are also needed to validate the hierarchy and test effect sizes at the larger level. Note that econometric survey studies sometimes come close to testing a needs hierarchy even without reference to life expectancy in the first place. For example, studies of elasticity of demand or 'willingness to pay' can be applied to many different products or states, ranging from salt, bread and branded cars through to health, wealth and happiness. This approach is later used to confirm results but the base metric of the dollar introduces symbolic and methodological complexities across cultures and economic contexts. As already mentioned, even bundled goods require a different econometric approach that precludes testing across time because they are based on the Consumer Price Index (CPI), even without reference to the perceived relative utility of wealth itself. At least life expectancy, as a proxy of survival time, is more available across many different disciplines and studies, providing a basic unit of time which can still be converted and re-converted into dollar values.

The key issue for the original definition of sustainability is the universality of human needs across cultures and generations. Human needs must be gauged against a direct, simple and harmonised measure that transcends economic, disciplinary, cultural and temporal contexts. If not, the variable might be an adaptive coping strategy peculiar to the particular time, culture and/or economic context. Before exploring more immediate measures of SWB, this work suggests the appropriate metric for measuring the hierarchy must begin with life expectancy - a universally valued time metric that reflects survival and can be used as a single key that unlocks the intrinsic hierarchy operating within any of the 9832 indices now available across countries, cultures and time.

As described, life expectancy is an aggregate average of longevity based on current death rates weighted by population sizes among age groups. It can be measured across time and countries and even estimated from palaeoanthropology and allometric regression across species (as longevity), allowing further confirmation of results long before 1960 (the start of broad UN data collection) and outside of current cultural contexts. Life expectancy is also a key index across disciplines where even causal data are available across large, longitudinal studies (e.g. the Heart Health Study and HILDA). So it is a prime candidate for validation that could triangulate results from different disciplines and aggregation levels without pollution by economic concerns. Vast datasets collected across countries now offer an opportunity to test and re-test almost any index against life expectancy, at least given the right methods to distil a harmonised set of survival curves. This was never available to Maslow.

Even the physiological data on time to death was mostly unavailable at the time Maslow developed his theory. Maslow had to rely on his intuitive sense of psychophysiology and a series of studies on extraordinarily successful individuals, an approach that was perhaps prescient of modern Positive Psychology.

What is seen when looking at the basic physiological evidence is that time to death under complete deprivation can range from minutes to days whereas overconsumption can range from hours to years (see Figure 1-27). So rather than seeking a key metric in the form of time to death, it becomes just as appropriate to use a more expansive measure of survival time. Returning to the IRA hunger strike, note that food deprivation caused death after several months, much later than would be expected for water deprivation (up to 10 days), which is certainly more than oxygen deprivation (usually 10 minutes). This suggests the survival period under deprivation should range from minutes to months, and start building a comparable hierarchy.

Much higher needs should be less pressing and more elastic than basic needs, such that deprivation might range from months to decades; its zero intercept likewise much more variable across and within time. Although no country deprives *all* of its citizens to the point of death, there is partial deprivation among developing countries that raises the possibility that the zero intercept can be extrapolated across countries to represent an estimate of survival time to the point of zero input, for whatever that input might be. If the period of survival under complete deprivation could be extrapolated with stable confidence intervals, it could begin to rank many different indices against the survival metric of life expectancy.

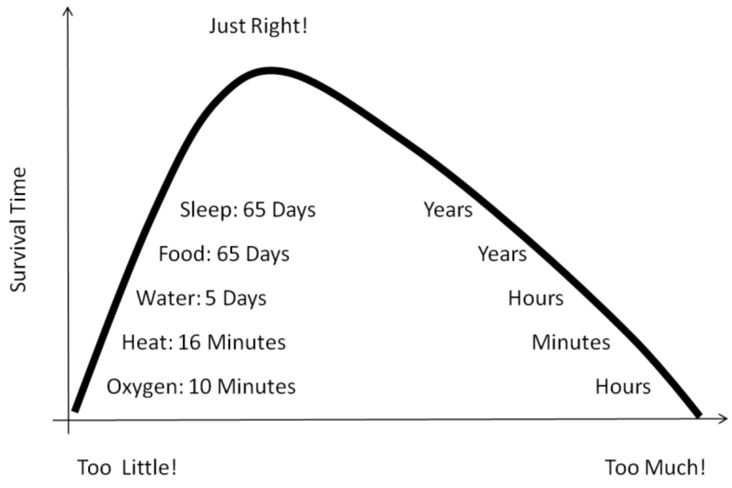


Figure 1-17 The Goldilocks Curve for Human Needs

Although SWB is a more immediate proxy of social conditions, life expectancy itself remains the only proper measure of needs across countries because it is the only measure of actual 'survival'. The biggest objections to this approach would be ecological fallacy, where the curve shape can change when shifting across aggregation levels from the international to the intra-national, or vice versa (Robinson, 1950). This can even reverse the sign of the relationship, as happens with diabetes and wealth in the presence of Simpson's Paradox (explained earlier, see Simpson, 1951).

In the context of this study, however, Simpson's Paradox or milder forms of ecological fallacy become important findings of themselves. This is because it becomes a warning sign that the index is not a true need. To be classified as a true need, the rationale turns ecological fallacy on its head by arguing that the same curve must always triangulate across different levels of aggregation. This demonstrates that the particular input is not merely an adaptive or learnt value that might shift across different cultural contexts and/or time.

The overall rationale regarding needs thresholds and hierarchies will be tested in the current work using frontier regression, starting with calorie consumption across countries and time as a test case to see whether it works with a known value, followed by carbon emissions using the same methods, and then a series of tests on competing indices ranging from diseases of affluence to economic growth and freedom. The final study will test whether the emergent needs hierarchy is stable across time and how some countries are, by reference to this hierarchical dashboard, achieving the best of human health and sustainability despite their comparatively meagre resources. It is hoped this will solve some problems confronted by the HDI and HPI, even if it merely helps ask the right questions in the first place.

The importance of this effort hinges mostly on sustainability. In terms of human health, much less the threat of climate change, it would become nonsensical for the developing world to pursue the same linear trajectory as the world's wealthiest and most resource-intensive countries if it turns out that actual 'human development' stalled long ago; even more so if it causes human harm, not only to living but future generations.

2. Methods

2.1 INTRODUCTION TO THE METHODS

This chapter will outline the *general* approach to the methods, starting with the rationale, issues of reliability and validity, discussing previous approaches to the issues, outlining key metrics and data sources, and then offering a short introduction to frontier sampling. It should be read with the expectation that further detail will be elaborated in the next chapter where more specific details and results are given for each of the six studies. This was deemed to be the clearest way of presentation as the metrics cover so many issues across different disciplines.

2.1.1 An Attempt at Synthesis

The idea of Synthesis comes from the work of Eckersley (2005) on bridging the gaps between disciplines to gain a broader and deeper understanding of the grand challenges facing society. Over the decades, the two main disciplines of econometrics and psychology, for example, have increasingly found common ground in the newly emergent realm of ‘happiness economics’ (e.g. Khaneman, Wakker & Sarin, 1997; Oswald, 2003 ; Frey & Stutzer, 2002; Graham, 2005 , 2010 ; Layard, 2006). While findings from econometrics and psychology are increasingly converging, their methods are only beginning to be shared. Most models also tend to add more issues without making it clear how important (or trivial) each variable might be. They are carved up into reductionistic units and reported without context (leaving the public none the wiser and more distrustful of the science). Their curves and slopes, if they could be contextualised against one another across disciplines using a single metric, could offer much more public understanding if they could be seen in broader context.

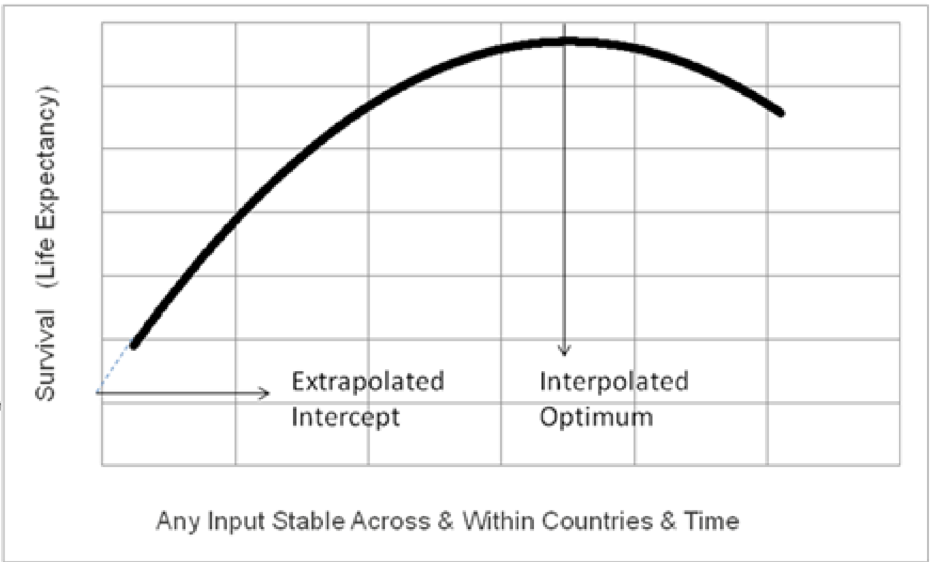
This study attempts to apply psychometric validity tests to an econometric method from disciplines other than 'happiness economics' and multivariate modelling. It then applies the same methods to the HPI (based mostly on the work of psychologists) and the HDI (based mostly on the work of economists). It especially strives to keep the logic and statistical approaches as simple as possible.

2.1.2 Summary of Hypotheses Emerging from Needs Theory

Is any kind of balance between people and planet ever going to be possible? The Goldilocks Curve suggests a more optimistic outcome might be possible if it can be tested (Figure 2-1).

Ha 1

Despite flaws in extrapolation, zero intercepts using the same metric (LE) for many divergent cross-sectional indices, including equity, can be validated across and within time using frontier regression and split-half reliability; if stable across time, the intercept will change for each key metric, building a hierarchy of human needs across time and cultures



Ha 2

Interpolation, much stronger, can also be validated across time, countries, disciplines and aggregation levels, in which case the moderation of consumption, based on existing data for both biological and socioeconomic needs, suggests a moderate, not linear, path to development, which means sustainability is actually possible whilst reducing resource consumption

Ha 3

Subjective wellbeing as measured by life satisfaction should be better predicted by a nation's proximity to the optimum across all identified needs

Figure 2-1 The Goldilocks Curve for human needs and its natural implications expressed as three primary hypotheses

2.1.3 Major Data Sources

To test the Goldilocks Curve first requires a set of harmonised datasets across countries and time where different types of metrics can be matched with life expectancy to explore their stability as candidate needs. As this is early work using a new statistical approach, this work restricts its analyses to testing some of the most important metrics flowing naturally from key themes and composite indices, as listed below.

Composite Indices

1. The NEF HPI, including LE, LS and EF
2. The UN HDI, including LE, GDP and Education
3. The MDGs, including LE, Infant Mortality, Malnutrition and Calories
4. The WHO Economic Health Gradient on Death Rates and Disease

Key Themes

5. Climate Change, including EF and Carbon Emissions
6. Equity, including Income, Gender and Age
7. Set-Point Theory, including LE, SWB and Human Height
8. Maslow’s Hierarchy, covering a selection of available metrics
9. Elasticities of Demand, covering Food, Clothes & Shelter
10. Allometric Regression, covering Body Mass, Brain Weight & Lifespan

A necessary part of this work was an initial review of available cross-country metrics, including their timescales and representation across countries. The metrics were first counted and collated arriving at 9832 indices worldwide, of which 80% were represented by WHO and UN datasets.

Only those that were carefully harmonised across nations and time were found to be shared across other agencies like the World Bank, NEF and MDGs. Checks were made to ensure the same numeric figures were regularly reported across agencies for key metrics. Most of the SWB data are now reported by the UNHDI Reports but their original sources generally come from the World Values Survey and Gallup Poll, with additional indices collected by individual studies, national statistical agencies and authors focused on cross-national data harmonisation like Hofstede (1967), Inglehart and Veenhoven, among others.

Of the original 9832 indices counted, some were replicated and others were yet more composite constructions like the HPI and HDI themselves, often based on further mathematical adjustments (like the DALY, QALY, HLY, HLE, and various Gender and Income Equity Adjusted versions of the HDI itself). In addition there are various league tables like the World's Most Liveable Cities, Forbes Rich List and others that were not useful. The most questionable among them included metrics like the McDonalds and Madonna indices.

In the end, the project sought only those metrics that came with a strong research pedigree, were consistently reported across respected agencies and covered as many countries and time series as possible. The final and main datasets are listed below, including their online sources.

1. NEF 1.0 Report (2006) www.happyplanetindex.org/public-data/files/happy-planet-index-first-global.pdf
2. NEF 2.0 Report (2009) www.happyplanetindex.org/public-data/files/happy-planet-index-2-0.pdf

3. World Values Survey (2009) www.wvsevsdb.com/wvs/WVSAnalizeQuestion.jsp
4. Human Mortality Database (2011) www.mortality.org/cgi-bin/hmd/hmd_download.php
5. Health Behaviour in School-Aged Children (HBSC, 2006) www.hbsc.org/downloads/IntReport04/Part3.pdf
6. Health Behaviour in School-Aged Children (HBSC, 2008) www.euro.who.int/__data/assets/pdf_file/0005/53852/E91416.pdf
7. Food Balance Sheets of the UN Food & Agriculture Organization & Aquastat (UNFAO, 2012) www.fao.org/icatalog/inter-e.htm; www.fao.org/docrep/016/i2845e/i2845e00.pdf
8. UN Human Development Report (2013) http://hdrstats.undp.org/en/tables/
9. UN Human Development Report (2010) http://hdrstats.undp.org/en/tables/
10. Boston Sleep Phylogeny Database (2013) http://www.bu.edu/phylogeny/about/index.html

The way these datasets are handled is detailed in the *Results* section for each individual study. Key to linking these many disparate databases is always life expectancy, later extended to life satisfaction because it resonates with the global cognitive evaluation of human needs satisfaction. For both, the method based on frontier sampling is now described in its broader methodological context, with some additional background rationale included as appropriate.

2.1.4 Using Frontier Regression for Cross-Sectional Curves

Most of social science is engaged in trying to identify relationships that explain the variation around the average, a task that requires increasingly complicated models that keep adding more variables and are difficult to understand for the lay-person, especially when using models to validate causal relationships. What is equally useful and more easily understood, however, is the existence of boundaries that limit causal relationships in the first place, especially if they are stable across time. These are too often ignored or obscured in statistical methods that focus on the average and rely on the assumption of linearity between variables.

Yet boundaries and curves are not so hard to find when composite indices are deconstructed and replicated across time, as was shown with the Preston and Easterlin curves. They are usually curves that can be linearised but are not of themselves linear.

One of the best ways of testing boundary processes across datasets comes from econometric methods, notably frontier regression that was first suggested by Farrell (1957). Frontier regression models "explain boundary, frontier or optimal behaviour rather than average behaviour as in ordinary regression models" and are "desirable alternatives in many circumstances" (Troutt, Hu, Shanker & Acar, 2001, p.1). In such circumstances, it is not the average that is sought as the target outcome, where variation around the average is always influenced by complex interactions so much as the best possible benchmark at the upper extremes of the curve, sometimes called the 'ceiling'.

Because maximising life expectancy is one of few human outcomes that is universally valued across cultures (CSDH, 2008), this work argues for the use of the frontier rather than the average as a more appropriate form of analysis.

Frontier regression was first applied by Aigner and Chu (1968) using a Cobb-Douglas production function[15] looking at profit maximisation among firms. This identified the maximum boundary of profit achievable for every level of input (Sieford & Thrall, 1990; see also Coelli et al., 2005). However, even in these early approaches, the aim was still to explain how factors of production could be more efficiently exploited to maximise performance by using econometric modelling and interaction effects. They wanted to capture and explain the error variance below the ceiling to explain how interacting inputs could be balanced to maximise profit, which later stimulated concepts of productive efficiency controlled for error variance below the curve. This led to stochastic frontier regression where the error was split between a half-normal term based on curve variation with the remainder being an estimate of total inefficiency, and sought to explain sudden shifts in factors of production.

Many more complex forms of frontier regression have since emerged such as Data Envelopment Analysis (DEA), where more than one input or output again devolves to complex modelling in order to control for all factors whilst preserving the integrity of micro- and macro-economic assumptions (see, for example, the discussion of naïve bootstrapping and the Monte Carlo method in Simar & Wilson, 2010). In light of the complexity, few authors applied the approach across industry sectors or countries, although a few were brave enough to explore issues like income (Sen, 1981), health expenditure (Evans et al., 2000), life expectancy (Dietz, Rosa & York, 2009) and the Millennium Development Goals (Jayasuriya & Wodon (2003).

[15] The Cobb-Douglas production function is a curve formula used to maximise production by finding the right combination of physical capital and labour, usually applied to firms and using two inputs against one output, and assuming all other things being equal; note the assumption of *ceteris paribus* is more robust at the frontier

Yet even these works continued to focus on the variance below the curve, usually called productive efficiency, and they usually skimmed over the more robust limits of the curve, called technical efficiency, a finding in itself of deep importance to other disciplines like health, sociology and psychology.

Where the current work diverges is that no explanatory model is needed to empirically estimate a threshold boundary of life expectancy or life satisfaction across the full range of observable inputs. Although it uses regression techniques, it does not attempt to model a functional form that explains or controls for omitted variables across countries. Rather, it argues that frontier regression already goes some way towards eliminating the gross effects of omitted variables such as war, infection and extreme inequity by focusing on the absolute limits of key outputs achievable across the input range.

More importantly, the project does not attempt to decompose and explain the variance below the ceiling using other metrics (as in Dietz, Rosa & York, 2009), but validates technical efficiency as a stable threshold across time that uses the maximum gain achievable against baselines demonstrated by the variables themselves.

The main concern of this work is to test human needs using a proxy of survival. Life expectancy is the main dependent variable as it represents a universal human output based on a ratio scale with a true zero point that also offers:

1. A survival measure resonating with human needs (Brundtland, 1987)
2. A harmonised formula across time and countries (HMD, 2011)
3. A universally valued outcome independent of cultures and disciplines (CSDH, 2008)

4. A heritage of comparable data going back to 18th Century France (HMD, 2011)
5. A wealth of literature linked to paleo-anthropological data (Steckel, 1983)
6. A wealth of laboratory data from medicine, public health and psychology (McNair, 2008)

These advantages allow tests of one key metric that, unlike wealth, is less affected by subjective cultural relativism and much more founded in basic human survival, so is equally important across countries and time regardless of cultural contexts. As a consequence, it is one metric that should be just as relevant to future generations as it was in the past, and so a more fundamental metric of development and sustainability in terms of human needs. It is also a metric shared across many disciplines as the primary dependent variable.

The original background question posed by this work was whether the increasingly competing needs of people and planet could be balanced on behalf of future generations.

Using life expectancy as the key output metric for satisfying human needs begins to provide an appropriate measurement framework that is perhaps more grounded in the broader psychosocial and economic literature than, for example, the HPI and HDI. Moreover, by using the frontier rather than the average, the relationship to LS should hold as countries come closer to the set-point optima across major candidate needs. Although regression is used, the process does not yet attempt to model a functional form that controls for omitted variables or even causality. As said, this is not a modelling study but instead goes back to the basic stylised curves across newly available metrics in order to explore their implications for future studies and offer a process to empirically place human needs in the context of global sustainability.

So the statistical rationale is more mercenary than previous modelling studies as it exploits an econometric regression technique with the sole aim of interpolating a stable empirical threshold at the maximum of LE. In this sense, it suffers all the problems confronted by, for example, the environmental Kuznet's curve (see Stern, 2004) and would deserve just as much caution were it not for the fact that the work has a very different aim. It is not so much the explanatory form of the curve that is of key interest as the threshold that can be calculated across time. Using pure frontier regression goes some way towards eliminating the gross effects of omitted variables but this was not the original reason for its use.

Originally, the same logic as Farrell's frontier was naively developed independently to overcome problems in the HPI and HDI themselves. It was first noticed when re-analysing the datasets of the HPI that its efficiency metric made some of the most 'miserable' (and inequitable) countries appear more sustainable. By later adding two constants to the numerator and denominator, the HPI shifted the target upwards towards more acceptable human outcomes (Marks et al., 2006; Abdallah et al., 2009). Yet this still glossed over an empirical target for human outcomes, forcing the NEF to develop a Traffic Light System (NEF, 2009) that still leads to researchers making value judgements about the importance of competing indices rather than being guided by the actual data. This same problem is why the HDI had to adjust its own definitions of development based on arbitrary statistical manoeuvres as more countries kept shifting from the 'developed' to the newly created 'highly developed' categories around the same time (UNDP, 2010).

So when looking at these problems, the current work sought a method that would allow the data to speak for itself in terms of generating an empirical threshold that transcended the use of arbitrary constants or categories of development. The rationale that emerged was eventually based on pure frontier subsampling, which is uniquely useful in testing life expectancy. Using the frontier on other metrics can be challenged on multiple levels but life expectancy is a unique case because of its transcendent importance to human survival.

Because maximising LE is one of few human outcomes that is universally valued across cultures (CSDH, 2008), this work argues for the use of the frontier rather than the average as a more appropriate form of analysis. But rather than attempting to decompose and explain the variance below the ceiling (as in Dietz, Rosa & York, 2009), this work focuses on validating the term of *technical* efficiency as a stable threshold across time. So its main challenge is to validate stability, where the error term becomes horizontal across time rather than vertical within time. The functional form of pure frontier regression used by this paper is given by the following formula adapted from Troutt and associates (2001):

$$y_j = \beta_0 + \beta_1 x_j + \beta_2 x_j^2 + \beta_3 x_j^3 - \omega_j$$

where y_j = *Input Variable x* for Year j, x_j = (Year-2000) and ω_j = a non-negative error for Year j

This, of course, depends on the curve of best fit, which is later tackled for each study. In the interim, note the optimal LE can be interpolated from the curve formulae for every year for which matched data are available, usually from 1960-2007. To test horizontal stability, this project then borrows from psychometrics using split-sample reliability. It then tests the variance across time to see whether there is a stable input threshold that matches optimal LE. Regardless of causality, the results empirically prove, if only by appealing to simple falsification, that greater input across various candidate indices is not always needed to improve human outcomes. This is slightly more optimistic than economic studies might predict for an increasingly carbon-constrained world.

Why should this emerge? It hinges on the idea that many modern societies might be at odds with human evolutionary needs and those societies that are closer to the evolutionary ideal will display better human outcomes in terms of longevity, health and probably also happiness. This is an idea described by Eckersley (2005) and Boyden (2004) as the 'Evolutionary Health Principle'.

As noted previously, problems in the concept of subjective human wellbeing still suggest that some countries rate their wellbeing against structural inequities (for example, the United States) whereas others rate their wellbeing against needs satisfaction (for example, Costa Rica). But even despite these problems (possibly related to learnt cultural preferences or secondary adaptations) the broad trend at the frontier should be that as societies come closer to reaching the various interpolated set-points or thresholds across a growing set of candidate needs. So their global perceptions of life satisfaction and life expectancy should be maximised.[16]

To briefly summarise the methodological rationale, the frontier describes the absolute maximum of life expectancy that can be observed at different levels of any input, no matter how much the most efficient countries might seek, exploit or consume, and no matter how much other countries fall away from the optimum

[16] Note this requires a multivariate model which would be the next natural step in the work but is not yet included.

because of other problems. The logic, by comparison with linear models of economic growth, is probably unassailable because immortality is, as far as we know, probably impossible.

A set-point, bell-curve or benign threshold would mean no amount of material consumption affecting the planet will greatly impact on human outcomes beyond incremental progress operating in the background. Moreover, some input variables themselves might actively reduce life expectancy beyond a metabolic limit of consumption.

Rather than being undermined by Ecological Fallacy (see Section 1.1.3), the rationale for this work argues that ecological convergence across disciplines and countries is a key sign of a true universal human need – for example, the same threshold value should emerge at different aggregation levels and using different study designs. Moreover, if stable and predictive across times sampled in the past, the human needs identified in this way should be equally relevant to generations living in the future. The major studies test the methods against one basic human need – food consumption – to make sure they predict what is already known from the dietary literature. If the results across countries converge with known physiological studies, it argues that frontier regression can then be applied to socioeconomic needs, which is where the other studies in this work begin to explore the broader trends for human needs theory.

2.1.5 Mathematical Hypotheses Emerging from Needs Theory

Three key characteristics of human need emerge at the individual level and the same results should also emerge across countries. To begin building an empirical framework, three important characteristics of human need at the metabolic level can be measured, being rank, threshold and stability. These can be explored using extrapolation, interpolation and retest reliability at the frontier of life expectancy.

1. Extrapolation of rank based on partial deprivation across countries,
2. Interpolation of threshold based on the shape of the curve, and
3. Stability of these measures across half a century.

Extrapolation is an approach usually reserved for the brave or stupid, which is why most authors, if they use it all, tend to bury it deep in a footnote or equation. However, given past findings across disciplines, it would still be expected that the extrapolated estimate should range from zero to many years as the hierarchy climbs – notwithstanding growing and overlapping error. The extrapolated survival time under conditions of deprivation (the zero intercept) should place basic needs like food at the base of the hierarchy because survival time is counted in months whereas higher needs like shelter should be measured in years. Even higher needs like respect or social inclusion might have deprivation periods that will be extrapolated to higher levels of life expectancy again. That is if they follow Maslow. There is every reason to believe that some so-called higher needs might be more important than previously thought and even some lower needs might be less important than previously thought. This has never been explored across so many indices before.

In each case, there are some intra-disciplinary studies that can be used to contextualise the cross-national extrapolations. The existing inequalities between the developed and developing worlds are useful for this purpose as they begin to provide what might be described as a vast natural experiment for testing a human needs hierarchy against partial deprivation of life expectancy. Given the constraints described in the last chapter, there is probably no other way to test needs outside of culture. Of course there will be many more intervening variables as the hierarchy climbs, making the deprivation period more variable (or elastic) and this should be reflected in the confidence intervals. The elasticity of the need should increase as the survival time increases, reflecting things like greater ‘product’ substitution or adaptability, which begins to raise issues of opportunity cost and interaction, possibly distinguishing Alderfer’s primary and secondary needs (Alderfer, 1969), which will later be explored by reference to allometric regression.

Human needs, as they climb the hierarchy towards ‘actualisation’, should begin to shift from universal and biological needs towards more individualistic and elastic values that are either culturally learnt, adaptive, or both. Unfortunately, some of these ‘higher’ values may become destructive to the individual, the society and/or the ecology. So a third hypothesis is that using life expectancy as the key output will begin to show how some cultures are pursuing strategies that fail to serve both human and ecological needs. This returns to the idea that levels of an index beyond threshold might have either no effect or a negative effect on human outcomes.

This can be measured by interpolating the second key characteristic of a human need, being threshold, which also has profound implications for sustainability. Threshold is a key element of a metabolic system that sustains life by regulating appropriate ranges via feedback loops (whether simple or complex). A threshold is a point, or more usually a resilient range depending on the degree of elasticity, where the survival (or sustainability) of the system is maximised. As mentioned, such thresholds operate at both planetary and human metabolic levels. One good example for both is temperature. All animals have metabolic limits for temperature, creating a range of resilience outside of which death occurs, whether it is too cold or too hot. Once again, this can be stylised as a bell-shaped curve where the threshold optimum is interpolated at the peak of the curve. This means complete deprivation as well as over-exposure can both cause death, with optimal survival at a more moderate level.

When thinking of higher needs like wealth, the idea of a threshold is almost nonsensical to many people in the developed world because development within living memory has emerged on the other side of the subsistence curve. Yet many economists over the years have already identified thresholds or break-points in optimal wealth against life expectancy. Too often these break-points are confounded by the CPI base year, creating the illusion that the threshold increases across time.

Although most theories of economic growth and development assume there is no ceiling threshold, all aggregate data across nations, as we saw earlier, tends to suggest a plateau at the very least, and one which applies whether the input variables are GDP or EF against equally diverse outputs like the HDI, LE, LS or HLY. These curves suggest the linear pursuit of wealth and further resource consumption are either unnecessary or even maladaptive to human welfare, even before counting ecological costs. Once again, multiple controversies emerge, some of which can be addressed by examining the third key characteristic of human need, which is stability.

Any true human need should assert itself at any level of aggregation, across both developing and developed countries. Even before causality is addressed, this means both the threshold and ranking must remain stable across countries and time. If this level of stability is not sustained within reasonable confidence intervals, it suggests the index might be an adaptation to socioeconomic or individual circumstances peculiar to the culture and/or the era.

To be classified as human needs, both thresholds and intercepts should be stable across cultures and time. This work uses cross-sectional data over the past 50 years to explore stylised facts which might help build a hierarchy of human needs in the context of sustainable development. It will also provide evidence across time that human development, especially in an era of globalisation, requires a re-conceptualisation of social progress that moves from linear to curvilinear forms, or at least a consistent break point that signifies a plateau.

The next section will now describe further how multivariate and causal analyses could be informed by an adapted form of pure frontier regression that simultaneously explores stability, ranking and threshold across time and disciplines. This offers a more detailed map of stylised facts in the service of future research and provides the first exploratory test of Maslow's hierarchy based on a single metric across countries, time and disciplines, a luxury that was never available to Maslow.

2.1.6 Issues of Reliability and Validity

The philosophy of science demands testability (falsifiability), reproducibility of results (empiricism), and usefulness in the 'real world' (scientific realism) (see Chalmers, 1999). This further relies on two main approaches in the application of scientific method. One is passive observation, from which induction informs theoretical hypotheses, and the other is active experimental control, against which logical hypothetical deductions can be tested in a controlled environment. The former is typically used in sociology, epidemiology and economics whereas the latter is more available to reductionistic methods in physiology, medicine and experimental psychology at the laboratory level. Depending on their levels of experimental sophistication, all of these disciplines hinge on basic concepts of reliability and validity.

In classical theory, validity is defined as accuracy whereas reliability is defined as consistency (see Novick, 1966; Lord & Novick, 1968; Allen & Yen, 1979). Accuracy (validity) is usually more important than consistency (reliability) when testing human states rather than human needs. Half of this thesis is concerned with states (outcomes changing with ecological inputs such as resources), whereas half is concerned with human needs (outcomes that remain stable despite changing ecological inputs such as resource usage and its ecological damage to the environment). Any human characteristic that is thought to be a stable need (rather than a state responding to changing external conditions) must demonstrate, along with validity, two additional aspects of reliability (Tull & Hawkins, 1980). These are:

1. *Test-Retest Reliability*, where the same result emerges across time despite many changing circumstances.
2. *Split-Sample Reliability,* where the same result emerges within time despite randomly splitting the original sample in half.

Although rarely explored in the context of human needs, both can be done with many of the thousands of competing cross-national indices of human welfare and sustainability now collected by the World Health Organization, United Nations and World Bank. This work directly tests many of these indices for human needs, which are, by definition, time invariant and universal. If time-invariant, they should display test-retest reliability and, if universal, they should display split-sample reliability. To be classified as needs, any candidate metric measured across and within countries should display both of these characteristics, as well as two other forms of reliability proposed here:

1. *Aggregation Reliability,* where the same result emerges at different aggregation levels, whether tested within a single country or across all countries
2. *Cross-Disciplinary Reliability,* where the same result emerges across many different theories, methods and disciplinary languages

Further issues of validity are a major concern to all disciplines and these are summarised below because each will be addressed in this work to the extent that they can, either by reference to the data or the extant literature.

1. *Empirical Validity,* which includes whether an abstract concept can be measured in the first place (representational validity), makes sense to experts and lay people alike (surface validity), makes sense in terms of past studies (construct validity) and embraces all the possible domains that should be relevant to the concept (content validity)
2. *Correlational Validity,* where the metric correlates with another similar metric that already has empirical validity (convergent validity) or the main metric seems a little weak on some counts but still correlates with some other more powerful, even if less useful, metric (criterion validity); the same emerges when the original sample is generalised to much broader samples (ecological validity) or even across time (predictive validity)
3. *Experimental Validity* includes whether the original sample is unbiased and represents the total population of interest (external validity), whether

the correct measures of central tendency are matched to the right statistical tests (statistical validity), whether confounding variables have been eliminated in a controlled environment, usually in a laboratory context (internal validity), and whether the metric offers ‘real world’ sensitivity and specificity, usually in a medical context (diagnostic validity)

If this brief discussion of reliability and validity is treated as a pocket précis, the whole work of this thesis can be contextualised visually as to where it is hoping to sit in the process by showing which elements of reliability and validity are discussed or tested for the key outcome metrics of life expectancy (LE), life satisfaction (LS), human development (HDI), sustainability (HPI) and human needs (see Table 2-1).

Table 2-1 Key metrics in this project and how they are treated with reference to reliability and validity (whether merely discussed ① or actually tested ②)

TEST	**LE**	**LS**	**HDI**	**HPI**	**NEEDS**
Representation	①	①	①	①	①
Surface	①	①	①	①	①
Construct	①	①	①	①	①
Content	①	①②	①	①②	①
Convergent	①②	①②	①②	①②	①②
Criterion	①	①	①	①	①
Ecological	①②	①②	①②	①②	①②
Predictive	①②	①②	①②	①②	①②
Concurrent	①②	①②	①②	①②	①②
Statistical	①	①	①	①	①
External	①②	①②	①②	①②	①②
Internal	①	①	①	①	①
Diagnostic	①	①	①	①	①
Retest	①②	①②	①②	①②	①②
Split Sample	①②	①②	①②	①②	①②
Aggregation	①②	①②	①②	①②	①②
Disciplinary	①	①	①	①	①

To summarise, the work will attempt to show that most of the main metrics of human development, including Gross Domestic product (GDP), the United Nations Human Development Index (HDI) and even the Happy Planet Index (HPI) are essentially unsustainable by reference to validity; whereas human needs, with reference to both validity and reliability, emerge as more sustainable, with more optimistic outcomes across and within both countries and generations.

From the very outset, one key issue must be concurrent validity, where the experimenter carefully ensures that paired metrics are actually collected at the same time before making any other tests. In the past, lack of data collection among countries in concurrent years has often forced researchers to assume that one or more metrics were stable across contiguous years and sometimes across decades. This is not so excusable in recent years where more data are available and it is known that various metrics change in response to external circumstances, sometimes at a constant rate and sometimes not, as in times of war. Concurrent validity is carefully preserved in this work as a general rule. If it must be violated, it is highlighted in the methods for each study.

Beyond this, the first consideration is empirical validity - whether the concept can be locked down to a measurable test in the first place. In the case of the development metrics under review, wealth is represented by the dollar value, life expectancy by survival years, education by adult literacy and years of formal education, and ecological footprint by geographic space. Life satisfaction, as always, remains contentious. As it stands, cross-national surveys using Likert scales across words like ‘satisfaction’ and ‘happiness’ are the only tests available across countries. They can be skewed by either misunderstanding of the question or even faking by the respondent, one due to linguistic issues and the other due to social desirability and the cultural preferences driving it. The only way to validate them outside of these concerns is by reference to convergent validity with so-called ‘objective’ measures, usually presumed to be biological or, at the very least, convergent with third-party ratings. Attempts to measure subjective wellbeing outside of the perception of the individual, despite years of work, have not often succeeded. Although there are good tests emerging with technologies from psychophysiology and medicine such as cortisol secretion, electroencephalography, heart rate reactivity and now Magnetic

Resonance Imaging (MRI), none are yet available across enough countries and even these are not entirely immune to subjectivity.

The next consideration is surface validity, whether the metric is intuitively understood. When comparing GDP, HDI and HPI as an output metric of human development, the most intuitively understood measure must be HPI because it measures human health and happiness. By contrast, GDP offers good surface validity *as a measure of wealth* but not as an intuitively understood metric at the level of lived experience, even when weighted per capita. This is because issues like inequity and the complexity of its measurement change across time, countries and context as well as base year, PPP, CPI and even the cultural value of wealth itself. Similar problems apply when education is treated as an output in the HDI, where some people feel education is not as important as their own health, wealth or happiness.

Because lived experience is also constrained by the fallibility of people's perceptions within their own cultural contexts, there are often reasons why informed expert opinions from within and across disciplines are critical. Expert opinion embraces construct validity, the degree to which a metric actually measures what it claims to measure based on known theory and evidence (Anastasi & Urbina, 1997) and the more important aspect of content validity, the degree to which a metric captures *all* of the important domains beyond single disciplines (Foxcroft et al., 2004). To illustrate, GDP has strong construct validity as a measure of national wealth but fails in terms of content validity because it ignores equally important human outcomes like life expectancy, life satisfaction and ecological footprint, all emerging from other disciplines. Like the fallibility of lived experience, both construct and content validity are challenged by the fallibility of experts themselves, especially when their assumptions are constricted within a single discipline.

Once a metric makes sense to experts and lay-people alike, statistical validity raises a few more issues in terms of how much it properly represents whole populations. Inductively, the degree to which a sample reflects the population to which they are generalised is called external validity, based on the *Law of Large Numbers*. Apart from the issues of statistical power and error, all studies in this work avoid a biased sample, which appears to be strong with wealth and life expectancy across whole countries until expert opinion weighs in to point out that wealth ignores non-monetary transactions that vary across countries and life expectancy depends on variable birth and death registrations. When it comes to life satisfaction, the problem is much worse because it turns out that sampling for the World Values Survey and Gallup Poll mostly relies on 42-year old adults and even then using country sample sizes ranging downwards to the mere hundreds. This issue will be tested later by replicating the exact methods of the HPI when disaggregated by age and gender to see if the same league tables emerge.

In the meantime, even metrics that fail on some of these counts sometimes deserve a second look if they display various forms of correlational validity. For example, two metrics that tend to correlate in a small sample, suggesting convergent validity, might also be correlated when the sample is much expanded, suggesting ecological validity. This can be tested purposely by randomly splitting a large sample to see if the same effect emerges across both split halves (and will be used frequently in this work by splitting country samples).

Ecological validity is also important when expanding findings from small groups of countries (e.g. OECD) to larger groups of countries (e.g. UN), or else when expanding findings within countries to across countries. In some ways, predictive validity is similar because it is demonstrated whenever correlational results re-emerge across time as well. Even then, however, one problem with predictive validity is that it cannot, obviously, be shown for the future. So predictive validity depends on data from the past being used to predict the present. Later it will be argued that predictive validity across key metrics used to predict the present from the past is crucial for inter-generational equity; moreover, ecological validity and split-sample reliability are important to both intranational and international equity. All such tests are later used for human needs across countries, stretching to half a century of time series, and also using split-samples.

This work is not yet capable of testing experimental validity, whether instrumental, internal or diagnostic. This is because internal validity is deductively impossible to test in cross-national studies. It requires complete, usually laboratory, control of an independent variable such as wealth to confirm any causal effect on dependent output variables like life expectancy or life satisfaction. The only way to test causality at the aggregate level is with reference to an instrumental variable that causes sudden change in the input variable without affecting any other possible omitted variable or even bi-directional effects on the outcome variable itself. True instrumental variables are hard to find and usually rely on historical moments such as the fall of the Berlin Wall (wealth) or the Icelandic eruption of the Eyjafjallajokull[17] volcano (carbon emissions). But even then, instrumental variables can only work in the presence of perfect content validity, which can never really be known, even after the fact.

The final test of validity, often used in medicine, is extremely relevant to the problem of sustainability but likewise untested in this work. Medical studies are

[17] Phonetically pronounced 'Eh-ya-fyat-la-yuh-cuttle'

especially concerned with whether a metric is accurate enough to guide decisions about treatment, which sometimes carries more risk than the disease itself. Clinical diagnostic validity is measured by comparing sensitivity, the degree to which a test accurately identifies an underlying disease (eliminating false negatives, where the disease is missed by the test and puts the individual at risk because of lack of treatment) versus whether it also accurately identifies the opposite (eliminating false positives, where the disease is mistakenly identified and again puts the individual at risk because of treatment). The relevance of diagnostic validity to sustainability can be conceived in terms of the tensions between constricting carbon emissions (treatment) in order to avoid extinction (disease), even though the treatment itself might cause painful economic loss like economic recession or depression (much like chemotherapy).

Other key notions of validity were explored in the history of testing personality (Catell, 1952) and IQ (Spearman, 1950). This began with early work based on using Spearman's correlation coefficient to develop personality tests (Cattell, 1952). Cattell began by collecting simple adjectives of personality from the dictionary, applying a Likert scale and then testing how much people agreed that the adjective described them personally. After a large sample was tested, Cattell used Spearman's work to find that certain adjectives clustered into 16 different correlated factors (see Cattell, 1978). Once he found the strongest predictive adjectives for each factor, he could throw out the least useful adjectives and keep a series of questions that not only distilled the pure factors but were simultaneously uncorrelated with any of the other 15 competing factors. This process is called Factor Analysis, and has been recently applied to multiple indices from the UNHDI in search of parsimony in new and known composite indices (see Saltelli et al., 2007). Neither modelling nor factor analysis is used in the current work, but would be extremely useful once the main needs in the hierarchy were identified. This brief overview helps contextualise some issues of validity that emerge, especially for readers across other disciplines.

2.1.7 Basic Frontier Subsampling & Split-Sample Reliability

The life expectancy frontier is sampled by ranking all countries and finding all the highest life expectancies progressively observable at each lower and higher value of the input metric, above and below the life expectancy maximum. This captures the highest life expectancies achievable across the range of input metrics, whatever they might be. Fitting a curve allows calculation of the interpolated input value required to maximise life expectancy and the extrapolated zero intercepts for each metric can be used, with some caution, to rank the importance of each metric.

The frontier subsample is denoted by the Greek letter zeta, ζ, partly to denote its status as a mnemonic for the 'ultimate' letter in the English alphabet, Z, but mostly to avoid cross-over of notation by other authors. Pure frontier regression is easy to apply when simply looking at the boundaries of technical efficiency and its stability across time because no error term beneath the curve is needed to explain multiple inputs or explore more complex aspects of productive efficiency, at least in preliminary explorations of cross-national curves. More complex time-demeaned and multivariate studies are warranted once the implications of the main curves have been identified as stable across time in the first instance – a level of basic context rarely explored and often glossed over despite the availability of data.

A lot of the data were taken from the UN Human Development Report (2013), itself drawing upon many other resources that are detailed for each index throughout the analyses. This data are available by accessing and downloading selections from:

http://hdrstats.undp.org/en/tables/ The key metrics against which all other metrics are analysed are carbon emissions and life expectancy. The 2013 HDR itself sources these datasets as follows:

Table 2-2 Matched-Year Availability of 2013 UNHDR Metrics (2000, 2005 & 2010)

Variable	Source	Code	2000/ 2005	2010
Adolescent fertility rate (women aged 15-19 years) (births per 1,000 women aged 15-19)	UNDESA (2012b).Population Division Database. Detailed Indicators. Accessed May 2012.	AFR	194	194
Average annual population growth rate (%)	Average annual population growth rate: UNDESA (2011). 2010 Revision of World Population Prospects.	PGR	194	194
Carbon dioxide emissions per capita (tonnes)	Carbon dioxide emissions per capita: World Bank (2012a). "World Development Indicators 2012." Washington, D.C.: World Bank. http://data.worldbank.org. Accessed April, 2012.	CE	188	0
Combined gross enrolment in education (both sexes) (%)	Combined gross enrolment in education (both sexes): UNESCO Institute for Statistics (2012). Data Centre. Accessed 15 October, 2012	EDEN	124	48
Consumer Price Index	Consumer Price Index: World Bank (2012a). "World Development Indicators 2012." Washington, D.C.: World Bank. http://data.worldbank.org. Accessed April, 2012.	CPI	170	176
Deaths due to Cholera (#)	Deaths due to Cholera: WHO (2012b). Global Health Observatory. http://www.who.int/gho/epidemic_diseases/cholera/deaths/en/ Accessed March 21, 2012.	CHL	60	47
Employment to population ratio, population 25+ (% aged 25 and above)	Employment to population ratio, population 25+: ILO (2012). ["Key Indicators on the Labour Market: 7th edition". Geneva: ILO.].http://www.ilo.org/empelm/what/lang--en/WCMS_114240. Accessed March 2012.	EMP	170	170
Fixed and mobile telephone subscribers per 100 people (per100 people)	Fixed and mobile telephone subscribers per 100 people: HDRO calculations based on data on cellular subscribers and telephone lines from ITU (2012) and population data from UNDESA (2011).	TEL	189	191
Fixed broadband internet subscription (per100 people)	Fixed broadband internet subscription: International Telecommunication Union (2012). http://www.itu.int/ITU-D/ict/statistics/ Accessed March 23, 2012.	INT1	65	185
Forest area (% of total land area)	Forest area (% of total land area): HDRO calculations based on data on forest and total land area from FAO (2012). http://faostat.fao.org/site/377/default.aspx#ancor	FOR	193	193
Gross primary enrolment ratio (% of primary school-age population)	Gross primary enrolment ratio: UNESCO Institute for Statistics (2012). Data Centre. Accessed 15 October, 2012	PED	170	99
Gross secondary enrolment ratio (% of secondary school-age population)	Gross secondary enrolment ratio: UNESCO Institute for Statistics (2012). Data Centre. Accessed 15 October, 2012	SED	152	83
Gross tertiary enrolment ratio (% of secondary school-age population)	Gross tertiary enrolment ratio: UNESCO Institute for Statistics (2012). Data Centre. Accessed 15 October, 2012	TED	123	61
Expected Years of Schooling (of children) (years)	Expected Years of Schooling (of children): UNESCO Institute for Statistics (2012). Data Centre. Accessed 15 October, 2012	SCH	187	0
GDP per capita (2005 PPP $)	GDP per capita (2005 PPP $): World Bank (2012a). "World Development Indicators 2012." Washington, D.C.: World Bank. http://data.worldbank.org. Accessed April, 2012.	GDP	180	177
GNI per capita in PPP terms (constant 2005 international $) (Constant 2005 international $)	GNI per capita in PPP terms (constant 2005 international $): HDRO calculations based on data from World Bank (2012), IMF (2012) and UNSD (2012).	GNI	185	187
Income Gini coefficient	Income Gini coefficient: World Bank (2012).	GINI	46	16
Life expectancy at birth (years)	Life expectancy at birth: UNDESA (2011). 2010 Revision of World Population Prospects.	LE	194	194
Mean years of schooling (of adults) (years)	Mean years of schooling (of adults): HDRO updates of Barro and Lee (2011) estimates based on UNESCO Institute for Statistics data on education attainment (2012) and Barro and Lee (2010) methodology.	SAD	160	187
International inbound tourism (thousands)	International inbound tourism: World Tourism Organization (UN WTO) (2012). Yearbook of Tourism Statistics, http://statistics.unwto.org/en accessed on April 15, 2012.	TR	109	105
Internet users (per100 people)	Internet users: International Telecommunication Union (2012). http://www.itu.int/ITU-D/ict/statistics/ Accessed March 23, 2012.	INT2	185	183
Labour force participation rate, female-male ratio (Ratio of female to male shares)	Labour force participation rate, female-male ratio: ILO (2012). ["Key Indicators on the Labour Market: 7th edition". Geneva: ILO.].http://www.ilo.org/empelm/what/lang--en/WCMS_114240. Accessed March 2012.	LBR-F	177	147
Population with at least secondary education, female/male ratio (Ratio of female to male rates)	Population with at least secondary education, female/male ratio: Barro, R. J. and J. W. Lee. 2011. Barro-Lee dataset of Educational Attainment. http://www.barrolee.com/ Accessed April, 2012.	SED-F	143	143
Maternal mortality ratio (deaths of women per100,000 live births)	Maternal mortality ratio: UN Maternal Mortality Estimation Group (MMEIG) WHO, UNICEF, UNFPA and the World Bank (2012),http://www.childinfo.org/maternal_mortality_ratio.php. Accessed May 16, 2012.	MAT	179	179
Natural resource depletion (% of GNI)	Natural resource depletion: HDRO calculations based on World Bank (2011a).	NAT	180	154
Population, urban (%) (% of population)	Population, urban (%): UNDESA (2012a). World Urbanisation Prospects, 2011 Revisions.	URB	194	194
Sex ratio at birth (Male births per100 female births)	Sex ratio at birth: UNDESA (2012b).Population Division Database. Detailed Indicators. Accessed May 2012.	SEX	181	181
Share of TPES from fossil fuels (%)	Share of TPES from fossil fuels: HDRO calculations based on data on total primary energy supply from IEA (2012).	FOSS	133	34
Share of TPES from renewable sources (%)	Share of TPES from renewable sources: HDRO calculations based on data on total primary energy supply from IEA (2012).	REN	133	34
Shares in parliament, female-male ratio	Shares in parliament, female-male ratio: IPU (2012). [Parline database on women in parliament.] http://www.ipu.org/wmn-e/classif.htm. Accessed May, 2012.	PRL-F	106	182
Total dependency ratio (per 100 people aged 15-64 years)	Total dependency ratio: UNDESA (2011). 2010 Revision of World Population Prospects.	DEP	181	181
Total fertility rate (births per woman)	Total fertility rate: UNDESA (2011). 2010 Revision of World Population Prospects.	TFR	181	181
Youth Unemployment (% aged 15-24)	Youth Unemployment: ILO (2012). ["Key Indicators on the Labour Market: 7th edition". Geneva: ILO.].http://www.ilo.org/empelm/what/lang--en/WCMS_114240. Accessed March 2012.	UNE:Y	80	75

After matching indices to maximise sample sizes across both developing and developed UN member states, the best range of data across the biggest range of indices identified the years 2000 and 2005, where the sample size is maximised at around 196 countries.

All estimates and projections are first eliminated with reference to the technical notes of the HDR 2013 such that only exact data for each year is included. Only those metrics fully represented in 2000 and 2005 are indexed above, although many additional metrics are explored for earlier and later years if considered important to the overall project. Metrics with sample sizes below N=80 had to be ignored as unreliable following frontier tests showing such samples were probably too range-restricted. If the results are still unstable in any way, a third interim year is sampled wherever available.

Table 2-3 Latest Data Availability for Additional 2013 UNHDR Metrics (2010 Only)

Variable	Source	Code	2010
Child labour (% aged 5-14 years)	Child labour: UNICEF (2012). "The State of the World's Children 2012". New York. http://www.unicef.org/sowc2012/. Accessed March 7, 2012.	CHL	101
Children under-five who are under weight for their age (moderate and severe) (%)	Children under-five who are under weight for their age (moderate and severe): UNICEF (2012). "The State of the World's Children 2012". New York. http://www.unicef.org/sowc2012/. Accessed March 7, 2012.	MAL	113
Gallup: Trust in other people (% answering "'yes'" to having the element)	Gallup: Trust in other people: Gallup (2012).Gallup World Poll database. https://worldview.gallup.com/	TRS	59
Homicide rate (per 100,000)	Homicide rate: UNODC(2011).["2011 GLOBAL STUDY ON HOMICIDE TRENDS, CONTEXTS, DATA"] Accessed May, 2012.	HOM	191
Immunization coverage among 1-year-olds, DTP 1 (%)	Immunization coverage among 1-year-olds, DTP 1 (%): WHO (2012a). ["World Health Statistics 2011"]. Geneva. Accessed March 2012.	DTP	191
Immunization coverage among 1-year-olds, measles (%)	Immunization coverage among 1-year-olds, measles (%): WHO (2012a). ["World Health Statistics 2011"]. Geneva. Accessed March 2012.	MSL	191
Infant mortality rate (per 1,000 live births)	Infant mortality rate: WHO (2012b). Global Health Observatory. http://www.who.int/gho/epidemic_diseases/cholera/deaths/en/ Accessed March 21, 2012.	INF	193
Stock of emigrants as a percentage of population (% of population)	Stock of emigrants as a percentage of population: HDRO calculation based on data from World Bank 2011, Migration Factbook and UNDESA 2011, 2010 Revision, World Population Prospects.	EMG	192
Stock of immigrants as a percentage of population (% of population)	Stock of immigrants as a percentage of population: HDRO calculation based on World Bank bilateral matrix on emigration, immigration and population.	IMG	192
Suicide rate: female (per 100,000)	Suicide rate: female: WHO (2012c). ["Mental Health"]. Geneva. Accessed April 2012.	SCD:F	91
Suicide rate: male (per 100,000)	Suicide rate: male: WHO (2012c). ["Mental Health"]. Geneva. Accessed April 2012.	SCD:M	91
Under-five mortality (per 1,000 live births)	Under-five mortality: Inter-agency Group for Child Mortality Estimation (UNICEF, WHO, UN Population Division and World Bank) 2012. Accessed March 2012.	CHM	193

The general aim of this study was to start contextualising a range of human development indices for current and future generations by building a simple 3x3 table where the data could objectively speak for itself outside of relative values (Table 2-4).

Table 2-4 The ultimate aim of the project simplified and summarised

	Good for People	**Bad for People**
Good for Planet	Maximises human survival at minimal carbon emissions	Minimises emissions at odds with human survival
Bad for Planet	Maximises human survival at unsustainable emissions	Unsustainable emissions at odds with human survival

Most of the work is therefore focused on using two key metrics across studies:

1. Carbon dioxide emissions per capita: World Bank (2012a). World Development Indicators 2012. Washington, D.C.: World Bank. http://data.worldbank.org. Accessed April, 2012.
2. Life expectancy at birth: UNDESA (2011) 2010 Revision of World Population Prospects.

Using frontier subsampling, a series of targets can then be calculated based on frontier regression that focuses on the ceiling of life expectancy versus the floor of carbon emissions. This is a form of DEA but requires no intrinsic value judgments. It does assume that the ceiling of maximum life expectancy is achievable against the floor of minimum carbon emissions for each index as this can be influenced by outliers and data density at the extremes of both, which is why the two main validity tests are conducted:

1. Split-sample reliability
2. Predictive validity

For most analyses, split-sampling is done by splitting countries alphabetically (which is stronger than random splits in this context[18]). The frontier subsamples are then recombined to minimise the influence of outliers; the formula from the A-K subsample is used to predict the results for the L-Z subsample, providing an estimate of split-sample reliability. Similarly, the recombined split samples for early years provide a formula that can be used to predict the actual recombined results for later years, providing an estimate of predictive validity. Though the idea is sound, the full range of analyses were not entirely completed due to limitations of thesis size, leaving many more studies available for the future.

[18] Alphabetical splits are thought to increase the likelihood of finding spurious differences between groups whereas the current study expects confirmation of the null hypotheses in this context

3. Results

3.1 INTRODUCTION TO THE RESULTS

This chapter details six exploratory studies, each with their own internal logic, methodological approaches and summary conclusions. If necessary, a brief literature review is provided for each study by way of introduction to fill out any gaps that were not covered in previous chapters. Sometimes, a study also has to contextualise preliminary analyses in their own right before exploring the main issue, which means some must be explored in the introduction using non-standard but brief descriptions of methods and results. The statistical methods are also kept as simple as possible for reasons of empirical replicability, gradually becoming more complex and moving from basic Excel to GNR R as the base statistical programs used to measure, test and replicate curves. The first study tests the frontier for one basic human need and then explores whether the same method suggests there are limits to both life expectancy and life satisfaction beyond which further planetary exploitation offers little in the short-term, challenging the sustainability of the UN-HDI which is predicated on a linear association. The second study uses new data to challenge the validity of the NEF-HPI. The third and fourth studies use new methods to test their implications for human needs and sustainability, whereas the fifth explores the limitations of the proposed methods with reference to basic human needs addressing the global food system. Results using the frontier approach support both Set-Point Theory and the Easterlin Paradox but are not quite as perfectly accurate as expected, suggesting Ecological Fallacy is still operating but not so much as to undermine the main cross-sectional curves and their implications for human needs equity, wellbeing and sustainability.

3.2 STUDY ONE: FRONTIERS OF FOOD CONSUMPTION

3.2.1 Abstract – Exploring the Frontier Method for One Basic Human Need

Caloric intake is one basic need that has been measured consistently by the UNFAO since 1962 and can be matched to LE for every available year since. So it can be used as a test case for the frontier methods on a variety of fronts. This section must first revisit detailed evidence leading up to the cobenefits of climate change mitigation before testing the frontier methods across nations. It requires a literature review in itself. The study then tests the proposed method using split-sample reliability and predictive validity, plus robustness to disaggregation by age and gender. It is mainly interested in what the frontier method says about the stability, validity and reliability of the interpolated target value of calories that maximise LE at the frontier, ensuring it manages to approximate the results of major studies within countries, across cultures and across time.

3.2.2 Introduction – Food and the Cobenefits of Climate Change Mitigation

Cooking food was invented at least 1.8 million years ago and had the effect of using energy to inactivate or kill bacteria, viruses and parasites. It also had the happy effect of making food taste good. Boiling water also improved hygiene as did the invention of chopsticks and forks to avoid E. coli transmitted from the anus via food handling. Adding salt provided an important supplement for balancing electrolytes and improving brain function and was later used as a preservative for surplus foods. So it's not surprising that the earliest industrial saltworks are dated to around 10,000 BCE, roughly matching the establishment of agriculture and settled communities, from which the first surpluses of food emerged. Salt, water and food are all basic needs with low elasticities of demand (Parkin, Powell & Kent, 2002). Along with knives and forks, chopsticks, pots, pans and fire, all use energy and resources.

Multiply this by the number of people in the world and the impact of food preparation alone begins to have a profound impact on energy use. The global food system now accounts for about 30% of carbon emissions, but not all of them are necessary to maximise human health and wellbeing. Overconsumption of salt alone is linked to cardiovascular disease and stomach cancer. Like every other human need, rapid overconsumption results in rapid death and slow overconsumption leads to slower death. Thankfully, there are metabolic feedback loops that constrain rapid overconsumption, but not so the kinds of slow overconsumption that leads to increased carbon emissions. The feedback loop is too slow to change market behaviour.

The move from hunter-gathering to settled communities based on agriculture (usually monoculture) was one of the greatest changes in human society since people first stood upright (tools, spears and even fire were/are already used by earlier and other species). From settlement, emerged the domestication of local animals (if they were already social species) along with property rights, alcohol from rotting surpluses, specialisation of productive roles ranging from farmers, artisans and warriors, to the invention of trade, money and inequity. Moving on from Stone Age spears and axes extant among hunter gatherers for 500,000 years previously, pottery, writing, mathematics and astronomy emerged around this time but religion, war and slavery also became more prominent during the Bronze Age as settlements grew and infringed upon other people's territories. The domestication of the horse and the invention of the bit (6,000 BCE) gave some settlements more power over others. Only the wealthy and powerful had access to enough nutrients and protein to grow tall, and this remains to the present day.

Food - The Human Need

Foremost among the eight Millennium Development Goals (MDGs) is a focus on hunger. Globally, 870 million people continue to go hungry, 10 million die from starvation, and 57 million of the world's children are stunted by malnutrition. In the year 2000, 193 member states of the UN agreed to uphold the MDGs by working towards halving the number of hungry people in the world by 2015. This was to be measured against two main outcomes, one being to halve the prevalence of underweight children and the other being to halve the ratio of people living on less than their minimum required levels of energy consumption.

But starvation is only one side of the global food equation. Although 15% of the world's people are starving, another 20% are obese or overweight (see Edwards & Roberts, 2009; UNFAO, 2012). This means almost equally large portions of the world's people may be dying early as a consequence of either under-consumption or overconsumption of food alone. Some level of consumption between these two extremes would appear to maximise human health.

The UN traditionally put this value at daily consumption of 3000 kilocalories per capita (see Bissio, 1997, pp. 15-17). Supporting this, early data from the Heart Health Study, which focused on tobacco use provided death rates for calories as a secondary variable. When tobacco use was eliminated by averaging, the reported data suggested zero death rates at 3000 calories within the USA. More recently, zero death rates for obesity against calories across nations (WHO, 2004) settled at 3126 calories. When available datasets were later pitted against malnourishment across countries (WHO, 2007) zero death rates settled on 3091 calories. All settle on about 3100 calories *as the population average.*

Food - The Ecological Cost

The first complete study of the global food system was recently published by the Consultative Group on International Agricultural Research (CGIAR), a partnership of 15 research groups from around the world (Vermeulen et al., 2012; Thornton et al., 2012). In their first report, the global food cycle in 2008 was estimated at releasing around one third of total emissions for that year, mostly attributable to production and transport, land clearing, fertilizer manufacture and refrigeration. The whole food system, including agriculture and its impact on land use accounts for somewhere between 16-29% of global GHG emissions (Bellarby et al., 2008). Although different methods were used, note the figure for agriculture, land use and waste for the year 2000 (based on the World Resource Institute Climate Analysis Indicators Tool) was also put at 35% (Stern, 2006). Around 80% of these emissions come from livestock (both feed crops and methane; UNFAO, 2006; McAlpine et al. 2009) and 14% from burning fossil fuels in transport once they leave the farm (Friels & Dangour et al., 2009).

The second report of the CGIAR predicted the likely effect of global warming on food production across 22 major crops, where yields by 2050 would fall by around 15% for wheat, rice and maize. If global warming exceeds 2°C, other studies predict a 25% increase in famine across Africa and West Asia (see Stern, 2006). The

UK Committee on Climate Change said 2050 emissions should be reduced by 80% compared to 1990 and a major step towards this would be halving emissions from livestock as early as 2030 (Friels et al., 2009). The figure below shows total grams of carbon emissions equivalent per kilocalorie for different foods, incorporating methane and fossil fuels in their production and distribution.

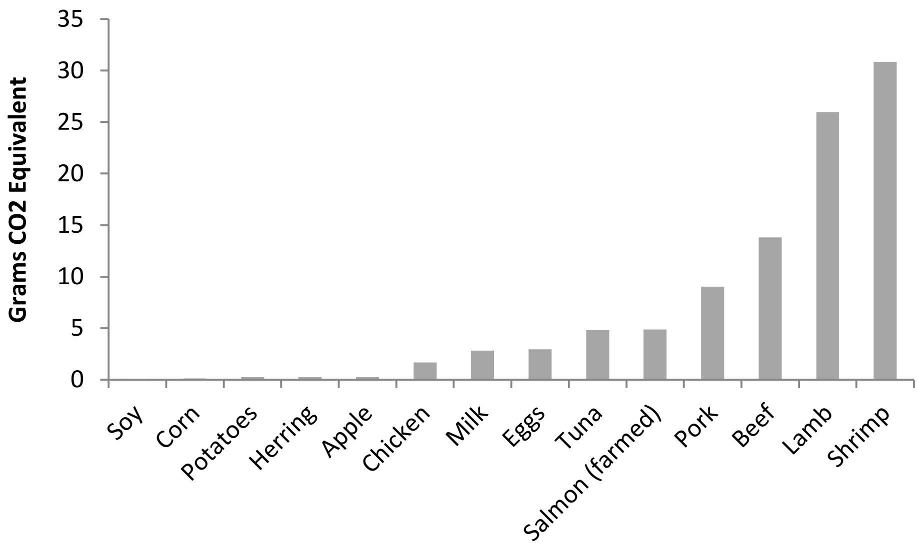


Figure 3-1 The carbon costs of different food types (Friels, et al., 2009)

The typical US diet now derives 27.7% of calories from animal products which disproportionately account for 93% of food-related carbon emissions. By comparison, diets that restrict animal products to milk and eggs (lacto/ovo diets) reduce the carbon footprint by 44%. Pure vegan diets again reduce the carbon footprint by 91%.

The reason white meat and eggs are less carbon intensive than beef, mutton, lamb and milk is that ruminants like cows and sheep are less efficient in feed-crops, land use and gastric production of methane than white meat species like chickens and pigs (Friels & Dangour et al., 2009). Notwithstanding, humans can make just as much use of feed crops used to sustain white meat species and even red meat species still have their role to play on degraded land where cereals and soy cannot be grown for human consumption.

The main problem is that demand for red meat is pushing large-scale production into richer, not degraded landscapes, such as old growth forests that serve as major natural emissions sinks. On top of this, food-related emissions are inflated by transport, packaging and easy-access food choices, preference for processed foods, out-of-season and exotic produce and meat, along with supermarkets, packaging and advertising (WHO, 2000).

Although providing protein, iron, calcium, vitamin B12, and zinc (Randolph & Schelling et al., 2007), especially for growing children and malnourished communities (Diamond, 1987), overconsumption of livestock is a major source of saturated fats causing cardiovascular disease (Popkin, 2004; Hu, Manson & Willett, 2001) - the developed world's leading cause of death (WHO, 2008). Obesity is further linked with cancers affecting the prostate, breast, endometrium, ovaries, cervix, colon, kidneys and gallbladder (WHO, 2000).

Living burden of disease is also affected. When using DALY and QALY methods applied to a sample of 3.5 million US adults over 16 years, the impact of obesity on lost years of high quality living, as of 2008, exceeded that of smoking (Jia & Lubetkin, 2010). Obesity impacts on the living burden of disease through stroke, metabolic syndrome, Type 2 diabetes and limb amputation, osteoarthritis, dementia, asthma and sleep apnoea, back pain, learning problems, precocious puberty, altered body image and depression, along with more general effects from stigma on quality of life, subjective wellbeing and self-concept (Gustafson et al., 2003; Lobstein et al., 2003; Koplan et al., 2005; SA Government, 2006).

In searching for an instrumental variable linking human health with emissions, a recent study by Friels and colleagues (2009) compared UK data with Sao Paulo as a test case for Brazil, which is undergoing an economic and dietary transition (Speedy, 2003) affecting the Amazon via cattle and cattle feed (McAlpine & Etter et al., 2009; Fearnside, 2000). Directly looking at the health co-benefits of climate change mitigation, a 30% reduction in livestock consumption alone could reduce the ischaemic heart disease burden across both countries by about 15%, with similar reductions in years of life lost by premature death.

The Friels model did not include emissions from transport, retailing and waste associated with livestock consumption, nor did it focus on production efficiencies that cannot directly affect health outcomes. Their model starts with the most plausible pathway from emissions to heart disease, noting consumption of saturated fats operates on heart health via serum cholesterol, both at the experimental and epidemiological levels (WHO, 2003; Hu, Manon & Willett, 2001), and is directly associated with early mortality (Sinha & Cross et al., 2009). They did not expand the model to include its effects on obesity (WHO, 2003) and colorectal cancer (AICR, 2007), which meant their model underestimated the true effects. Over the next 30 years, transition economies such as Brazil, India and China are predicted to demand an 85% increase in livestock food production compared to the year 2000, all impacting on carbon emissions (Monteiro, Mondini & Costa, 2000; Popkin & Du, 2003; Popkin & Horton et al., 2001; World Bank, 2008).

Theoretically, studies from both public health and climate science are converging on the idea that moderation in food consumption could simultaneously enhance the actual health of current generations against the potential health of future generations. If moderate consumption could achieve viable redistribution between malnourished and over-consuming nations, it could also trend towards achieving Pareto efficiency, where nobody loses, at least when the key metric is life expectancy and not the symbolic value of the dollar. In the current study, life expectancy is used as the output variable and caloric intake treated as an input variable as a proxy of energy consumption across nations

Traditionally, energy consumption is defined by the calorie whereas being underweight is defined as a Body Mass Index (BMI) below 18.5 kg/m^2 (WHO, 2000). BMI is easily calculated by weight in kilograms divided by the square of height in metres. Being overweight is defined by a BMI of 25-30 kg/m^2 and obesity is defined as being in excess of the upper value. Edwards & Roberts (2010) looked at BMI in a population of one billion UK adults (20-59 years), showing the normal BMI in 1970 averaged only 24.5 kg/m^2 whereas the equivalent BMI in 2010 was 29 kg/m^2. In the same period, the rate of obesity rose from only 3.5% of the population to 40%, and the same trends emerged across the United States and Australia. Although BMI cut-offs arose as an easy rule of thumb in Western medicine (Gray & Fujioka, 1991), they sometimes underestimate obesity in Asian, Indian and Aboriginal people due to slightly different genetic distributions of body fat. Hence, China puts the obesity cut-off at 28 kg/m^2 (Bei-Fan, 2002) whereas Japan puts it at 25 kg/m^2 (Kanazawa et al., 2002). This complicates cross-national measures using BMI as the key metric, which is partly why this paper prefers using caloric intake alone.

The calorie was first described by Clement (1821) as the amount of energy required to heat a gram of water by one degree Celsius. In nutrition, it is multiplied by 1000 and expressed in kilocalories (Kcal) or else the European preference (kilojoules) by multiplying Kcal by 4.184. The metabolic approach to human food energy started in the late 1800s using a respiration calorimeter box big enough to house a person so as to measure the energy differential between oxygen input and carbon dioxide output (Atwater, 1902). It was used by agricultural chemist Atwater, who showed the First Law of Thermodynamics equally applied to humans as it did to animals. As he explored different activities and food intakes in humans, he began to notice changes in the energy differentials, later published as a series of league tables for age, gender, height and weight by his collaborator, Francis Benedict. More recently, the same approach has been more cost-effectively measured using the 'doubly labelled' water method. Using the same logic as the respiration calorimeter, this method calculates the oxygen/CO_2 differential by asking people to drink a given volume of chemically labelled water and testing urine output.

Recently, Pontzer and colleagues (2012) used this method in 30 people from the Hazda tribe in Tanzania, a small community of people whose diet is rich in berries, tubers and protein from traditional hunting. As well as measuring body mass, height and physical activity (using GPS tracking) the authors used the doubly labelled water method to infer basal metabolic rate. As it turned out, Hazda women consumed only 1877 Kcal whereas Hazda men consumed 2649 Kcal. The study concluded that how much and what we eat is just as important as physical activity. Let us not jump to conclusions that these represent optimal outcomes because life expectancy among the Hazda is only 33 years (Jones, Hawkes & O'Connell, 2002), even when mostly due to infant mortality.

Further, the difference between men and women, although not a major focus of their work, suggested the Hazda men consumed 50% more than would be predicted from standard gender equations. Likewise, the Ache tribe of Paraguay consume

2700 Kcal (Hill et al., 2003), 83% of which is usurped by adult males. The Ache can live to about 55 years if they manage to avoid the homicidal violence that kills about 40% of children below the age of 15 years (Hill & Hurtado, 1996).

Since the time of Atwater and Benedict (1902), large-scale surveys were launched by the United States Department of Agriculture (USDA) from 1916 onwards, leading to the development of the Food Pyramid in 1992 (for a history, see Susan Welsh, 1994). The emergent themes during the intervening years dealt with the impact of the Great Depression and World War II, after which greater and growing consumption, plus the availability of fast-foods in the 1970s, highlighted the possibility of excess consumption affecting chronic disease patterns. The term ‘overconsumption’ gained more currency around the release of the food guide jointly released in 1980 by the USDA and the Department of Health and Human Services (DHHS). Since then, the notions of dietary moderation and variety have been the main themes reiterated by American USDA Guidelines updated every five years.

Japan, boasting one of the longest life expectancies in the developed world, restricts consumption to 2700 calories whereas more short-lived developed nations (for example, Luxembourg) consume 3800 calories. Recent studies on both humans and primates suggest *mild* levels of caloric restriction increase lifespan. In fact newer recommendations from the UK, Australia and USA, as well as tribal data, suggest caloric consumption more aligned to Japan is better for health, especially if those calories include nutrient-rich fruit and vegetables rather than meat, processed and packaged foods. The fact that low-quality foods are more likely to be more carbon-intensive, especially when imported, is not lost on public health researchers focused on climate change, with studies now converging on the health co-benefits of mitigating global carbon emissions related to food overconsumption and wastage.

Although it is recognised that issues like food wastage are also a growing problem that might pollute the data used, the study explores whether the cross-national data, when using frontier regression, predicts similar moderation. Given food wastage, it is not expected that the results will be perfect but it is expected that more basic human needs like caloric intake will be far more stable across time than more abstract needs like, for example, education, freedom of the press or economic growth. It is for this reason that the frontier curve will be tested across many different time periods to assess the stability of its main features in terms of targets and intercepts. The aim here is find a method that simultaneously stabilizes the targets and intercepts across and within time, allowing future applications to other variables.

3.2.3 Methods - Testing the Frontier Method for Calories

Daily caloric intake (shorthand *calories* or *CAL*) is defined in kilocalories (kcal) per capita per day. It is drawn directly from the Food Balance Sheets of the UN Food & Agriculture Organization (UNFAO, 2011), offering time series for up to 171 countries matched in each year on life expectancy at birth (LE) as the output variable. The frontier sampling procedure ranks all countries by LE, continuously takes the next highest and next lowest caloric intake countries as the subset and then fits the best curve.

The stability of the frontier method is first explored by reference to equivalent data for 1962 and 2005, allowing tests of predictive validity across the broadest possible timeframe. Split-sample reliability is then tested by splitting the raw country samples in half and replicating the curves again. Theoretically, any difference in values should reflect pure measurement error within time periods.

Recombining the two subsamples into a single frontier for each year then tends to reduce the impact of outliers that might have affected the pure curve *without eliminating any outlier in the first place.* This is important because it leaves the entire method completely outside control of the researcher and can be exactly replicated.

3.2.4 Results I - Testing the Frontier Method for Calories 1962-2005

First, a simple visual look at the raw data across countries is almost enough to validate the shape of the curve before moving onto the simplest form of frontier sampling that fits a more exact mathematical curve to the highest levels of LE achieved at every observed level of caloric intake across countries (Figure 3-2).

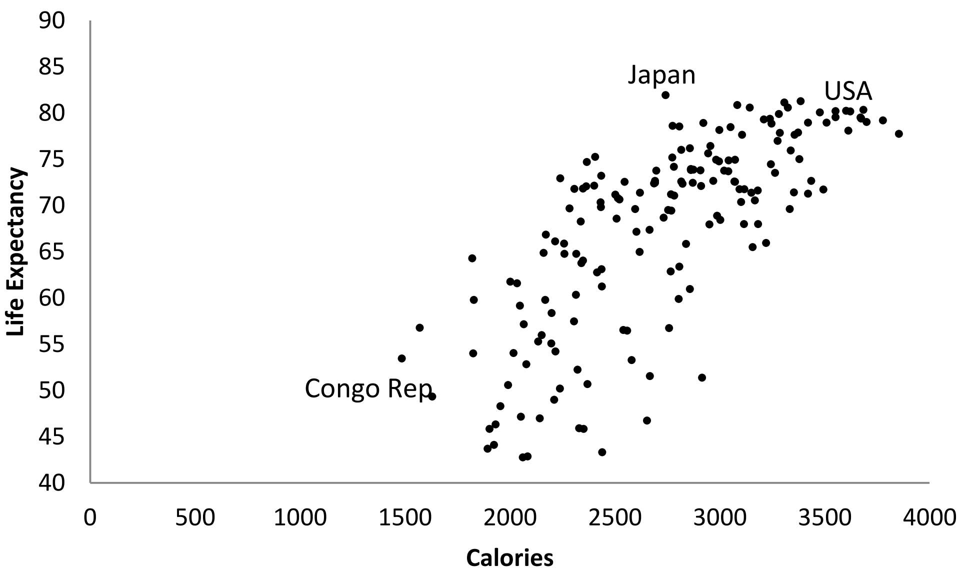


Figure 3-2 Data for LE against kCal/cap/day depicting some frontier nations (2005)

The issues raised by the following analyses will later affect other metrics as well. One is that Japan has enjoyed peak LE's the past the past three decades, always affecting the frontier among these years. So it is important to show the same curves still emerge in earlier decades when different cultures like Norway reached the peak, or even the latest WHO data where Andorra begins to supplant Japan.

These issues will be tested now using comparisons across time, within time and across split-samples. The same curves are now shown below for both 1962 and 2005 in Figure 3-3.

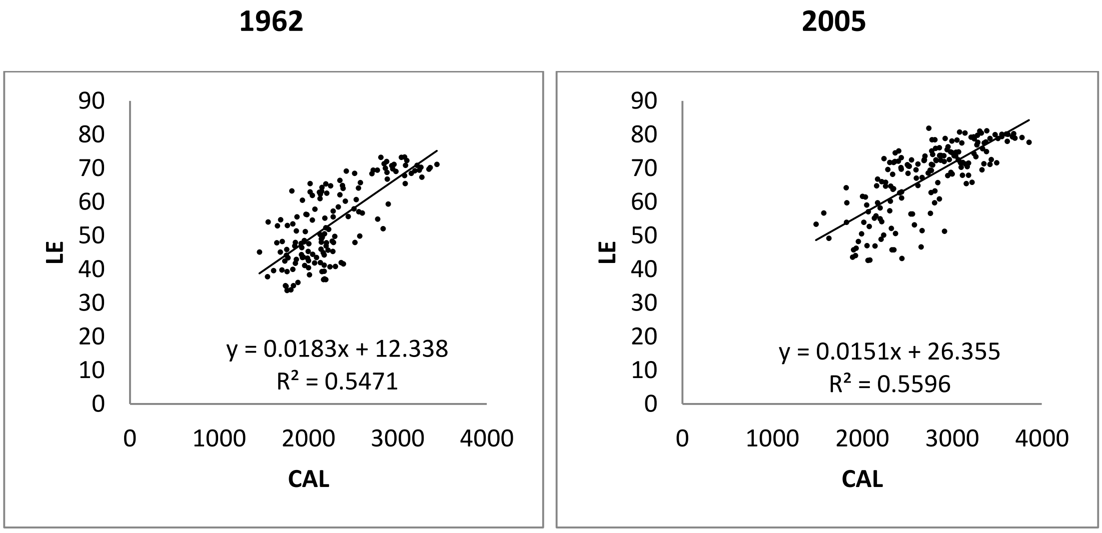


Figure 3-3 Linear curve for raw datasets with LE against calories for 1962 and 2005

Looking at the raw datasets across 145 countries in 1962, the average LE was 54±12 years on 2290±457 calories whereas 171 countries in 2005 enjoyed 68±11 years on 2730±520 calories, all normally distributed. Across the 43 years sampled, this suggests an increase of about 14 years of LE on a gain of 440 calories. A stronger test of change across time is to match countries on their own changes, but identical figures emerge for the averages and standard deviations. This does not mean that these average values reflect optimal human targets because they change across time and they do not yet capture the highest LE's attainable. Although the linear curve applied in 1962 predicts the actual data in 2005 (r^2=0.55, p<01), the linear curve suggests two nonsensical outcomes – that immortality can be achieved if only food consumption was unlimited and had no metabolic set-point for satiety.

A more sensible frontier is now distilled by sampling only those nations that sit at the highest LE at every observable value of calories and then fitting a mathematical curve as in Figure 3-4. This substantially reduces the sample sizes to n=11 in each year but the predictive validity rises (r^2=0.69, p<01), with both curves converging close to 3000 calories to maximise LE, matching the UN recommendation (Bissio, 1997, pp. 15-17).

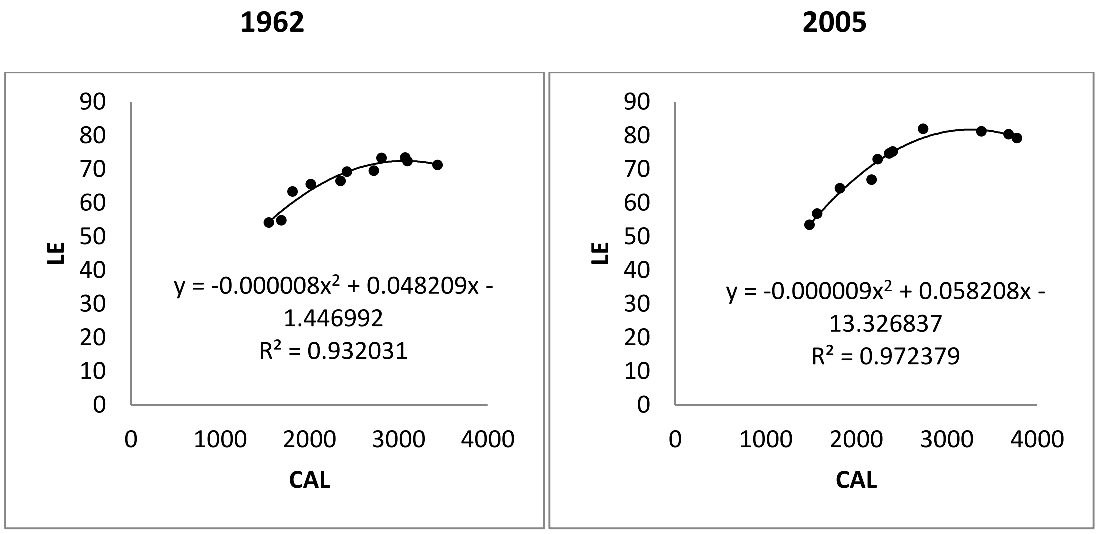


Figure 3-4 The simplest (pure) frontier curves for calories in 1962 and 2005

Despite being very different cultures, Norway achieves the highest LE in 1962 (73 years on 3080 calories) and Japan achieves the highest LE in 2005 (82 years on 2743 calories). Note the LE gain at the frontier is only nine years, smaller than the 14 years expected from the full sample, suggesting the frontier is properly acting like a ceiling to the effects of caloric consumption outside of major omitted variables.

Despite changes across time, the actual caloric target maximising LE in any given year remains stable at an average of 3032±64 SD. This is now demonstrated for all the available years between 1962 and 2005 (Figure 3-5).

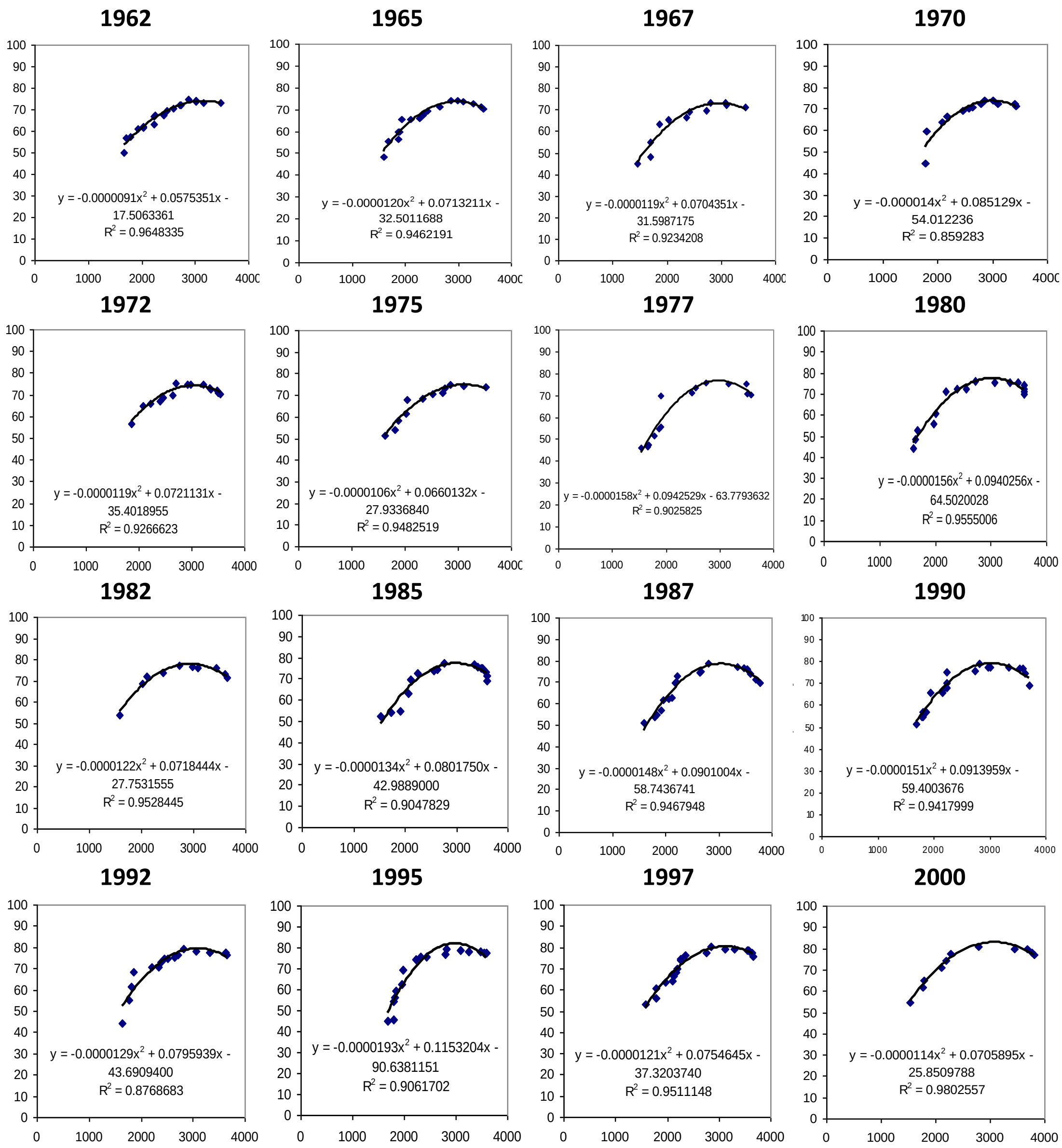


Figure 3-5 With LE on the y-axes and daily calories on the x-axes, the frontiers are all bell-shaped over the past half century

These curves confirm that the frontier subsample creates a bell-shape in every available year as expected by needs theory for a basic need like calories. Note also the curve becomes more pronounced in more recent years, suggesting greater consumption among the most advanced nations is allowing a more bell-shaped curve to manifest as their LE's start to slide down the right-hand side of the slope. This is the same trend the World Bank reported for GDP – where the curve becomes more pronounced in later years as already wealthy countries become wealthier and start consuming more than they might perhaps ‘need’. Although GDP results are always distorted by inflation, the same cannot be said for a basic need like calories, where results should remain stable regardless of different treatments.

Split-sample reliability is one useful treatment that minimises any measurement error in the peaks of countries like Norway and Japan. The raw datasets are first split for countries A-K and L-Z before distilling frontier subsamples from each. The curve is then calculated again and the formula from the A-K subgroup used to predict the results in the L-Z subgroup. Standard practice is to split samples randomly but the alphabetical split is actually stronger in this context because it marginally increases the Bayesian probability of a Type I error whereas this study is more vulnerable to a Type II error. Random splits are equally strong but the alphabetical split is retained for ease of replicability. Although not reported here, splits have been conducted continuously until the sample sizes become negligible yet all produce the same curve. Moreover, differences in the split-sample curves, providing an estimate of pure measurement error within each year sampled, is usually small and insignificant. Only a slight trend suggests the latest data are less prone to error, as would be expected as data collection becomes more sophisticated among governments across time.

Split-sample reliability and predictive validity for the frontier is now tested for 1962 and 2005 (see Figure 3-6). As the first example, the split-sample in 1962 converges on both axes despite using two different sets of countries to sample different frontier nations. The split-sample reliability is $r^2=0.75$ ($p<0.01$). For 2005, the split-sample reliability is stronger again at $r^2=0.89$ ($p<0.01$). What later becomes more important is that predictive reliability rises when the two split-halves are recombined into samples of around 30 nations each.

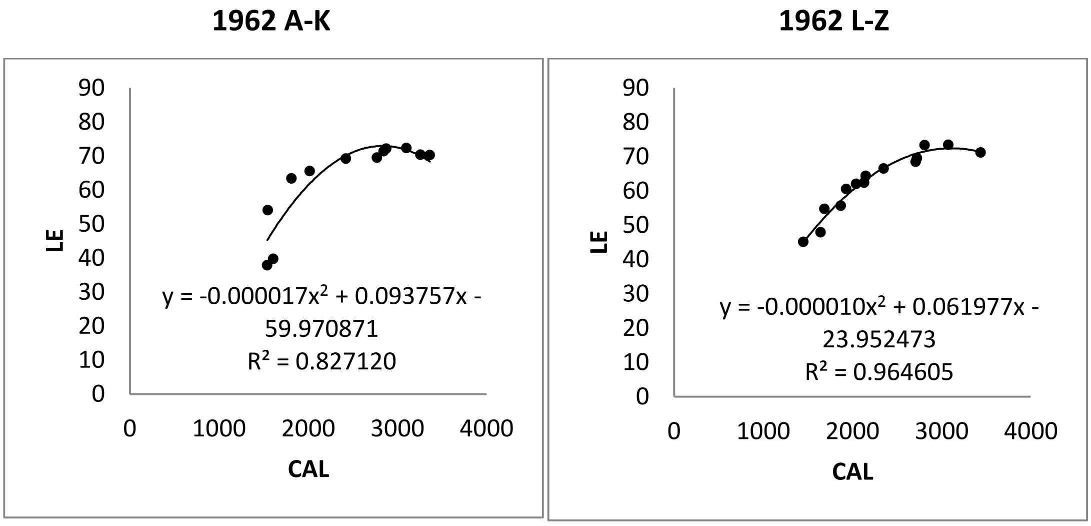


Figure 3-6 Alphabetically split sample frontier curves for calories in 1962

In the meantime, the target optimising LE across split-samples averages 2980 for 1962 and grows to 3260 calories in 2005. The apparent increase will be tested later. Basic results are tabled below (Table 3-1).

Table 3-1 Split-sample frontier results for calories in 1962 and 2005

Year	**1962**		**2005**	
	A-K	***L-Z***	***A-K***	***L-Z***
n/N	12/70	14/71	11/86	17/85
ζr^2	0.83	0.97	0.94	0.92
P Value	0.01	0.01	0.01	0.01
Target	2810	3140	3330	3190

Recombining the two alphabetical splits doubles the frontier sample sizes, minimises the effects of outliers and further stabilises both the interpolated and extrapolated intercepts. Using these split-half frontiers further increases predictive validity across 43 years to a more impressive $r^2=0.83$ ($p<0.001$). Moreover, when the curve shape is reversed, it mirrors death rates *within* countries based on half a million US people tested by Adams and associates (2006), as follow in Figure 3-7.

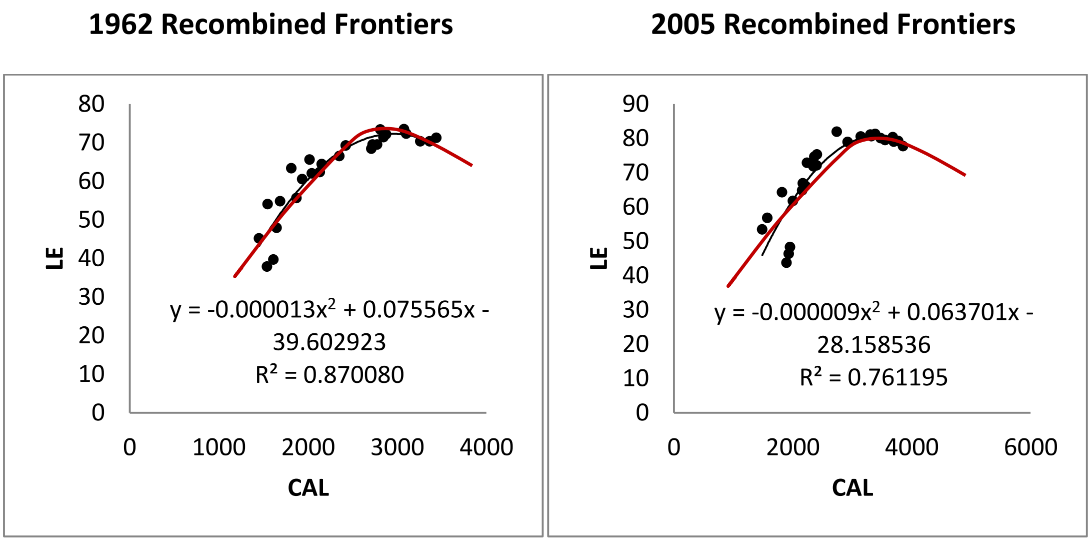


Figure 3-7 Recombined split-half samples improves accuracy and fits the expected within-country curve based on death rates and BMI (reversed)

The next step is to see whether the interpolated optimal caloric targets for maximising LE is stable across the decades. The results are tabled below (Table3-2) for every available year from 1962 onwards. Note the stability of the interpolated target is always stronger than the more extrapolated intercepts, as would be expected as estimates based on the curve move further away from the observed data. Detailed coverage of this trend will be provided in *Study Five* where issues of significance and confidence surrounding the various intercepts will be explored, supported by key datasets and results tabulated in the *Appendices.*

As expected, the actual level of consumption that maximises LE using the frontier remains stable at 3030±138 calories in every available year from 1962-2005. This remains stable even as the more advanced nations begin to consume more across time, meaning the stability of the peak remains stable despite all the many background changes and increases in both life expectancy and caloric intake (see Figure 3-8)

Table 3-2 Interpolated targets and extrapolated zero intercepts across 40 years

Year	Target	LE Intcpt	kCal Intcpt	Year	Target	LE Intcpt	kCal Intcpt
1962	2950	-32	489	**1991**	3100	-44	610
1965	3040	-54	720	**1992**	2988	-91	935
1967	2962	-33	489	**1993**	3112	-37	535
1970	3162	-18	330	**1994**	3100	-26	393
1972	3112	-28	458	**1995**	2950	-32	489
1975	3025	-35	532	**1996**	3040	-54	720
1977	2975	-64	785	**1997**	2962	-33	489
1980	3012	-65	797	**1998**	3162	-18	330
1982	2950	-28	420	**1999**	3112	-28	458
1985	2988	-43	598	**2000**	3025	-35	532
1987	3038	-59	745	**2001**	2975	-64	785
1990	3025	-59	735	**2002**	3012	-65	797
				Mean±SD	3032±67	-44±18	590±168

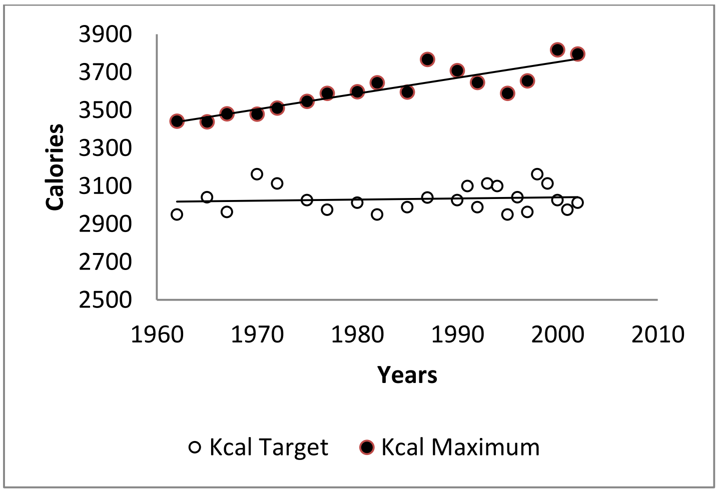


Figure 3-8 Stability of caloric intake maximising LE (Kcal Target) over 43 years

So far, the adapted form of frontier regression applied in this study is working as it should to identify a more moderated, metabolically-constrained 'set-point' for calories using only cross-sectional datasets. Before completing this preliminary exploration of the methods, a few more tests can be applied. For example, does the frontier curve still hold when disaggregated by age or gender?

3.2.5 Results II – Do the Curves Still Hold for Age and Gender?

Infancy and old age are the two primary peaks of mortality and infant mortality in some, mostly underdeveloped, countries can account for up to half the overall mortality. This has the effect in life expectancy league tables of increasingly underestimating the adult life expectancy as we slide down the left-hand of the calorie curve, perhaps explaining why the LE zero intercept averages -44 years rather than approximately +0.17 years (65 days), raising issues of Ecology Fallacy to be explored in *Study Five*. In the meantime, the WHO Mortality League Tables can be used in 1990 and 2000 because the datasets in these years were disaggregated. Unfortunately, the caloric data from the UN-FAO cannot be disaggregated, but the results still support the broad curve results (Figure 3-9).

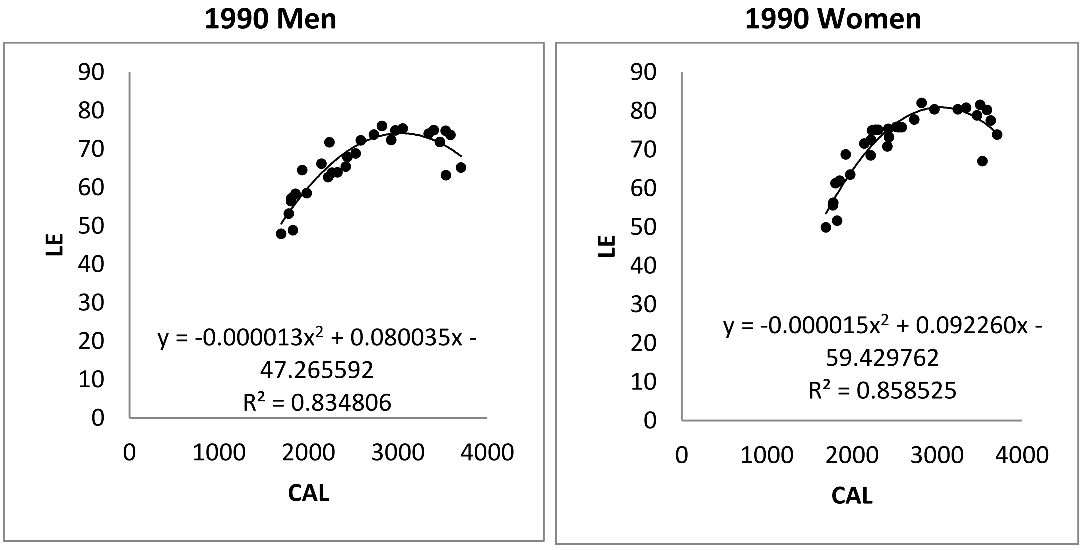


Figure 3-9 Stability of the caloric intake levels maximising LE across gender (1990)

Starting in 1990, the method produced virtually identical curves where longevity for both men and women was maximised at exactly 3050 calories. This was despite the curves predicting women would live six years longer (82 vs. 76 years, as expected from well-known background gender effect of 8% in favour of women). A form of split-half reliability in its own right, the gender split again confirms the ability of the frontier to predict much more sensible caloric targets than would the more linear full-sample curves (which imply infinite gains in LE from infinite caloric intake).

The next step was to see what happened when men and women were compared at the age of one year to eliminate the impact of infant mortality and medical infrastructure. The frontier peaked at 3000 calories for males and 2800 calories for females. Although the difference was not significant, it was certainly heading in the right direction. In the same year, the data disaggregated by six main age groups again show the same curves (Figure 3-10). The interaction effect is not explored here.

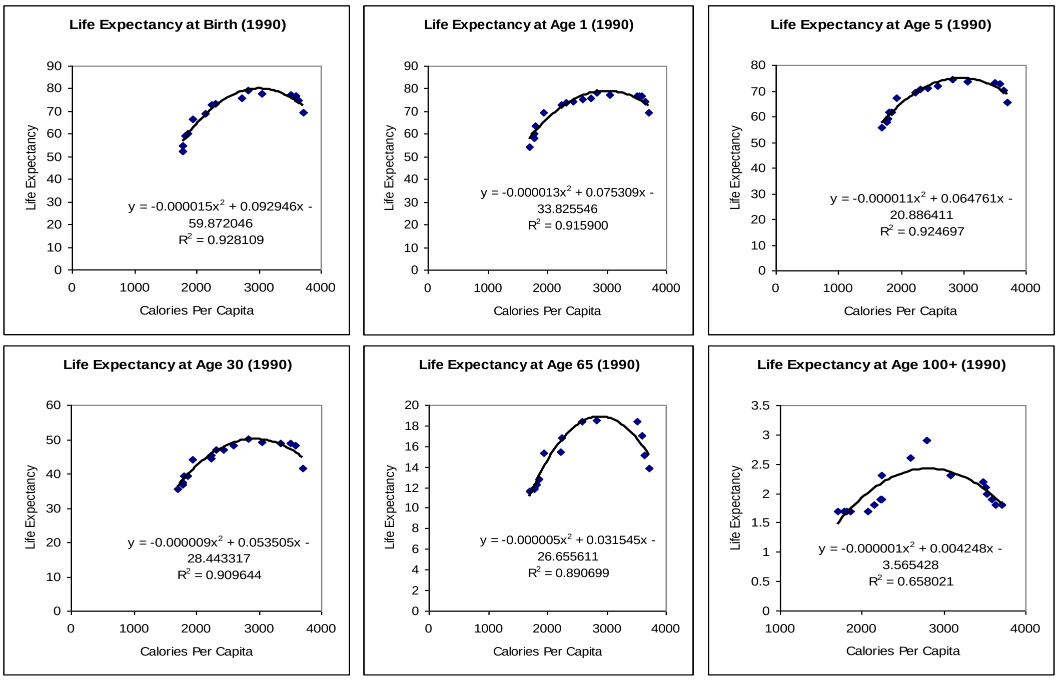


Figure 3-10 Stability of the caloric intake levels that maximise LE across age (1990)

Raw data for these curves are tabled in *Appendix One*. As can be seen, the remaining LE available falls appropriately as age increases. Again the maximum age is always interpolated around 3000 calories although a few outliers become more pronounced in later years. The importance of this brief analysis is merely to show that the frontier curve is consistent across age and gender, making the method more empirically replicable across countries and time when applied to data that is publicly available in the form of aggregated summaries. As promised, the same curves are depicted for the year 2000, here expanded across 22 age groups split into five-year cohorts to underline the point (see Figure 3-11 overleaf).

A few points should be highlighted. One is that the outliers for supercentenarians in the 1990 data become more smoothed in the 2000 data, suggesting perhaps greater accuracy with time. Given the exact birth dates of supercentenarians are often questionable, this is not surprising. To test whether this was measurement error, the analysis was replicated for a different dataset from the World Bank. Directly comparing the selection of nations based on WHO versus World Bank changed the selection of nations but not the nature of the curve. Sweden, Canada and Switzerland, Sri Lanka, Dominican Republic, Vietnam and Ghana were replaced by Iceland, France, Panama and Djibouti. Regardless, the curve formulae still solved to 3050 and 3100 calories respectively. The second interesting point is that the age cohorts with positive zero intercepts, suggesting greater resilience to caloric privation *at the population level* range from 1-29 years and peak at ages 5-9 years. This might reflect some redistribution of food to children but this is yet to be tested. Using the frontier formulae, LE at birth solves to 3050, age 1 to 2900, age 5 requires 2950, age 30 requires 3000, age 65 requires 3125, and supercentenarians require 3000 calories.

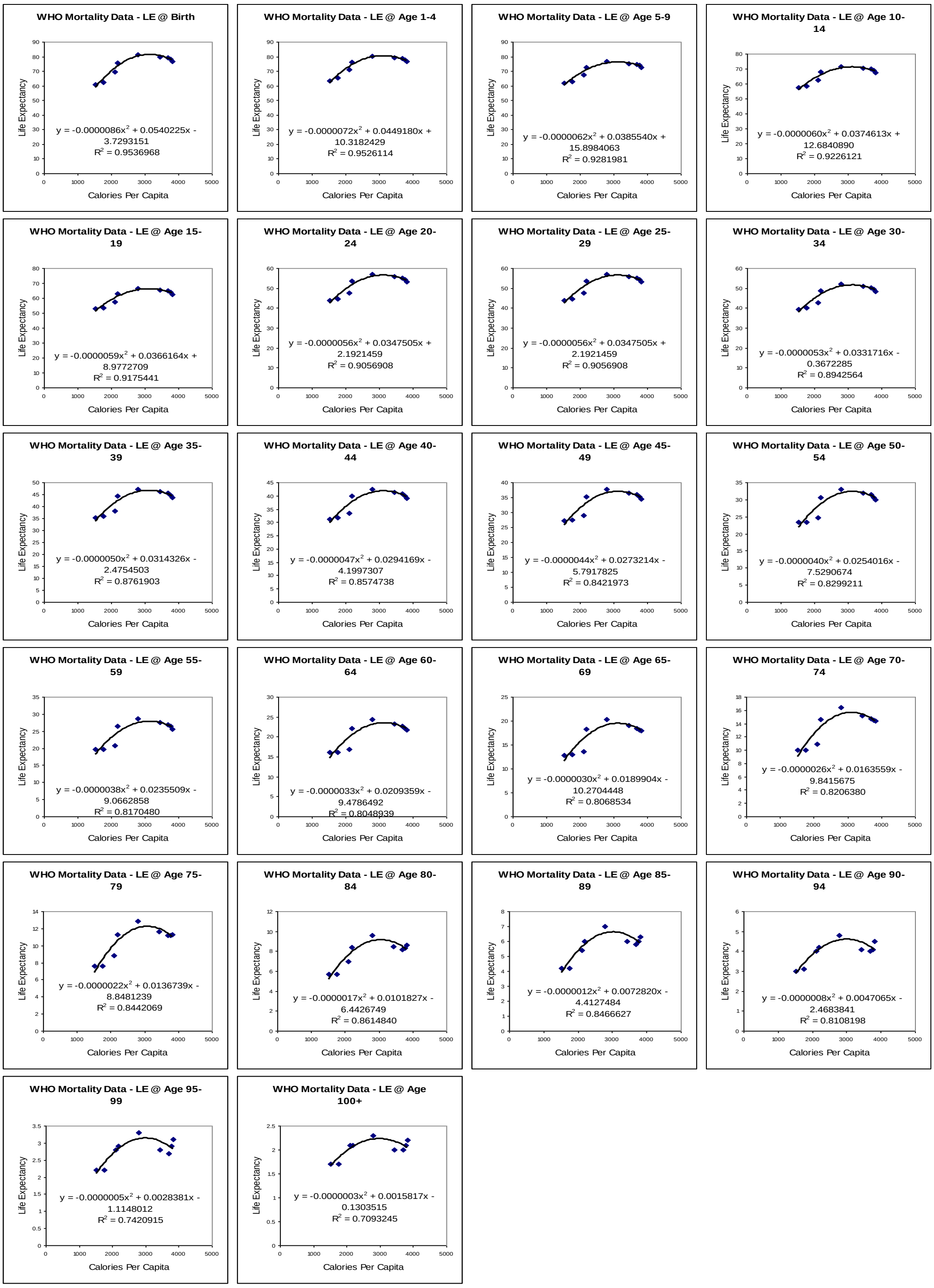


Figure 3-11 Five year age cohort replications for 2000 data across frontier countries

Note the data at age 1 effectively eliminates the impact of infant mortality and successfully eliminates not all but around half the divergence in the zero intercept.

The main ages 1-70 years provides a mean zero intercept of +0.20 years, correctly averaging 77 days (the same for age 30 in 1990, *viz.* IRA hunger strike). This could be nothing more than a happy coincidence given the weakness of extrapolation and will not be revisited until *Study Five*. Having looked at the individual life expectancy curves for each of the WHO's 191 nations, there is not just an infant mortality impact but also a clear increase in child mortality among many less developed nations.

Some countries consistently appear along the frontier peak for different age cohorts whereas some only emerge among supercentenarians, such as Brunei, Kuwait, Belize and Mexico, perhaps suggesting higher levels of inequity as the number of super-centenarians falls to a subsample of wealthier people. By contrast, Japan at age 5 offers a remaining LE of 74 years, which exactly matches Japan's observed LE of 79 years when 5 years is added, suggesting Japan is equally efficient across age groups.

Previously, age 30 represented a watershed age when the extrapolated zero intercept came closest to the zero intercept suggested by the IRA hunger strike (2000 data). But this result is not consistent for 1990 as the extrapolated zero intercept again plunges to -28 years. The optimal value comes to 3000 calories predicting 51 years, again matching the observed Japanese value of 50 years. To gain some perspective on how this maximum value compares to life expectancy at birth (84 years), add 30 years and it becomes 81 years. Note also that by age 30, the subset gains Switzerland and loses Ireland among the over-consumers, but gains Nicaragua among the under-consumers, all suggesting some interesting issues for future study.

3.2.6 Discussion - Testing the Frontier Method for Calories

This study confirms that caloric intake manifests in a bell-shaped curve operating at the extreme frontiers of life expectancy across the past half century, as would be predicted from metabolic needs theory and past studies within countries. A moderated caloric intake target seems to maximise life expectancy and is consistently interpolated at an average of 3030 calories, a value confirmed using various combinations of test-retest stability, split-sample reliability and predictive validity. This value matches traditional UN recommendations but is higher than more recent intra-country recommendations, as will be discussed in *Study Five*.

The use of caloric data across countries has some theoretical and practical advantages compared with the BMI metric currently used by the Millennium Development Goals (MDGs). Moreover, what this study has shown is that a form of split-half frontier subsampling adapted by combining two accepted processes from econometric and psychometric methods can be judiciously used to make sensible projections and hypothetical predictions. It seems to tease out curves from the cross-national datasets that were previously only thought to be possible *within* countries using expensive multivariate analyses of tightly controlled time series across many different variables.

These sorts of large-scale epidemiological studies are too costly for most developing nations. So they traditionally had no way of estimating their own needs beyond referencing work undertaken in the developed context. In India, for example, urban and rural communities maintained a fairly stable caloric intake of 2200 calories from 1973-1997 but their life expectancy over this period reached not much more than 61 years (National Sample Survey (NSS) Organisation, 1997). Even in the developed context, dietary studies are rarely tied to death rates or life expectancy for reasons of cost.

The largest so far was the longitudinal study of death rates and BMI in the United States (Adams *et al.*, 2006). Even then it was based on a sample within a single developed country and so might not have been universally representative. By contrast, the method proposed here identifies a stable target across five decades and 170 countries, at least at the aggregate. It is cheap, fast, simple, empirically replicable and can be used across many different variables, as long as it is understood that the results hold at the aggregate level only and do not inform individual needs.

Another constraint is that the method of split-half frontier subsampling used here only works when the dependent variable is a more or less universally shared and tightly harmonised human output such as life expectancy. This tends to put most of the error in the camp of the independent variable, which is then thought to be minimised at the frontier. The use of split-sampling and recombining the pure frontiers is then applied to minimise the influence of outliers whilst still retaining them, ensuring that the results are always impervious to the researcher having to make ‘line calls’ about data removal.

Of course, there remain problems but these seem to emerge at the extrapolated intercept much more than the interpolated target. In this case, the relationship between caloric consumption and life expectancy can be distorted by equity and wastage within each society as well as differences in height and body mass, the preponderance of children, genetic differences in metabolism, cultural habits and food preferences. The greatest irony in this work is that rising height and BMI themselves might be pushing higher energy requirements in advanced economies

(DHHS & USDA, 1989). By the same token, however, none of this explains the consistent fall in life expectancies beyond target.

Notwithstanding, the importance of this preliminary analysis is to build a rationale that will at least make different candidate human needs more directly comparable using a standard metric and method that tends to suggest moderation, even at the aggregate, and supports global sustainability by mitigating consumption. Later in *Study Five*, when food consumption is contextualised against its actual impact on carbon emissions, it will become more clear how the current study suggests that some countries in the developed world are over-consuming and/or wasting food - not only to the detriment of themselves but to the detriment of future generations.

3.3 STUDY TWO: EXPLORING HUMAN LIMITS TO GROWTH USING THE FRONTIER

3.3.1 Abstract – Human Limits to Life Expectancy and Life Satisfaction

This study uses the frontier to test whether a boundary or ceiling effect is operating on either life expectancy or life satisfaction, perhaps offering a fourth line of evidence for the ‘fuzzy’ metabolic ceiling for life expectancy and set-point theory for life satisfaction. Results suggest that development might have reached an optimum beyond which further absolute planetary exploitation offers little or no further gain in human outputs among nations that are already advanced.

3.3.2 Introduction – A Brief History of Lifespan

The received wisdom is that human life expectancy did not range much higher than 40 years until the past 500 years (Galor, 2005). In the absence of a sophisticated culture pre-agrarian Homo sapiens' life expectancy during the Upper Palaeolithic period was thought to be only 33 years (Caspari & Lee, 2004; Hillard-Kaplan et al., 2000). After the rise of the agrarian city-state of Ur in Mesopotamia (Sherratt, 1980), life expectancies were thought to have rapidly fallen because of the Mesolithic shift from a varied hunter-gatherer diet to monoculture, falling again during the Bronze Age due to urbanisation and the consolidation of social inequity. By the time of Classical Greece and Rome, both of which were sophisticated cultures with a moneyed currency based on the trade of goods and services, life expectancies were only 28 years. It was not until the 15th century that modern Britain achieved life expectancies beyond 40 years, whereas the Industrial Revolution more rapidly halved the death rates of under-five-year-olds from 74-32% (Mabel, 1926).

Height follows the same punctuated development as life expectancy (Baten, 2000; Craig and Weiss, 1998; Cuff, 2005; Steckel, 1995; Sunder, 2004; Woitek, 2003) The main input to height has been related, almost exclusively, to the availability of meat-based protein, which was mostly only available to the ruling elite, as evidenced by comparisons based on bone palaeoanthropology, dental analysis and military records (Prince & Steckel, 2001). Note however, that despite the greater heights achieved by higher-status individuals in agrarian and feudal societies, the stature of a medieval knight was still much smaller than the six-foot heights attained by some Palaeolithic hunter-gatherers (Diamond, 1987). In fact, modern Danes, now recognised as the tallest in the modern world, have only recently caught up to the heights of the Great Plains Indians of North America as measured in the 1700's (Prince & Steckel, 1987).

In the current era, the Japanese city of Okinawa still has some of the highest rates of supercentenarians in the world, an area with restricted caloric intake, whereas more carbon-intensive countries like the United States, Australia and the United Kingdom display life expectancies that are much lower than expected. In Australia, half of all adults and a quarter of all children are either overweight or obese (ABS, 2009b). Obesity is a growing cause of premature death (Barness et al., 2007) linked with cancer, stroke and cardiovascular disease (AIHA & NHF, 2004) that also reduces quality of life (SA Government, 2006; Australian Institute of Health & Welfare, 1999).

The various lines of evidence suggest there are metabolic limits to longevity, height and SWB. Although Veenhoven (2010) recently began to explore this history in respect of SWB, and Steckel (2009) continues to build an evidence-base for height, the lines of evidence have not yet been combined in any single study.

3.3.3 Methods – Human Limits to Life Expectancy and Life Satisfaction

Time series data for life expectancy is taken from the UN-HDI whereas data for life satisfaction is taken from the NEF-HPI. Both sets stretch back to 1960 but the sample sizes vary greatly. Whereas the data for life expectancy covers between 156-160 countries, life satisfaction has never been so represented across such a large time span and covers only 26 countries, mostly the same kinds of nations originally available to Easterlin (1974). As before, once frontier sampling is applied, the sample sizes fall again because only those countries at the extreme upper limits are included in the final curve fitting.

The procedure applied here again starts by matching countries on life expectancy across time periods and eliminating any missing cells. All available years are matched by country. Columns or rows with large numbers of missing cells are eliminated for ease of analysis, leaving 160 countries across all decadal years. Gain (or loss) is calculated by: $(T_2-T_1/T_1)x100$, where T is time (the year sampled). The datasets are then ranked on T_2 from highest down to lowest. Any pairing can be made between sample years. If the pairing is from 1960-2007, the gain will be large whereas pairings between closer years, say 1980-1990, produce smaller gains.

Treating 2007 as T_2, and any other paired year as T_1, the list starts with Japan (as always) and this is included in the frontier subsample as the first 'subject'. Looking down the list, the next highest gain achieved is selected and this becomes the next country in the dataset. The same process is followed until the largest gain in the dataset has been reached. This completes the frontier sampling procedure, against which the curve of best fit is applied using robust regression on 1000 iterations. They are always almost perfectly linear. From this, β slope reflects the average gain achieved along the frontier whereas α is a zero intercept that reflects the highest possible life expectancy in the absence of any gain. Having applied the methods to a series of year pairings for life expectancy, a series of identical tests are applied to life satisfaction. To further validate the methods, data from the Human Mortality Database (2013) is used on a smaller sample of nations going back 250 years.

3.3.4 Results I – LE and LS over the Past Half Century

Life Expectancy

Beginning with the two most distal years, the LE for 1960 is subtracted from 2007 to produce a measure of gain across 47 years. The average gain across 47 years was 13.7±7.7 years, amounting to four months per year. The gain in 2007 is then graphed against the original 1960 LE, as below (Figure 3-12).

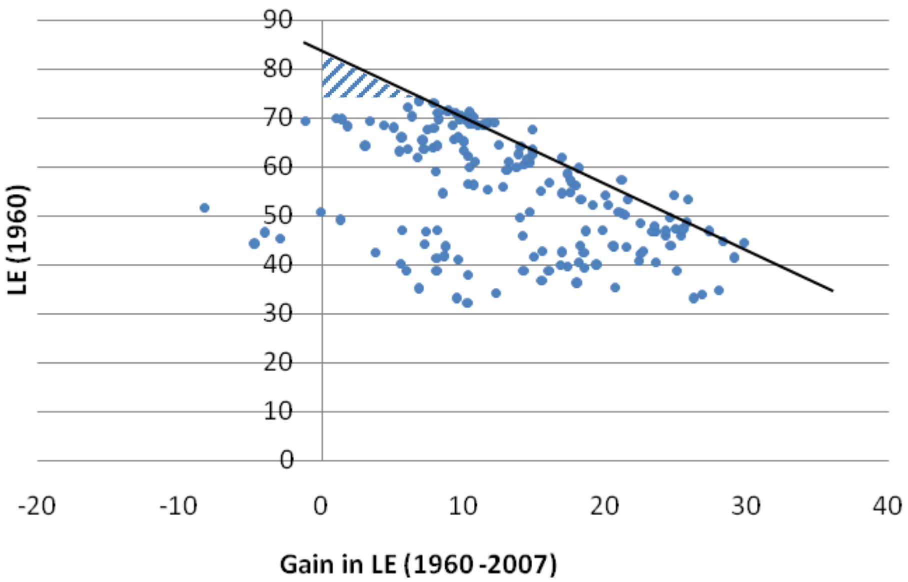


Figure 3-12 The linear frontier for country gains in LE from 1960-2007; note the triangular gap in the upper left quadrant

At the extreme upper limits of the curve, a series of more or less linear values suggest the possible gain grows as countries start out at lower levels of LE in the first place. This line creates a ceiling beyond which further growth cannot expand at different levels of starting values. The corollary at the other end of the line is that growth in LE dwindles to nothing at a certain extrapolated starting point at around 85 years. This is not a limit to longevity as the longest recorded human lifespan is 122 years, but it does reflect a novel estimate of the highest level of LE at which 50% of the population will be dead, with the remainder having a chance to reach the maximum recorded.

This approach has interesting implications for identifying a possible upper limit to LE and various other ‘output’ metrics such as subjective wellbeing. But it cannot be taken at face value unless it remains consistent across time and is not just an artefact of that particular sample of matched years. To this end, a series of tests are applied using the same methods for decreasing time periods, again depicted below (Figure 3-13). Once again, the line appears to extrapolate to a maximum of 85 years for every combination of years, even when the slope becomes greater at more contiguous years such as 1980 and 1990. So the line cannot be an artefact of particular pairings.

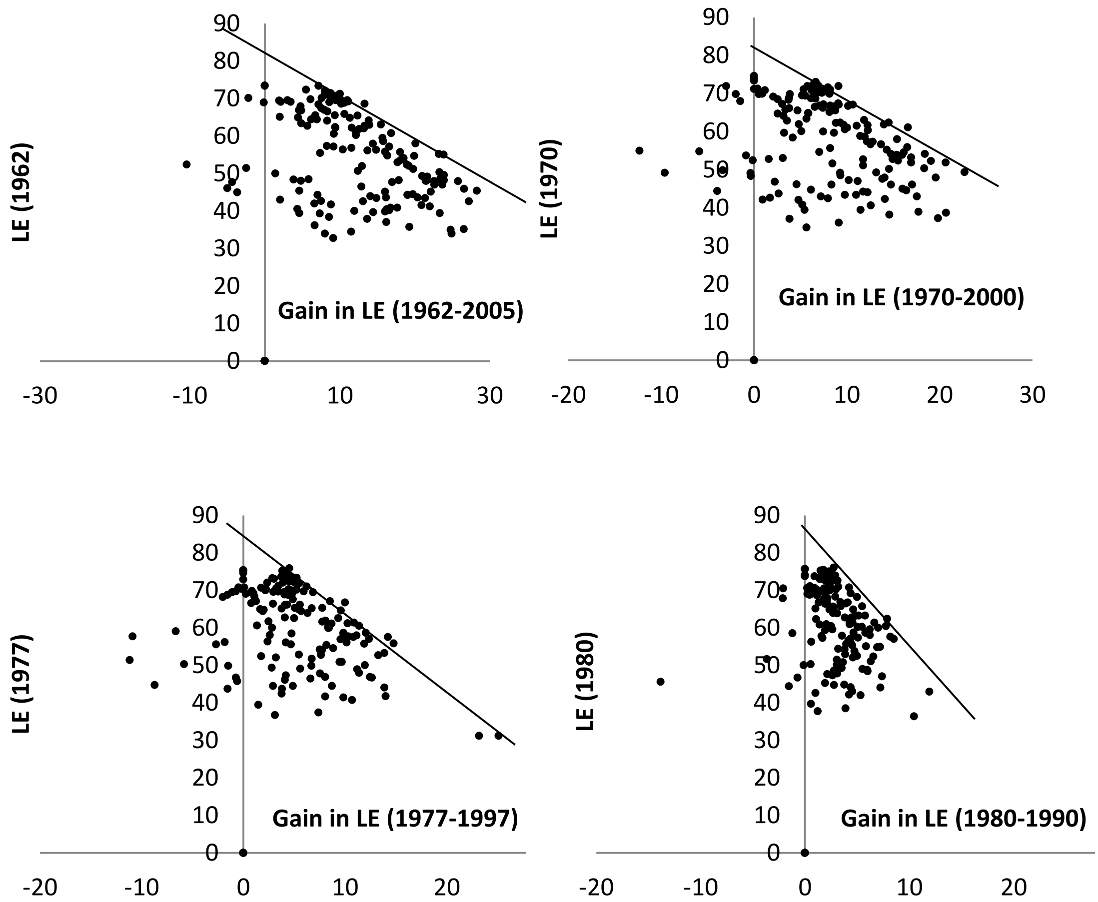


Figure 3-13 The linear frontier for country gains in LE using different year pairings

When applying a more exact linear curve to the frontier subsamples, remarkable consistency emerges, as depicted below in Table 3-3 using a two-tailed test on Pearson's r.

Table 3-3 Frontier results for life expectancy suggest a stable limit

MATCHED YEARS	1960-2007	1962-2005	1970-2000	1977-1997	1980-1990
n/N	20/159	18/156	9/156	15/160	13/160
ζr2(p)	-0.84(0.01)	-0.97(0.01)	-0.96(0.01)	-0.97(0.01)	-0.96(0.01)
β slope	-1.3	-1.4	-1.5	-2.2	-3.2
Zero Intercept	83.6	84.3	83.1	85.2	83.5

This small sample of paired years averages a maximum possible LE of 84±0.82 years, stable regardless of changes in slope or distance in time between baseline and gain periods. Another interesting point is that the following countries consistently achieved the frontier ceiling in every one of these pairings: Chile, Costa Rica, Japan, Vietnam and the United Arab Emirates – all very different cultures. Other countries that achieved the frontier across three or four pairings also included a mix of Latin, Nordic and Middle Eastern nations.

Life Satisfaction

An identical process is now applied to the data for life satisfaction. Tabulated below are the results across similar time periods (although 1960 was changed to 1961 and 2007 was changed to 2005 due to data availability).

Table 3-4 Frontier results for life satisfaction suggest a stable limit

MATCHED YEARS	1961-2005	1970-2000	1977-1997	1990-2000	1990-2005
n/N	8/26	5/26	6/26	6/26	8/26
ζr2(p)	-0.98(0.01)	-0.89(0.01)	-0.70(NS)	-0.92(0.01)	-0.88(0.01)
β slope	-1.7	-2.8	-1.4	-1.4	-1.4
Zero Intercept	8.2	8.6	7.6	7.8	7.7

Although all curves moved in the direction of the correct sign, the much smaller sample sizes at the frontier left some insignificant, such as the range from 1977-1997. If it is assumed the weakness is due to small sample sizes of life satisfaction since 1960, then this small sample of paired years averages a maximum possible LS of 8±0.41 points on the 10-point scale. Even these relatively weak results suggest life satisfaction displays a consistent boundary. Interestingly, the countries that consistently reach the life satisfaction frontier also include countries like Costa Rica and Cuba. This exploration needs further work.

3.3.5 Results II - Life Expectancy over the Past Two Centuries

Although both LS and LE suggest sensible boundaries, the methods need more context, and this was more immediately available for LE. So data from the Human Mortality Database (HMD) was sourced going back more than 250 years to 1751 in Sweden. The HMD offers much more detailed data across a smaller sample size (n=34) than the UN/WHO datasets and uses more complex methods up to 2011. But it can be split by gender and this will be tested to make sure the same trends are achieved when disaggregated.

Preliminary tests of convergence between the UNHDI and HMD datasets were applied first to make sure the two were more or less identical. However they were not. Using the HMD suggests the equivalent maximum averages 80±1.9 years, slightly less than that using the UN/WHO dataset and the greater *SD* suggests less stability, which could result from one of two effects – either the smaller sample size or divergent methods. This was briefly tested by checking whether matched countries produced the same results in 11 different years. It turned out that extrapolations on the frontier were always correlated but the exact values varied with the sample size.

This meant variation in the HMD and UN methods was having an effect on the comparability of the maxima from each dataset but not in a way that introduced a consistent bias. So it would appear that the loss of accuracy in the extrapolated maxima when using the HMD is mainly due to its smaller sample size, making the broader UN/WHO datasets more useful and exact at the frontier, a useful finding that should be kept in mind as the studies unfold. Notwithstanding, the identical trends displayed (overleaf in Figure 3-14) by men and women for the HMD since 1890 still suggest the trends, if not the exact values, can be trusted.

Using the HMD, the earliest start dates were found among the following 12 countries: Finland (1878), England and Wales (1841), Belgium (1841), Italy (1872), Scotland (1855), France (1816), Norway (1846), Netherlands (1850), Switzerland (1876), Sweden (1751), Iceland (1838) and Denmark (1835), allowing direct comparisons for the latest matched year of 1878. The next group of countries with early data began with New Zealand (1901), Northern Ireland (1922), Australia (1921), United Kingdom (1922), Spain (1908), Canada (1921) and the United States (1933), allowing an expanded group of 19 countries matched on the latest year 1933. A third group with start dates at least five years prior to 1960 include New Zealand Maori populations (1948), Czech Republic (1950), Bulgaria (1947), Japan (1947), Hungary (1950), Austria (1947), Portugal (1940), Slovakia (1950) and Ireland (1950), allowing a total cumulative sample of 28 countries in 1950. Using the raw HMD data, the new analysis builds data over the period of 131 years where pairings can be made using datasets only three years apart.

A series of new pairings can now be analysed going back to 1838, disaggregated by gender and ranging through the 1900s up to the present time (Figure 3-14). Notwithstanding the lack of accuracy due to smaller sample sizes when stretching back in time, the results suggest there is an actual rise in maximum possible life expectancy that tends to level out in recent years. No major jumps in maximum LE seem to occur across half centuries. Rather, a steady increase emerges from 1840-2010, as below (r^2=0.99, p<0.001), again suggesting a gain of about three months per year.

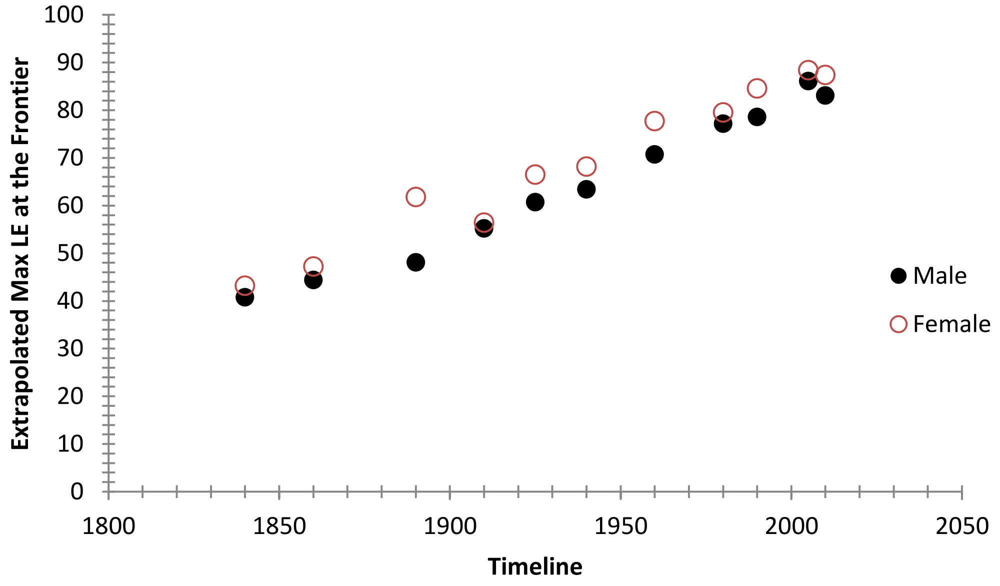


Figure 3-14 Extrapolated maximum life expectancies since 1840

When comparing differences in slope, larger gains by women compared to men seem to emerge in 1890, 1925, 1950, 1960, 1990, 2005 and 2010. The rest were fairly matched, even during the war years and the 1980s. Recall these data are based on frontier nations achieving the very best outcomes regardless of major omitted variables like war, inequity and disease. These values effectively represent what other countries might have achieved outside of their individual circumstances and do not reflect high levels of gender inequity among other countries. Even in 1838-1841, where the sample sizes are still too small, the difference between male and female optima suggested women could live 6% longer than men at the extrapolated frontier. This difference changes in 1908-1911, where the two converge more than usual at around 56 years, and again in 1960, where women make a sharper gain of up to 10%. The results suggest women, even among frontier nations, had a comparatively harder time during WWI and a comparatively better time in the 1960s.

3.3.6 Discussion – Human Limits to Life Expectancy and Life Satisfaction

Most of the previous work on frontier regression is deeply ingrained in the tradition of econometric simulations focused on the productive efficiency of firms and exploring complex mathematical arguments with reference to economic assumptions (see Simar & Wilson, 2010). By contrast, this simple study has applied frontier regression to the maximum gains achievable across time for human life expectancy and life satisfaction, from which extrapolation to a zero possible gain was tested to see if it was a stable boundary.

Over the past half century, a boundary was confirmed for both metrics that remained relatively stable despite changes in slope. Significance was affected by frontier sample size but the sign of the relationships were robust for both LS and LE, suggesting boundaries were operating in each set of years tested. For life expectancy, a fuzzy boundary sat at around 84 years whereas the boundary for life satisfaction was around 8 on a 10-point scale. Whereas the first tends to match the fuzzy boundary suggested by studies of supercentenarians, the second tends to confirm the work of Cummins (2005), suggesting a boundary of life satisfaction of around 7.5. By contrast, Veenhoven has previously suggested an upper limit of 9 (Veenhoven, 2010). So the concept of ‘fuzziness’ is retained because the limit proposed here could almost equally apply to both arguments.

By the same token, however, the limits proposed by Cummins (2005) make much more sense on a psychophysiological level and are much more sustainable. For example, using the observed frontier figures emerging from the current study would calculate Veenhoven’s Happy Life Year at a maximum of 67.2 ‘perfectly happy years'. Only one country has ever come close, Costa Rica, reaching 66.7 against a GDP per capita of only $10,180 per year ($PPP) in 2005. Costa Rica also came very close to achieving One Planet Living (only 8% above the limit for that year). Interestingly, however, the fuzziness of the boundaries reasserts themselves here as well. Costa Ricans achieved an exemplary HLY mainly because they might be an extraordinarily happy people (8.5), but they still have room to reach another four years of LE (against the observed maximum of 82.3 in that year). When combined, these two figures bring the fuzzy boundary of HLY up slightly again to 70 years but it is more likely the LS figure is an outlier in the first place due to original sample size, linguistic and cultural effects.

If Veenhoven is correct on 9/10 maximum LS, then the maximum possible HLY in this year should have been 74 years. If Cummins is correct on 7.5/10 maximum LS it should have been 62 years. The actual observed frontier of 67 years is closer to Cummins' prediction by a factor of 1.4. Moreover, Veenhoven has suggested almost limitless gains in HLY with greater wealth and planetary exploitation whereas the data presented here suggests that the limits might already have been breached in the last few years. The LE data tends to suggest the beginning of a fall in the maximum for both men and women in the current era, even when using small sample sizes, and even when removing all statistically insignificant frontier curves. It is not yet known whether this will continue to fall or else level out at a ceiling around the mid to high-80s in terms of LE when UN data becomes more available over the next year.

Otherwise, the fall between 2005 and 2010 might reflect the impact of the GFC and represent a minor blip in stable progress. This is unlikely. During the timelines sampled, much greater effects on public health included the pasteurisation of milk

(1862), the discovery of penicillin (1928), both world wars and the Great Depression of the 1930s, the polio vaccine (1954), the ‘pill’ (1960), the global eradication of smallpox (1977) and the emergence of HIV/AIDS (1981). Other effects that were less abrupt and more gradual included improvements in sanitation, medical treatment, road safety, work safety, fluoridation of water and public awareness and policies directed at tobacco, alcohol, gambling, violence and many others. As none of these had an abrupt effect, it is assumed they are operating in the background of social progress. Only this slow and gradual progress – probably more related to human learning and technology – is driving the steady gains largely regardless of major upheavals in wealth and further material consumption affected by war and economic depression.

The gain at the frontier has been slow and stable across centuries.

The fuzziness for life expectancy is also retained because, no matter what pairings are made, a stable and replicable characteristic emerges at the upper limits where no countries seem to come close to the frontier boundary based on their former baselines. This is a strange finding – a small triangular gap as countries come close to the extrapolated boundary. Life expectancy seems to vanish without trace as if it were some sort of methodological Bermuda Triangle. This recurring gap tends to suggest that the gains achieved by countries heading close to the boundary are being pulled down by some other effect. It could mean that the boundary is not a first order linear curve but rather a second (or greater) order polynomial, which might be one reason why fuzzy boundaries have emerged, and continue to emerge, across various types of studies. In other words, it’s a bell-curve.

In the interim, even if these fuzzy boundaries apply, the implication for wealth is that no amount will achieve any gains, at least at the average, once the boundary is breached. For sustainability, it means that the ecological impact of wealth could be more moderated than is currently utilised by some of the world's most carbon-intensive economies. In fact, one of the only ways to maximise health and happiness within an advanced economy might be to move absolute consumption to more equitable consumption, having the effect of moving the average closer to the observed maximum. Depending on the baseline inequity of the nation, however, this could still have the broader effect of forcing greater wealth and ecological impact to achieve intranational equity. It would also begin to shift the average upwards, ironically shifting the boundary. Hence fuzziness.

This simple study tends to suggest a boundary is always operating within the technological constraints of the era; but there is still room for social progress, at least when defined by human health and happiness across broader timelines, hence the apparent fuzziness of boundaries within more contiguous and short-term time periods. This would likely become a major source of contention across arguments surrounding the validity of any tests using these metrics and the way in which they interact with wealth and ecological impact. Hence the battle between Easterlin and Veenhoven, among many others.

The next study will now explore some elements of validity applied to the main composite metrics of human progress so far discussed, the UN-HDI and the NEF-HPI.

3.4 STUDY THREE: THE VALIDITY OF THE HAPPY PLANET INDEX

3.4.1 Abstract – Validity of the HPI

Study Three explores the validity of the Happy Planet Index (HPI) on two fronts and is split into two parts. Part One looks at comparative validity between the HDI and HPI with reference to empirical, correlational and experimental validity. Part Two explores the external validity of the HPI by applying its own methods to newly available data disaggregated by age and gender. Part One is the *Introduction* below and subsumes in its own right many elements of methods, results and discussion concerning the validity of the HPI. This lays the foundations for Part Two, which is set out in the standard format. Results again confirm set-point theory and further suggest the HPI is not representative of women and children in pursuing an all-encompassing composite of sustainable development. This further lays the foundations for a 'dashboard' approach based on human needs theory presented in *Study Four*.

3.4.2 Introduction – Validity of the HPI (Part I)

The HPI *appears* to be sound because it captures human development outside of wealth. It measures human outcomes like health and happiness beyond GDP and there is no real problem with EF as the denominator given its superior correlations with satellite measures of national energy consumption. Yet a few concerns remain.

First, the idea that life satisfaction and human happiness are commensurate is always questionable. The HPI actually relies more on LS data from the World Gallup Poll rather than cross-national surveys of 'happiness' (NEF, 2009). Next, most serious 'happiness' studies (e.g. Veenhoven, 1989; Diener & Suh, 2000;

Easterlin, 2005; Inglehart, 2000; Headey, 2007; Stevenson & Wolfers, 2009; Cummins, 2013) still converge on the idea that wealth drives 'happiness' but the subtleties of set-point theory and the Easterlin Paradox are not reflected in the HPI.

The Easterlin Paradox and the relativity of human happiness has profound implications for the sustainability of the index because it suggests any gains are intrinsically predicated on the interactions between intranational social inequity and an upwardly moving target. If the metrics are still thought to be influenced by economic growth but are actually bounded at a set-point, then trying to increase them through more economic growth is like trying to ride up the mountain on an exercise bike. Or, for nations that are already advanced, like trying to keep climbing after you've already reached the peak.

By way of introduction, this study revisits some of the major forms of validity outlined in the methods chapter and discusses them in terms of the HPI and the subindices at issue. It illustrates validity using examples from classical test theory borrowed from psychometrics, later arguing that the convergent validity of the HPI and HDI suffer from problems of singularity. Although the convergent validity of LS can be directly tested against LE, there are many more problems affecting the basic rationale of the HPI.

These problems are contextualised with reference to the Easterlin Paradox and the relativity of human happiness using the argument that the HPI, despite its best intentions, might be unsustainable itself because of these inherent characteristics. The HPI subindices are then used to falsify human happiness as an absolute. Rather, the cross-national results still support the idea that it is simultaneously relative and bounded to a set-point. After discussing these implications, this study further challenges the HPI by using its own methods on new data available from the World Values Survey, Human Mortality Database and Innocenti Report to see whether the results still hold when disaggregated and matched by age and gender – a test of its external validity.

3.4.3 Preliminary Results and Discussion on the HPI's Validity (Part I)

Moving straight into issues of correlational validity, the more established HDI can be used to test the much newer HPI for its convergent validity. This is where the metric correlates with another similar metric that already has empirical validity, much like EF with satellite imagery. So this would *seem* to be reasonable. Datasets from the NEF 2.0 Report are a useful starting point as they include multiple measures across 141 countries, all based on high concurrent validity because they sample the same data for 2005. The metrics cover GDP, HDI, LE, LS, HLY, EF and HPI (Abdullah et al., 2009). Using the same data, some of their results are now replicated in the spirit of empiricism. As one way of testing convergent valdity, Figure 3-15 shows an apparently strong correlation (r^2=0.82, n=141) between HDI and HLY.

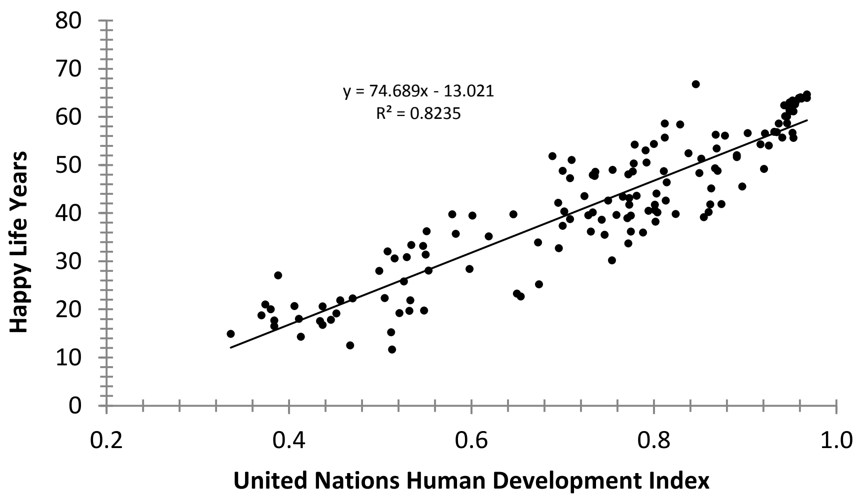


Figure 3-15 Convergent validity between HLY and UNHDI

Although the correlation is strong, countries reaching the same UNHDI (e.g. 0.85) can still range from 39-67 years. Another major problem with this apparent test of convergence can be illustrated with reference to the work described earlier by psychometric tests of personality (see the *Methods* chapter). Imagine the HDI represents one factor that has been combined from three adjectives and the HPI is another factor combined from another three adjectives. If just one of those adjectives is shared by both factors, then the factors suffer from the problem of singularity. Rather than being wholly independent factors, singularity will usually produce a spurious correlation. Even if the factors do not share any single adjective, the first three adjectives might still correlate with the other three adjectives had factor analysis not been applied to tease out uncorrelated factors, which they were not, raising the equally vexatious problem of multicollinearity. Although the correlation as displayed above has been used as evidence by NEF to test the convergent validity of the HPI, the underlying logic is unconvincing because they both share a common subindex – life expectancy. So tests of convergent validity should be applied mostly to the subindices themselves.

Unpacking the main indices provides a better test of whether life satisfaction can be validated by life expectancy without the issue of singularity, especially given their vastly different sampling and calculation methods. Using data for each of these indices from the NEF 2.0 Report, LE and LS are significantly correlated at r^2=0.69 ($p<0.01$), as seen in Figure 3-16.

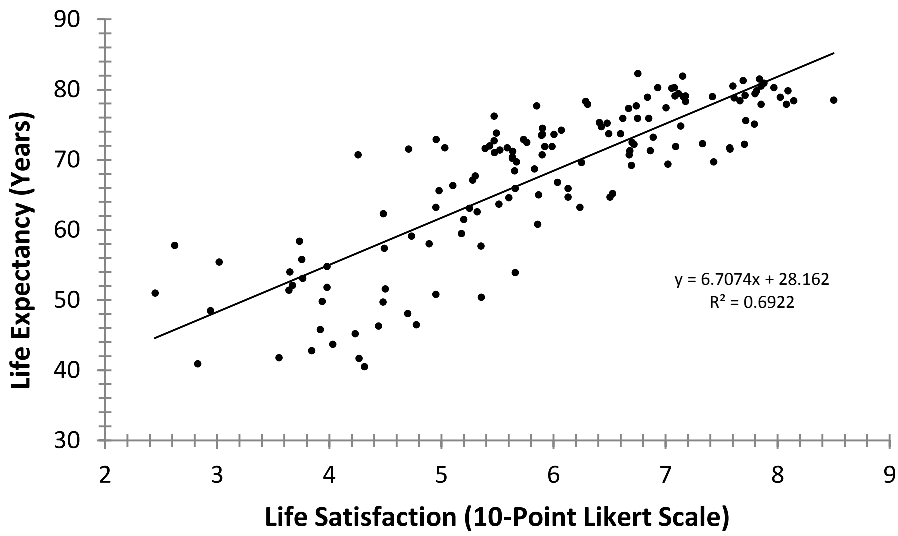


Figure 3-16 Convergent validity between LE and LS is reasonably strong (r^2=0.69)

Note the fuzzy threshold for LS again appears to emerge at around 8 points. Also of interest is the zero intercept, which suggests people could conceivably live until age 28 in a state of complete dissatisfaction – a weak extrapolation but one that, interestingly, embraces the UNHDI minimum of 21 years for reproductive feasibility. This tends towards showing a minimum standard at which human survival collapses. Moreover, supporting Veenhoven, the problem of multicollinearity is partly solved by using HLY as a composite of these two correlated factors. The two indices are not completely redundant because there is enough variation around the curve that they capture different aspects of a correlated factor, especially where divergence grows at the lower end. Here, countries reaching the same level of LS can range from 40 to almost 60 years of LE. We already know that EF has high convergent validity with satellite imagery and so the overall picture for the HPI is so far looking good.

As for statistical validity, the picture is not quite so clear. Unlike the HDI, the HLY does not weight the two indices by their observed range. This means the HDI expresses any gain against the actual baseline minimum in any given year – a baseline minimum which can vary across years and gradually increases at a constant rate with each passing decade, unless it was first set at a confirmed minimum, as was done for LE at 21 years for the HDI. The HLY, by contrast, expresses any gain against a true zero point, at least for LE, allowing tests of monotonicity against returns to scale. The same cannot be said, however, for LS, which is an ordinal scale with no true zero point. Although some economists and mathematicians have attempted to prove this does not matter (Ng, 1997, McKelvey & Zavoina, 1975) the major challenge remains that HLY multiplies an ordinal scale (LS) by a ratio scale (LE), a statistically shaky endeavour in the first place.

Further, like Veenhoven (1989), the HPI tries to equalise ‘happiness’ across countries by attempting to harmonise various datasets (e.g. Gallup Poll and World Values Survey) and often uses algorithms or data from different years to make estimations that broaden the sample size up to n=180, which then simultaneously challenges concurrent and external validity. This includes using adjustments to carbon emissions in place of EF wherever EF is unavailable, which again challenges external validity across countries. Other forms of statistical validity arise from methodological problems like outliers, error variation and heteroscedasticity to be explored later in more detailed tests.

In the meantime, the next section explores one of the most problematic issues for life satisfaction – whether it is relative versus absolute – and then offers a third study by showing that the assumption of absolute happiness can be falsified by the HPI data under review, even when using a criterion variable like human height.

Although it offers more face validity than the HDI, the complexity of the HPI is mostly hidden in the relativity hypothesis. Datasets from the HPI are now used to demonstrate that life satisfaction cannot be absolute, at least when using life expectancy and human height to test criterion validity. This brief exploration will also show how data from the HPI itself leads to serious problems in relation to its own sustainability.

Recall that data from the NEF 2.0 Report (2009) showed a reasonable correlation between LE and LS (r^2=0.69) and this was useful in testing the convergent validity of life satisfaction against an arguably more objective measure in the form of life expectancy. Revisiting this data, the divergence around the average line is extremely telling in terms of Veenhoven's absolutist argument against Easterlin's relativity (Veenhoven & Hagerty, 2006). At the lower end, countries reaching the same level of LS still range in LE from 40-71 years. A country such as Zambia where 50% of the population was dead at the age of 40 was just as 'happy' as a country where half the people lived up to 71 years such as Georgia. This confirms that subjective measures can diverge from objective measures, suggesting relativity. In terms of the falsifiability of absolutism it is compelling evidence. For example, Georgia was much less satisfied than the equally long-lived Saudi Arabia (7.7), even though its level of 'happiness' was equal to Switzerland, a country that happened to live yet another 10 years on top of this.

The test-retest reliability and temporal validity of this finding can now be explored by considering the same curves depicted for the earlier HPI dataset from the NEF 1.0 Report (2006). Again the same effect emerges. Using average human height as a criterion variable, an even more objective measure, the same effect emerges again in Figure 3-17. As the curves are visually clear and no transformations were made to the raw data, the actual boundary and ceiling effects at the frontiers have not been calculated. Suffice to say that the absolutism of

Veenhoven and Hagerty (2006) is falsified given the widening divergence at the lower parts of the curves (Figure 3-17).

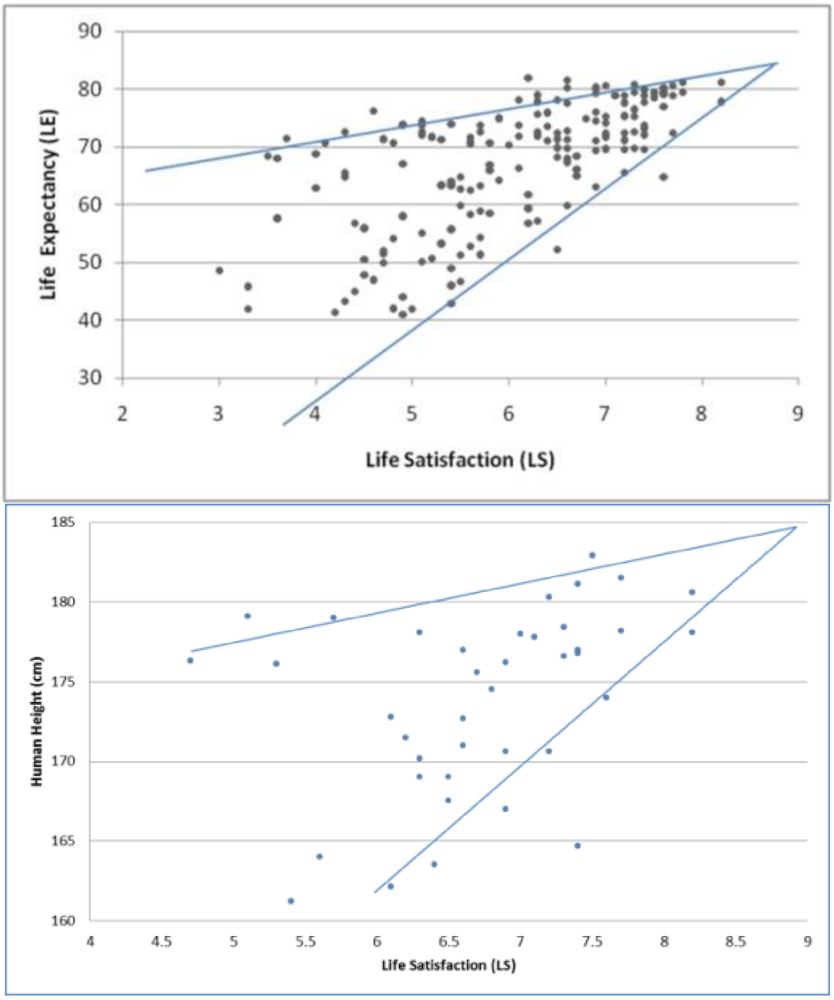


Figure 3-17 Convergent validity of life satisfaction against life expectancy and human height supports the relativity of life satisfaction

This presents a major challenge to the sustainability of the HPI itself. If LS is more affected by relative rather than absolute consumption, then populations will continue to pursue more and more against their peers without any actual gain in terms of happiness. In other words, the use of LS as a key output makes the HPI unsustainable if happiness is predicated on having and consuming and enjoying more than others. This means material resource consumption, whether measured by GDP or EF, becomes virtually insatiable. By including LS as a key metric in the HPI, it means the HPI is fundamentally unsustainable itself – the same problem as outlined earlier that afflicted the HDI in its use of GDP.

Another problem with the HPI emerged in its use of two mathematical constants to adjust the index in favour of either people or planet. To illustrate, the earlier HPI (2006) datasets would have put Haiti and Bangladesh as the most sustainable countries in the world had it not been for these constants. Both nations have life expectancies of around 60 years and life satisfaction of only 5/10, producing (as per Veenhoven) a miserable HLY of only 30 years, roughly half of what might be expected from the earlier study on boundaries (up to 70 years). The high HPI scores of these relatively short-lived and miserable countries come from their extraordinarily low EF, even much below that required for sustainable One-Planet Living. To adjust for this anomaly, the HPI resorted to a combination of constants, which can be adjusted by the researcher using challengeable assumptions.

$$\text{Happy Planet Index} = \frac{\text{Happy Life Years}}{\text{Ecological Footprint} + \alpha} \times \beta$$

The constants, α=3.35 and β=6.42, ensure a country scoring 100 on the HPI is achieving maximum HLY within the boundaries of One Planet Living (Abdallah et al., 2009; p 54). But the adjustments are made to ensure no single index dominates another (Marks et al., 2006 pp.51-52). For example, any country doubling its EF, which ranges by a factor of 20, has a much smaller real-world human impact than doubling its HLY, which ranges by a factor of only 5.5. To account for this, the α constant of 3.35 was added to the EF index to ensure the coefficient of variation (SD/Mean) was matched to that of the HLY. Using these constants across 103 countries for which the NEF had pure (non-estimated) data ensured the standard deviation for both HLY and EF became 0.14. The final result is then multiplied up by the constant β=6.42 to ensure the final HPI ranges from zero up to an ideal country scoring 100 (figures beyond 100 are still possible although unnecessary for One Planet Living).

Whereas the first iteration (2006) of the HPI used constants in favour of ecology to identify Vanuatu as the most sustainable country on Earth (receiving much publicity), the second (2009) seemed to adjust the constants more in favour of human outcomes to identify Costa Rica. Although Vanuatu retained a high position, Costa Rica had higher levels of both SWB (8.5) and LE (78.5) against EF slightly above the sustainability limit of 2.3 (2.1 being One-Planet Living for 2005). Although the EF value is relaxed for Costa Rica – and appears more palatable compared with Vanuatu's tighter benchmark - this slight adjustment would represent a gain of 1% per annum in global EF. This still implies that the world would confront another sustainability crisis in 100 years, even if everyone today suddenly started to live like Costa Ricans and world population growth stopped.

Data for the most recent iteration of the HPI is detailed overleaf in Table 3-5, providing an introductory dataset that helps demonstrate how these constants do not always capture the individual importance of the subindices in the composite metric. This is why the HPI sensibly developed a Traffic Light System that allows readers to make their own value-based adjustments in order to paint a fuller picture of the issues at hand. Using the Traffic Light System, it becomes clear that the HPI suffers the same problem as the HDI in failing to capture the full picture in a single index. This is not so much a criticism of these indices in particular - the same problem affects all composite approaches and is almost impossible to balance.

Table 3-5 The Traffic Light System Ranked from Highest to Lowest HPI (NEF, 2009)

Countries	Life Sat	Life Exp	HLY	EF	HPI
Costa Rica	8.5	78.5	66.7	2.3	76.1
Dominican Republic	7.6	71.5	54.2	1.5	71.8
Jamaica	6.7	72.2	48.5	1.1	70.1
Guatemala	7.4	69.7	51.8	1.5	68.4
Vietnam	6.5	73.7	47.8	1.3	66.5
Colombia	7.3	72.3	53.0	1.8	66.1
Cuba	6.7	77.7	52.4	1.8	65.7
El Salvador	6.7	71.3	47.6	1.6	61.5
Brazil	7.6	71.7	54.3	2.4	61.0
Honduras	7.0	69.4	48.7	1.8	61.0
Nicaragua	7.1	71.9	51.0	2.0	60.5
Egypt	6.7	70.7	47.2	1.7	60.3
Saudi Arabia	7.7	72.2	55.6	2.6	59.7
Philippines	5.5	71.0	38.9	0.9	59.0
Argentina	7.1	74.8	53.4	2.5	59.0
Indonesia	5.7	69.7	39.5	0.9	58.9
Bhutan	6.1	64.7	39.7	1.0	58.5
Panama	7.8	75.1	58.5	3.2	57.4
Laos	6.2	63.2	39.4	1.1	57.3
China	6.7	72.5	48.6	2.1	57.1
Morocco	5.6	70.4	39.7	1.1	56.8
Sri Lanka	5.4	71.6	38.6	1.0	56.5
Mexico	7.7	75.6	58.3	3.4	55.6
Pakistan	5.6	64.6	36.2	0.8	55.6
Ecuador	6.4	74.7	48.0	2.2	55.5
Jordan	6.0	71.9	43.1	1.7	54.6
Belize	6.6	75.9	50.2	2.6	54.5
Peru	5.9	70.7	41.7	1.6	54.4
Tunisia	5.9	73.5	43.3	1.8	54.3
Trinidad and Tobago	6.7	69.2	46.3	2.1	54.2
Bangladesh	5.3	63.1	33.1	0.6	54.1
Moldova	5.7	68.4	38.7	1.2	54.1
Malaysia	6.6	73.7	48.6	2.4	54.0
Tajikistan	5.1	66.3	33.8	0.7	53.5
India	5.5	63.7	35.1	0.9	53.0
Venezuela	6.9	73.2	50.4	2.8	52.5
Nepal	5.3	62.6	33.3	0.8	51.9
Syria	5.9	73.6	43.4	2.1	51.3
Burma	5.9	60.8	35.6	1.1	51.2
Algeria	5.6	71.7	40.1	1.7	51.2
Thailand	6.3	69.6	43.5	2.1	50.9
Haiti	5.2	59.5	30.8	0.5	50.8
Netherlands	7.7	79.2	61.1	4.4	50.6
Malta	7.1	79.1	56.0	3.8	50.4
Uzbekistan	6.0	66.8	40.3	1.8	50.1
Chile	6.3	78.3	49.2	3.0	49.7
Bolivia	6.5	64.7	42.1	2.1	49.3
Armenia	5.0	71.7	36.1	1.4	48.3
Singapore	7.1	79.4	56.5	4.2	48.2
Yemen	5.2	61.5	32.0	0.9	48.1
Germany	7.2	79.1	56.8	4.2	48.1
Switzerland	7.7	81.3	62.6	5.0	48.1
Sweden	7.9	80.5	63.2	5.1	48.0
Albania	5.5	76.2	41.7	2.2	47.9
Paraguay	6.9	71.3	49.0	3.2	47.8
Palestine	5.0	72.9	36.1	1.5	47.7
Austria	7.8	79.4	61.9	5.0	47.7
Serbia	6.0	73.6	44.2	2.6	47.6
Finland	8.0	78.9	63.3	5.2	47.2
Croatia	6.4	75.3	48.3	3.2	47.2
Kyrgyzstan	5.0	65.6	32.7	1.1	47.1
Cyprus	7.2	79.0	56.6	4.5	46.2
Guyana	6.5	65.2	42.6	2.6	45.6
Belgium	7.6	78.8	60.0	5.1	45.4
Bosnia and Herzegovina	5.9	74.5	44.0	2.9	45.0
Slovenia	7.0	77.4	54.2	4.5	44.5
Israel	7.1	80.3	56.8	4.8	44.5
Korea	6.3	77.9	49.1	3.7	44.4
Italy	6.9	80.3	55.7	4.8	44.0
Romania	5.9	71.9	42.6	2.9	43.9
France	7.1	80.2	56.6	4.9	43.9

Countries	Life Sat	Life Exp	HLY	EF	HPI
Georgia	4.3	70.7	30.1	1.1	43.6
Slovakia	6.1	74.2	45.1	3.3	43.5
United Kingdom	7.4	79.0	58.6	5.3	43.3
Japan	6.8	82.3	55.6	4.9	43.3
Spain	7.6	80.5	61.2	5.7	43.2
Poland	6.5	75.2	48.7	4.0	42.8
Ireland	8.1	78.4	63.8	6.3	42.6
Iraq	5.4	57.7	30.9	1.3	42.6
Cambodia	4.9	58.0	28.4	0.9	42.3
Iran	5.6	70.2	39.5	2.7	42.1
Bulgaria	5.5	72.7	39.8	2.7	42.0
Turkey	5.5	71.4	39.4	2.7	41.7
Hong Kong	7.2	81.9	58.6	5.7	41.6
Azerbaijan	5.3	67.1	35.4	2.2	41.2
Lithuania	5.8	72.5	41.8	3.2	40.9
Djibouti	5.7	53.9	30.5	1.5	40.4
Norway	8.1	79.8	64.6	6.9	40.4
Canada	8.0	80.3	64.0	7.1	39.4
Hungary	5.7	72.9	41.8	3.5	38.9
Kazakhstan	6.1	65.9	40.4	3.4	38.5
Czech Republic	6.9	75.9	52.0	5.4	38.3
Mauritania	5.0	63.2	31.3	1.9	38.2
Iceland	7.8	81.5	63.9	7.4	38.1
Ukraine	5.3	67.7	35.9	2.7	38.1
Senegal	4.5	62.3	27.9	1.4	38.0
Greece	6.8	78.9	54.0	5.9	37.6
Portugal	5.9	77.7	45.5	4.4	37.5
Uruguay	6.8	75.9	51.2	5.5	37.2
Ghana	4.7	59.1	28.0	1.5	37.1
Latvia	5.4	72.0	39.1	3.5	36.7
Australia	7.9	80.9	63.7	7.8	36.6
New Zealand	7.8	79.8	62.3	7.7	36.2
Belarus	5.8	68.7	40.1	3.9	35.7
Denmark	8.1	77.9	62.9	8.0	35.5
Mongolia	5.7	65.9	37.3	3.5	35.0
Malawi	4.4	46.3	20.6	0.5	34.5
Russia	5.9	65.0	38.1	3.7	34.5
Chad	5.4	50.4	27.0	1.7	34.3
Lebanon	4.7	71.5	33.7	3.1	33.6
Macedonia	5.5	73.8	40.5	4.6	32.7
Congo	3.6	54.0	19.7	0.5	32.4
Madagascar	3.7	58.4	21.8	1.1	31.5
United States of America	7.9	77.9	61.2	9.4	30.7
Nigeria	4.8	46.5	22.2	1.3	30.3
Guinea	4.0	54.8	21.8	1.3	30.3
Uganda	4.5	49.7	22.3	1.4	30.2
South Africa	5.0	50.8	25.2	2.1	29.7
Rwanda	4.2	45.2	19.1	0.8	29.6
Congo, Dem. Rep. of the	3.9	45.8	18.0	0.6	29.0
Sudan	4.5	57.4	25.8	2.4	28.5
Luxembourg	7.7	78.4	60.1	10.2	28.5
United Arab Emirates	7.2	78.3	56.2	9.5	28.2
Ethiopia	4.0	51.8	20.6	1.4	28.1
Kenya	3.7	52.1	19.1	1.1	27.8
Cameroon	3.9	49.8	19.6	1.3	27.2
Zambia	4.3	40.5	17.5	0.8	27.2
Kuwait	6.7	77.3	51.6	8.9	27.0
Niger	3.8	55.8	21.0	1.6	26.9
Angola	4.3	41.7	17.8	0.9	26.8
Estonia	5.6	71.2	40.1	6.4	26.4
Mali	3.8	53.1	20.0	1.6	25.8
Mozambique	3.8	42.8	16.4	0.9	24.6
Benin	3.0	55.4	16.7	1.0	24.6
Togo	2.6	57.8	15.2	0.8	23.3
Sierra Leone	3.6	41.8	14.8	0.8	23.1
Central African Republic	4.0	43.7	17.6	1.6	22.9
Burkina Faso	3.6	51.4	18.7	2.0	22.4
Burundi	2.9	48.5	14.3	0.8	21.8
Namibia	4.5	51.6	23.2	3.7	21.1
Botswana	4.7	48.1	22.6	3.6	20.9
Tanzania	2.4	51.0	12.5	1.1	17.8
Zimbabwe	2.8	40.9	11.6	1.1	16.6

Looking at the Traffic Light System, most of the countries at the lowest end of the HPI are African nations suffering malnutrition, infection and war. Yet the same category also includes the United States and Luxembourg because of their high EF values. This means comparable groups cannot be identified because the efficiency measure is too vulnerable to divergent characteristics, preventing useful analyses that attempt to identify other inputs to sustainability based on group comparisons. This immediately challenges the ability of this index to properly identify actual pathways to sustainability on behalf of each country - the HPI achieves little more than identifying that most sustainable countries are island nations with particular features, which is relatively useless to other countries seeking to enhance their own sustainability.

Ranging from a low of 16.6 for Zimbabwe, the island nation of Costa Rica emerges without doubt as one of the world's most sustainable countries achieving the highest HPI of 76 on the 100-point scale. This country was also identified much earlier using different methods, for example in the work of Hertzman (1999). It was, and will be, identified again and again by the frontier methods used in this work, along with many other especially efficient countries that have consistently achieved the frontier since 1960. The major problem for the HPI, however, is that Costa Rica might not be representative of pathways to sustainability that are achievable by other countries. The problem of outliers becomes even more important as neither the HPI nor the HDI actually takes into account just how much their indices might be polluted by extreme values that are, at the very least, unrepresentative of the greater majority of human societies.

From Costa Rica, we can read down the list to the first red 'stop signs' where the Philippines and Sri Lanka are both achieving good LE against a low and sustainable EF but their HPI fails to highlight their extremely low SWB. Moving further down the list, a few others follow this pattern until we reach Haiti, where all the basic human outcomes are miserably low and yet the final HPI is high because of its extraordinarily low EF.

Next, we come to a cluster of three countries reflecting the mode of the dataset, being Germany, Switzerland and Yemen that all achieve a moderate HPI of 48. Whereas Yemen achieves this by virtue of its low SWB, the others achieve good outcomes but their EF inputs are much too high and unsustainable. Below this, the mean and median are both 43, embracing Japan, the United Kingdom, Georgia and Slovakia. Once again, Georgia and Slovakia achieve a comparable level of HPI based on their relatively low EF, despite being miserable and short-lived compared to Japan and the United Kingdom.

Note that Japan has long been identified as an outlier both in terms of high longevity and low wellbeing, the latter profoundly affected by East-West dichotomies in the value of expressing happiness, which is then affected by cultural dimensions of Hofstede's collectivism (see Diener & Suh, 2000). Past research has shown this cultural effect on reporting SWB can be generalised across many more Asian nations, which means the HPI for these countries would be underestimated by the HPI (or conversely over-estimated among Western nations).

Finally, the most important finding when looking at the HPI is that the world's most developed nations fail to increase their human outputs despite growing ecological impact. Below Japan, the HPI identifies apparently advanced nations such as Norway, Canada, Iceland, Australia, Denmark, the United States and Luxembourg. This immediately suggests a threshold level of human outputs regardless of increasing ecological inputs, and might even suggest a bell-shaped curve where higher levels of impact start to reduce human outputs.

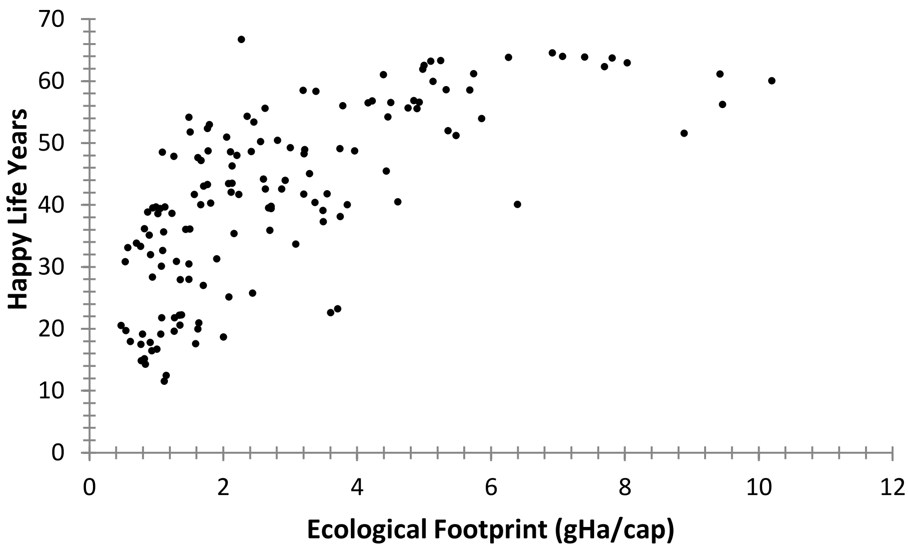


Figure 3-18 Bypassing GDP altogether, the cross-sectional relationship between EF and HLY looks like a classic growth curve with a diminishing marginal return

Ignoring the outlier of Costa Rica, the peak of HLY appears at around 6.5 gHa/cap of EF (Figure 3-18), much greater than that required for One-Planet Living. Note, however, that HLY begins to fall slightly with greater EF beyond this point, which could be either measurement error or a real world effect.

If the apparent minor fall in HLY beyond around 6.5 EF is a real-world effect, then it has some interesting implications for sustainability. It means the cross-sectional relationship between EF and HLY also looks like a classic growth curve with a diminishing marginal return – the same as GDP itself. The same curve is now replicated for HLY when reinserting GDP as the main input variable (Figure 3-19).

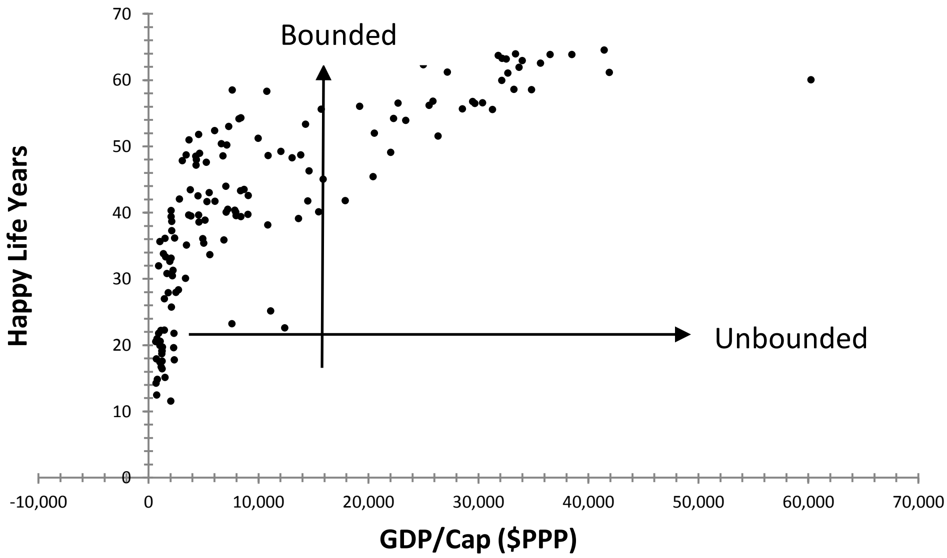


Figure 3-19 HLY is bounded but GDP is unbounded

Both curves suggest that human outputs are bounded whereas wealth and ecological inputs feeding these outputs can be unbounded and unsustainable. The trend suggests there are human as well as ecological limits, possibly even negative metabolic externalities linked with over-consumption of material resources. In other words, quite apart from the ecological limits to growth, there might be metabolic and social limits to growth operating within the human organism itself. These can only be observed at the frontier, not the average, of human survival. The frontier focuses on those people and societies sitting at the very extremes of human adaptability.

Having explored some introductory themes and data of relevance to the validity of the HPI in Part One, Part Two now tests the final challenge to the HPI – its *external validity*. Highlighting the importance of considering all people in a population, the study applies the exact methods of the HPI to new data available from the World Values Survey, Human Mortality Database and *Innocenti Report* to see whether the HPI results hold when disaggregated and matched by age and gender. The results suggest the HPI is not wholly representative.

3.4.4 The Happy (Little) Planet Index (Part II)

At the heart of sustainability is the wellbeing of children as they grow towards the future that older generations bequeath to them. But the ideal of One-Planet Living gets tighter every year as the international community dithers on climate action. As of 2011, the upper limit for a sustainable EF fell to 1.8 g/Ha per capita (2011). Revisiting the 2009 HPI report then puts Costa Rica as more unsustainable than was represented. So the mantle of sustainability must be passed to the Dominican Republic on the Caribbean island of Hispaniola. This country achieved almost 72 years of life expectancy and an HLY of 54 years against only 1.5 g/Ha per capita.

One major problem confronting the HPI is that life expectancy is averaged across all age groups in a nation whereas LS is only averaged for adults (42 years according to the WVS). As wellbeing (or LS) changes with age, it means the sampling procedure underlying the HPI may not be representative of the country as a whole, nor would Veenhoven's (1989) measure of wellbeing be as strong as its age-weighted subindex of life expectancy in calculating the HLY. This suggests that there is good reason to believe there could be differences in the HPI – and hence the most sustainable countries – if women and children's wellbeing were properly accounted for.

Until recently, life satisfaction was always measured for adult samples across countries and no such equivalent data existed for children. Only one international study, the Innocenti Report, has surveyed child wellbeing using a 10-point Likert scale similar to those used among adults (Currie et al., 2004). This is the WHO collaborating project on Health Behaviour in School-Aged Children (see also HBSC, 2006), which first surveyed wellbeing among children in 2001/02 and again in 2005/06. This now presents the first chance to replicate the 2005 HPI methods for children in a relatively concurrent year.

The rationale of the HBSC resonates with the HPI and the current work on subjective wellbeing metrics for children and youth (see Seligman & Csikszentmihalyi, 2000; Huebner, 2010). Optimising child health, just like adults, should go beyond the absence of illness or distress to embrace multi-factorial elements of wellbeing such as positive affective states, not just in terms of overall life satisfaction but also in domains like home and school (Diener, 1984; Wilkinson & Walford, 1998). School experience has a significant impact on child wellbeing in the expected direction (Ravens-Sieberer, Kokonyei & Thomas, 2004), and lower levels of wellbeing among children is related to greater substance abuse (Zullig, 2001), obesity, eating disorders and lower physical activity (Thome & Espelage, 2004). As measures of SWB for children are highlighted across more countries, they are beginning to find traction in discussions on the Rights of the Child (Huebner, 2010). Across countries, the Innocenti Report says high wellbeing among children, defined by a score >6 on a 10-point ladder, is thankfully strong across most countries and family affluence remains a factor. The problem is that "a widening gender gap is observed as children grow older, with boys more likely to report high life satisfaction by age 15" (HBSC, 2006, p.65).

This study is the first to explore the HPI using data for boys and girls aged 11, 13 and 15 years. It will compare adult versus child wellbeing and replicate Veenhoven's (1989) HLY using disaggregated life expectancy from the Human

Mortality Database. It will then move on to examining the relationship with Ecological Footprint by generating a ‘Happy (Little) Planet Index’ for comparison with its standard adult version.

3.4.5 Methods - The Happy (Little) Planet Index

Much of the work in this study was devoted to checking formulae, cleaning data and harmonising datasets across time and countries before some simple, final analyses were conducted to compare rankings. The samples were often progressively decreased as various data-limiting problems emerged in terms of comparability across nations. The first was that this study completely removed any HPI data based on estimates or algorithms, leaving a pure set of actual data across 103 nations, the three NEF 2.0 HPI subindices being LE, LS and EF (Abdullah et al., 2009).

The next sample-limiting variable was child wellbeing, where the number of countries represented in the HBSC Report (2008) is much smaller, only 39 countries in 2005/06. Within-country sample sizes ranged from 1,000-9,000, totalling 204,534 children across the ages of 11.6, 13.6 and 15.6 years (all±0.30SD). Note that the HBSC classifications of Scotland, England and Wales had to be averaged to create an equivalent value for the United Kingdom, reducing the HBSC set by another two countries. After this, all subindices are available for each HBSC country except in the case of Greenland, further bringing the sample size down to N=36.

The next sample-limiting variable was life expectancy (LE). To match the HBSC age cohorts, LE required more exact data than that used by the HPI (originally sourced from the UNHDI, itself derived from the official WHO Life Tables). The reason is that HPI (like the UNHDI and WHO) uses LE at birth for the nation in each *year* sampled, whereas this study also requires LE at each *age* sampled.

So this work uses the equivalent Life Tables for appropriate ages from the Human Mortality Database (2011). These Life Tables provide more granular data for each age based on grouping intervals of a single year. Whereas the WHO provides 5-year block data, the Human Mortality Database (2011) publishes data exactly matching all possible age cohorts, here matched to ages 12, 14 and 16 years (by rounding up the HBSC data). Like the WHO Life Tables, the HMD (2011) generates LE from algorithms based on central death rate (m), probability of death (q), number of survivors to age x (l), death number at age x (d), person years lived at age x (L) and after age x (T); all weighted by the country's population size at each age (based on birth and death registrations). After matching the HBSC against the WMD data, the children's sample further lost Croatia, Greece, Macedonia, Romania and Turkey, leaving 31 countries. This sample of 31 countries is the strongest possible dataset for children.

Only the HPI data for Ecological Footprint was retained from the original HPI dataset (2009). Sourced from the WWF and Global Footprint Network's Living Planet Reports (2008), the HPI dataset again covers more than 100 countries by averaging EF for adjacent years. There is (as yet) no way of disaggregating this measure by age. The original data for EF matching the HBSC countries was free of various step-wise transformations made by the NEF 2.0 HPI for countries in Africa, Asia, Latin America and the Middle East. Most of the HBSC countries were OECD members and so EF was not a sample-limiting variable.

After maximising the sample size for children across NEF and WMD, a further sample-limiting issue arose for adults. Adult LS was taken directly from the World Values Survey matched to the child sample year but covering a smaller group of 100,026 adults (WVS, 2009). This further limited the adult dataset matched to the HBSC to 17 countries. The WVS rather than the Gallup Poll (the NEF's-preferred dataset) was used for LS because published data allowed for disaggregation by another three adult ages: 23 ($\pm$3.5SD), 39 ($\pm$5.6SD) and 61 ($\pm$4.6SD). Within-country samples for these countries were all around 1000 respondents, mostly surveyed in 2006 across a total of 21,000 people.

Despite the uniquely comparable data for LS, a few other problems remained. The first was that measures of adult and child wellbeing, although close, were not identical. Both datasets use a 10-point scale, but a closer look reveals that the HBSC offers children a scale from 0 representing dissatisfaction (like the NEF's preferred Gallup Poll) whereas the equivalent for WVS is anchored at 1. After considering the use of a constant to adjust for this difference, the divergent LS figures for the relevant countries was so close as to render the issue moot (no mean difference, both 7.15, and r^2=0.90). By using the Cantril ladder, the HBSC also primes the respondent to view the extremes of the scale as a variation from 'worst' to 'best' imaginable lives, which is different from the simpler WVS question used for adults:

"All things considered, how satisfied are you with your life as a whole these days?"

Results using this question correlate with the Cantril ladder (Abdullah et al., 2009, p.53) but the second problem is that the HBSC data publishes only the percentage of children ticking above the mid-point and not the actual mean. As the mean is required to calculate the HLY, an adjustment still had to be made to the children's data. This was done with reference to the linear correlation between equivalent values among adults using WVS data (before being matched to the HBSC). The formula was significant, $r^2=0.96$ ($N=71$, $p<0.001$), allowing the equivalent children's mean to be estimated by inserting Ch>5% in place of the equivalent adult value, Ch=0.5582*(Ad>5%/10)+2.8571. Ultimately, these issues signal caution, although the results tend to confirm previous studies.

The full data-matching process ultimately allowed for 31 countries for children and 17 countries for adults to provide the strongest available matches across key HPI indices.

3.4.6 Results - The Happy (Little) Planet Index

Checks were first made to assess how much LS and LE data from the NEF (2005) were matched to equivalent data from the WVS (2006) and WMD (2006). As expected, the two life expectancies at birth were correlated at $r^2=0.96$ ($N=31$, $p<0.001$). The correlation for LS using NEF against the WVS (adult mean) was only slightly weaker at $r^2=0.89$ ($N=17$, $p<0.001$). This result offers reasonable confidence in the comparability of data between NEF and WVS.

As this data were rounded, checks were also made by using the reported NEF data to recalculate itself ($r^2=0.99$, $N=31$, $p<0.001$). Together, these preliminary analyses support the comparability of the key data using different datasets.

The first major result is shown in Figure 3-19 below, where both LS and LE are converted to a 100-point scale. It can be seen by reference to the standard error bars that LE gradually increases as people reach greater ages, which is entirely expected from the broad literature and methods applied to the metric itself. Of equal interest is the more dramatic fall in LS as age increases, a finding also consonant with past literatures on SWB (Diener & Suh, 2000). What this immediately means is that sustainability as measured by the HPI, given EF is held constant for countries in this study, will be subjectively felt differently at different ages, even though average HLY from age 11 to 61 years remains constant– due to the effects of LS and LE cancelling each other out in the calculation of the HLY.

What's more interesting is the growing variation around the measure of happiness as people age, suggesting growing inequity in subjective wellbeing across the life course (again well known in the extant literature).

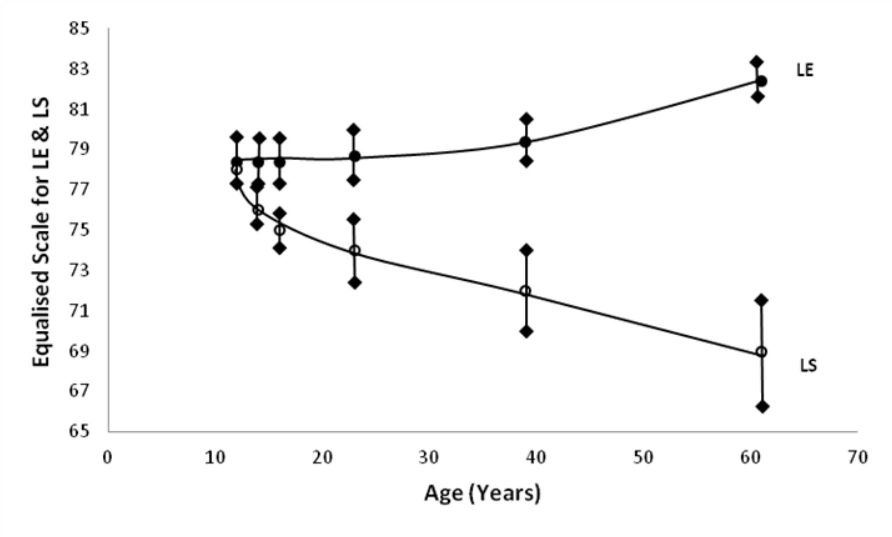


Figure 3-20 LE and LS diverge by age and gender

The next major finding is the degree to which the original NEF data match the new data generated for children across 31 countries and other age groups across 17 countries. The new set is detailed in Table 3-6 for 2005.

Table 3-6 Original NEFHPI data plus recalculations for ages 12, 14, 16, 23, 39 and 61 years

Country	NEFHPI	12 HPI	14 HPI	16 HPI	23 HPI	39 HPI	61 HPI
Austria	48	49	48	47			
Belgium	45	49	48	47			
Bulgaria	42	62	58	54	46	44	40
Canada	39	38	37	38	39	37	37
Czech	38	41	42	42			
Denmark	36	36	35	35			
Estonia	26	38	37	37			
Finland	47	49	48	47	49	48	48
France	44	49	48	47	47	44	44
Germany	48	52	50	50	50	50	49
Hungary	39	53	52	49			
Iceland	38	38	38	37			
Ireland	43	43	42	40			
Israel	45	51	50	49			
Italy	44	50	48	48	46	44	45
Latvia	37	50	49	49			
Lithuania	41	52	52	49			
Luxembourg	29	30	29	28			
Netherlands	51	54	54	53	52	52	53
Norway	40	40	40	39	40	42	42
Poland	43	51	49	48	50	48	47
Portugal	38	50	49	48			
Russian Fed	35	46	45	45	43	39	39
Slovakia	44	56	56	54			
Slovenia	45	50	49	48	50	48	46
Spain	43	47	45	45	44	44	41
Sweden	48	49	47	46	46	48	50
Switzerland	48	50	49	49	50	50	53
UK	43	46	45	44	45	45	47
Ukraine	38	55	54	53	46	46	41
USA	31	30	30	30	30	29	31

The data suggests that the original HPI is not representative of different age groups, as shown below in Figure 3-21. Only key countries are highlighted for context. Note that the curve fails across ages 12 (r^2=0.42), 14 (r^2=0.43) and 16 years (r^2=0.46), until reaching age 23 years (r^2=0.71), where the relationship starts becoming much stronger with age 39 (r^2=0.83) and 61 years stronger again (r^2=0.86).

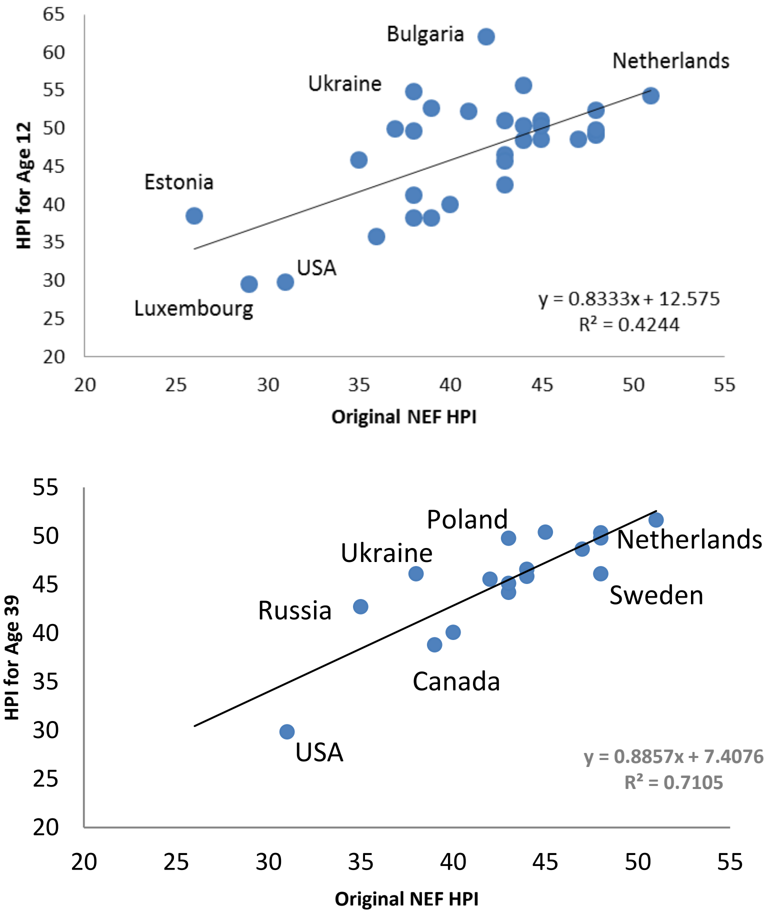


Figure 3-21 The original NEF-HPI is more correlated with age 39 than age 12

As expected, these results demonstrate that the HPI is far more representative of older ages and not significantly representative of children. The same result is now replicated when disaggregated by gender across the smaller sample size of 17 countries. For children, this is a reverse form of split-sample validity by halving the sample size (though biased towards OECD nations). So too the same can be said for the split by gender itself. Regardless, the same effect emerges, as shown in Figure 3-22.

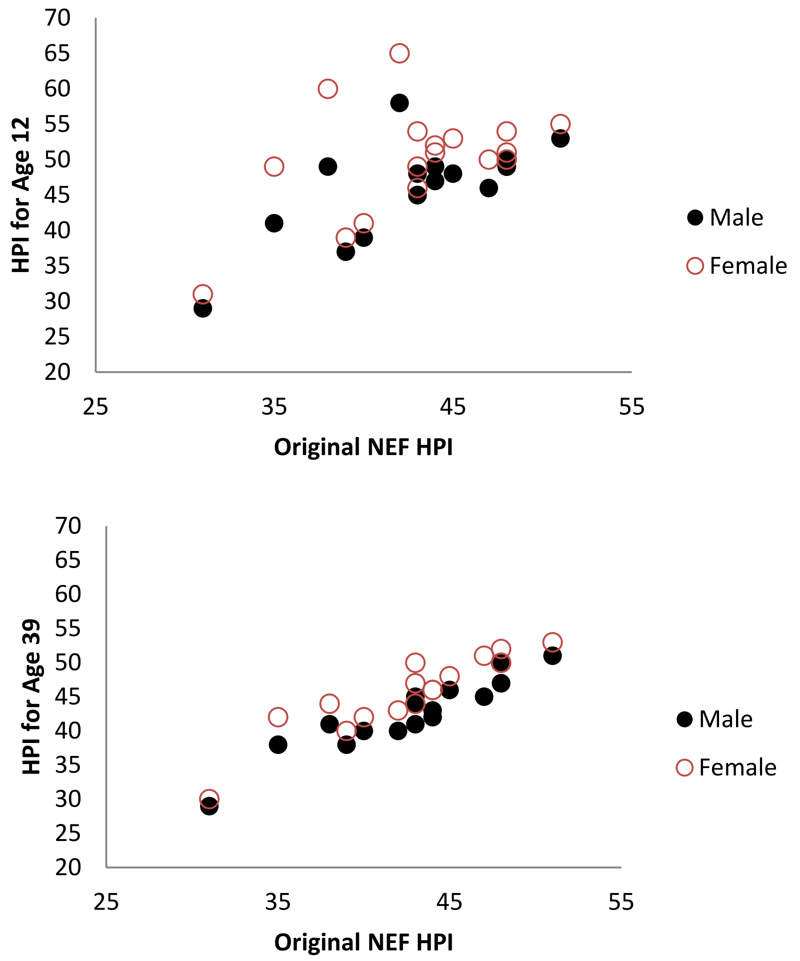


Figure 3-22 The original NEF-HPI is more gender biased at age 12 than at age 39

These results suggest the original HPI is biased towards older age groups and diverge by gender in earlier years. They suggest 12 year-old boys and girls are more ‘sustainable’ than adults and that girls are apparently more ‘sustainable’ at the age of 12. Various replications, including the data from 2001/02 wave of the HBSC (not reported here) suggest that although life expectancy is always greater for women and girls, their levels of happiness are usually lower compared to males. The strength of the relationships between the original HPI and the gender disaggregated datasets is now summarised across all available ages in Table 3-7.

Table 3-7 Correlations between original NEFHPI and HPI recalculated by age and gender

HPI	Age 12	Age 14	Age 16	Age 39-42
Male	0.51	0.54	0.56	0.88
Female	0.24	0.23	0.23	0.85

The correlations between male and female data across ages for the main subindices are also given in Table 3-8.

Table 3-8 Correlations between male and female data for recalculated HPI subindices

HPI	Age 12	Age 14	Age 16	Age 39-42
LS	0.91	0.71	0.72	0.96
LE	0.92	0.92	0.92	0.93
HPI	0.89	0.84	0.83	0.96

For life expectancy, the correlation is stable across all ages at around r^2=0.92, all significant. So it is not surprising, given singularity, that the same occurs for HPI. But the variation around the curve is still interesting. For example, those countries that significantly favour women across all age groups include Russia and the Ukraine, a result that might reflect higher levels of self-destructive behaviours among adult males in the former Soviet Union. But this is challenged by applying the same argument to life satisfaction where the general trend by reference to the zero intercept across countries suggests girls and boys are equally happy at age 12 and only the Ukraine achieves equity between boys and girls at age 14 (both genders 7.4). By contrast, Italy and Sweden seem to favour boys by 0.5 out of 10. At age 16, the same pattern emerges. Once again, only the Ukraine achieves equity (both genders 7.2), whereas the countries most in favour of boys now include Bulgaria and the UK, again by 0.5 points each. Only by age 39 do the levels of life satisfaction by gender converge across all countries, although the gender difference in favour of males increases to 0.7 points.

Does this mean that the lower ‘happiness’ of women across all ages except 12 years is biological or social? If social, it means the majority of nations might not be nurturing women as well as they could, including Sweden. If biological, it could mean that any country achieving divergence below 0.5 is making social efforts to raise female wellbeing. As yet, the divergence is too small to assess but the overall trend confirms that the HPI is not as representative of populations as it might claim.

3.4.7 Discussion - The Happy (Little) Planet Index

The question of whether child versus adult measures of SWB are strictly comparable is valid but studies within countries using similar metrics suggest psychometric equivalence for both children and adults (Tomyn et al., 2013). Moreover, the results follow trends within countries as well. SWB significantly falls with age using the Personal Wellbeing Index in Australian adolescents from ages 12-20 (Tomyn & Cummins, 2011). Note that this study found girls were happier than boys on average, which reverses the current findings but might be due to factors peculiar to the Australian culture, either more supportive of younger girls or less supportive of younger boys. The latter is more likely as a new report shows 20% of young Australian men aged 16-25 years now believe ‘life is hardly worth living’, 10% contemplated suicide in the past year, 8% made suicide plans and 2% attempted suicide – one in 50 (Burns et al., 2013). Australia has had an aggressive gender equity policy for many years that has focused more on comparative/competitive wealth and power than on healthier forms of integration and equity respecting both gender and generations. It is also one of the least sustainable countries despite achieving high SWB when compared with other OECD nations.

Notwithstanding, the Happy (Little) Planet Index described by this section of the work challenges the original HPI on several counts. Within the constraints of the smaller sample of countries available, the original HPI puts the Netherlands and Sweden as the most sustainable countries sampled whereas the same methods applied to children demotes both nations in favour of at least six and up to 16 other countries, topped by Bulgaria. If the HPI actually surveyed life satisfaction across different ages, and then matched those ages against the more granular data available for life expectancy, it would probably move towards achieving a more inclusive and equitable measure, even more so if EF could be adjusted for the same age groups. Whilst this ideal would be helpful, the results of this analysis still signal caution in the handling of life satisfaction.

The original HBSC findings demonstrated significant differences in wellbeing between boys and girls, as found here. Whereas boys were generally happier at ages 12 and 16 years, some countries reported no difference. These included Belgium, Hungary, Iceland, Israel, Latvia, Macedonia, Turkey and Ukraine, again found here. A re-analysis of their data suggested the reason was not that girls were happier (their average score being 7.8) but that boys were slightly less likely to be happy (8.1) compared to other countries (8.6). Only in Bulgaria and the Ukraine was life satisfaction consistently matched between genders, yet this hardly guarantees sustainability. Despite its laudable levels of gender equity, the Ukraine still remains one of the most energy-intensive economies in Europe (per GDP generated), around half from oil and gas and the other half from nuclear power. It was the site of the

Chernobyl disaster 110 km north of its capital, Kiev, and still hosts the largest nuclear facility in Europe. Meanwhile Bulgaria has good levels of equality (Gini) and gender equity but LE is below the European average.

All of this suggests that a single composite index can never capture the subtleties impacting on its subindices. The HPI not only fails to disaggregate age but also fails to disaggregate gender. A summary of HPI findings without disaggregation shows that no country achieves all three goals of optimising wellbeing, longevity and sustainability. Whereas Japan, Hong Kong and Liechtenstein do well in terms of LE (>80 years), Malta, Vanuatu, Bhutan and Costa Rica achieve higher levels of life satisfaction (>8.5), with Ireland, Norway and Denmark just behind. Countries that tread most heavily on planetary resources are Luxembourg, the United Arab Emirates and the USA, with Australia close behind based on carbon emissions.

Moving Away from the Holy Grail of a Composite Metric

The main problems with the external validity of the HPI and its reliance on the Traffic Light System highlights issues of keen importance to all composite indices and league tables. Note first that despite the addition of constants, the 'real world' value of life satisfaction and life expectancy against ecological footprint has to be mathematically assumed in the HPI or else left to the reader to make their own judgements using the Traffic Light System. The same applies to the HDI where the composite of LE, GDP per capita and education intrinsically weights each metric as if they are equally valued – simply by dividing by three (see Haq, 1995). The HDI would have to assume that all people value each outcome equally, which is clearly not the case in the 'real world'. Equal weighting suggests that several decades of longevity might be happily substituted for some equally long period of formal education (HDI) or happiness (HPI). Whereas the actual value of education, wealth or even happiness can rise or fall in different cultures as an appropriately adaptive response to social, material and political circumstances.

So the weighting of each input to the composite metric should probably be based on temporally stable β coefficients against more or less universally valued human outputs which, unfortunately, are not yet known. There is too much work yet to be done to apply 'real-world' weightings, and this has been the object of many complex studies in recent times, especially when using forms of Factor Analysis and Data Envelopment Analysis by the *Beyond GDP* network.

In summary, both the HPI and HDI try to build a universally appropriate composite of human outcomes, but the equal weighting of very different subindices raises serious challenges to their universality across countries and generations. Unfortunately, as the complexity of a composite measure grows, so does its intuitive usefulness begin to fall. So the development of yet another composite index simply litters the landscape of cross-national datasets. This work now explores an alternative and tests whether the proximity of a county to disparate LE targets begins to predict LS based on human needs.

3.5 STUDY FOUR: TESTING THE HUMAN NEEDS DASHBOARD

3.5.1 Abstract – Human Needs

The study to be laid out in this section is the conceptual lynch-pin between this five-part series because it uses the frontier to make explicit the mathematical assumptions obscured in the HPI formula, in doing so providing a method that can be replicated across many different human needs. If the frontier across countries can be trusted for basic physiological needs like food (as shown in Study 1), then it might also work across many different kinds of human needs, including more psychosocial and economic 'needs' that are usually studied within countries – wealth, equity and wellbeing being some of the proposed candidate metrics.

The basic rationale is that the extrapolated and interpolated values for any true human need should remain stable across time, whether measured using cross-national or intra-national datasets. For true needs, the same results should always emerge if the cross-national sample is split or whether the earliest data are used to predict the latest. The frontier should also appropriately reverse the sign for metrics that are antagonistic rather than essential to human survival. They should also match, with due respect for divergent methods, results within and across countries and disciplines. If they do, this process could start building the kind of dashboard increasingly called for by governments worldwide.

3.5.2 Introduction – Human Needs

More recent approaches to the measurement of human outcomes have moved away from seeking a perfect composite measure in the tradition of Kuznets, favouring instead a dashboard model where the key metrics are laid out side by side to help ‘drive’ the economy or society.

Imagine a steering wheel to shift direction between health, equity and happiness as required, a speedometer to moderate economic growth, a tachometer for Ecological Footprint and a fuel gauge for One Planet Living. Three important points should be made for this study.

The first is that the frontier method should successfully reproduce traditionally accepted targets for basic needs like food, water and sleep. As touched on earlier, they traditionally settle on daily needs of 3000 calories (Bissio, 1997, pp. 15-17), 8 hours of sleep and 3.7 litres of water. All differ, as would be expected, by age and gender. They also differ by ambient temperature, workload and health, among many others such as the major effects of war – all presumed to be mostly eliminated at the frontier. Because the data deals with population averages, the main question is whether the method converges on *population-level* recommendations outside of these basic effects. Further refinements to the methods could make the results more accurate and these will be explored later for appropriate indices.

The second important point for this study is that not all indices collected across countries should behave like human needs in the first place. Many are completely antagonistic to public health, such as crime and disease. For these kinds of variables, the frontier method should successfully predict that life expectancy is maximised at zero – not at some moderated level of input. Rather, the actual curve should be linear and negative rather than a bell-curve suggesting over-consumption or a logistics curve suggesting a threshold or set-point.

The third important point for this study is that, if the frontier method offers a plausible test of a needs hierarchy, then basic human needs like caloric intake and sleep should predict a zero survival intercept that is lower than for higher perceived needs like wealth or even ‘happiness’. The use of extrapolation in this context does not attempt to identify an exact deprivation value but simply to make sure the method builds a plausible hierarchy. The hierarchy that emerges is compared with Maslow’s original work along with results from research on subjective wellbeing, sustainability, medicine and economics.

These predictions are now tested with reference to data of relevance to the HDI, HPI and MDGs, alongside death rates from the WHO, key metrics on the economic gradient identified by the Global Burden of Disease (2006), data on sleep from the OECD (2009) and whatever data are available on water from the MDGs and UNFAO.

3.5.3 Methods and Results (Part I) – Exploring Frontiers for Different Indices

The first series of results compares the frontier for life expectancy in the presence of death rates per 100,000 people for key indices on the economic health gradient for 2002 (WHO, 2004). These should produce a negative sign. The frontier subsamples are always smaller but tend towards appropriate negative signs where the curves of ‘best fit’ are mostly linear. Later versions of these curves up to 2011 suggest the same results when testing validity across and within time periods. Results are given in Table 3-9 and example curves presented in Figure 3-23.

Table 3-9 Simple frontiers for death rates of metrics for the main indices of the Economic Health Gradient across developing and developed nations

Death Rates (2002)	n	ζr^2	β Zero	β 1	β 2	Intercept
Malnutrition	9	-0.95	-0.57	NA	NA	81
Malaria	9	-0.94	+0.02	-1.4	NA	78
Infant Mortality	10	-0.91	+0.00	-0.03	NA	79
HIV AIDS	8	-0.98	-0.20	NA	NA	80
War Fatalities	4	-0.99	-0.90	NA	NA	80
Tobacco (COPD)	10	-0.84	-0.01	NA	NA	79
Homicide	6	-0.95	-0.18	NA	NA	80
Cancer	6	-0.65	-0.00	NA	NA	80
Alcoholism	9	-0.90	+0.02	-0.02	NA	80
Heart Disease	8	-0.70	-0.00	NA	NA	80
Diabetes	8	-0.98	+0.00	+0.00	-0.06	80

So far, the frontier method successfully predicts that negative impacts like death rates from various social and medical problems are extrapolated to sensibly high intercepts of LE. The average is 80 (±0.80) years, tending towards the fuzzy boundary in the absence of each variable. All behave in the appropriate manner. Despite concerns about extrapolation, this means other variables might be plausibly compared using this simple method. It is expected that actual human needs will follow one of three separate curves, all with a positive sign based on the largest β values – linear, bell-curve or a form of logistic threshold. It is unlikely that material consumption will be linear in any sense whereas human-centered metrics could be.

These results are all centered on 2002 data because it is focused on the top ten causes of death in the developing and developed world highlighted by the Global Burden of Disease (Figure 3-23). As will be shown, the same curves also emerge for 2000, 2005 and 2010, where many more countries and broader types of metrics have become increasingly available over the past decade. This provides an opportunity to test the stability of the curves for many different candidate 'needs'.

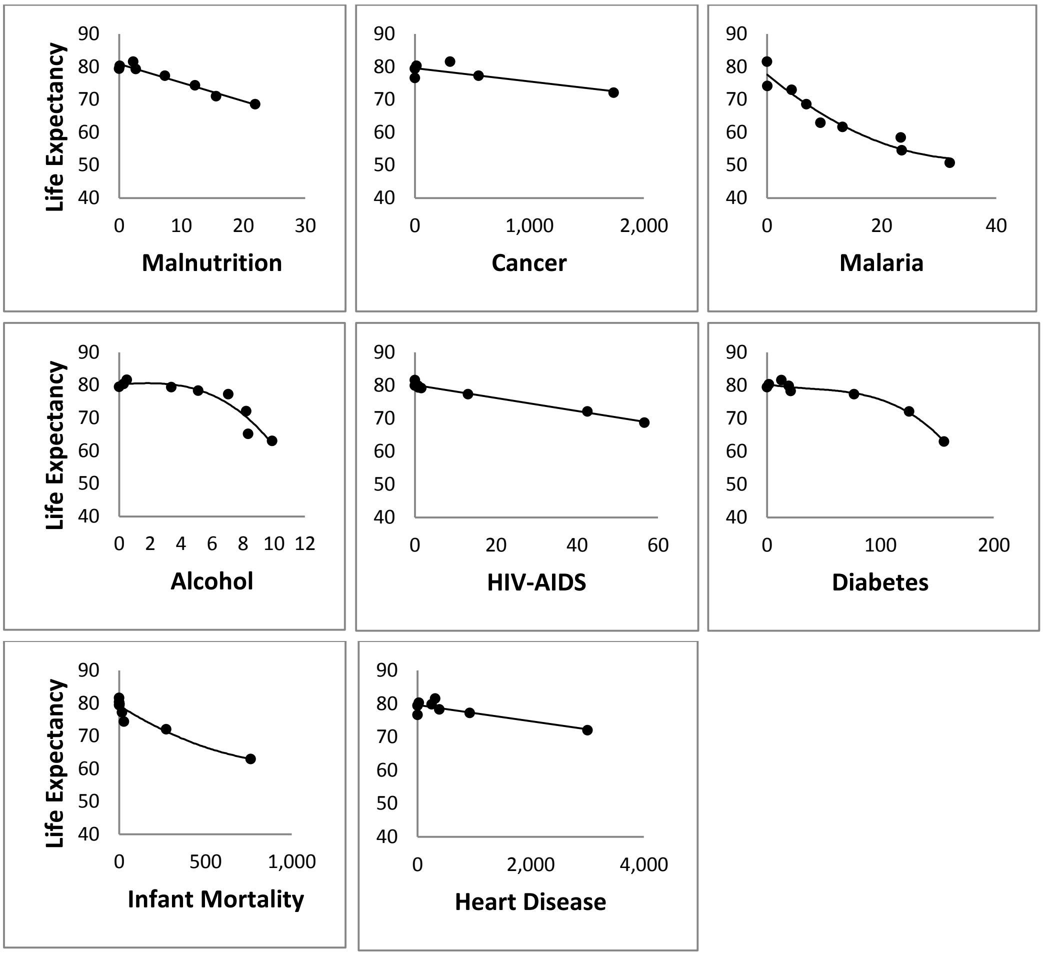


Figure 3-23 Example frontier curves for some key metrics for death rates

The next dataset now replicates available data as they climb the ladder of Maslow's original needs hierarchy. It is expected that the extrapolated intercept of life expectancy in the absence of each candidate need will increase as it climbs the ladder. Few available metrics exactly match the original hierarchy proposed by Maslow but some key variables collected by the HDR (2010), FAO Aquastat (2002), and World Gallup Poll (2010) serve as reasonable proxies. The collection years range 2002-2007, the majority settling on 2005.

By contrast with actual death rates, where the curves are mostly linear and negative, the curves for basic survival needs should be more positive and bell-shaped. The optimal life expectancies achievable should be constrained at both higher and lower levels of 'input' unless excess consumption is essentially benign, in which case a threshold should emerge, which tends to suggest they are secondary needs, after Alderfer (1969). The data for these curves are detailed in Table 3-10 in a ranking based on the zero intercept to show how the hierarchy might emerge across variables.

Table 3-10 Simple frontiers for other candidate need metrics available from the UNHDR, including some tentative categorisations based on needs theories

Needs (2005)	n	ζr^2(p)	Intercept	Target	Category
Water Quality	15	0.96	-24	100%	Survival*
Water Consumption	20	0.98	-20	325 litres	Survival*
Calories	13	0.94	-12	3260 kcal	Survival*
Feeling Safe	13	0.74	+15	100%	Safety*
Safe from Assault	15	0.69	+15	100%	Safety*
Socially Supported	19	0.94	+22	100%	Belonging*
Gender Equity	29	0.90	+23	100%	Capability?**
Income Equity (Gini)	13	0.93	+27	25/100	Capability**
Life Satisfaction	20	0.95	+32	7.8/10	Actualisation?*
Feeling Respected	17	0.84	+34	100%	Esteem*
Feeling Free	19	0.75	+37	80%	Capability**
Education Years	19	0.99	+45	10 years	Capability**
Press Freedom	18	0.83	+69	100%	Capability**

Categories roughly matched to Maslow (1969)*, Sen (1999)**

Example curves are again depicted overleaf (Figure 3-24) and include most of the main subindices of relevance to the UNHDI and NEFHPI including education and life satisfaction. Wealth, along with a few other basic food variables, will be explored later because they require transformations that distort the zero intercept. Note all are based on the pure frontier without trimming or transformations but here use recombined split samples to minimise the effects of outliers – the next simplest curve at the frontier that generally doubles the sample size. The curves are very different across these varied indices but strong across the frontiers, with implications for the interpolated optima as well as the extrapolated intercepts at which populations might maximise life expectancy at the point of zero 'input' for each metric.

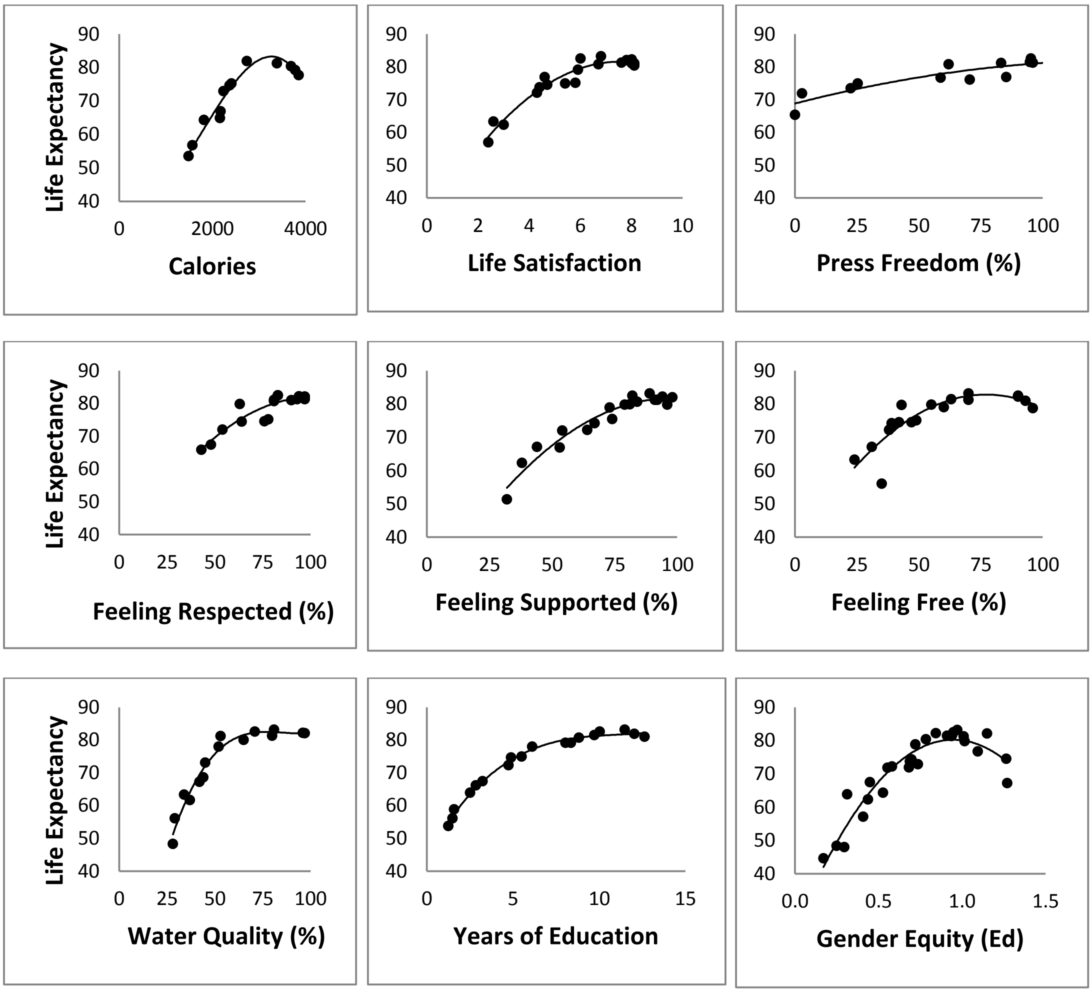


Figure 3-24 Example frontier curves for some key metrics for death rates

Additional datasets covering equity and human rights, economics, health, education, poverty and gender are also available from the World Bank Millennium

Development Goals (2005), United Nations Human Development Index (2007) and New Economics Foundation Happy Planet Index (2005). Using the same methods, preliminary results are shown in Table 3-11 alongside all of the indices so far tested, once again ranked on the zero intercept. All are based on raw data whereas indices requiring log transformations are left for the next part of this study to explore more detailed statistical results, subtler curve shapes and confidence intervals for key metrics used in the UNHDI, NEF-HPI and MDGs. This kind of data could start building a β-weighted model to test interactive and additive effects across variables, but this would further overreach the immediate aim of this work, which is simply to provide a foundational overview of comparable stylised curves in the first instance.

3.5.4 Discussion (Part I) – Exploring Frontiers for Different Indices

Although the emergent hierarchy appears plausible against various theories and past results, the reliance on the extrapolated intercept must be viewed with caution. When the intercept for a primary need as basic as caloric consumption can range by $1.8^{\pm}$SD across time series, it is likely that more adaptive needs would display such variability that the individual indices could overlap by several decades and not just years. So far, confidence intervals have not been reported because they add another layer of complexity to the analysis that would obscure the emerging argument. In the interim, a brief discussion of the results is offered in terms of past studies and known effects.

First, life satisfaction. Once again, the set-point for LS is supported at 7.8 and it is generally seen that LS is more important to human survival than, for example, freedom of the press. As expected, water and food is more important again, but gender equity emerges as almost as important, among a few others like feeling safe.

Table 3-11 Further expanding the list using non-transformed data and curves

Subindices	Category	n	ζr^2	Zero Intrcpt	Optimum
Water Quality	Survival	15	0.96	-24	100%
Water Consumption	Survival	20	0.98	-20	325 litres
Calories	Survival	13	0.94	-12	3260 kcal
Income share of richest 10%	Survival?	10	0.92	5	30%
HALE	Survival	22	0.96	12	100%
Feeling Safe	Safety	13	0.74	15	100%
Safe from Assault	Safety	15	0.69	15	100%
Socially Supported	Belonging	19	0.94	22	100%
Gender Equity	Capability?	29	0.90	23	100%
Income Equity (Gini)	Capability	13	0.93	27	25/100
Life Satisfaction	Actualisation?	20	0.95	32	78/100
Feeling Respected	Esteem	17	0.84	34	100%
Feeling Free	Capability	19	0.75	37	80%
Education Years	Capability	19	0.99	46	10 years
Income share of poorest 20%	Capability	10	0.90	46	6%
Gini Coefficient (1997-2002)	Capability	9	0.92	57	33
Income share of poorest 10%	Capability?	8	0.91	61	3.5%
Press Freedom	Capability	18	0.84	69	100%
Recent Inflation (2006-07)	Capability	13	0.93	76	1.7%
Malaria	Antagonist	9	-0.94	78	0
Infant Mortality	Antagonist	10	-0.91	79	0
Tobacco (COPD)	Antagonist	10	-0.84	79	0
HIV AIDS	Antagonist	8	-0.98	80	0
War Fatalities	Antagonist	4	-0.99	80	0
Homicide	Antagonist	6	-0.95	80	0
Cancer	Antagonist	6	-0.65	80	0
Heart Disease	Antagonist	8	-0.7	80	0
Diabetes	Antagonist	8	-0.98	80	0
Sustained Inflation (1990-2007)	Antagonist	12	-0.90	81	0
Malnutrition	Antagonist	9	-0.95	81	0

Next is wealth. Although tests of absolute wealth need log transformation in the next few studies, its equitable distribution still emerges as being of keen importance. The optimal equity values for life expectancy suggests the richest 10% should derive not more than 30% of national income and the poorest 10% should derive not less than 3.5% of national income, rising to 6% for the poorest 20%. On the surface, this might seem to be extremely inequitable, but it turns out to be neither pro-capitalist nor pro-communist. Rather it suggests there should be moderation, which is further supported by the interpolated Gini Coefficient which maximises life expectancy at 33/100. Although suffering serious methodological issues of their own, past studies also match this value and tend towards 25-35 (see OECD, 2012). This needs further work because the value can be polluted by age distributions affecting income versus wealth.

In the meantime, the more moderated levels of equity that emerge in these exploratory analyses suggest the curve is bell-shaped, allowing for the satisfaction of basic needs whilst still incentivising the labour force towards economic growth and productivity – issues of importance to basic arguments between capitalism and communism. This then hinges on the next cluster of indices surrounding economic growth itself, where moderation again maximises human health in terms of longevity. Here, sustained growth over many decades tends to reduce life expectancy whereas recent moderate growth at 1.7% maximises life expectancy. This is almost half that traditionally predicted by macroeconomic models as 3% being the optimum.

So far, the results tend to support and expand on past studies in terms of the interpolated optima. So too, the emergent hierarchy based on extrapolation seems plausible, even if statistically unconvincing as yet. Most tend towards the hierarchy originally proposed by Maslow (1968) at the lower levels of Alderfer's primary needs (1969). The capability needs proposed by Sen (1985) tend towards being focused on higher, possibly secondary needs, as would be expected from Sen's background in economics rather than Maslow's focus on psychophysiology. Again, these stylised cross-sectional curves merely offer a contextual foundation for more sophisticated studies across metrics that might have been overlooked in the past. For example, at the time Maslow developed his theory, gender equity was an emerging political issue post WWII. It was not included as a basic human need. By contrast, this work suggests that gender equity in education tends towards being as important as income equity and social support. The fact that education *per se* emerges as less important suggests educational equity across gender is probably tapping into gender equity rather than education itself. Another example is that freedom of the press appears to be not quite as important as some interest groups would like to suppose.

This is not iconoclastic but merely contextualises survival issues across many more countries outside of those enjoying much higher levels of human development. It would be nice to argue that income and gender equity are primary needs but none of these results can be used to confirm a hierarchy as yet. To be classified as a true primary need, the index must first display test-retest and predictive reliability. Otherwise, it might just be an adaptive secondary need peculiar to social context, an extreme example being female infanticide in dowry cultures – a maladaptive social construct driven by market distortions in resource allocation. By contrast a true human need, especially if it is to remain relevant in a carbon-constrained future up to and beyond 2050, should be just as stable over the past 50 years at least.

Yet only a handful of key metrics have been properly measured – not just estimated – across a decent range of nations over the past half century. Unfortunately LS is not one of them; nor is water or sleep. If they have been measured (as in LS back to 1960), they only cover advanced nations, which raises the spectre of Simpson's Paradox (a problem with Gini as well). For example, a recent range-restricted study put Australia as the world's 'happiest' nation which was only true within the range of OECD countries measured by that study in that year (OECD, 2013). A hierarchy can only be measured in an unrestricted dataset using the same methods across decades.

So before moving on, a series of brief tests is made to the frontier method on additional food metrics that have been regularly measured across countries and decades, these being proteins and carbohydrates. The only other findings that might triangulate with the results in the absence of broader time series include econometric studies of consumption elasticity and zoological studies of allometry across species. The problem here is that elasticity is focused on econometric concerns whereas allometry, with a few exceptions, is focused on the phylogeny of sleep. Notwithstanding these problems, the available data across species can still offer a rough idea of what human life expectancy might have looked like in the complete absence of 'civilised' development, which begins to help contextualise the separation between primary and secondary needs.

3.5.5 Further Studies Testing the Frontier Methods

Three brief studies are touched on below; the first two are focused on external validity of the frontier based on two alternative approaches that should converge on the same results – consumption elasticities from econometrics, and allometric regression from zoology. Because allometry data are focused on food and sleep, the second and third also explore convergent validity for human food and sleep datasets from the UNFAO and OECD respectively. This moves from calories alone to proteins and carbohydrates. Beyond confirming the frontier methods, of particular interest is that allometric regression of expected lifespan across species suggests any need variable with a zero intercept above the age of 26 years represents a societal adaptation that lifts life expectancy above that expected by our basic biology. This might help define Alderfer's split between primary and secondary needs.

External Validity Using Consumption Elasticities

At its most basic level, elasticity of demand is calculated by dividing the percentage change in quantity demanded by the percentage change in price (or income or taxation). The concept of elasticity is one of few that can measure human needs as an alternative to the frontier method because it measures the degree to which expenditure on different items remain constant regardless of changes in price or income, both reflecting the elasticities of demand by the consumer under different conditions. For example, basic staples like bread have lower elasticities, and so are always less responsive to change, whereas luxury items like truffles have much higher elasticities and tend to be consumed more as income increases or prices decreases. Econometric studies of elasticities are used to determine whether certain goods are normal goods, attracting more consumption with higher incomes, or inferior goods, attracting less consumption with higher incomes. Most studies are constrained within countries and so continue to fail in terms of universality, so a comparable study across countries would be a better test of human needs.

Very few have done so but a recent study on 73 countries (Hertwich & Peters, 2009) managed to tease out the domestic share of consumption elasticities across eight final consumer products ranging from food, shelter and clothing to transport mobility, trade and services. They even included carbon elasticities. Although slightly range-restricted, data for each country was constructed using the Global Trade Analysis Project database (Dimaranan, 2006) and results reflected Maslow's needs hierarchy almost perfectly. In their study, Hertwich and Peters (2009) found the following expenditure elasticities in rank order: food (0.64), clothing (0.91), shelter (0.97), construction (0.99), trade (0.99), mobility (1.07), end-user products (1.09) and all services (1.16). Using exactly the same datasets across 71 of their countries matched to LE, split-half sampling was used and the frontier curve applied to the recombined splits to see if the same or similar rankings emerge using Spearman's Rank. The correlation between their results and their consumption elasticity data matched to the frontier of LE reached $r^2=0.72$ ($p<0.01$).

External Validity Using Allometry across Species

Using allometric regression to explore human behavioural (as opposed to metabolic) tendencies is still in its infancy. Outside of purely ecological studies (Calder, 1984; McMahon & Bonner, 1983; Niklas, 1983; Peter, 1983; Reiss, 1989), the work of Huxley (1972) inspired the first behavioural studies focused on the metabolism of sleep (see Campbell & Tobler, 1984; Tobler, 1995, 2005; Kryger et al., 1994; Mignot, 2008). Adapting similar methods, another early study then looked at differentials between male and female body sizes and heights to estimate human preferences for monogamy (see Diamond, 1991). The idea was later adapted to explore human social groupings, where functional sizes of 500 individuals made up of four subgroups were validated by comparing the sizes of primate troops against the sizes of human archaeological settlements, military organizations from Ancient Rome to the modern era and the functional size of administrative departments in government and industry (see Dunbar, 1993). As the literature grew, it encouraged serious attempts to start collating vast repositories of datasets across species, now managed by Boston University (2009). In this spirit, three brief exploratory tests of are outlined here to help show how allometry could be used to validate the present results across countries. Two look at how cross-sectional results using frontier regression might match results on the allometry of sleep and sexual maturity respectively, having first looked at the implications for life expectancy alone, as follows.

Figure 3-25 Allometric regression of body mass and lifespan across 592 species

Across species, there is a well-known correlation between lifespan and body mass in grams that tends towards having metabolic significance in terms of heart rate, brain size, fertility, age at sexual maturity, hours of sleep and amount of food required. Datasets taken from studies of sleep across 592 species are depicted (Figure 3-25). The exponential function based on the natural logarithm of body mass in grams is $y=2.2097e^{0.2187x}$ (r^2=0.69, p<0.0005). By inserting the average (developed world) human value (Walpole, et al., 2012) into the formula, it predicts a lifespan averaging 26 years (or 36 years at the frontier). This can be viewed as a very rough approximation of human tendencies outside of the ‘nurture’ of a more sophisticated social context. If this is accepted, then the emergent hierarchy can be split between zero intercepts below 26 years, representing ‘primary’ needs versus ‘secondary’ needs above 26 years (or else 36 years as the cut-off at the maximum). It would be expected that primary needs are more inelastic and probably hard-wired whereas secondary needs are more adaptive and probably learnt.

Now compare some allometry findings (He, 2008; Bogin, 1997) with available data across countries such as the number of hours spent sleeping and the legal age of consent (Robertson, 2013; CHNM, 2013). For sleep, the average across 18 OECD countries in 2006 (OECD, 2009) is 8.4±0.3 SD hours; the highest LE is achieved at 7.8 hours and the highest LS at 8 hours. Although the OECD sample is too range-restricted to properly test the frontiers, the result matches allometric data for sleep (He, 2008). In the case of reproductive age, there tends to be a growth-spurt post 14 years that precedes sexual maturity (Bogin, 1997) that can be compared with the minimum age of consent across 143 nations. This averages 15.4 years and ranges 12-21 years (mode 16 years), in both cases producing bell curves that maximise both LE and LS at age 16 years. Overall, these results tend to support the idea that results from different disciplines can be used to triangulate findings.

Although further work is much needed, the original OECD (2009) study found leisure averaged 24% of daily time favouring Nordic countries compared to Mexico, Japan and New Zealand, which enjoyed as little as 16% (OECD, 2009). This compares unfavourably with primate studies in the wild where 25-43% of time is spent in recreation, including resting and grooming by chimpanzees (Dunbar, 1993); suggesting ‘development’ might sometimes be counter-productive. The highest LE’s were achieved among countries with a split of 33% leisure against 65% paid or unpaid work, and this also matched LS. Unreported data for both metrics showed about 7% of time should be spent on sports and active recreation, with at least 1.5 hours spent eating.

Convergent Validity for Additional Food Metrics

The frontier is now replicated for an additional 20 food groups that have been collated by the UNFAO (2010) from 1962-2005. This dataset is especially useful in providing a test of how stable the extrapolated intercepts might be over time, mainly because the metrics are exactly replicated in both 1962 and 2005 (as opposed to the broader set of metrics given in Table 3-11 that were restricted to later decades). Using the same methods, the equivalent table is now replicated for these 20 new variables, including confidence intervals, and the results from 1962 are then correlated with the results from 2005 (Table 3-12).

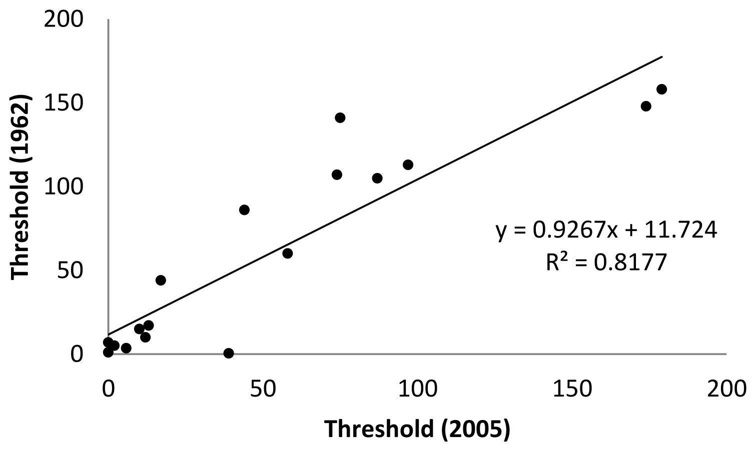
Curves were based on 1000 iterations of robust regression using the simplest and strongest curve shapes out of a selection of polynomial, quadratic, power, logarithmic and exponential formulae (1962 n=145; 2005 n=176). The two years were analysed blind to each other's results because the selection of curves still required some judgment in terms of balancing strength and simplicity.

The final results (see Figure 3-26) suggest that thresholds were correlated across time at the level of $r^2 = 0.65$ ($p<0.01$), rising to $r^2 = 0.82$ ($p<0.01$) when removing starchy roots and treenuts, which might suggest some product substitution over time (e.g. between meat and nut protein sources). When the same metrics are removed, the results also suggest that the use of the frontier to create a rank hierarchy might be reasonably robust, reaching $r^2 = 0.73$ ($p<0.01$), but this should be viewed with caution because of the overly influential effects of calories and proteins, as below.

Table 3-12 Results for 20 additional food variables (grams/cap) using non-transformed data and curves for 1962 and 2005 (UNFAO, 2010)

	1962		2005	
Subindices	**Intercept ±CI**	**Optimum**	**Intercept ±CI**	**Optimum**
Calories/cap	-17±29	2878	-11±32	3232
Proteins (g/cap)	17±6	87	25±9	105
Fats (g/cap)	53±22	97	43±6	113
Animal Fats	55**	13	74**	17
Cereals	38**	174	49**	148
Eggs	52±5	12	56±6	10
Seafood	54±6	17	64±7	44
Fruits	40±3	74	56±8	107
Meat	35**	44	70±3	86
Milk	46±6	179	57**	158
Offals	52**	5.8	70±2	3.6
Oilcrops	70±4	2.0	71±2	5.1
Pulses	76±6	0.0	79±5	6.9
Spices	69±3	0.0	80±1	1.1
Starchy Roots	56±4	91	48**	34
Sugar & Sweeteners	45±5	39	62±5	0.4
Treenuts	40±7	89	79±4	4.0
Vegetable Oils	67**	10	53±9	15
Vegetables	48**	75	72**	141
Alcohol	56±3	58	80±2	60

** Denoting ***non-significant*** curves at α=0.05



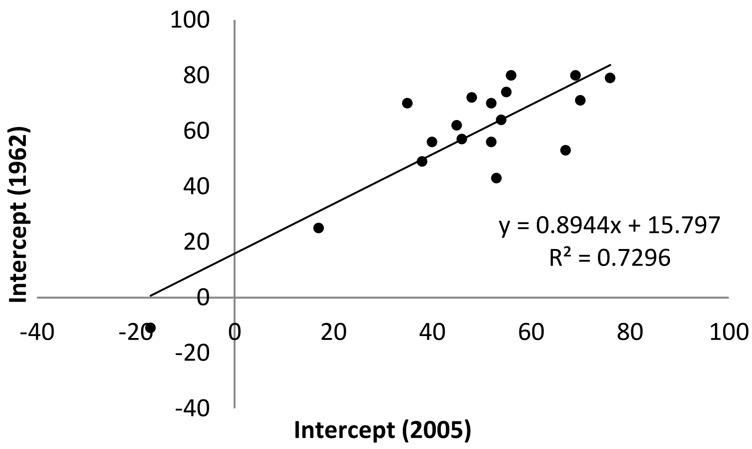


Figure 3-26 How the frontier method is replicated from 1962-2005 when used to estimate thresholds and intercepts for key UNFAO food metrics.

If the figures across time are averaged to build a healthy eating plate (HEP)[19] (excluding alcohol and the meta-data on calories, proteins and fats), food types ranked on the hierarchy create almost the same graphic (see Figure 3-27) as that now used and accepted worldwide by the Harvard School of Public Health (2008; Willett et al., 2005).

[19] The HEP now replaces the traditional 'food pyramid' because it is easier to communicate at the public level.

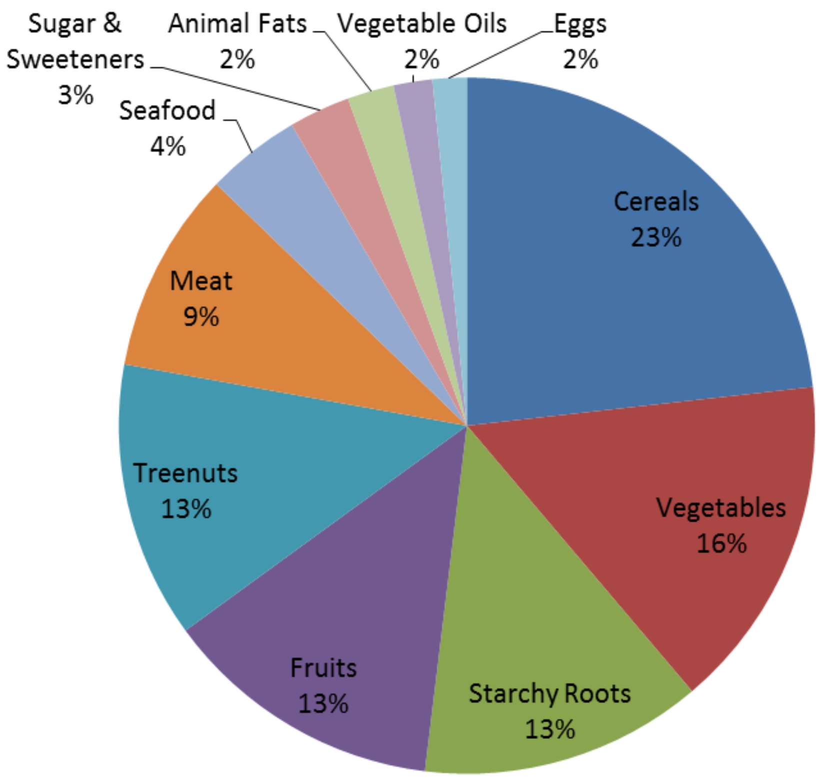


Figure 3-27 How the frontier method tends to match dietary recommendations (note that dairy was excluded as per the HEP but still tends to match cereals as a basic need)

3.5.6 Methods (Part II) – Frontier Studies of Sustainable Needs

The next section aims to explore the implications for key indices of relevance to sustainability such as absolute wealth, ecological footprint and carbon emissions.

The irony is that their existing inequitable distributions across countries create yet another methodological obstacle. Whenever a single index displays extreme inequity between developed and developing countries, fitting a curve to the raw frontier becomes impossible without some form of transformation. In each case, the great majority of nations rely on much smaller levels of 'consumption' with a minority pursuing comparatively vast levels of wealth.

When the raw data are graphed, it creates what looks like a broken stick, as seen previously with the Preston Curve and again shown in Figure 3-28. The frontier, when graphed, looks exactly the same – yet another broken stick.

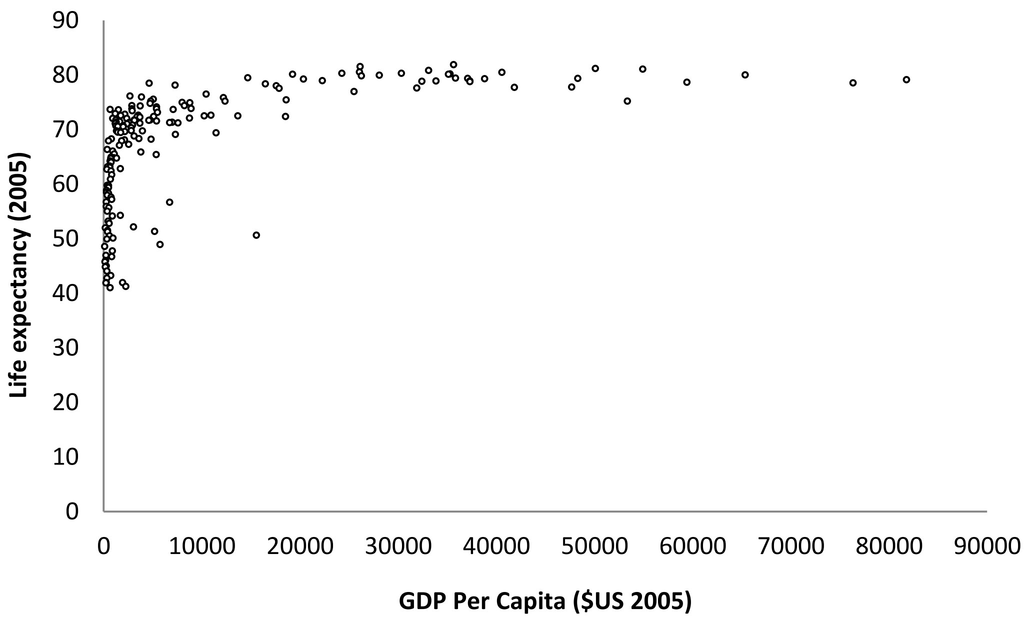


Figure 3-28 Standard plot for full dataset of 186 nations in 2005.

As discussed earlier, the raw data always obscures the more subtle gain that might be achieved among lower levels - countries ranging from Ethiopia and Eritrea, through Nepal and Vietnam, heading towards Japan and Switzerland via Costa Rica and Malta. To see and test the subtler effects of gain at all these levels usually requires a log transformation, as shown in Figure 3-27 for these and other frontier nations using the natural log. The natural log is the preferred transformation used by the UNHDI, and is the power to which every value must be raised to equal the irrational constant, e (approx. 2.718). In econometrics, the preference is usually log 10, but the actual choice makes little difference as all the raw data are converted by a constant in both cases. Both are applied to help 'linearise' a curve for graphical presentation or for use within statistical algorithms - as long as the result is reconverted back to its original form when interpolating optima.

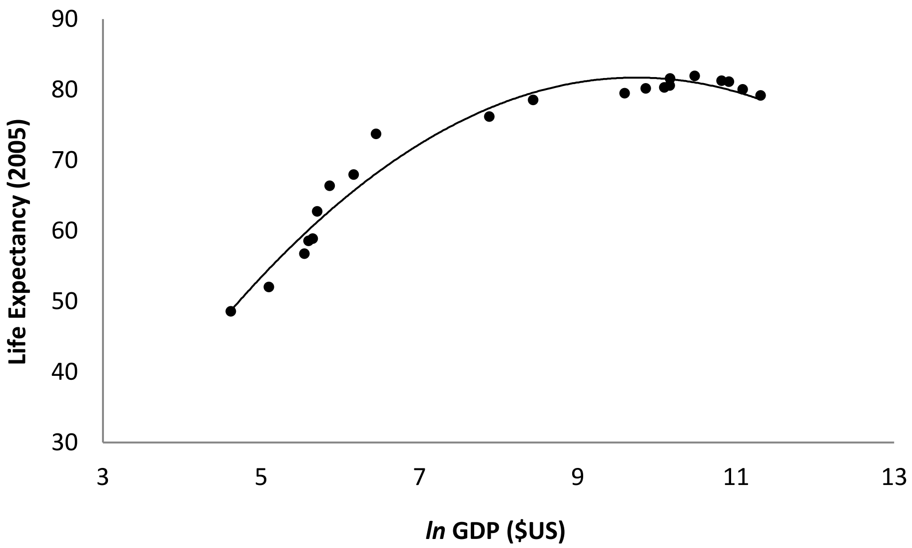


Figure 3-29 The frontier curve for the natural log of GDP (2005)

In the context of this work, however, trying to compare curves using transformation creates another unique problem. Although the transformation spotlights the gain at lower levels and still maintains the validity of the interpolated optimum, it still pollutes the extrapolated intercept, making it useless in the context of any hierarchy comparing indices. A variety of solutions were tested across many different metrics to see if the simplest methods could be retained but this was not possible.

These tests tried to restrict the methods across the whole hierarchy of human needs in such a way that they might be replicated with minimal statistical training and nothing more than a computer with MS Excel, an Internet connection, and without removing any outliers. This works for most of the results in this work but not so when it comes to balancing accuracy across different curves, time series and indices affected by profound inequity across countries in the first place – the broken stick – which can also change across time. Various permutations and combinations of simplified transformation, split-sampling, trimming and analyses above and below targets were tested across years. In the end, seeking to balance all issues whilst retaining the comparability of the extrapolated intercepts, the following analyses were forced to use GNU R in order to test and select competing curve shapes based on robust regression applied to the *non-transformed* frontiers. Outliers were still not removed but 1000 iterations were used to reduce their impact (as per robust regression requiring at least 10 iterations). F tests and confidence intervals (CIs) are now reported for the main metrics of interest to the HPI, HDI and MDGs. To begin, some context is given to all these subindices by using Veenhoven's HLY against a composite of EF and Carbon Emissions.

For this study, all data were taken from the UN Human Development Report (2013), accessible at http://hdrstats.undp.org/en/tables/ As usual all are cross-sectional and stylised curves that make a number of assumptions yet to be challenged. In the meantime, the graphics for each index display the actual raw data for recombined subsamples. Raw data are presented and tabled against each metric and statistics reported on the curve of best fit; insignificant curves were eliminated and the remaining metrics checked for split-sample and predictive reliability; curves without split-sample and predictive reliability were eliminated and the remaining metrics tested for extrapolated intercepts and interpolated optima in the case of LE and LS and minima in the case of CE and EF (plus confidence intervals). As an example, the target for maximising life expectancy would be zero adolescent fertility and the extrapolated carbon cost of achieving this would be as small as 3.5 carbon emissions per capita. This means that minimising adolescent fertility rate is good for both people and planet. Various data transformations are needed to equalise some complex curves and these are detailed for each formula using the simplest possible procedures.

3.5.7 Results (Part II) – Further Studies of Sustainable Needs

In 2011, the highest LE was again achieved by Japan at 83.4 years. Japan's LS was lower (as expected) at 6.1/10, making its HLE only 51 years at an estimated cost of 4.7 EF (2007) and 9.5 tonnes of CE per capita (2008). Denmark topped LS but achieved only 78.8 years of LE, rising to 61 years HLE at an estimated cost of 8.3 EF (2007) and 8.4 tonnes of CE per capita (2008). The highest HLE in 2011 was achieved by Canada at 62 years at an estimated cost of 7 EF (2007), quite low, but still requiring an unsustainable 16.4 tonnes of CE per capita (2008). Multiplying EF by CE creates a quick summary indicator similar in logic to HLE. When graphed, the two metrics create the picture depicted in Figure 3-30 (natural log is shown for the multiple of CE and EF to more easily view the curve).

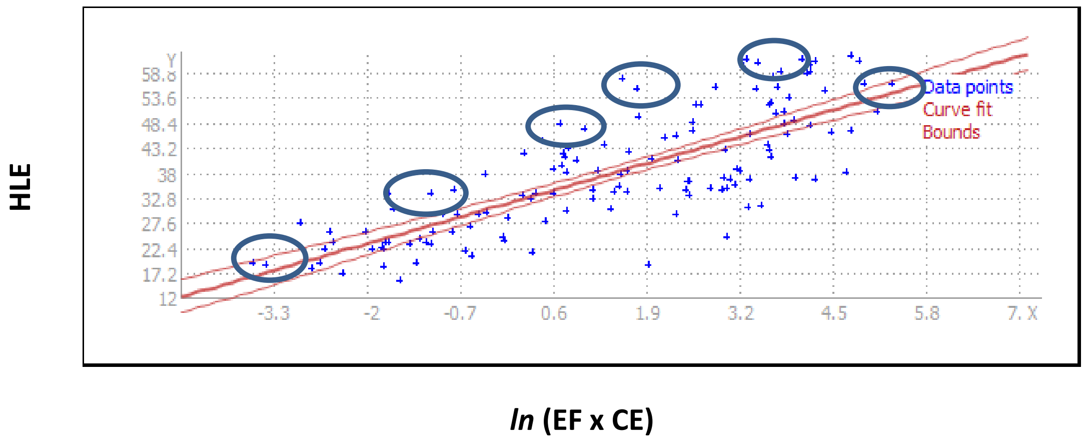


Figure 3-30 Human outputs (HLE) against the log of ecological impacts (EFxCE)

The red linear curve achieves $r^2=0.62$ (136 df on $p<0.001$) and HLE = 32 + [(4.3 x *ln* (EF x CE)] but suggests people need infinite levels of EF and CE to achieve infinite levels of LE and LS, on one level unsustainable and the other nonsensical. By contrast, the circled countries are those that achieve the very highest boundaries of human outcomes, creating a very different picture - a logistic curve that hits a ceiling of human outputs beyond which further ecological or carbon costs achieve virtually nothing. This curve is important because it provides a conceptual context for all of the following analyses by showing how human outputs like ‘health’ and ‘happiness’ – as well as their many inputs - might require less ‘cost’ in terms of EF and CE.

The easiest and most empirical way to capture these countries is to rank each of the 139 matched nations by their HLE and then take the next lowest and next highest levels of the CE/EF multiple (Figure 3-31). The curve suggests that the bounded logistic curve might even be replaced by a Gaussian function where countries like the United States and United Arab Emirates achieve less ‘health’ and ‘happiness’ than their more sustainable peers.

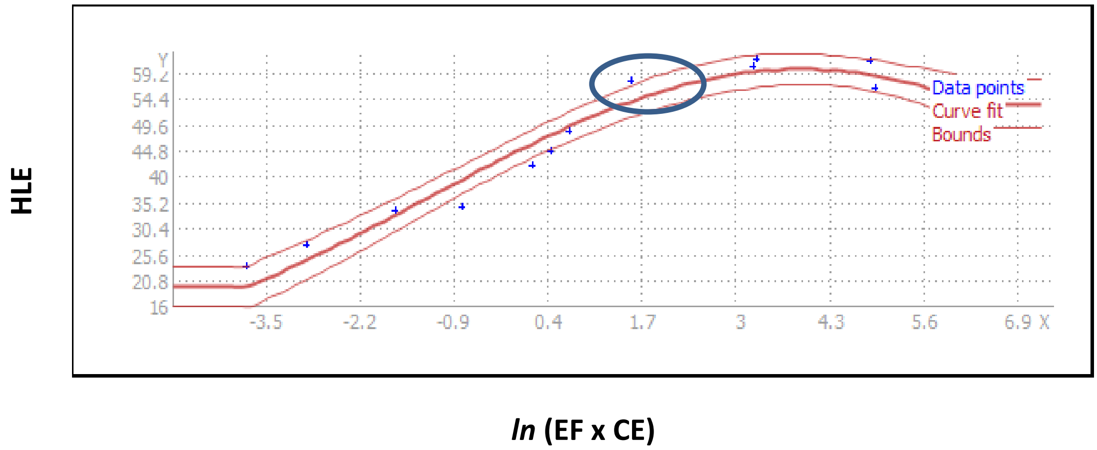


Figure 3-31 The frontier of HLE against the log of EFxCE

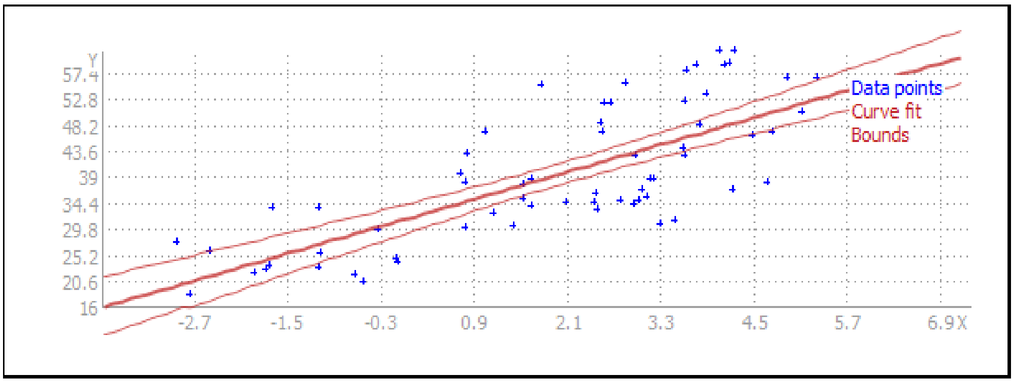
The circled nation, as always, is Costa Rica, achieving strong human outcomes at much lower ecological and carbon costs than, for example, the United States and United Arab Emirates. This ‘frontier’ curve is much stronger at r^2=0.95 because it covers only 11 df with the standard error minimised. But it still achieves significance at F=57 (p<0.001), even assuming a half normal distribution. The ‘frontier’ nations are shown in Table 3-13 with their original data ranked by CExEF to highlight their ‘sustainabilty’. Many of these countries later appear as consistently important when contextualised against different subindices and even different time periods across half a century.

Table 3-13 The main countries achieving the latest 'sustainability' frontier (2011)

Country	**LE**	**LS**	**EF**	**CE**	**HLE**	**CExEF**
Qatar	78.4	6.8	10.5	53.5	53.3	561.9
United Arab Emirates	76.5	7.1	10.7	34.6	54.3	369.3
United States	78.5	7.2	8	17.3	56.5	138.1
Australia	81.9	7.5	6.8	19	61.4	129.7
Canada	81	7.7	7	16.4	62.4	114.7
Switzerland	82.3	7.5	5	5.3	61.8	26.7
Israel	81.6	7.4	4.8	5.4	60.4	25.8
Costa Rica	79.3	7.3	2.7	1.8	57.9	4.7
El Salvador	72.2	6.7	2	1	48.4	2
Guatemala	71.2	6.3	1.8	0.9	44.8	1.6
Nicaragua	74	5.7	1.6	0.8	42.2	1.2
Myanmar	65.2	5.3	1.8	0.3	34.6	0.5
Bangladesh	68.9	4.9	0.6	0.3	33.8	0.2
Malawi	54.2	5.1	0.7	0.1	27.6	0.1
Afghanistan	48.7	4.8	0.6	0	23.4	0

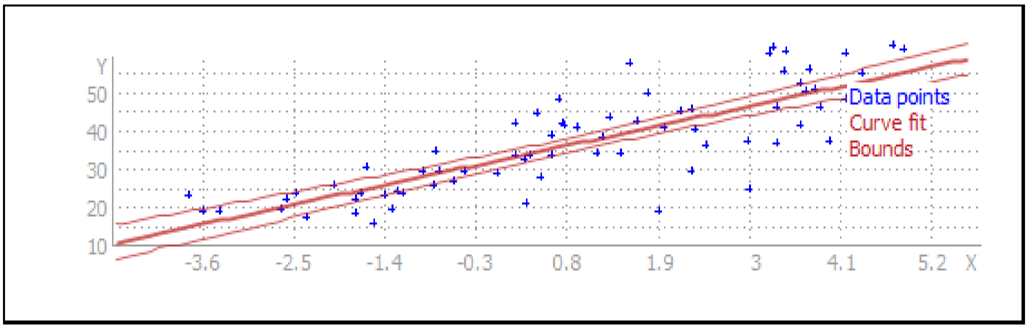
The foregoing curves can also be explored by splitting the full sample in two halves before conducting the frontier subsampling process, as shown in Figure 3-32.

A-K HLE



A-K *ln* (EF x CE)

L-Z HLE



L-Z *ln* (EF x CE)

Figure 3-32 Close results emerge for split-sampling of countries

The following analyses now examine other candidate ‘needs’ using the same datasets from latest Human Development Report (2013). The full sample and then frontier curves tend to show that the frontier is always more sustainable and less costly in terms of human effort. The main indices are relevant to the HPI, HDI and MDGs as well as issues of sustainability, gender and generational equity. The y-axis is always LE unless otherwise specified and then usually LS, whereas the x-axis is the raw, untransformed data for each metric. Many more indices are available but these preliminary analyses are restricted to the following by way of showing the way frontier sampling can be used:

1. The HDI itself
2. Carbon Emissions
3. Ecological Footprint
4. Mean Years of Schooling
5. Expected Years of Schooling
6. GDP per capita
7. GNI per capita
8. Income Ratio
9. Adolescent Fertility Rate
10. Youth Unemployment

Human Development Index (2011)

The HDI analysis is offered for context only as it suffers from singularity in the LE metric that artificially inflates the correlation. The HDI curves depicted in Figure 3-31 are all quadratic, positive and significant: r^2_{LE}=+0.81 (F=404 on 3,183 df, p<0.01), r^2_{LS}=+0.59 (F=104 on 3,147 df, p<0.01), r^2_{EF}=+0.69 (F=162 on 3,145 df, p<0.01), and r^2_{CE}=+0.32 (F=43 on 3,181 df, p<0.01). However, they suggest the highest possible HDI should maximise LE and LS at a cost of 8.8 EF and 17.2 CE, both unsustainable.

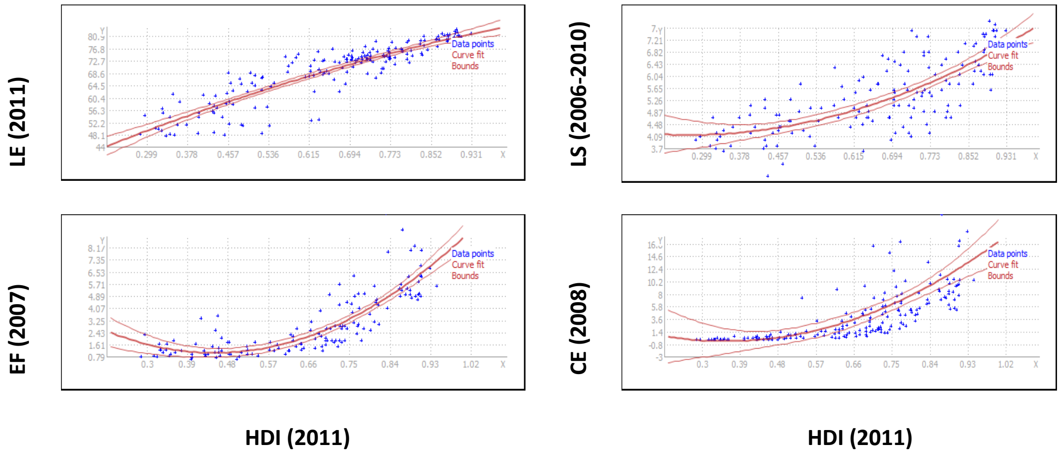


Figure 3-33 Raw curves for the HDI are essentially unsustainable

Based on the Meinshausen budget of 0.33 CE post 2050, the average global HDI in that year could fall to 0.47, the average LE falling to 60 years and LS falling to 4.4, both matching Ethiopia. At present, Norway tops the HDI at 0.94 but a closer look reveals that both LE and LS are maximised at the lower level of 0.90 by Japan and Denmark respectively, decreasing the apparent costs to 6.5 EF and 12.2 CE. To uncover these more nuanced relationships, the two main frontiers are shown in Figure 3-33, with the equivalent EF/CE costs interpolated from the curves above, where the HDI impact on EF (0.69) is strong ($p<0.01$).

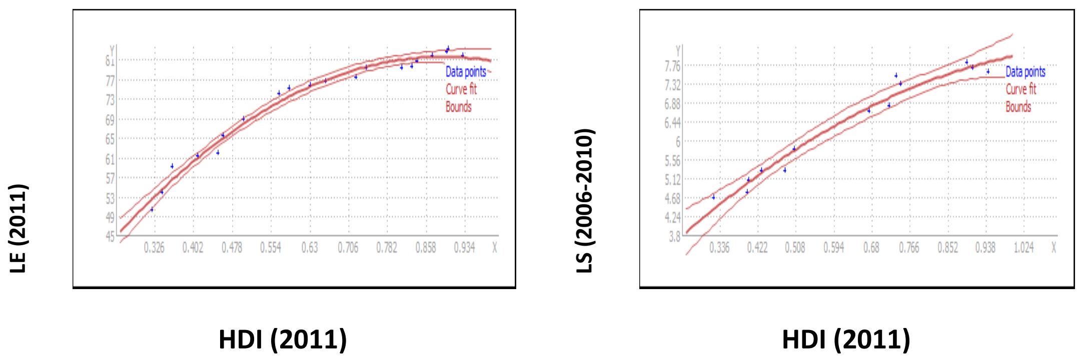


Figure 3-34 Frontier curves for the HDI suggest LE is more sustainable than LS

The actual target for maximising LE averages only 0.86 HDI at more sustainable costs whereas the LS tends towards the maximum HDI. The UK is an example of 0.86 HDI on 4.9 EF and 8.5 CE, achieving the same LE as Costa Rica (only 0.74 HDI on even lower levels of 2.7 EF and 1.8 CE), offering much more hope. To summarise (Table 3-14), the HDI is unsustainable as a linear metric.

Table 3-14 Supporting statistical analyses for the HDI (2011)

Frontier Curves	**LE Ceiling**	**LS Ceiling**
Best fit	Quadratic (2)	Quadratic (2)
R^2 (±SE)	0.98 (1.5)	0.97 (0.24)
F (df) Significance	441 (3,17) $p<0.01$	168 (3,10) $p<0.01$
Intercept (±CI)	11 (8.2)	1.3 (1.7)
HDI Target (Frontier)	0.86	1.00

Ecological Footprint and Carbon Emissions

What was found in the previous analysis for HDI is now replicated for the two main sustainability metrics so far available. For additional context, Table 3-15 shows how the same countries tend to emerge at the frontier of LE and LS for both EF and CE. Together, these results provide cross-validation of the broad trends.

Table 3-15 The main countries at the frontiers of CE and EF against LE and LS

Ecological Footprint (2007)	**EF**	**LE**	**LS**	**CE**
United Arab Emirates	10.7	76.5	7.1	34.6
Costa Rica	2.7	79.3	7.3	1.8
Japan	4.7	83.4	6.1	9.5
Denmark	8.3	78.8	7.8	8.4
Bangladesh	0.6	68.9	4.9	0.3
Carbon Emissions Per Capita (2008)	**CE**	**LE**	**LS**	**EF**
Qatar	53.5	78.4	6.8	10.5
Costa Rica	1.8	79.3	7.3	2.7
Japan	9.5	83.4	6.1	4.7
Denmark	8.4	78.8	7.8	8.3
Congo (Democratic Republic of the)	0.0	48.4	4.0	0.8

Again both the raw and frontier data points are displayed in Figure 3-35 because they demonstrate cross-validation of the frontiers for LE and LS, whilst demonstrating slightly different trends when comparing CE and EF.

Table 3-16 Supporting statistical analyses for EF (2007)

Frontier Curves	**LE Ceiling**	**LS Ceiling**
Best fit	Quadratic (2)	Quadratic (2)
R^2 (±SE)	0.70 (2.5)	0.72 (0.2)
F (df) Significance	15 (3, 13) NS	8 (3,6) NS
Intercept (±CI) at Zero EF for LE/LS	68.5 (3.9) years	2.3 (3.2)

Table 3-17 Supporting statistical analyses for CE (2008)

Frontier Curves	**LE Ceiling**	**LS Ceiling**
Best fit	Quadratic (2,√x)	Quadratic (2,√x)
R^2 (±SE)	0.77 (2.5)	0.77 (0.4)
F (df) Significance	27 (3, 10) NS	21 (3,10) NS
Intercept (±CI) at Zero CE for LE/LS	67.5 (3.4) years	5.1 (0.6)

What can be seen is that carbon emissions per capita (2008) show even more dramatic falls for human outcomes at higher levels, even when relying on the raw samples alone, and especially in the case of LE.

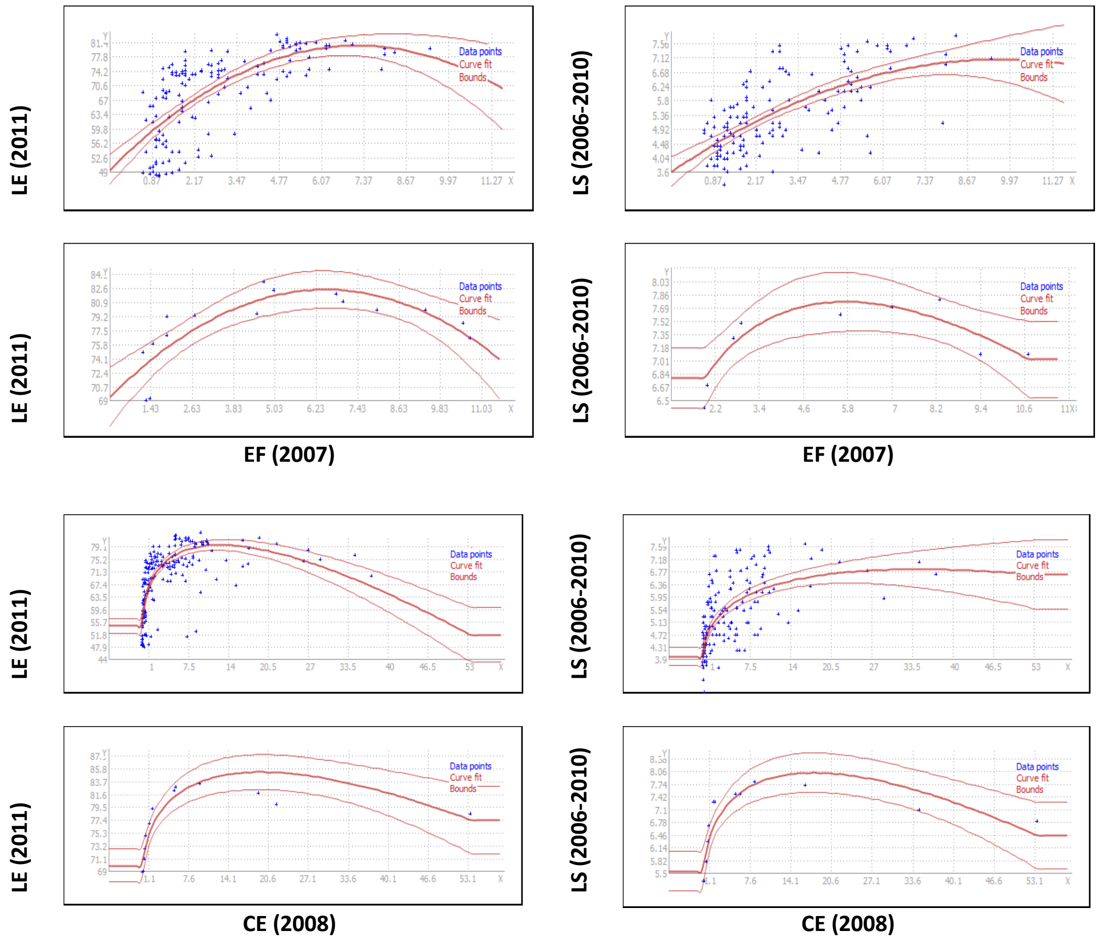


Figure 3-35 Frontier curves for EF and CE suggest both LE & LS could be sustainable

Moreover the extrapolated results across both EF and CE suggest that people could theoretically live to a solid LE of 68 years without either (disregarding omitted variables), but would be much less satisfied in the absence of EF versus CE by a factor of half (at least if the curves still hold across time). If the earlier studies are to be trusted, this puts these metrics in the same league of importance as freedom of the press, a rather shabby outcome in terms of actual need when viewed in the light of the potential impact across greater timescales affecting children.

Mean Years of Schooling (2011)

Mean Years of Schooling (MYS) is one of the main subindices used to calculate the HDI. Again, the full sample curves are positive and significant for MYS but LS and CE are linear rather than quadratic: r^2_{LE}=+0.54 (F=105 on 3, 183 df, p<0.01), r^2_{LS}=+0.38 (t=91 on 147 df, p<0.01), r^2_{EF}=+0.42 (F=56 on 3, 145 df, p<0.01), and r^2_{CE}=+0.32 (t=37 on 181 df, p<0.01). Norway tops the MYS at 12.6 years and the raw curves suggest this requires 9.9 tonnes per capita of CE and 6.2 EF, rising infinitely. These raw results suggest infinite numbers of formal schooling years will achieve infinite human outcomes at infinite ecological costs – all nonsensical.

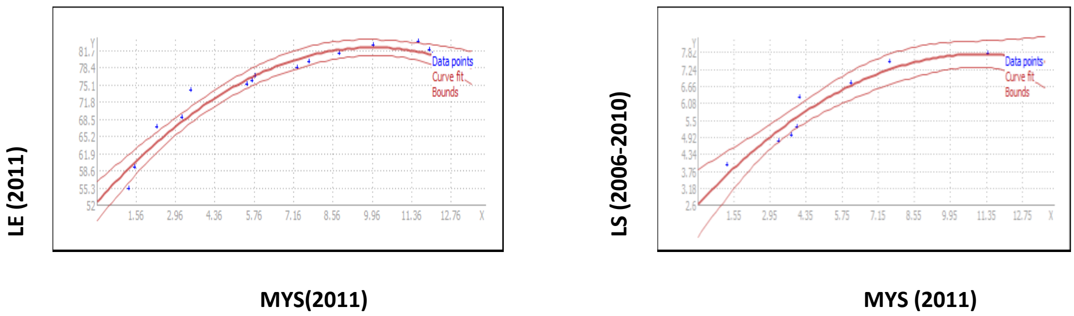


Figure 3-36 Frontier curves for Mean Years of Schooling (HDI, 2011)

By contrast, the frontier curves depicted in Figure 3-36 again provide more sensible and moderated estimates[20] averaging only 10.5 years of MYS to maximise LE and LS, especially interesting given recent trends showing higher levels of clinical depression with 'over-education' (see JRF, 2013; Rettner, 2013). The more moderated target also reduces ecological costs - 8.8 tonnes CE and 5.2 EF, which are both lower than the HDI costs reported in the previous section.

Table 3-18 Supporting statistical analyses for MYS (2011)

Frontier Curves	**LE Ceiling**	**LS Ceiling**
Best fit	Quadratic (2)	Quadratic (2)
R^2 (±SE)	0.94 (2.1)	0.94 (0.4)
F (df) Significance	112 (3,14) p<0.01	55 (3,7) p<0.01
Intercept (±CI)	52 (4.1)	2.5 (1.2)
MYS Target	10	11

Expected Years of Schooling (2011)

Since 2010, EYS has also been used to calculate the HDI, although the maximum is now capped at 18 years in its calculations, and usually averaged with MYS. Identical frontier curves emerge and, moreover, the extrapolated zero intercepts for both LE and LS for EYS almost exactly match the same levels of 'hierarchical' importance suggested by MYS, viz. about 45 years and 2.5/10 LS. Although it has long been recognised that education is key to various domains of life supporting wealth, health and wellbeing, the idea of being 'over-educated' is relatively new but clearly supported by these frontier analyses of both MYS and EYS.

[20] Note the t test is used for linear curves whereas F must be used for all others, especially frontiers using robust regression..

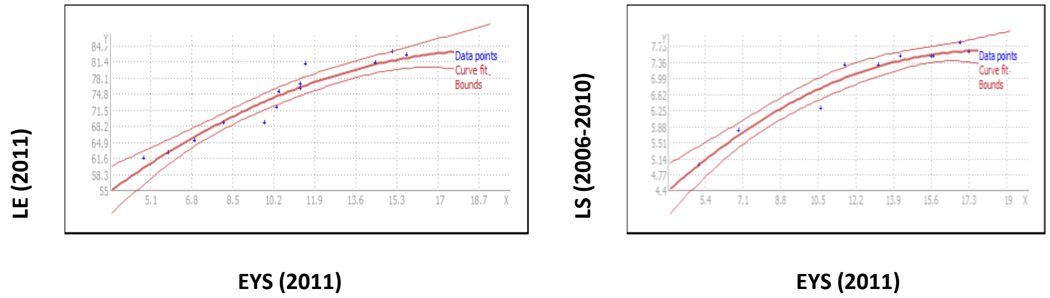


Figure 3-37 Frontier curves for Expected Years of Schooling (HDI, 2011)

Table 3-19 Supporting statistical analyses for EYS (2011)

Frontier Curves	**LE Ceiling**	**LS Ceiling**
Best fit	Quadratic (2)	Quadratic (2)
R^2 (±SE)	0.92 (2.2)	0.95
F (df) Significance	73 (3, 11) p>0.01	80 (3,8) p>0.01
Intercept (±CI) at Zero EYS for LE/LS	41.8 (10.4) years	2.6 (1.3)

Gross Domestic Product (2009) and Gross National Income Per Capita (2011)

Again GDP metrics are used to calculate and confirm the HDI. So both, like EYS and MYS, are used here to test the frontier, the main countries in Table 3-20 being almost identical as those listed earlier for EF and CE.

Table 3-20 The main frontier countries – not all – that form the 'wealth' curves

Gross Domestic Product Per Capita (2009)	**GDP**	**LE**	**LS**	**EF**	**CE**
Qatar	91379	78.4	6.8	10.5	53.5
Costa Rica	11106	79.3	7.3	2.7	1.8
Japan	32418	83.4	6.1	4.7	9.5
Denmark	37720	78.8	7.8	8.3	8.4
Congo (Democratic Republic of the)	319	48.4	4.0	0.8	0.0
Gross National Income Per Capita (2011)	**GNI**	**LE**	**LS**	**EF**	**CE**
Qatar	107,721	78.4	6.8	10.5	53.5
Costa Rica	10,497	79.3	7.3	2.7	1.8
Japan	32,295	83.4	6.1	4.7	9.5
Denmark	34,347	78.8	7.8	8.3	8.4
Liberia	265	56.8	4.2	1.3	0.1

Because GDP is a metric of keen importance to the UNHDI, both the full-sample and frontier curves are again displayed for LE and LS in Figure 3-38. The main statistical analyses, including CI's, are given for all these metrics in Table 3-21.

As with MYS and EYS, the extrapolated intercepts for both GDP and GNI again match at around 53 years for LE and 4.3 for LS.

Table 3-21 Supporting statistical analyses for GDP (2009) & GNI (2011)

Frontier Curve (GDP)	**LE Ceiling**	**LS Ceiling**
Best fit	Quadratic (2,√x)	Quadratic (2,√x)
R^2 (±SE)	0.82 (3.9)	0.94 (0.26)
F (df) Significance	38 (3,21) p<0.01	88 (3,13)
Intercept (±CI) at Zero GDP for LE/LS	59 (4.3) years	4.2 (0.42) points
GDP Targets Optimising LE/LS	$34,603 GDP	$35,788 GDP
Frontier Curve (GNI)	**LE Ceiling**	**LS Ceiling**
Best fit	Quadratic (2,√x)	Quadratic (2,√x)
R^2 (±SE)	0.82 (2.6)	0.91 (0.31)
F (df) Significance	29 (3, 16) p>0.01	75 (3,16) p>0.01
Intercept (±CI) at Zero GNI for LE/LS	65.5 (3.6) years	4.4 (0.41) points
GNI Targets Optimising LE/LS	$37,729 GNI	$39,020 GNI

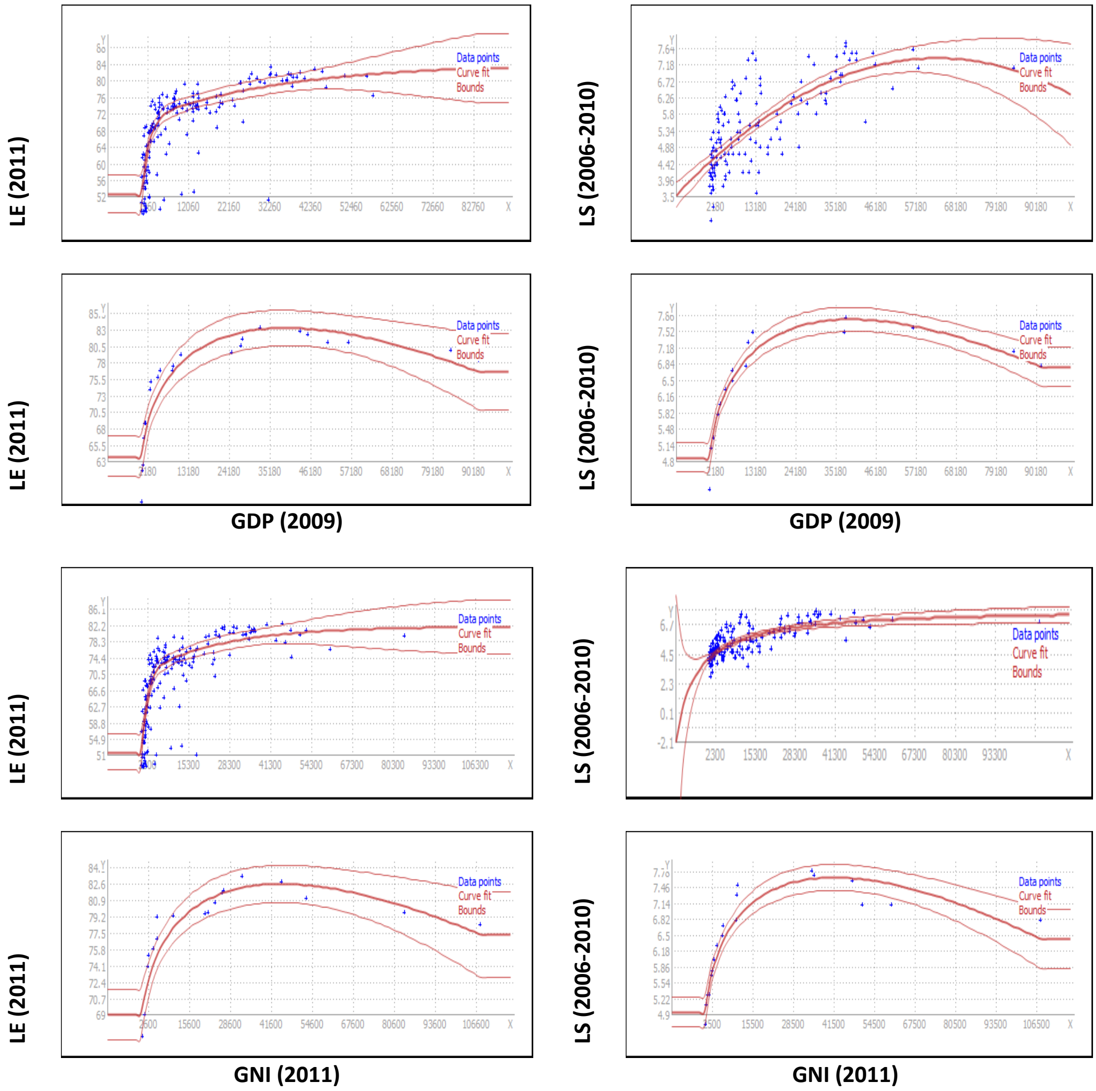


Figure 3-38 The curve shapes for GDP and GNI converge when using the frontier.

Adolescent Fertility Rate

Adolescent Fertility Rate (AFR) is measured per 1000 women aged 15-19 years and can be used to test the frontier against species allometry and legal age of consent, along with criminological data on child sexual abuse (UNESDA, 2012b). It is also a strong example of how moving towards healthier human outcomes need not impose major costs on the ecology. The main curve for LE is shown in Figure 3-3 using recombined data for 2000 and 2005.

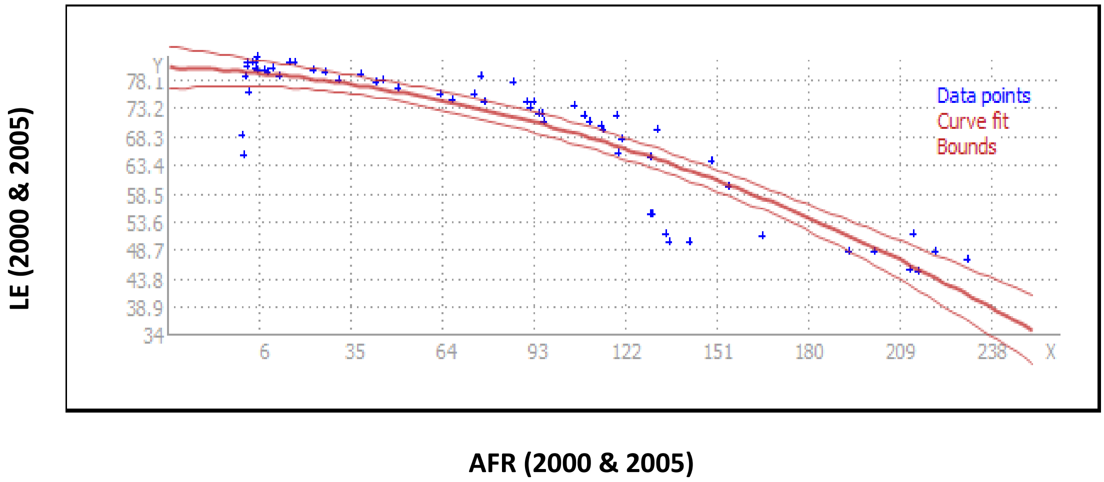


Figure 3-39 Despite some outliers (still included) adolescent fertility is 'unhealthy'

Life expectancy is maximised at 80 years at zero adolescent fertility (polynomial) and there is no significant carbon cost of zero AFR (see Table 3-22).

Table 3-22 Supporting results for AFR using recombined frontier subsamples

Statistics	**LE Ceiling**
Transformation Required	None
Simplest Best Fit Curve Type	Quadratic Polynomial
Statistics (r^2, SE, F, p)	r^2=0.82, SE=4.96, n=62, df=58, F=133, p<0.01
Formula	LE=-0.0005AFR^2-0.045AFR+79.7
Predictive Validity (2000)	r^2 = 0.83, n=30, p<0.01
Split Sample Reliability (2005)	r^2 = 0.98, n=14, p<0.01
Zero Intercept ±CI (%)	79.7 ± 2.5 (3.1%)
2000 Zero Intercept (±CI, %)	78.6 ± 3.8 (4.9%)
2005 Zero Intercept (±CI, %)	80.3 ± 3.7 (4.6%)
Target	0
Lowest CE at Target	3.5

Table 3-23 Frontier data for AFR on LE versus CE (2000 & 2005)

Life Expectancy								Carbon Emissions							
2000				2005				2000				2005			
A-K		L-Z		A-K		L-Z		A-K		L-Z		A-K		L-Z	
AFR	LE	AFR	LE	AFR	LE	AFR	LE	AFR	CE	AFR	CE	AFR	CE	AFR	CE
4.4	81.2	2.7	80.6	5.8	82.3	15.8	81.3	40.1	0	190.9	0	29	0	189.5	0
3	76.1	5.7	79.9	4	81	5.3	81.3	31.1	0.6	155.1	0.1	130.4	0.1	149.5	0.1
1.4	65.3	7.7	79.8	17.3	81	2.6	81.2	11.8	1	117	0.1	136.2	0.2	119.9	0.1
5	80	8.9	79.6	2.2	78.8	10.3	80	6.8	2.7	53.5	0.1	165.7	0.2	213.5	0.1
23.5	79.7	12.6	78.7	76.4	78.6	27.1	79.6			23.7	0.2	28.8	0.6	44.7	0.1
86.9	77.8	31.5	78.2	91.2	74.5	38.5	79.1			8.4	2.1	17.4	1.5	19.3	0.3
106.3	73.5	45.6	78.2	94.7	72.4	43.1	77.6			5.7	5.4	8.5	3.3	6.5	2.3
111	70.8	50.5	76.8	95.7	72.3	63.5	75.8			4.7	9.5	1	3.5	5.3	5.6
114.6	70.4	67.3	74.7	109.6	72	74.4	75.6							3.8	9
121.1	67.8	77.8	74.3	115.4	69.7	92.1	73.2								
130.5	64.7	93.2	74.2	1	68.4	119.4	72								
130.9	55.1	96.5	70.9	130.5	55.1	119.9	65.6								
136.2	50.3	132.6	69.7	134.9	51.5	149.5	64.1								
142.8	50.1	155.1	59.7	165.7	51.1	213.5	51.7								
193.4	48.5	220.6	48.3	201	48.6										
212.4	45.3			230.6	47										
215.1	45.2														

This is an important example as it shows how societies can engage with some issues to improve health and wellbeing without any direct cost in terms of CE or EF (as shown in Figure 3-40 and detailed in Table 3-23).

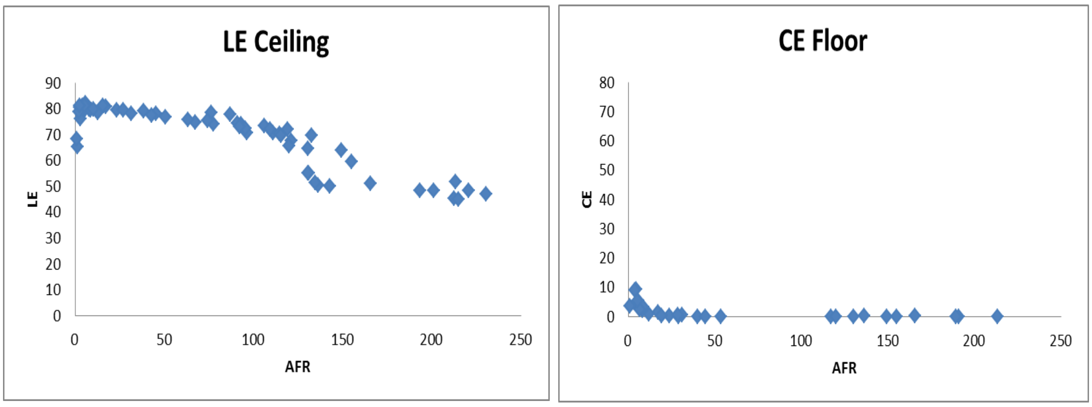


Figure 3-40 Results for AFR using recombined frontier subsamples across both years

Identical analyses were also made for the percentage of Youth Unemployment (15-24 years) to further contextualise how the frontier affects younger age groups. The result for YU suggested LE was maximised at 16% and extrapolated at 49±2 years (r^2=0.96, F=173, df=47, p<0.001). These results can be used to place issues like AFR and YU as more important than, for example, GDP.

3.5.8 Discussion - Summary of Study Four and its Implications

Based on the foregoing analyses, the data offers a series of measures that can be ranked on LE intercept as a proxy of need strength, possibly costed for CE and EF according to its target and also compared with SWB based on a nation's divergence from needs satisfaction. Costs should always be viewed against the strength of the curve used to generate them as many are significant but very weak, suggesting many other factors come into play. Yet still the main findings can be tabled to demonstrate where the greatest tensions and trade-offs will have to be met – in that quadrant that is 'good for people' but 'bad for planet', meaning, by implication, that they will have intergenerational trade-offs and unintended consequences. All of the metrics contextualised in Table 3-24 were significant for both LE and LS.

Table 3-24 How needs can be ranked by LE & LS using the frontier

Frontier Rankings			
Life Expectancy	**Intercept (r^2)**	**Life Satisfaction**	**Intercept (r^2)**
HDI	11±8 (+0.98)	**HDI**	1.3±1.7 (+0.97)
MYS	32±10 (+0.97)	**MYS**	2.0±1.9 (+0.92)
EYS	42±10 (+0.92)	**EYS**	2.6±1.3 (+0.95)
GDP	59±4.3 (+0.82)	**GDP**	4.2±0.42 (+0.94)
GNI	66±3.6 (+0.82)	**GNI**	4.4±0.41 (+0.91)

These preliminary studies begin to outline one way in which the frontier might help build some interesting and often stable curves that tend to suggest different human needs can be achieved at lower levels of ecological impact. They cautiously suggest the following final needs hierarchy (Table 3-25) when negative effects are scale reversed (LE_{MAX}-X_{INT}) and food subgroups are also included based on 2005 data (without non-significant terms).

Table 3-25 Emergent needs hierarchy rankings across all indices tested so far

Subindices	Zero Intercept	Subindices	Zero Intercept
Water Quality	-24	**Feeling Free**	37
Water Consumption	-20	**Fats (g/cap)**	43
Calories	-12	**Education Years**	46
Minimise Malnutrition	1	**Moderate income share of poorest 20% ≤ 6%**	46
Moderate Inflation	1	**Starchy roots**	48
Minimise Diabetes	2	**Youth Unemployment**	49
Minimise Heart Disease	2	**Cereals**	49
Minimise Cancer	2	**Vegetable Oils**	54
Minimise Homicide	2	**Fruits**	56
Minimise War Fatalities	2	**Eggs**	56
Minimise HIV AIDS	2	**Moderate Gini Coefficient**	57
Minimise Adolescent Fertility Rate	3	**GDP Per Capita**	59
Minimise Tobacco (COPD)	3	**Sugar**	62
Minimise Infant Mortality	3	**Seafood**	65
Minimise Malaria	4	**GNI Per Capita**	66
Moderate income share of richest 20% ≤30%	5	**Carbon Emissions Per Capita**	68
UNHDR	11	**Ecological Footprint**	68
HALE	12	**Press Freedom**	69
Feeling Safe	15	**Offals**	70
Safe from Assault	15	**Meat**	70
Socially Supported	22	**Oil Crops**	71
Gender Equity	23	**Recent Inflation (2006-07)**	76
Proteins (g/cap)	25	**Pulses**	79
Income Equity (Gini)	27	**Treenuts**	79
Life Satisfaction	32	**Spices**	80
Feeling Respected	34	**Alcohol**	80

Although the broad trend is promising, not all of these rankings make sense. For example, the placement of fats, fruits and cereals in particular seem to be further down the ranking than would be expected based on prevailing dietary recommendations. What is interesting, however, is the way in which the hierarchy appears to be far more dynamic than proposed by many need theorists, especially in the way physiological and socioeconomic factors diverge across the rankings in a way that suggests no fixed distinction between primary and secondary needs based on physiology alone. Note also that key sustainability metrics tend to cluster around economic measures like GDP and GNI, as would be expected given their strong associations outside of this study.

Further studies also need to find out whether country convergence across the full range of stable optima for LE might tend to predict LS across countries as a more global measure of a nation's dissonance from needs satisfaction. This is a corollary hypothesis that is not fully covered by this work as yet because it requires further thinking about how metrics should be weighted above and below thresholds based on changing β slopes across the curves. This was briefly touched but the main issue is how LE relates to carbon emissions at the aggregate, which is the focus of the next study. This study is more formalised and robust, providing a benchmark for how the foregoing analyses should be treated in the future. Indeed, the main findings just presented should be further tested and validated, perhaps using factor analysis, before moving onto studying interaction effects using multiple regressions. Such studies are beyond the limits of the current work but must be completed, especially if the emergent hierarchy is to be trusted and applied to policy.

3.6 STUDY FIVE: TESTING CONTRACTION AND CONVERGENCE (C&C)

3.6.1 Abstract – The C&C Target

This study now uses the frontier method to explore the broader implications of climate change for human life expectancy, without regard for the many human needs that ultimately influence it. The importance of this study is that it offers the first human-centred target for Contraction & Convergence (C&C). As yet, there is no target for carbon emissions (CE) empirically established for human development. Respected economists have made educated guesses ranging 2-6 tonnes per capita (Stern, 2008; Ekins, Meyer & Shmidt-Bleek, 2009; Hansen, 2009; Shmidt-Bleek, 2009; Garnaut, 2011), but the issue spans climate science, public health, economic development and human ethics under the umbrella of global warming (e.g. Stern, 2006; Frumkin, McMichael & Hess, 2008). This study bypasses Ecological Footprint entirely by using Carbon Emissions instead, which directly places the work within the most recent climate change literature whilst also extending the data back to 1960.

3.6.2 Introduction – The C&C Target

As discussed in Chapter 1, delayed international action makes the rate of change in the future much steeper and harder to adapt to for both advanced and developing economies. This is because we are close to reaching the precipice of exceeding the 2°C limit without allowing the bulk of the world's developing nations to reach parity with a minority of wealthier, carbon-intensive economies. Moreover, because global emissions (IEA, 2010) and population (UN, 2011) are both steadily growing, the yearly amount of allowable emissions compound the ethical problems yet to be confronted.

One principle that tries to balance the dilemma is Contraction and Convergence (C&C). Although the implementation rate was a stumbling block at Copenhagen and Durban (Meyer & O'Connell, 2010), C&C begins to provide a fair platform for multilateral negotiations. This principle (see Global Commons Institute, 1996) first assumes that global CE will negatively impact human and planetary health in the longer term and so must be 'contracted' if we care about the likely impact on younger generations (e.g. Sherwood & Huber, 2010).

If it were not a normal public good, this would not present a problem, but because CE is tied to economic development (York, Rosa & Dietz, 2003; Rosa, York & Dietz, 2004), it means any pursuit of global contraction could result in recession or depression among advanced economies. This was suggested when the Global Financial Crisis (GFC) reduced world emissions (see Jotzo et al., 2012). Although there is resistance to the idea of contraction, whether by a Pigovian tax or a trading scheme (Garnaut, 2011), climate science suggests we have no choice. The alternative could be resource and energy wars and further destruction of ecologies subserving human survival (e.g. Parry et al., 2004; Thomas et al., 2004; Malcolm et al., 2006).

The second element of C&C is 'convergence', where every nation must be granted an equal portion of emissions per capita under a constrained global budget (GCI, 1996). This applies the same ethical principle of unity across nations as contraction applies across generations (see Stern, 2006; Nordhaus, 2007). Together, the two principles of C&C try to balance the carbon budget across every living person, both now and in the future.

Having defined C&C, we can now look at the implications of the climate science. Hansen's tighter budget of 750Gt would mean around 450Gt will be subtracted from the cumulative budget by mid-2013, leaving 300Gt remaining. Given a global population of 6.8 billion in 2011, that leaves a C&C target of only about 1.3 tonnes per capita for every year leading up to 2050.

The more optimistic Meinshausen budget allows 1.8 tonnes for a population heading towards 9.2 billion by 2050 (UN, 2011), roughly matching Stern's original suggestion of 2 tonnes per capita in 2008 (Stern, 2008). The problem is that both are a much greater challenge to advanced economies than the global average of 6 tonnes per capita. They also suggest the current rate of technological development aimed at decoupling growth from CE (see Steinberger et al., 2012) will not avoid the 2°C limit.

It appears widespread and dramatic mitigation and adaptation is inevitable, that advanced economies must contract their emissions and developing countries should not pursue parity at the upper levels. The current study explores what these C&C targets might mean for human LE, hoping there might be a more optimistic outcome. If stable and moderate, this limit might offer a more optimistic C&C target up to 2050. It uses two national indicator variables that have no mechanistic basis for being causally linked but serve as proxies of:

1. Human health as an 'output' variable (LE)
2. Ecological impact as an 'input' variable (CE)

Even when seeking an instrumental variable like the recent volcanic eruption in Iceland, there is no evidence that CE *per se* has any direct impact on localised LE (Carlsen *et al.*, 2012). At the aggregate level, both are merely proxy indicators of human and planetary health that treat the social unit, here the nation state, as a big 'black box' in which thousands of omitted variables operate in complex pathways spanning wealth, equity, growth, production, distribution and consumption of everything from food and medicine to debt and education.

3.6.3 Methods – The C&C Target

The World Bank provides data from 1960-2007 for 205 countries. For CE, 195 countries are included, estimated from the burning of fossil fuels plus the manufacture of cement, derived from the United States Carbon Dioxide Information Analysis Center (2009). They include solid, liquid, gas fuels and gas flaring but not equivalent emissions (CO_2e). Datasets are matched against one another in each year, eliminating missing cells and leaving a total sample of up to 192 countries from 1960-2007.

As usual, data are rounded to the third decimal place and the frontier is tested against split-sampling reliability, predictive validity and test-retest stability that interpolate optimal LE against CE per capita (CE/cap) stretching back to 1960. As one of the more important studies in this work, F tests are reported for 1000 simulations of cubic versus quadratic curves, with confidence intervals for the interpolated optima, using GNU R.

3.6.4 Results – The C&C Target

Raw data for 2007 are shown below in Figure 3-42. Again, by converting input to the natural logarithm (*ln*) of the CE term, the curve is more easily viewed as in Figure 3-43. For 2007, LE increases from Zimbabwe up to a threshold, via Costa Rica, declining from Japan down to Qatar, via Australia.

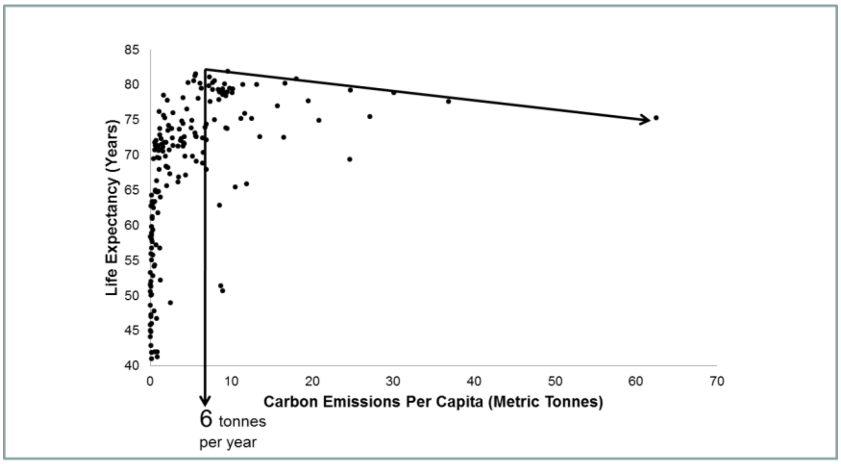


Figure 3-41 The relationship between LE and CE across 185 countries in 2007

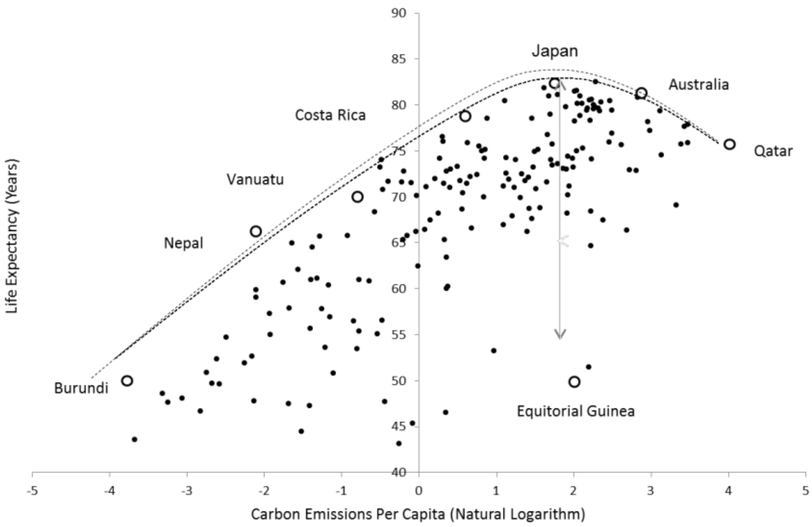


Figure 3-42 The relationship between LE and lnCE highlighting the pure frontier

If the full sample rather than the frontier is used, the optimum LE for 2007 is calculated at only 77 years on 19 tonnes whereas the frontier more accurately predicts the observed LE maximum of Japan's 83 years on 10 tonnes. Because the curve from the average fails to match the observed optima for LE, it demonstrates distortions in the curve, now eliminated using the frontier. For both 1960 and 2007, the frontier captures the highest LE's achieved across the whole datasets. The optimal LE calculated by the frontier curve for 1960 is 73 years on 7 tonnes CE/cap, much closer to the observed maximum of 74 years for Norway. Likewise, the optimal LE predicted by the 2007 curve is 82 years on 9 CE/cap, again much closer.

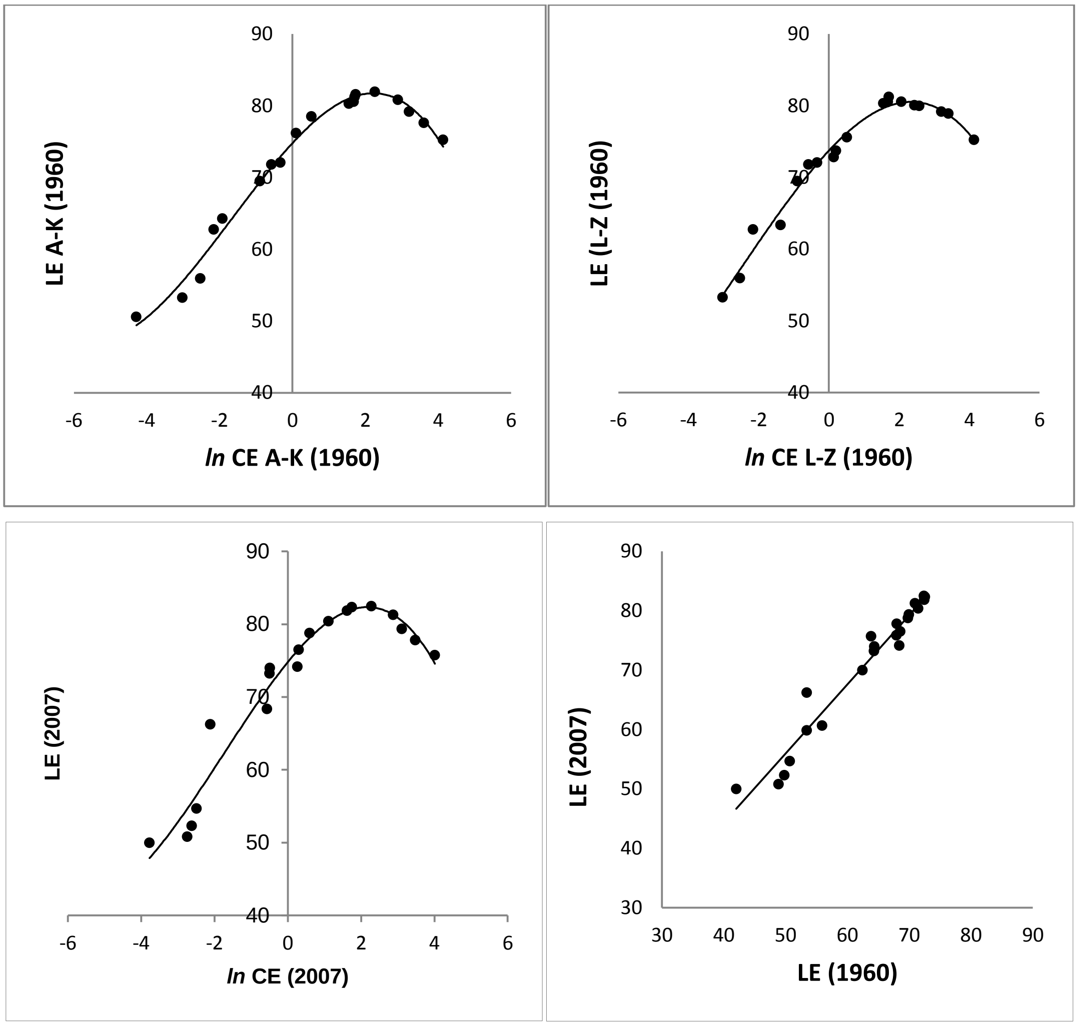


Figure 3-43 Stability of the carbon emission (CE) curves that maximise LE split in 1960, replicated and then used to predict LE in 2007

As an example, the split-sample reliability for the frontier curve in 1960 is given in Figure 3-44. For 1960, the split-sample reliability was r^2=0.96 (p<0.01) and this was sustained in 2007 at r^2=0.92 (p<0.01).

More importantly, using the frontier formula in 1960 to predict the observed results in 2007 demonstrates an equally powerful predictive validity of r^2=0.95 (p<0.01). The pure, not recombined, frontier subsamples are enough to confirm stability, which is now confirmed among key decadal years from 1960 until 2005 (Figure 3-45). Once again, all years display an identical curve despite background increases in life expectancy.

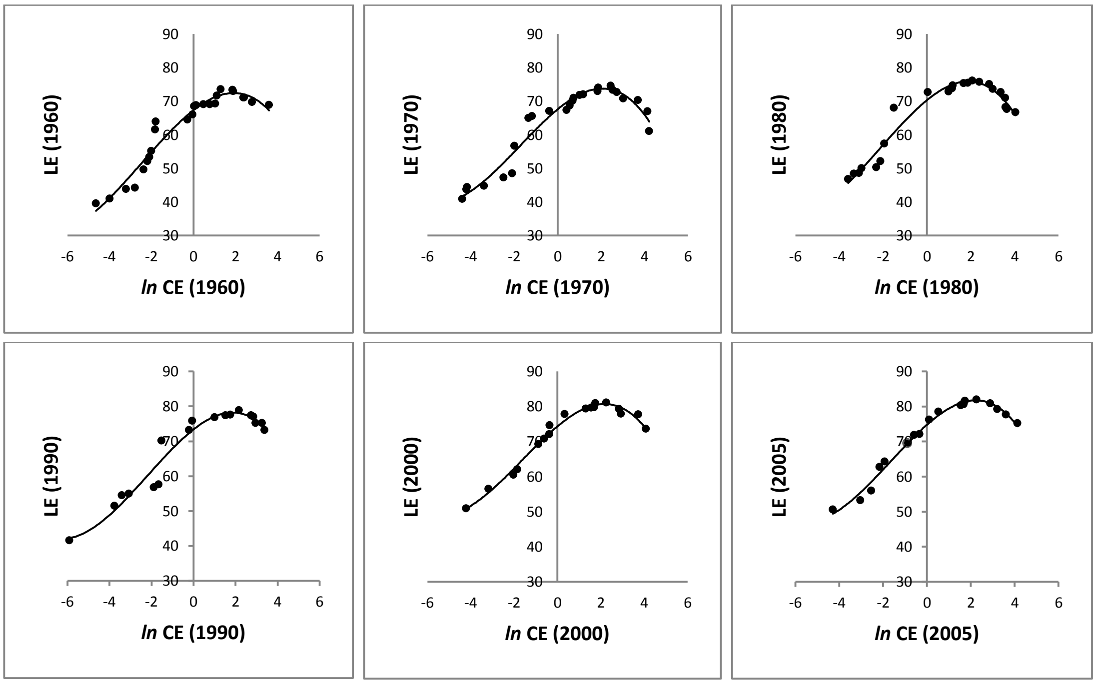


Figure 3-44 Stability of the carbon curve across decades from 1960-2005

These curves were all produced using publicly available data and standard software for the sake of empirical replicability. The curves are now tested in every available year using 1000 GNU-R simulations for robust cubic and quadratic curves.

The third order quadratic formula is supported both within and across years ($p<0.001$). Results are tabulated below with F tests and the corresponding 95% Confidence Intervals (CIs) of the interpolated optima. As can be traced from Table 3-26, the mean of the predicted optima across all years is 6.6 CE/cap.

Whereas LE steadily increases across time at a rate of three months per year ($r^2=0.99$, $p<0.005$), the CE that maximise LE does not significantly change. Although pure frontier regression is notoriously vulnerable to outliers, the consistency across time is powerfully supported outside of 1990, 1992 and 1994, where Namibia was an outlier based on its divergence from the frontier but not removed.

As with the calorie data, the LE target is stable despite vast changes in CE at the maximum (Figure 3-46).

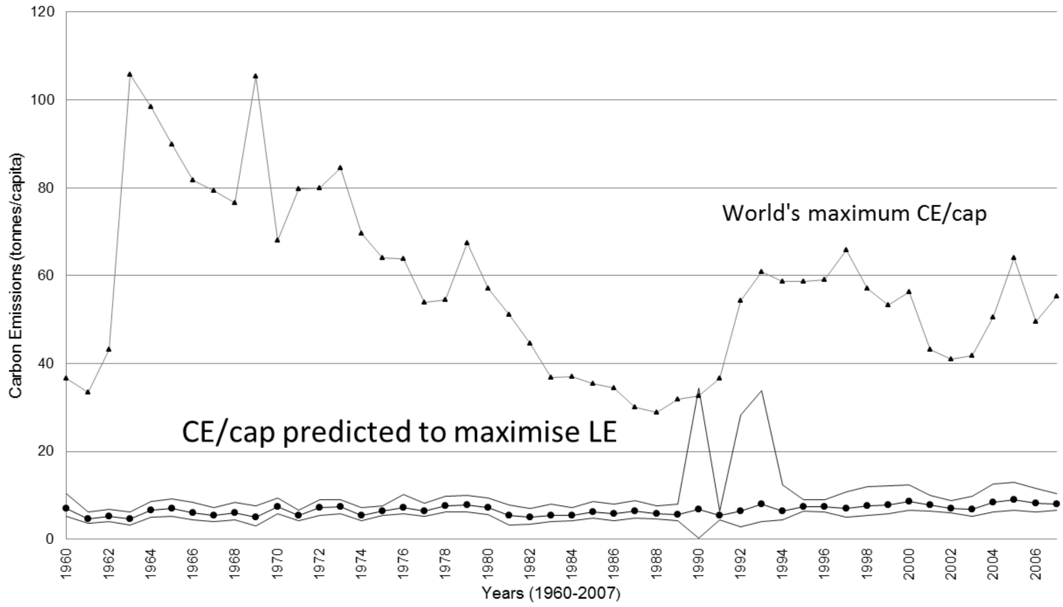


Figure 3-45 CE/cap that optimises LE is always lower than maximum CE/cap

Table 3-26 Testing quadratic curve fitting of the frontier plus stability across time

Year	**Frontier Curve Function**				**r^2**	**F**	**P**	**LE_{max}**	**CE_{max}**	**Confidence Intervals**	
	B Zero	***B 1***	***B 2***	***B 3***						***0.025***	***0.975***
1960	67.1	11.9	-4.9	-1.7	1.0	219	0.0	72.6	6.9	5.3	10.4
1961	68.0	11.6	-6.2	-2.7	0.9	104	0.0	72.2	4.5	3.6	6.1
1962	68.8	11.2	-5.8	-1.9	1.0	120	0.0	73.1	5.1	4.0	6.8
1963	69.0	9.0	-5.8	-1.0	0.9	90	0.0	72.1	4.5	3.2	6.1
1964	67.4	12.2	-4.8	-2.2	0.9	74	0.0	73.0	6.6	5.0	8.6
1965	67.7	12.5	-4.8	-2.1	0.9	83	0.0	73.6	7.0	5.2	9.1
1966	68.6	10.4	-4.9	-1.6	0.9	54	0.0	73.0	5.9	4.3	8.4
1967	69.4	9.7	-5.0	-1.5	0.9	64	0.0	73.2	5.5	4.1	7.2
1968	68.5	11.8	-5.3	-2.0	0.9	49	0.0	73.5	5.9	4.3	8.4
1969	69.8	8.4	-5.1	-0.9	0.9	35	0.0	72.9	5.0	3.1	7.7
1970	68.1	12.1	-4.7	-1.8	1.0	121	0.0	73.9	7.3	5.8	9.3
1971	69.9	8.2	-4.8	-0.8	1.0	211	0.0	73.1	5.4	4.2	6.7
1972	69.2	9.6	-3.8	-1.4	0.9	91	0.0	73.7	7.1	5.4	8.9
1973	69.2	9.9	-4.1	-1.2	1.0	139	0.0	73.9	7.3	5.8	9.0
1974	71.0	7.8	-4.8	-0.5	1.0	230	0.0	73.9	5.4	4.2	7.2
1975	70.3	11.1	-5.0	-1.6	1.0	221	0.0	75.2	6.4	5.4	7.6
1976	69.2	12.1	-4.5	-1.9	1.0	118	0.0	75.0	7.3	5.7	10.2
1977	70.2	10.4	-5.3	-0.9	1.0	276	0.0	74.7	6.5	5.3	8.1
1978	69.8	11.3	-4.9	-1.2	1.0	250	0.0	75.2	7.5	6.2	9.8
1979	69.7	12.4	-4.7	-1.7	1.0	225	0.0	75.8	7.7	6.2	10.0
1980	69.5	13.5	-4.9	-2.3	1.0	115	0.0	76.1	7.2	5.6	9.4
1981	72.3	10.4	-5.8	-1.3	0.9	55	0.0	76.3	5.3	3.2	7.7
1982	72.9	10.5	-6.0	-1.5	0.9	57	0.0	76.9	5.0	3.5	7.1
1983	71.7	12.2	-5.8	-2.2	0.9	71	0.0	76.6	5.5	4.0	8.1
1984	72.3	12.7	-6.0	-2.4	0.9	76	0.0	77.4	5.4	4.1	7.2
1985	71.9	14.8	-5.5	-3.2	0.9	83	0.0	78.5	6.2	4.8	8.6
1986	72.6	11.6	-5.3	-2.0	0.9	80	0.0	77.4	5.8	4.3	8.0
1987	72.6	9.6	-5.0	-0.8	1.0	157	0.0	76.6	6.3	4.8	8.8
1988	73.3	10.3	-4.6	-2.0	1.0	119	0.0	77.7	5.7	4.6	7.5
1989	73.7	10.3	-4.8	-1.8	1.0	70	0.0	78.0	5.7	4.2	7.9
1990	75.4	3.1	-2.1	0.2	0.9	28	0.0	76.6	6.8	0.3	34.4
1991	75.4	8.4	-3.4	-2.2	1.0	56	0.0	78.9	5.4	4.4	6.5
1992	74.8	5.2	-2.8	-0.4	0.9	37	0.0	77.0	6.3	2.8	28.2
1993	73.8	5.7	-2.6	-0.4	0.9	34	0.0	76.5	8.0	4.0	33.8
1994	75.0	7.4	-3.6	-0.8	1.0	65	0.0	78.2	6.5	4.4	12.3
1995	73.7	11.1	-4.3	-1.7	1.0	245	0.0	79.1	7.3	6.3	9.1
1996	73.6	13.8	-4.6	-2.6	1.0	154	0.0	80.4	7.4	6.3	8.9
1997	74.9	11.3	-4.7	-1.6	0.9	48	0.0	80.1	7.0	5.1	10.7
1998	74.2	13.2	-4.8	-2.1	0.9	53	0.0	80.7	7.5	5.4	11.9
1999	73.5	14.9	-4.8	-2.7	0.9	66	0.0	81.1	7.8	5.9	12.2
2000	72.9	15.8	-4.8	-2.7	0.9	76	0.0	81.4	8.5	6.6	12.3
2001	73.9	14.9	-4.8	-2.7	1.0	131	0.0	81.4	7.7	6.5	10.0
2002	74.8	13.8	-5.5	-2.2	1.0	237	0.0	81.3	6.9	6.0	8.7
2003	75.9	11.4	-6.0	-0.7	1.0	242	0.0	80.8	6.7	5.2	9.8
2004	74.3	14.4	-5.0	-2.0	1.0	103	0.0	81.7	8.4	6.2	12.6
2005	75.0	12.9	-4.8	-1.4	1.0	111	0.0	81.7	8.9	6.6	12.9
2006	75.1	13.7	-5.2	-1.7	1.0	144	0.0	82.0	8.2	6.2	11.6
2007	75.2	13.9	-5.0	-1.9	1.0	147	0.0	82.2	8.1	6.6	10.4
Mean	71.8	11.1	-4.8	-1.7	0.94			76.8	6.59	4.88	10.46
SD	2.65	2.61	0.85	0.72	0.02			3.17	1.11	1.25	5.97

From 1960 until 2007, 88 countries achieve the frontier. Costa Rica retains its position at lower levels of CE for an astonishing 41 years. Among lower levels of CE, Vietnam, Cuba and Malta do extremely well but China and India fail to reach the frontier in any given year. By contrast, countries that reach the frontier at higher levels of CE include Canada and Hong Kong (39 years), the United States (34 years), Japan (33) and Luxembourg (28). Countries like Qatar, Kuwait, United Arab Emirates and Bahrain achieve the frontier for many years but with low LE and much higher CE. Australia reaches the frontier across 18 years but always emits more than the predicted optimum.

3.6.5 Discussion – The C&C Target

This work again suggests a stable curve that challenges the idea that greater carbonisation is needed for raising or sustaining average aggregate longevity. It suggests better health outcomes might be achieved by countries where CE is much lower than pursued by many advanced economies. Confidence intervals for 6.6 CE/cap that maximise LE are tight for all except three years in the 1990s where outliers may have distorted the curve. But because this trend is replicable since 1960, it might also apply towards 2050, softened by background increases in LE that might add up to 9 years in 2050 based on the trend since 1960. On top of this, many more countries might decouple growth from carbonised energy sources via technological innovation, greater efficiencies, renewable energy sources and lower consumption. This is already being led by Northern European and developing countries like China.

When using the frontier rather than the average, there is also a consistent loss of LE at higher emissions in each year. Although this might be challenged by planned analyses, past studies confirm this trend (Bloomberg & Aggarwala, 2008) whereas others hint that such an effect might emerge from over-consumption at higher levels of CE (Edwards &Roberts, 2010).

On the production side, there is already much evidence that industrialisation is antithetical to human wellbeing and family cohesion; rates of stress, depression, accidents, suicide and drug addiction (e.g. Max-Neef, 1995; Zolatas, 1981; Eckersley, 2006; Hamilton & Denniss, 2005; Jackson, 2009; Bradshaw *et al.*, 2007; Stevenson & Wolfers, 2009). This idea is not new; it has a theoretical heritage spanning human development (Sen, 1999), synthesis (Eckersley, 2005), the economic health gradient (Lopez et al., 2006) and the health co-benefits of climate change mitigation (Frumkin, McMichael & Hess, 2008).

Moreover, the curve reported in this paper mirrors the shape emerging for more basic human needs like food consumption, which, by most analyses, accounts for about one third of global CE (Stern, 2006; Vermeulen et al., 2012; Thornton et al., 2012). Like CE itself, food consumption is inequitably distributed across the economic health gradient where 16% of the world's people are starving (causing half of all child deaths below the age of five; WHO, 2000) and 20% are obese or overweight, their diets now directly linked to higher CE (UNFAO, 2010; Edwards & Roberts, 2009). Both extremes reduce LE (whether across or within nations) and evidence consistently converges on a more moderated peak of food consumption that matches past laboratory studies informing the dietary recommendations of the UNFAO (2010). More equitable distribution of food (as just one example) would go a long way towards enhancing LE in both developed and developing nations whilst simultaneously reducing CE against the unhealthy consumption goals pursued among developed nations.

Much work is yet to be done to explore the underlying reasons for the CE curve and its long-run stability across many other different indices of significance to the MDGs and their feasibility across nations. One issue resides in whether the empirical optimum can be pursued by many different countries affected by different geographic, economic and socio-cultural circumstances, which is possibly more suited to Data Envelopment Analysis (DEA). In the meantime, the present study suggests a lower C&C target might be within reach. Putting aside issues of causality and national adaptability, we can generously estimate what might be possible for countries under different climate budgets.

From 2050 onwards, Meinshausen and colleagues (2009) allow an annual budget of 3.1Gt to accommodate 9 billion people in 2050 and (conservatively) 10 billion in 2100 (UN, 2011). This allows for a global target of only 0.33 CE/cap in 2050 falling to 0.30 CE/cap in 2100. Even if the smaller budget is applied as early as 2050, the frontier curve in this study might still offer a more optimistic outcome with no average *global loss* in LE, even when using the highest CE in 2005 (8.9 CE/cap).

It still requires an ideal and adaptable world where wealthier countries reduce emissions and poorer countries pursue a development trajectory that is more sustainable and possibly much healthier. The climate science will demand action on the C&C target as soon as possible if we are to achieve any sort of equitable balance in a carbon-constrained future. This study suggests a moderate C&C target might be a first step towards balancing the competing demands of both international and intergenerational equity. More detail on this study is available in the Appendices where the full published paper is included (Read, et al., 2013). The next study explores some challenges to the methods raised by a reviewer of this article by returning to calories as the base test of the methods overall.

3.7 STUDY SIX: METHODOLOGICAL STRENGTHS AND PROBLEMS

3.7.1 Introduction – The Problem of Outliers and Data Densities

Pure frontier regression is uniquely vulnerable to outliers and so often needs further tests to validate the curve characteristics, especially the more intrinsically vulnerable extrapolations where the confidence intervals grow with distance from the datasets. Consider, as an example, the raw data for 2005 calories depicted in Figure 3-47.

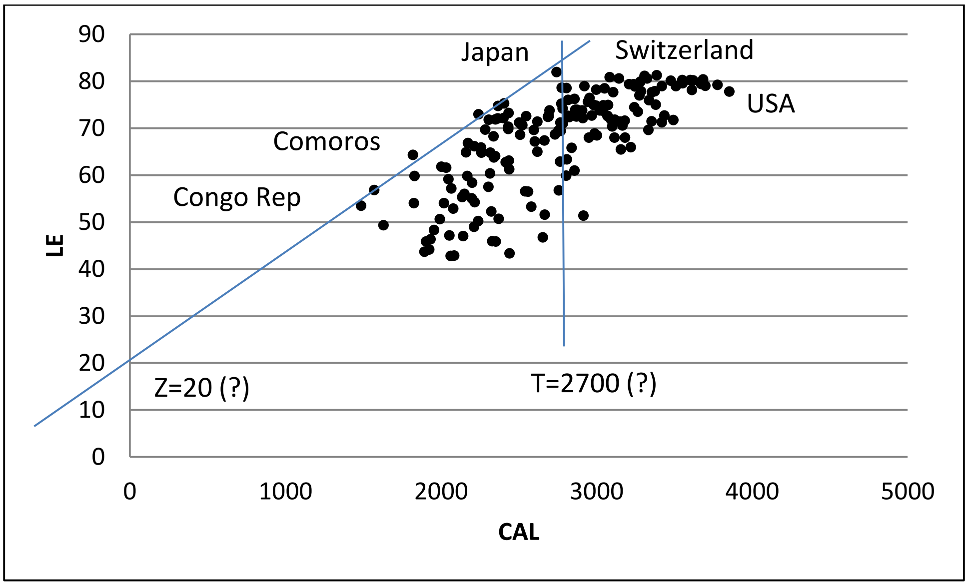


Figure 3-46 Revisiting the caloric sample to explore the impact of outliers

The extrapolated zero intercept of about 20 years of life expectancy is a full 2000 calories from the main dataset and nowhere near what might be predicted by the IRA hunger strike of about two months (0.17 years). Moreover, note the greater data density at the middle areas of the curve, especially around the observable target, which was the main concern of an anonymous economics reviewer.

First note the single data point for Comoros, when combined with the fall among Switzerland and the USA, creates a subset of only three nations having a disproportionate effect on the curve shape than others. The underlying logic of the pure frontier could produce a distorted curve based on different data densities such that the greater collection of data-points around the target would tend towards a greater chance of extreme values; whereas lower density at the extreme ends in either direction persistently dwindles down to only one value - Congo at one extreme and the USA at the other. This means the mid-point of the curve has a high risk of outliers but, even in their presence, a comparatively low impact on the interpolated target; whereas the extremes have a lower risk of outliers but, in their presence, a much higher impact on the extrapolated zero intercept.

A host of solutions present themselves, such as robust regression, spline regression, randomly splitting and recombining subsamples and α-trimming, but the removal of outliers has been avoided as a rule because it makes the approach less empirically replicable and puts the results back into the realms of the researcher’s own judgment. Even spline regression and further splits (unreported) could not avoid the problem of data density because it merely carved up the same densities. Although it challenges the methods, data density across the range could never be avoided because it is still a natural function of countries collecting around the most desirable level of caloric intake at the metabolic level.

As it turned out, the only way to overcome the problem was to retest the curve with data density more or less equalised across the range of input. As noted in all of the previous analyses, a solution was sought that would apply a general rule outside of the researcher’s own judgment so the datasets could be easily replicated. The only way of testing the effect of data density in a consistent fashion was to apply a general rule to α-trimming before the frontier sample was taken, as long as the raw datasets were already normally distributed (as they were). For α-trimming, the values are first standardised (z scores) and the top and bottom are then removed based on equal portions of the normal distribution, anywhere between 5-25% being the standard.

3.7.2 Methods – The Problem of Outliers and Data Densities

Data density had to be equalised in a way that *simultaneously* captured and removed outliers affecting both the input and output metric using a replicable rule. If the two metrics, here LE and calories (CAL), were trimmed without reference to each other, it would merely slice off the top and bottom margins of their datasets and still leave the problem of density intact. It would also lose a great deal of information. So a solution was tested based on the interaction between variables. Here, the easiest way to visualise the outliers is by graphing intensity (CAL/LE) against efficiency (LE/CAL) for the full samples, being 171 countries in 2005 and 145 in 1962 (Figure 3-48).

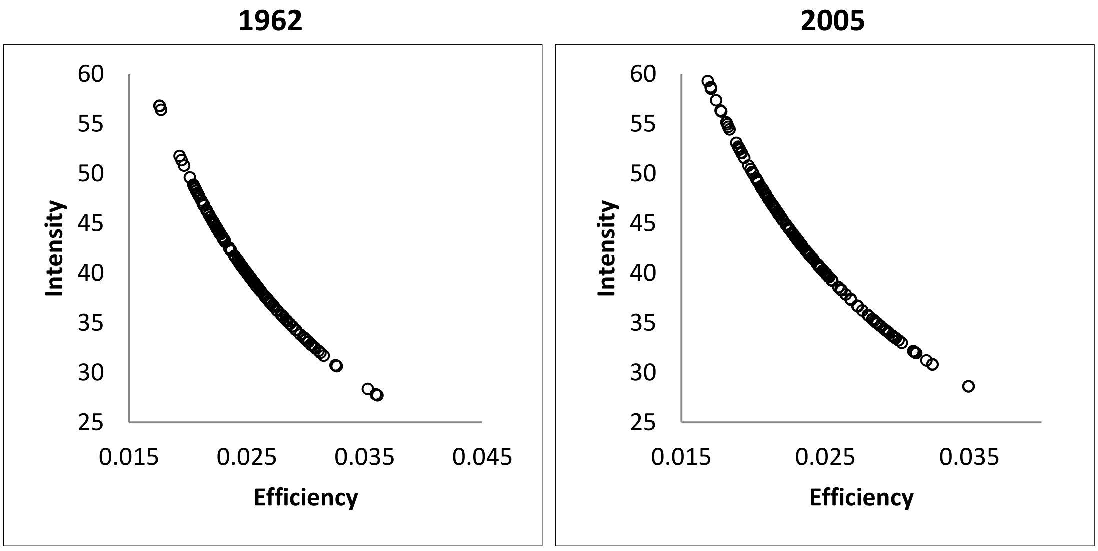


Figure 3-47 Using efficiency and intensity curves to identify outliers

In both years, the curve shows about six countries at either extreme that could be distorting the frontier at the *mid-ranges* and not extremes of either LE or CAL. In 2005, they include Eritrea, Congo Republic, Comoros, Haiti, Armenia and Ecuador at one end; at the other, countries like Nigeria, South Africa, Lesotho, Burkina Faso and Congo Democratic Republic (almost including the United States). If all of these 12 countries are removed it tends to equalise the data densities at different levels of LE because the mid-range outliers are removed.

To get some idea of what α level should be removed, the extremes were standardised in terms of both efficiency and intensity, identifying the lowest cut-off for both metrics at ±1.4 SD. Cutting out anything beyond ±1.4 SD is equivalent to α-trimming of 16% of the total distribution (8% at each end). Although data density was further improved outliers remained, so the harshest accepted criterion was applied by trimming 25% of the total distribution, ±1.15 SD reflecting 12.5% at each end. Using the transformed efficiency mean, 0.025±0.004 SD, this cut-off retains a respectable sample size of 133 nations in 2005 and 101 nations in 1962 that remain normally distributed across all metrics. What's more important is that data density is now much improved compared to the original sample (see Figures 3-49 and 3-50).

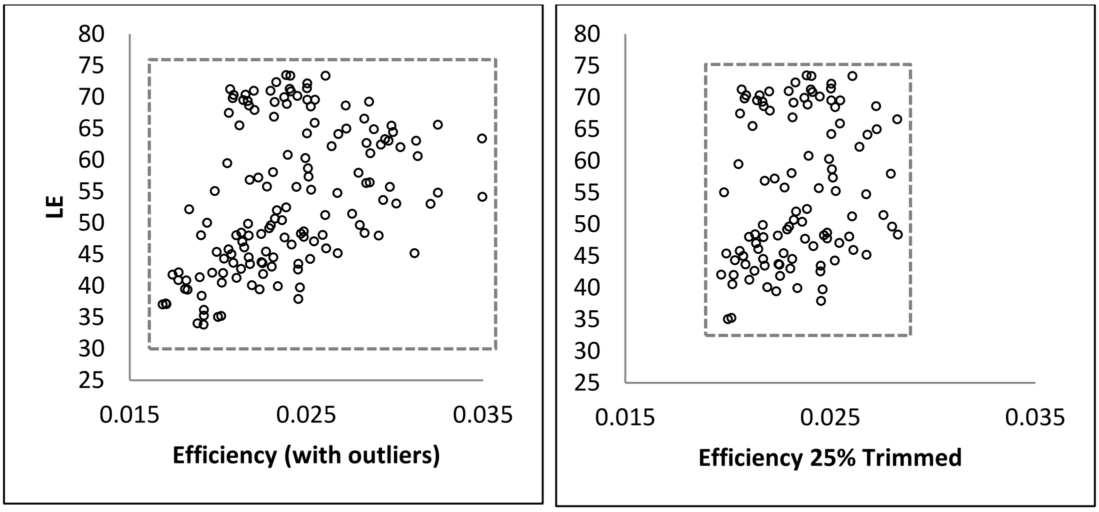


Figure 3-48 25% α-trimming equalises data density and removes outliers before frontier subsampling is undertaken in 1962

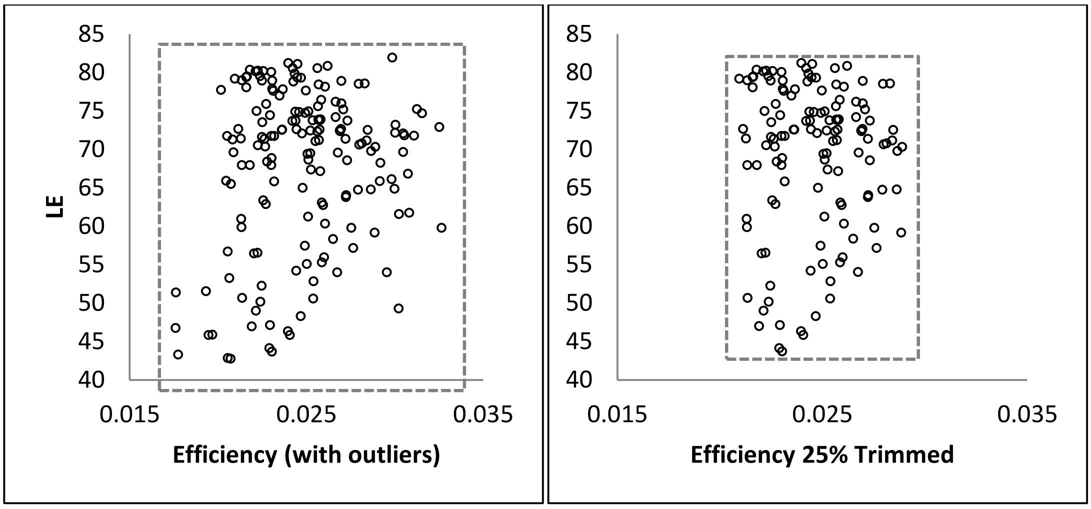


Figure 3-49 25% α-trimming equalises data density and removes outliers before frontier subsampling is undertaken in 2005

Having α-trimmed the raw data based on transformed efficiency, the frontier method can then be tested with some confidence for three main reasons:

1. Data density across the full range of both LE and calories has been equalised to the greatest possible extent within the limits of accepted statistical precedence (25%)
2. Outliers reflecting the most unusually efficient countries, whether because of unusual economic advantages, measurement error (deliberate or not) or both, are all removed
3. Leaving 75% of nations that now reflect, at the frontier, the best possible outcomes that can be empirically measured for the majority of normal nations facing normal conditions

The frontier curves for 1962 and 2005 can now be resampled and recalculated for their interpolated targets and extrapolated intercepts. Because the outliers are removed, the frontier subsamples are naturally increased and the curves become stronger again.

The distillation of the α-trimmed frontier results in a subsample of 16 in 1962, rising up to 27 for 2005. In 1962, an optimal LE of 73 years is again interpolated at 3040, almost identical to the original untrimmed sample frontier of 3030 ($r^2 = 0.99$, $p<0.001$). Likewise, the 2005 target is estimated at 3310 calories at an optimal LE of 82 years ($r^2 = 0.98$, $p<0.001$). Predictive validity is marginally increased to $r^2=0.86$ ($n=27$, $p<0.01$).

What happens to the error within time can now be estimated by further applying split-sample reliability to the α-trimmed samples themselves, where predictive reliability marginally increases again to $r^2=0.90$ ($n=32$, $p<0.01$). Once again, split-sample reliability within years is stronger using α-trimming, both $r^2=0.98$ ($n=13$ in 1962, $n=19$ in 2005). The average of the split-sample targets then becomes 3080±30 (±0.18 SD) for 1962 and 3305±5 (±0.01 SD) for 2005.

So far, these tests merely confirm what was already known – that pure frontier regression is a reasonably strong estimate of an interpolated target, even without controlling for data density and outliers. Data are now shown in Table 3-27 for all years.

Before providing the main analyses, note that some years have larger matched sample sizes than others, ranging from a matched sample of only 34 countries in 1991 up to 171 in 2005. This is because larger samples are taken in key years (>100), whereas smaller samples (<50) are restricted to more developed nations between key years. As was seen in *Study One*, years with smaller initial sample sizes should be dropped from each analysis because the frontier is always distorted by range-restriction across mostly developed nations.

Table 3-27 Reanalysis of caloric data using 25% α-trimmed samples

Year	Efficiency ±1.15 SD	Samples αn/αN/N	r^2	CAL Max	Zero LE	Zero CAL
1962	0.024±0.004	16/103/141	0.97	3040	890	-74
1965	0.024±0.003	14/49/60	0.99	3130	990	-85
1967	0.024±0.004	19/136/142	0.96	2960	500	-34
1970	0.024±0.004	21/109/144	0.98	3190	890	-69
1972	0.024±0.003	20/106/141	0.98	3120	880	-69
1975	0.024±0.003	13/44/59	0.99	3130	960	-79
1977	0.024±0.004	17/105/142	0.98	3310	690	-47
1980	0.024±0.003	22/105/143	0.95	3450	790	-52
1982	0.025±0.003	25/108/146	0.97	3290	930	-73
1985	0.025±0.003	17/114/146	0.97	3210	920	-73
1987	0.025±0.003	20/112/146	0.97	3210	930	-78
1990	0.026±0.003	17/111/146	0.96	3250	870	-68
1991	0.023±0.002	6/29/34	0.83	3370	1730	-251
1992	0.025±0.003	17/158/167	0.87	3110	590	-42
1993	0.023±0.002	11/39/47	0.93	3320	1550	-199
1994	0.023±0.002	11/39/45	0.93	3360	1860	-325
1995	0.023±0.003	29/128/170	0.98	3300	920	-73
1996	0.024±0.002	11/36/47	0.78	3310	1610	-220
1997	0.025±0.003	21/127/170	0.97	3330	860	-65
1998	0.024±0.002	10/38/46	0.95	3380	1490	-175
1999	0.024±0.002	8/37/47	0.77	3340	1460	-163
2000	0.025±0.003	19/133/170	0.96	3400	860	-64
2001	0.024±0.003	9/36/49	0.94	3470	1410	-148
2002	0.025±0.004	19/138/170	0.99	3430	780	-54
2003	0.024±0.003	9/40/50	0.95	3400	1550	-192
2005	0.025±0.004	27/132/171	0.98	3310	1150	-112

Where the control of outliers and density becomes most useful is in helping to validate (or not) the stability of extrapolation beyond the observable data range. This becomes important for studies where the extrapolated intercepts are used to estimate comparative need strength for different candidate variables. As was seen in *Study One*, all the frontier curves from 1962 onwards predicted negative LE intercepts when calories were zeroed. This meant a second intercept could be extrapolated at the point of zero LE measured in calories (not LE) - presumably reflecting the more aggregate level of shared consumption below which a population might die out.

Although less intuitively understandable than the interpolated target, these were equally interesting figures. So the next section briefly outlines results when α-trimming is applied to both forms of intercept, particularly as to whether findings support, or diverge from, the original pure frontier results. Both sets of results are now tabulated side-by-side for every available year from 1962 (Table 3-28). Across both types of extrapolated intercepts and interpolated optima, the trend is for the α-trimmed results to be higher (generally doubled for extrapolations). The results suggest the trimmed frontier inflates each value by around 30% on average across years. The interpolated targets are always stronger than the extrapolated zero intercepts for life expectancy. As was seen in *Study One*, no level of life expectancy could be achieved at zero calories in any given year.

The importance of the zero intercept can only be understood in terms of other variables outside of calories alone, where other candidate needs such as wealth and equity tend to reflect more intuitively accessible positive values under conditions of deprivation.

Because the zero intercept is always negative, it also means the second intercept could be extrapolated closer to the data range at the point of zero life expectancy rather than zero calories, presumably reflecting the more aggregate level of shared consumption at which a population cannot survive.

Table 3-28 Results comparing pure versus trimmed frontiers for calories maximising life expectancy (CAL Max), calories at zero LE (Zero LE) , LE at zero calories (Zero CAL)

	PURE FRONTIER RESULTS			SPLIT, RECOMBINED & TRIMMED		
Year	*CAL Max*	*Zero LE*	*Zero CAL*	*CAL Max*	*Zero LE*	*Zero CAL*
1962	2950	489	-32	3040	890	-74
1967	2962	489	-33	2960	500	-34
1970	3162	330	-18	3190	890	-69
1972	3112	458	-28	3120	880	-69
1977	2975	785	-64	3310	690	-47
1980	3012	797	-65	3450	790	-52
1982	2950	420	-28	3290	930	-73
1985	2988	598	-43	3210	920	-73
1987	3038	745	-59	3210	930	-78
1990	3025	735	-59	3250	870	-68
1992	2988	935	-91	3110	590	-42
1995	2950	489	-32	3300	920	-73
1997	2962	489	-33	3330	860	-65
2000	3025	532	-35	3400	860	-64
2002	3012	797	-65	3430	780	-54
2005	3260	473	-28	3310	1150	-112
Mean±SD	3023±86	598±175	-45±20	3240±141	820±130	-62±13

Although the caloric intercept makes much more sense as a population survival minimum, only the complete deprivation value can rank competing candidate needs on the identical scale of survival. Once again, regardless of method, this was always stronger than the zero intercept for calories but weaker than the interpolated optimum (Figure 3-51).

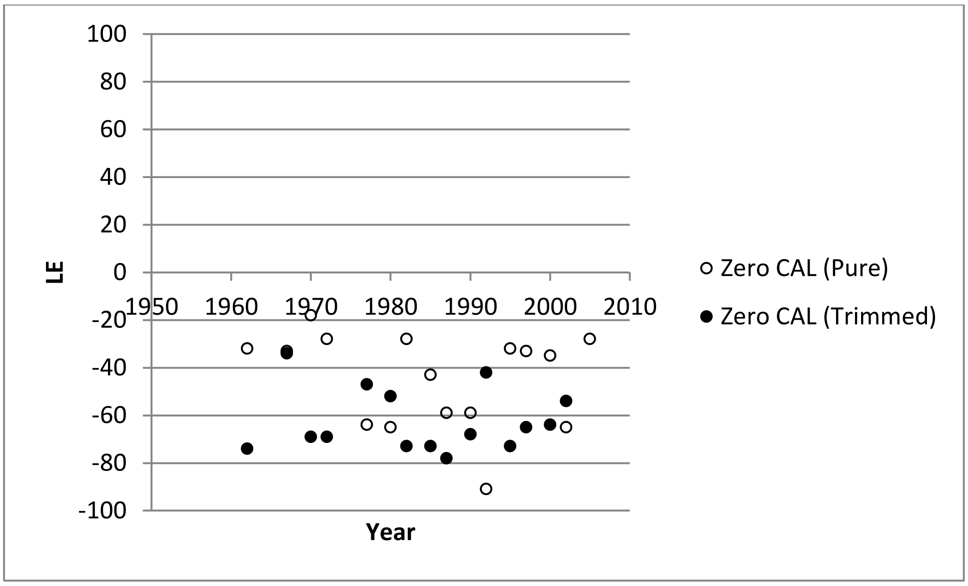


Figure 3-50 Comparing pure versus trimmed frontier results for LE at zero calories

Although the error increases as the estimate moves away from the observed data range, the two extrapolated intercepts remain highly correlated across both methods ranging -0.93 up to -0.97 ($p<0.001$). So although the distance from the data range increases error, the farthest extrapolations are still tapping into something much more than pure error (see Figure 3-52).

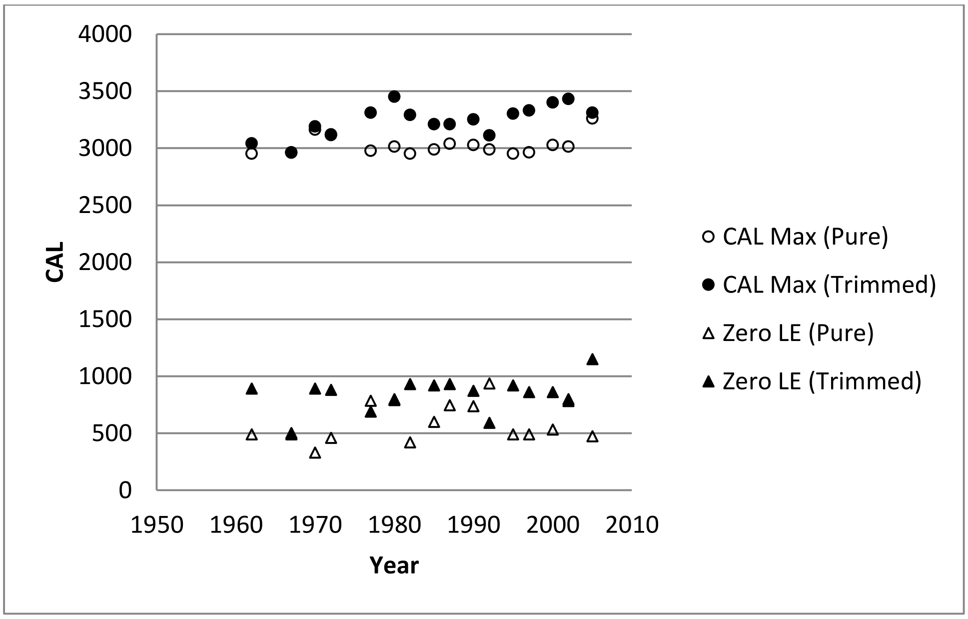


Figure 3-51 Comparing pure versus trimmed frontier results for calories across time

4. Discussion

4.1 CAN WE BALANCE THE NEEDS OF PEOPLE AND THE PLANET?

This chapter will outline how the results converge with known data as well as further exploring the constraints of the methods and the future work yet to be done, especially in terms of causality. A host of future studies emerge from this work. The methods offer stability across time periods and suggest that moving present levels of consumption to more moderated levels of human need satisfaction could be more sustainable on behalf of both current and future generations. The chapter finishes with emergent work that existential meaning and resilience is more fundamental to human wellbeing, again suggesting sustainability is more possible than previously envisioned, using a needs framework.

4.1.1 The Broad Implications

The main implication of this work is that genuine social progress tends to support moderate, not linear, pursuit of many different material and social inputs, including GDP, and that human outcomes might be maximised at more sustainable levels. The broad trends have been confirmed by another recent study proceeding from the same rationale but relying on different statistical methods applied to competing metrics. Instead of carbon emissions or ecological footprint, Kubiszewski and colleagues (2013) compared GDP with the Genuine Progress Indicator (GPI) and produced two key results. Recall that the GPI is based on Daly and Cobb's original index described in Chapter 1, and counts GDP only after subtracting the depreciation of community capital as an economic cost.

Kubiszewski and colleagues (2013) used data for 17 countries for which the GPI had been calculated from 1950-2003. What they found resonated with the main argument of the current work because greater wealth did not linearly follow genuine progress, especially since 1975, and produced a bell-shaped curve that maximised GPI at a moderated peak of only US$7000 GDP per capita[21]. Although the methods proposed by the current work need further confirmation, its results support the results of Kubiszewski and colleagues (2013) and offer further implications for a number of other pertinent questions.

To summarise these questions:

1. Study 1 suggests the frontier method correctly produces a validated bell-curve for food consumption and the peak suggests moderation would be more equitable and sustainable at the global level
2. Study 2 suggests there are limits, possibly metabolic, to human life expectancy and life satisfaction, beyond which further material consumption might be obsolete
3. Study 3 suggests that seeking a single composite index of social progress should be replaced with a dashboard approach of universal human needs taking into account age and gender, especially to support intergenerational equity and child wellbeing
4. Study 4 confirms that many other metrics of social progress also produce a bell-curve and tentatively suggests that extrapolation can be used to test a comparative needs hierarchy; going further to

[21] Recall that this always changes with inflation across years so the peak need not be stable in absolute terms when compared with more intrinsically stable metrics like LE and LS

show how the hierarchy might be confirmed by econometric elasticity and zoological allometry

5. Study 5, using very different methods, again confirms the findings of Kubiszewski and colleagues (2013) by showing that outcomes can be more sustainably maximised at moderate, not extreme, carbon emissions.

Both Studies 1 and 6 also explored methodological problems that might inform future work using alternative measures of human wellbeing, life expectancy and height. Recall that the original theoretical aim of this work was to bring together findings from different disciplines to start exploring how sustainability might be related to:

1. Human Needs
2. International and Intergenerational Equity
3. Health and Wellbeing
4. Global Development

In this spirit, there are implications of the current work that should be highlighted, even where further work is warranted:

1. That a *hierarchy* of human needs is empirically *suggested*
2. That *thresholds* of human needs might be more testable across countries and time, helping to redefine concepts of ‘development’
3. That more human-centered outcomes might be more relevant across generations and cultures; and
4. That pathways to sustainability might enhance human outcomes whilst minimising ecological damage

4.1.2 Utility, Hedonism, Happiness and Metabolism

In bringing together many different disciplines, some interesting thoughts emerge from this work. The first is that economic concepts of utility can be reconceptualised in terms of time rather than dollars. Partly inspired by the Magna Carta, the Enlightenment thinker Jeremy Bentham (1776) argued that the proper aim of government was to pursue policy that achieves ‘the greatest happiness for the greatest number’. From both Bentham (1748-1832) and John Stuart Mill (1806-1873), utilitarianism assumes happiness is the only intrinsic value and that everyone’s happiness counts equally (unity). So the classical Benthamite utility function is expressed as:

$$W\,(u_1, u_2, \ldots, u_i) = \sum u_i$$

Here, the wellbeing of society (W) is the sum of the ‘utility’ of all the members of society, inferred from prices paid by individuals within a society based on circumstances that reflect that society within a specific timeframe. Importantly, the pure market interest rate reflects the rate of pure time preference (Polleit, 2011) and so can be thought of *ceteris paribus* as the collective willingness to defer utility. This is an important point because it reflects the fact that humanity can, by use of sentience and memory, plan and negotiate for future happiness – saving for its own or future generations’ welfare

When constrained by a household budget, utility is inferred by the choices made between different products or bundles of products, including savings. The general presumption is that, the more of any particular good or service an individual consumes, the less the additional utility that will be derived from consumption of an additional unit, reflected in traditional downward sloping demand curves. This is called diminishing marginal utility. The Austrian school argues that maximisation of utility – even outside of satiation - is an axiomatic driver of consumer behaviour and that the end goal, from individuals to governments, is to maximise happiness. In this regard, Polleit (2011) warns against treating diminishing marginal utility as an epiphenomenon of psychological satiation (as per the praxeology of Carl Menger and Immanuel Kant). The present study found evidence for either a benign, essentially metabolic ceiling for life expectancy or else a set-point for life satisfaction. A benign ceiling would suggest an invariant slope, which did not happen as the slope did diminish before it hit the ceiling. More supported in this work was the less benign dose-response curve, for both life expectancy and life satisfaction against either wealth or carbon emissions, where overconsumption actually reduces utility. It was this that opened up possibilities that Pareto efficiency could be achieved with re-distribution, even within budget, if utility was measured as longevity (with life satisfaction as a pleasant side effect).

In this work, the utilitarian function was adapted by treating countries as individuals working against a global budget of either carbon emissions or One Planet living as measured by Ecological Footprint. Two common pathways are open to utilitarian-based policy within the bounds of Pareto efficiency – one classical and one Rawlsian (see Stopher & Stanley, 2014).

In terms of classical utilitarianism, if a social choice results in a situation where the relatively well-off person A (representing here the developed world) receives two dollars of benefit but person B (developing nations) loses one dollar, then the choice in question would be seen as desirable in terms of the dollar value of benefits exceeding that of costs, the implication being growing aggregate utility. However, this choice still allows for increasing inequity (person B, who is worse off, loses so, even as W expands, person B's absolute (and relative) position deteriorates. If actual individual 'utility' was measured, rather than dollars, the utility equivalent of the two dollar loss to person B may exceed the utility equivalent of the dollar gain to person A, suggesting that the choice in question is socially undesirable. Even before moving on, the idea that inequity itself can affect the real-world perception of utility offers a challenge to utility theory - if actual utility is influenced by relative wealth, then actual happiness across this hypothetical population would fall, even as its aggregate wealth increased.

The usual application of benefit-cost analysis for judging social choices implies a utilitarian social welfare function which directly equates dollars with utility, ignoring the evidence that the marginal utility of additional income (and consumption) declines as income rises (Stopher and Stanley 2014). Modern applications of cost-benefit analysis often seek to deal with this problem by 'weighting' the value of benefits and costs according to the economic status (usually assessed via a measure such as equivalised household income) of the affected people, recognising that the social welfare function is intended to be based in utility not dollars.

In contrast to the classical utilitarian approach Rawls suggests W should be enhanced not by increasing the wealth of person A, but by improving the wellbeing of those who are worst off, in this case by bringing the poorest towards the wealth of person A. If utility is conflated with dollars, then further economic growth is the logical pathway towards improved social welfare, because we must maintain Person A's wealth whilst bringing Person B to conditions of greater relative equity. When the individual in the utility function is replaced with actual countries, bringing the poorest to the highest levels of dollar-based utility causes climate-mitigated externalities that are potentially catastrophic. Under Rawls, the ecological cost of bringing people of the developing world (80%) to parity with the developed world (20%) would surpass the One Planet budget as well as the carbon budget. And yet to deny this is also to deny the egalitarian principles arising from and within unity. Under classical utilitarianism, that measures ‘utility’ (not just direct dollars), the utility gains from improving the well-being of the worst off would exceed the losses from re-distributing the same amount away from those who are better-off people, according to diminishing marginal utility.

"We hold these Truths to be self-evident, that all men are created equal, that they are endowed by their Creator with certain unalienable Rights, that among these are Life, Liberty and the pursuit of Happiness." US Declaration of Independence (1776, Preamble)

Despite their best intentions, none of these values were self-evident at the time and nor are they now. The term ‘men’ did not include women, children and races other than white (Persons A). Thomas Jefferson, a slave owner (Cohen, 1969), enshrined the ‘pursuit of happiness’ as a fundamental human right in the American Declaration of Independence (Rakove, 2009). So did Gouvernor Morris, who penned the final draft of the American Constitution and argued politics “embraces for its object the happiness of mankind.” (McDonald, 2013, p 1). This echoes John Adams who said politics is “the divine science of social happiness” and that “the happiness of society is the end of government, as all divines and moral philosophers will agree that the happiness of the individual is the end of man.” (Adams, 1776, p 86).

Quite so. If happiness is unbounded and drives further consumption beyond the limits of sustainability, it could well be ‘the end of man’. But not in the way originally intended. Lovelock (1991), Flannery (2005), Gore (2006), Hansen (2008) and Cairns (2007), among many others, worry that humanity might become just another transient species in the geological timeline.

To break the deadlock, W was tested in situ using either life satisfaction or life expectancy and, in both cases, appeared to follow the Law of Diminishing Marginal Utility, such that less and less life expectancy and/or life satisfaction was derived by more and more wealth and/or carbon emissions and/or Ecological Footprint. This meant that redistribution of resources could maximise both LE and LS even when taking away resources from developed nations and giving away to developing nations. In other words, aggregate social welfare (and Pareto efficiency) was enhanced if the dollar was replaced with life expectancy as the objective function to be maximized, all without increasing existing carbon emissions.

It also opens up discussions about why more GDP, for example, is actually reducing both LE and LS at extreme levels. One reason is that GDP and its growth is contingent on the number of people multiplied by the productivity per person. It is not such a stretch to imagine greater productivity per person cannibalising time that would ordinarily be devoted to healthier, happier and more sustainable pass-times – sustainable because many such activities simply do not raise an ecological or resource cost. Moreover, they are not measured in national accounts and so cannot be counted as 'utility' except in a time-based metric like LE.

Happiness as a construct is probably not the appropriate metric for utility, compared to life expectancy, because it is an epiphenomenon of needs satisfaction that can be distorted by imperfect information in the market. Moreover, it works in discrete situations in which individuals, operating like non-sentient creatures, make decisions without higher planning. This opens up discussions surrounding how much an individual decision focused on happiness can have unintended consequences for long-term survival, whether of the individual or the group. It is more respectful of human intelligence if LE, rather than happiness, is inserted into a welfare function in which countries are replaced with individuals, and we can assume that every life has equal value (Robertson & Walter, 2007); it makes the logical leap by recognising that happiness as the final outcome is merely an epiphenomenon in service of survival in the first place. This work puts time as the ultimate form of utility as, without life, no other form can exist, much less prosperity or even its relative perception.

Concepts of prosperity beyond material wealth have raised heated debate for centuries. Ancient Greek philosophers tackled human welfare as it related to the tensions between virtue, power and consumption. The term ‘arête’, similar to the pleasure principle (Freud, 1930), was the basis for hedonism, from which any physical pleasure was encouraged and led to ‘hedonia’. The most extreme form of hedonism was represented by Plato’s Thrasymachis, who said pleasure was the only goal of humanity and should be pursued by any means, including exercising power over the weak. By contrast, Democritus and Epicurus equated the good life with a more modest form of hedonic pleasure, including the absence of pain and the pursuit of personal peace.

At the other extreme, Plato and the Stoics defined the good life with human virtue, from which happiness (as ‘eudemonia’) was seen to be its own natural reward – an epiphenomenon. Aristotle was more moderate than any, arguing that some level of earthly consumption was needed before human virtue could ever assert itself, yet again resonating with the set-point emerging in this work once proper conditions are met.

These old ideas still resonate with modern discourse. Sometimes, there is still a misconception that SWB refers to hedonic pleasure alone whereas most psychosocial researchers would argue it is more aligned to Aristotle's views embodied in concepts of integrity and eudemonia embracing Maslow's self-actualisation (1968). Hedonic happiness still remains an important component of SWB but is still just one part of an overall biological and cognitive appraisal of global 'life satisfaction'. This thesis argues that life satisfaction, as an epiphenomenon of human needs satisfaction growing with social progress, is a more useful (quick) metric of progress than life expectancy, but only when applied across age, gender and especially cultures so as to minimise the impact of maladaptive social learning (called 'neurosis'). Whereas LE offers more equivalence across time and cultures, LE and LS should be used to validate main trends, along with height (for paleo work), as all three have methodological advantages when combined.

As for the relation to ecology, need theorists would agree with Aristotle more than the Stoics that happiness relies partly on external nourishment from the environment (here conflated with Alderfer's primary needs) as well as integral virtue, interpreted here as a form of Maslow's self-actualisation. Both require enough freedom to move and adapt within existing sociobiological constraints, embracing Sen's capability theory by allowing people enough adaptive capacity to balance both primary and secondary needs. Secondary needs should be more elastic, socialised, learnt and relative rather than the more hard-wired and heritable primary needs. The problem is that learnt secondary needs are not always healthy or adaptive in different cultures or economies. For example, advertising can make an art-form of exploiting pre-existing biological drives to greater consumption of food (and other commodities) that emerged from 2.3 million years of restricted subsistence. Some of these drives might not continue to serve people in some of the world's most 'advanced' nations, as evidenced by the rise of obesity. The same could be said of sexual competition being linked to product consumption.

Together, a more multidisciplinary synthesis suggests that the satisfaction of basic human needs should make way for a more enlightened view of happiness and freedom which is potentially more sustainable than hedonic consumerism alone, as long as the transition is made from material to non-material sources of wellbeing once basic needs have been equitably met and the set-point is allowed to manifest. The results of this study tend to argue that *true* freedom in the form of actualisation (not necessarily Hayek and Friedman's market freedom) can only be achieved beyond the satisfaction of equity, allowing the freedom for actualisation whilst also serving sustainability on behalf of future generations. This should increase SWB both within and across nations, at least to the point where the set-point is equitably achieved.

At its most basic level, the co-benefits of cultural change aimed at both health and the climate tend to emerge by multifactorial pathways. A few grassroots examples for people living in the developed world include, wherever feasible, replacing car-use with bicycles or walking; replacing passive entertainment choices with active social and recreational engagement, moving from consumption of mass-produced creative culture to reclaiming music and art at the local level, including cultivation of individual creativity and talent at the personal level; eliminating tobacco; moderating alcohol, eating less and replacing meat, fast and overly processed, packaged foods with more fibre, fruit and vegetables (Popkin, 2003;

WHO, 2003); spending more time with others and asserting the importance of household and volunteer economies as just as great, if not greater, than measurable economic production and consumption.

The first problem with these sensible recommendations is that they reduce measurable economic growth, government taxation and investment returns. At the individual level, the problem is that sustainable practices often require more time, effort and cost which directly compete with the time and effort required for economic subsistence imposed upon people by the discordant concerns of government (growth), industry (profit) and shareholders (investment). These more powerful aggregate forces are probably at odds with sustainable practices that enhance health, sustainability and human wellbeing, not only at the individual, household and community levels but even when measured at the higher population levels.

Whenever a time-poor 'consumer' chooses fast-food over a home-cooked meal, it shifts from unmeasured household production (see Folbre, 2008) to measured economic production, risks eroding the cultural integrity of the household, probably reduces subjective wellbeing, certainly lowers life-expectancy and supports further incursions of the economic production imperative into the traditionally healthier preoccupations of the household. The latter include conditions for social cohesion, health and human relationships – sources of existential meaning and long-lasting eudemonic wellbeing as opposed to short-lasting hedonic happiness. This suggests we must slow down 'uneconomic growth' (Daly, 1999) so people have more time to focus on these adaptive changes that serve needs at the family and individual levels, without which people continue to feel as if their real world efforts are increasingly at odds with their personal values, integrity and sources of basic joy. Moreover, in a world where economic growth must come from human creativity as much as material resource exploitation, the value of time, work-life balance, flexibility, sleep and active recreation becomes more productive for the overall economy when counting both the cost of carbon emissions and healthcare. Various studies are beginning to show that public health, human wellbeing and longevity is enhanced with moderate and stable economic growth, rather than large and rapid economic transitions (Sen, 1999; Read et al., 2000). It is increasingly argued that the developing world has an opportunity to avoid the mistakes of the West and to lead the world in terms of properly using economic growth to serve its own citizens.

4.1.3 Sustainability changes too fast for policy and research

The real-world referent to which the climate change concept refers is moving faster than research and policy can adapt. As of May 2013, the atmospheric concentration of carbon emissions had breached the threshold of 400 parts per million, putting the world on course for a temperature rise of at least 2°C by 2100. By analysing bubbles of gas trapped in ice, climate scientists have shown the last time this concentration occurred was 3.6 million years ago when the temperature was about 2.8°C higher. Should this concentration become more constant over the remaining course of 2013, the next decade will see a 25% increase in famine across Africa and West Asia, collapse of both the Amazon rainforest and Greenland ice sheet, and at least 20% species extinction (see Stern, 2006).

A newer report, released six weeks later in July 2013, used a much updated version of Stern's original PAGE model (Whiteman, Cole et al., 2013) to track the impact of methane released from the current melting of the Arctic. Methane, as a GHG, is 25 times more potent than carbon dioxide, so their results show that current levels of climate change will now cost the world more than previously estimated. In their report, this value was expressed in current 2013 prices and puts cost at 90% of global economic GDP in 2035 (Whiteman, Cole et al., 2013). Most of the costs again come from extreme weather events, rising insurance costs, biodiversity loss and deepening hunger and drought across Asia, Africa and now South America.

As of August 2013, the first meta-analytic reports started to come through, that climate change across India, Germany, Brazil and the United States have been associated with increased rates of civil unrest, ranging from domestic violence to homicide and rape (Hsiang, Burke & Miguel, 2013), a finding that also resonates with new data from the Oxfam Monash Partnership in Bangladesh (Alston & Akhter, 2013), where resource scarcity is having an impact on early marriage of young girls and violence towards women. The latest from Hsiang and associates (2011), based on 10,000 years of historical and modern data, suggests a global rise of 2°C would increase civil and domestic violence by about 16% and inter-group conflict by around 50% (see also Hsiang, Meng & Cane, 2011; Larrick et al., 2011).

In other words, the international community had already failed to limit temperature increases below the point at which human survival will be affected and passed on a much greater economic and human loss onto younger generations now living. It has essentially failed to act on its own agreed limit whilst pursuing policy that, even in the absence of climate change, is at odds with human needs across countries and time.

Some leading economists and politicians have described sustainability as the most diabolical moral dilemma of all time (Garnaut, 2011, Rudd, 2008). But bringing the least developed countries out of poverty so they achieve parity with developed nations would likely guarantee human extinction by 2100, at least if they pursued the same trajectory as developed nations and developed nations themselves were not willing to reduce their emissions towards international equity. The lack of action by resistant nations, and especially global corporations, as well as their voting populace/shareholders in the developed world, has consigned their own children to a much harder and steeper adaptation than they would themselves have had to endure had they acted sooner.

If it is accepted that anthropogenic threats to future generations are caused by current levels of economic development, and we care about their welfare, then international equity comes into direct conflict with intergenerational equity. Without both forms of equity, international climate negotiations stall because developing nations will not sign up to treaties that limit development below levels enjoyed by wealthier, more carbon-intensive economies. On the opposite side of development, carbon-intensive economies do not want to scale back growth for fear of loss, recession or depression, which equally affects their own children, even when their traditional arguments around the economic discount rate still devalues future generations. For example:

1. Extrapolating from past economic growth rates of only 1.5% means people living in 50 years will be twice as wealthy and more technologically advanced so they can handle climate change themselves (McDonald, 2005)

2. The costs of immediate mitigation would be too great an imposte on current generations if intergenerational wellbeing is not discounted, leading to 97% economic contraction (Dasgupta, 2007)

3. Why bother protecting the wellbeing of people in the future when the chances of complete extinction by something other than climate change (Stern's meteor strike) reduces their chance of existence by 0.01% per year (e.g. Stern, 2006)

4. If wellbeing is relative, then future generations will adapt to loss of wealth anyway (Veenhoven, 2008)

5. Future generations are unborn non-persons and so have no legal rights to equity in the first place (see Thomson, 2003)

These arguments mostly look at the problem from a confined intradisciplinary framework that is legally or mathematically defensible but usually fails to account for the real world impacts of climate change. Technology, whilst necessary, is not sufficient, leaving mitigation, adaptation and/or population control as the solutions. Mitigation argues we should cooperatively act to reduce emissions, adaptation argues countries should adapt to the inevitable and maximise their own welfare whereas the dark side of population control, beyond the more benign and positive effects of birth control, invoke the spectre of eugenics, war or genocide. The current work tries to build a fourth solution to the existing arguments surrounding mitigation, adaptation and population control where a more civilised solution requires changes to public and political attitudes supported by simple and empirical evidence.

By necessity, the work started by exploring themes using stylised and simplified curves (Kaldor, 1961) to show the universality of human needs led to moderate, less carbon-intensive targets across time, countries and disciplines. This supports emerging arguments that GDP 'mismeasures' human outcomes and should be replaced with more focus on measures of equity that embrace wealth alongside non-market dimensions of subjective wellbeing (Stiglitz, Sen & Fitoussi, 2010) . The challenge facing this vast effort was in finding appropriate measures for social outcomes that were previously thought to be unmeasurable and often collapsed into single composite indices that merely polluted the landscape of league tables. This is why the current study used frontier curves across countries to show many different human needs can have benign impacts on both people and planet whereas others are antagonistic to both.

Human needs go beyond basic physiology like temperature, oxygen, water, food and sleep to embrace issues of broader significance such as gender equity, safety and shelter, work-life balance, happiness, wellbeing, adaptive freedom and integrity. Wealth (to a point) is merely one secondary need that helps populations move towards the satisfaction of needs, and its success in doing so depends on which needs society itself promotes. The problem is that some learnt values, as opposed to needs, are not always rational or optimal, often in conflict, and often fail to serve the ecology, the society, or even the individual. Consider extreme examples such as female infanticide in India and China, or else freedom of speech versus pederastic grooming on the Internet; the tension between free market economic growth and sex tourism; consumption in the developed world against slave labour in the developing world; the tension between religious freedom, female circumcision and women's rights, and so on. Whereas values emerge from a combination of culture, politics, religion and education, universal human needs should, theoretically, transcend all four. If constant across time and cultures, they should always 'outrank' values when both can be measured against basic human survival. Even against dynamic flux, the hierarchy should always assert itself when survival time is used up in the service of socio-cultural or political values resulting in early death, whether in minutes, days, years or decades.

If the development of both individuals and nations follow the hierarchy of human needs, then it's not surprising that people in the developed world, having seen constant improvements *in primary needs* within living memory, still 'value' the idea that material development is unlimited, that more consumption is better. Developed nations have themselves progressively climbed the ladder of human needs satisfaction at the aggregate. By analogy, even if stretched, this work tries to lay some first stepping stones towards the self-actualisation of nations where sustainability becomes one component of national integrity. There can be no real happiness in the presence of starvation and slavery, there can be reasonable happiness when basic needs are met, allowing competitive status to become the next salient concern among wealthier nations, where the highest levels of actualisation can only be achieved once all these lower needs are transcended, including, but transcending, relative status and self-esteem. This pursues a more holistic path in the spirit of Eckersley's (2005) Synthesis Approach. Part of the development agenda should then embrace sustainability because it seeks to match personal to social needs at levels that go beyond the lives of either.

Is any kind of balance between people and planet ever going to be possible?

The answer would appear to be 'yes' but mostly if the relativistic pursuit of material consumption is rapidly replaced with moderated and healthier satisfaction of universal human needs across cultures, time and politics. Moderation enables the possibility of equity; and the satisfaction of human needs as the primary goal of society has the happy effect of maximising subjective wellbeing and minimising ecological impact. Moreover, it is the only way of achieving Pareto Efficiency where nobody actually loses from a climate change solution.

The results support the Brundtland Commission by putting economic growth and its externalities in its proper context across the full range of human needs, but even the current work suggests money and economic growth remain important to human needs and are not inherently unsustainable. In many ways, economic growth could be seen as an infinitely renewable resource as long as it serves the needs of humanity. Economic growth is a multiple of population and productivity per person, but it often fails to define the nature of the product, leading to bizarre conclusions – seeking bigger populations or else putting more pressure on existing human resources.

The only unsustainable aspect of economic growth resides not in money itself but with what is done with money on the consumption side (equitable wealth) and how economic growth is achieved on the production side (equitable effort). If production is shifted away from non-renewable resources and consumption shifted towards human needs, extending to equity and the needs of future generations, then economic growth could still be limitless, based mostly on human creativity and technology (see Fodor, 1983; deBono, 1990).

The original limits to growth described by the Club of Rome come into play only when the limits of the biosphere are breached by exploiting energy from natural sources and sinks that are needed to preserve the planetary ecology on behalf of other people, generations and species. By contrast, this work outlines an argument that suggests there are metabolic limits operating within the human organism itself. It suggests equity, including equitable distribution of resources in service of human needs, is fundamentally more important than economic growth in its current expression and form As economies and populations continue to grow against the boundaries of the biosphere, the imperative for change transcends all country borders, political persuasions, religious beliefs and secular values. The change would focus on the utility of human time, rather than the exchange value of the dollar, and only human time can be used to measure competing needs across cultures and time.

4.1.4 Revisiting the Hypotheses Based on Human Needs

Three key characteristics of human needs at the individual level were discussed in terms of rank, threshold and stability. By definition, any human needs should always manifest at the aggregate population level, bypassing Ecological Fallacy. So the same results were then explored using frontier subsampling across countries and time, helping to minimise the effect of some major omitted variables:

1. Extrapolation of rank based on partial deprivation across countries,
2. Interpolation of threshold based on the shape of the curve, and
3. Stability of these measures across half a century.

Given past findings across disciplines, it was expected that the extrapolated estimate could range from zero to many years as the hierarchy climbed, even if they became more elastic. The main hypotheses were summarised as below in Figure 4-1.

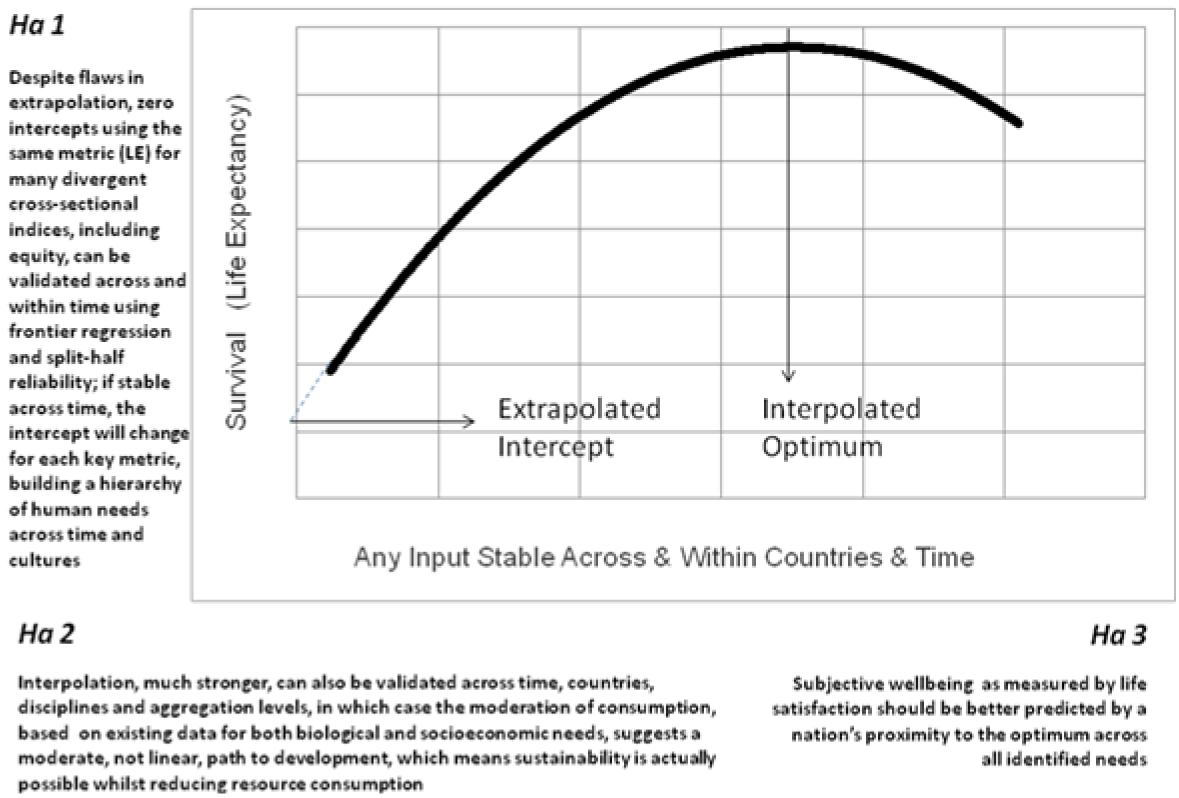


Figure 4-1 Revisiting the Goldilocks Hypotheses

Ha 1 Despite flaws in extrapolation, the use of the frontier against life expectancy as a proxy of survival time successfully built a hierarchy of human needs across many different indices that broadly matched the predictions of several different need theories

Ha 2 Interpolation of actual targets for each index was far more stable across time and, whilst not all indices displayed a bell-shaped curve, there was confirmation that more moderated and not linear pursuit of consumption maximised survival

Ha 3 Once a selection of key needs had been identified as stable, subjective wellbeing measured by life satisfaction better predicted a nation's proximity to the optimum target across some indices of needs satisfaction (although further work is required to test a more global metric)

Ha 4 A fourth hypothesis emerged as the study unfolded, that many of the moderated targets for human needs would require lower levels of carbon emissions than expected – this confirmed but also needs further work

4.1.5 The Human Limits to Growth

James Lovelock (1991) was the first to suggest the planetary system was a metabolic unit for life-support whereas the current work suggests there are metabolic limits to life support operating within the human organism. In the same way, the fundamental basis of metabolism, being homeostasis, cannot be captured in a single measure (even at the physiological level) and requires further exploration based on the complexity of systems (see Kaufman, 1995). The idea of an all-encompassing composite metric like GDP, HDI and HPI was challenged in favour of exploring subindices of psychosocial development focused on life expectancy and life satisfaction, where it seems that boundaries still operate to constrain human outputs whereas ecological and economic inputs remain unbounded.

Results suggested actual 'human development' stalled long ago, at least among developed nations. Even the *composite* curves suggested human outputs were bounded whereas wealth and ecological inputs feeding these outputs were unbounded and unsustainable. The fuzzy boundary explored in this study meant that no amount of material consumption affecting the planet would greatly impact on human outcomes beyond incremental progress operating in the background. The trends all suggested there were human, as well as ecological, limits and possibly even negative metabolic externalities linked with over-consumption of material resources. If this remains true, it becomes nonsensical for the developing world to pursue the same linear trajectory as the world's wealthiest and most resource-intensive countries, even more so if it causes human harm to both living and future generations.

Whilst the idea of the fuzzy boundary still perplexes authors on life expectancy, the ‘fuzziness’ was recently explored in detail by Cummins (2010) as a way of explaining the Easterlin Paradox on SWB. Using data spanning 15 years of successive waves of the Australian Unity Wellbeing Index, and using more complex structural equation modelling than offered here, Cummins offers an analogous model that could explain the ‘fuzziness’ of the boundary as well as the Easterlin Paradox. He says there are two main effects in operation. First, the set-point is a “genetically determined, individual difference” that ranges only ±0.6 points *within* populations. However, superimposed on this is the effect of equity (here in the case of wealth), where the main effect can force a population to range by as much as 3 points either side of a stable population average of 7.5. What this ultimately means is that “in favourable circumstances of living, where people are maintaining normal levels of SWB, the variance within any large, random sample, will be dominated by the distribution of set-points… and not subject to influence by wealth … [but that] … if all members of a demographic sample … are operating at the top of their respective set-point ranges, then the sample SWB should be about 7.5+0.6=8.1 points.” This description by Cummins (2010, pp 245-246) exactly matches the results of the present study using much simplified methods.

Moreover, Cummins’ (2010) model would explain why serious deprivation impacts SWB and LE across countries and yet still has an impact within countries, where “the stronger effect is due to an influence that changes the proportion of people who are, or are not, [capable of] maintaining homeostatic control of their SWB” (p 246). This is probably due to inequity and many other forces at the individual level outside of wealth alone – war, disease and deprivation. On wealth, Cummins says: "At lower income ranges, additional money acts by lifting the tail of the SWB distribution. At high incomes it acts through downward comparison with lower-income groups" (p. 249). Thus linking relativity beyond threshold.

As long as economic growth is tied to carbon emissions, is inequitably distributed and also remains the main metric of human wellbeing at both the individual and national level, another factor, fear of immediate loss, might become the greatest threat to achieving multinational collaboration on climate change and equity in all its forms. Loss is more powerfully felt than gain (see Powdthavee, 2010) and the threat of loss will probably be resisted by reference to the conscious and unconscious strategies previously described:

1. Rejecting the veracity of the climate science (Garnaut, 2008)
2. Rejecting anthropogenicity and appealing to helplessness (Bardi, 2011)
3. Obfuscating the findings with localised confirmation bias (Plous, 1993)
4. Relying on future technology and borrowing against the future (McDonald, 2005)
5. Suppression, denial and ego justification (Nordhaus & Shellenberger, 2009).
6. Compassion fatigue and systems conformity (Kalaugher, 2011),
7. Preserving the rhetoric but resisting personal action (Watson, 2013)
8. Shifting the obligation for change to other people, generations or countries (all argued by Wishart, 2009)
9. Resisting government interventions as an assault on freedom (Wilkinson, 2007)
10. Rejecting the Precautionary Principle
11. Giving up

These might also interact, depending on people's position in the lifecourse, their politics, culture, personality, understanding, existing wealth and their psychological attachment to it. The literature suggests that regardless of the strategies used to resist the implications of climate change the over-riding motivation for resistance emerges when loss aversion is combined with the relativity of subjective wellbeing tied to wealth and basic ignorance of other people's quality of life. By contrast, the motivation for action resides in human altruism, compassion and filial love, which is equally tied to subjective wellbeing.

The major problems in handling sustainability, much less climate change, will probably emerge in how different societies promote, preserve or pervert these competing psychological forces – the same old fight between nature and nurture, emotion and cognition.

4.1.6 Theoretical Rationale

This work proceeded from the original definition of sustainability as development that serves the needs of the present whilst preserving the ability of future generations to satisfy their own needs. Within this careful definition is an implicit call for inter-generational equity. But rather than being focused on economic equity, the definition explicitly shifts the focus to the equitable satisfaction of human needs, which can be social and psychological. Deeper again is the more subtle call for international equity. This is never explicitly stated but logically follows from the definition. If inter-generational equity is a moral imperative for sustainability, then so too is equity among present generations themselves. If equity itself turns out to be a human need, then the argument emerges again, that all forms of equity are fundamental to sustainability.

Following a review of the literature, all of these key themes kept re-emerging across disciplines. Some of the most contentious arguments were examined in detail because these tended towards unmasking the gaps between disciplines, wherein solutions might be found (see Eckersley on 'Synthesis', 2005; Stanley, 2010). Issues like the psychology of climate change, resistance to loss, the relativity of human happiness affecting the pursuit of wealth, intergenerational equity and the discount rate used in climate models, were all part of the broader dialogue but only touched on the central sustainability of human needs and their synthesis with extant knowledge.

This was entirely understandable because actual human needs have never been ethically testable. Ever since Maslow suggested a hierarchy that spans many different disciplines, reductionistic scientific methods were at a complete loss as to how to proceed. Diverse findings from physiology, medicine and a handful of historical accidents merely approximated a hierarchical structure for what Maslow called 'deprivation' needs and Alderfer later called 'primary' needs. The higher, more psychosocial and economic needs could never be contextualised against one another in a single study. These more abstract forms mostly fell under the category of 'secondary' needs, from which more economic and legal theorists like Sen and Nussbaum nominated freedom and capability as the most important, echoing Max-Neef. The present work made some arguments that moved towards testing the hierarchy, mostly with reference to what was already known about physiology and then applying similar logic at increasingly higher levels across countries.

First, it had to revisit the actual definition of need as a conditional requirement of human survival, without which death ensued. Second, it looked at physiological needs and found some key characteristics – universality, stability, hierarchy (even if dynamic) and some form of threshold or set-point.

One was that human time to death could range across minutes, days and months, which meant Maslow's hierarchy could be ranked on time to death under deprived conditions. This meant its reciprocal in the form of lifespan could be equally used to rank different needs, which then opened up using life expectancy as a proxy of partial deprivation.

The next characteristic was stability. Alderfer pointed out that dynamic flux in the hierarchy allowed some individuals to suppress basic needs in favour of a 'higher' need. But when it comes to basic physiological needs, their suppression eventually leads to death regardless, and the time to death will be stable across and within time, cultures and disciplines (metabolic factors being equal). From these two characteristics, it was thought that life expectancy across countries and time could be used as a key metric to unlock the underlying hierarchy of any other metric that is equally measured across countries and time. Datasets from the UN and WHO offered thousands of indices, many of which captured or approximated the range of Maslow's hierarchy – from water, sleep and food, through shelter and security, to self-esteem, respect and life satisfaction. So many were collected over the past half-century that stability could also be tested.

The other characteristic of physiological needs is that most indices follow a dose-response curve where moderated input maximises survival time – the Goldilocks Curve. From this it was argued that even higher needs might display a dose-response curve. If they did, it would mean that moderate and not extreme human consumption of planetary resources could maximise the satisfaction of human needs, opening up possibilities for redistribution of resources without any loss to countries or generations – a form of Pareto efficiency when purely economic concerns are bypassed in favour of much broader human needs.

The other word used in the original definition of sustainability by the Brundlandt Commission (1987) was ‘development’, a key notion that was later dropped by the literature because it was too often conflated with wealth alone. Once again, however, the development literature puts international equity as a key component of sustainability. This is why a detailed discussion of the United Nations Human Development Index was provided to explore its actual implications for sustainability. It was first noted that Veenhoven (1996) argued against the HDI because it mixed inputs like wealth and education with pure outputs like life expectancy.

The current work agrees with this critique, arguing that life expectancy is an output metric that applies across countries, generations and disciplines (CSDH, 2008). Moreover, it can be tested with reference to a harmonised formula going back to 1731 (HMD, 2011) and its relevance to human needs is further validated by reference to paleoanthropological data (Steckel, 1983), comparative physiology and even allometric regression across species (Diamond, 1991).

By reference to the Preston curve, it was argued that a metabolic limit to life expectancy would mean the HDI not only equalises GDP with LE, but is essentially unsustainable because it treats the gains in wealth as intrinsically linear when the actual effect hits a ceiling. The HDI becomes even more unsustainable if there is a bell-shaped dose-response curve where higher wealth becomes antagonistic to human survival in developed countries, which always appears across countries and cultures.

Veenhoven (1996) went further by noting that people could still live long and miserable lives versus short and happy lives, and so argued that life expectancy itself should be weighted by life satisfaction to create a proper output metric in the form of

Happy Life Expectancy. Across countries, he argued that changes in this metric reflected the satisfaction of human needs. Despite his resistance to set-point theory and the relativity of SWB, the same curves still emerged.

Veenhoven's logic was embraced by the Happy Planet Index and then weighted against Ecological Footprint to create the HPI as a composite metric of sustainability that bypassed wealth entirely (NEF, 2009). Both Veenhoven and Cummins ignored the index but probably for very different reasons – the former because it challenged the link between 'happiness' and growth, and the latter because it made little scientific sense as a composite rather than a more nuanced dashboard. Composite indices, by collapsing complex interactions into a single index, often fail to outline more direct pathways to sustainability on behalf of countries that fail to reach the heights of the league tables. What's more, yet another league table merely pollutes the complexity of the measurement landscape.

So this study sought to explore a 'dashboard' of key metrics that might help countries identify where they need to improve aggregate outcomes for their people as well as the global ecology outside of their own political and geographical boundaries. The idea of a needs hierarchy allowed many more competing subindices to be placed on a dashboard of development so nations might identify pathways to sustainability at the policy level.

But this still required more context across time and cultures. True needs could never be properly contextualised within a single country because gains in any human output could be distorted, especially in the case of SWB. Gains in SWB might rely on structural inequity within nations where people pursue more wealth than their peers or their past, in which case their ‘happiness’ is always relative to an upwardly moving target. Ironically, this means that the HPI is unsustainable.

Pursuing happiness might be dangerous in the presence of climate change. If happiness is more affected by relative rather than absolute consumption, then populations would continue to pursue more and more against their peers without any actual gain in terms of aggregate happiness. Previous studies suggested even sudden gains in population wealth would have short-lived effects whereas loss in the presence of climate change would have far greater and longer-term effects on future generations.

With reference to the Easterlin Paradox, the current work finds support for the idea that ‘happiness’ is absolute when applied to primary needs but becomes relative for secondary needs. This hardly dismisses the impact of wealth within and across nations, but attempts to explain apparently contradictory findings at a simple level. It still embraces wealth and resource consumption as one among many key inputs alongside freedom and capabilities but argues that the impact of wealth in developed nations can become less absolute and more relative as primary needs are satisfied. Beyond threshold, many needs have greater negative impacts on the ecology and even human outputs in the presence of a bell curve.

A more inclusive ‘dashboard’ of needs - over and above a single composite – then allows some insight into trade-offs and unintended consequences that might emerge in one area when its impact on others is quarantined. Without Synthesis, the legacy of reductionism in science manifests at the policy level as a game of cost-shifting between administrative units. The same is now becoming a major problem across countries in an era of accelerating globalisation of causes and effects.

4.1.7 Empirical Rationale

With this and the climate debate in mind, one of the main aims of this work was to seek a form of empiricism where the datasets were publicly available and the methods simple so they could be replicated by the lay-person and not quarantined by experts. If the science could be replicated by any citizen, then nobody could mount arguments based on denial, ignorance, obfuscation, systems justification, learned helplessness, conformity and differences in interdisciplinary theory. It invites a more level playing field for empirical analyses.

This is why the work made extreme efforts to avoid jargon, promote basic understanding of the issues and make sure the methods were not overly complicated - whilst simultaneously pursuing greater accuracy than previous (mostly theoretical) explorations of human needs. Basic frontier sampling was described in in a way that assumed minimal knowledge of statistics. Most of the analyses use Microsoft Excel and avoid using SPSW and GNU unless absolutely necessary. So too, the removal of outliers was avoided so that no person would have to use their judgment to replicate the results. Anyone interested in replicating the results could then refer to any of the datasets available online and apply the methods themselves. Split-sampling was used first and then recombined to minimise the influence of outliers. Wherever possible, stability was replicated across three matched time periods with reasonable concurrent validity whilst further eliminating data that was estimated rather than directly measured.

4.1.8 Methodological Rationale

Pure frontier regression was borrowed from econometrics and then validated using various tests from psychometrics. Traditional studies using frontier regression focused on the reasons why firms were not achieving maximum output given their levels of input. Long before any explanatory interactions were tested, pure frontier regression had to use the optimal levels of profit achieved by different firms as the benchmark for best practice, after which an individual firm's divergence from this ceiling was used to estimate its productive efficiency. Looking at trends across many different firms then allowed economists to build models of multiple inputs aiming to maximise profit by balancing the interactions between inputs. With this aim in mind, complicated forms of frontier regression manifested and the economic literature continues to identify new statistical, theoretical and mathematical adjustments that are increasingly impenetrable to all but a handful of experts in the discipline, much less the general public.

The current study, by contrast, was far more mercenary as it was only interested in the benchmark ceiling to begin with. It treated each country as if it were a firm that needed to maximise the satisfaction of human survival rather than profit. Instead of trying to model complex interactions between needs that were not yet known, it started with simple stylised curves between multiple candidate needs as the inputs and human life expectancy as the output. Rather than examining productive efficiency it was more interested in technical efficiency – the degree to which different levels of input maximises output, how the stylised curve is shaped and what it suggests about the levels of input that affect output at various levels across the input data range. These include the interpolated and extrapolated optima and intercepts, both of which would have to be stable across time to be classified as true human needs, whether primary or secondary.

If stable, the optimum was thought to reflect an estimate of the target that countries need to pursue whereas the intercept provided an estimate of how important a need might become as lower needs are progressively satisfied – an estimate of the hierarchy when contextualised across many different competing metrics. The use of extrapolation in this context does not attempt to identify an exact deprivation value but simply to ensure the method builds a plausible hierarchy.

4.1.9 Summary of Results

The use of frontier regression in this project was originally developed to address some serious concerns about the Happy Planet Index (HPI). As a composite metric, the HPI was a useful marker of countries moving towards sustainability but wholly failed to identify actual pathways towards sustainability for other countries. It mostly identified island nations as the world's most sustainable countries, which meant that tourism alone might have effectively exported their ecological footprint to more developed nations. So its calculation, whilst offering solid face validity, buried the impact of outliers and might have created a sustainability target that was impossible to achieve for the majority of nations under normal conditions. Moreover, some aspects of human 'happiness' remain tied to relative wealth, which meant the HPI could never achieve its aim to bypass GDP as a measure of sustainable development. Even if it did bypass wealth, its 'happiness' metric is tied to the unique concerns of adults by using WVS data averaging 42 years of age.

One of the first studies looked at the external validity of the HPI. Using its own methods, the study combined new data from the World Values Survey, Human Mortality Database and *Innocenti Report* to see whether its results held when disaggregated and matched by age and gender. As expected, the HPI was far more representative of adults and not significantly representative of children.

The Happy (Little) Planet Index described by this section challenged the original HPI, suggesting boys and girls at the age of 12 were more 'sustainable' by its own criteria. Within the sample of countries available, the original HPI put the Netherlands and Sweden as the most sustainable countries whereas the same methods applied to children demoted both nations in favour of 16 other countries topped by Bulgaria. If the HPI actually surveyed life satisfaction across different ages, and then matched those ages against the more granular data available for life expectancy, it would probably move towards achieving a more inclusive and equitable measure of sustainability.

The rest of the project then started exploring an alternative approach that moved away from a single composite metric of sustainability to a more useful and inclusive dashboard of human needs.

Although the NEF used the convergent validity between the HDI and the HPI as an argument supporting its methods, it turns out that singularity is a major problem because their shared subindices inflate the correlation. Instead, this work unpacked the subindices and used LE and LS as a form of convergent validity. The correlation was still respectable (0.69) but much weakened due to vast divergence in developing nations, where people could be just as happy regardless of living much shorter lives, even by 20 years! This already suggested that happiness is more relative than absolute. At the other end of the curve, results suggested happiness could never exceed a certain boundary no matter how much wealth was pursued. This again supported Set-Point Theory.

The superior form of convergent validity is criterion validity, which was then tested against both metrics using human height. Although less useful at a policy level and prone to genetic heritability, human height is more easily measured and understood and studies of identical twins show that being brought up in a more enriched, developed nation achieves heights that over-ride heritability (Silventoinen, 2003) – yet another good analogy heading in the same general trends as Set-Point Theory.

The criterion validity with human height was again respectable for both life expectancy and life satisfaction. This makes human height an especially valuable proxy of development as it can be measured from bone fragments going back millions of years under different ecological conditions (Steckel, 2002, 2005a, 2005b). Once again, however, the divergence at the lower ends of human height suggests life satisfaction, but not life expectancy, is more relative. In light of these results, the rationale of this work is probably unassailable. Although Veenhoven continues to argue that greater wealth offers greater happiness in the developed world, his arguments would also suggest that more and more human consumption of planetary resources would have to achieve a combination of immortality, heavenly bliss and gigantic heights. By contrast, three lines of evidence suggest there is a metabolic boundary operating to constrain all of these metrics no matter how much wealth or consumption is pursued. It tends to be a fuzzy boundary because background progress in medicine and technology tend to push the upper limits by about three months per year and it is perhaps this background effect that keeps the debate alive in terms of uncertainty and counterfactual findings.

Offering a new line of evidence for the fuzzy boundary, this work identified a consistently linear frontier for life expectancy when regressed on the maximum gain achievable against past baselines. No matter what comparisons were made over the past half century, all converged on a maximum boundary of 84 years. The same also emerged for life satisfaction where the possible maximum was 8 on the 10-point scale. Whereas the first matched the fuzzy boundary suggested by studies of supercentenarians, the second confirmed the work of Cummins set-point of 7.5. The boundary was again tested when extending the data to earlier periods using the Human Mortality Database going back to 1731. The broader timelines demonstrated a clear rise in maximum possible life expectancies for both men and women that again converged on a boundary of 84 years before peaking and beginning to fall from 2005-2010. If this trend continues, it would confirm Fiona Stanley's recent claim that younger generations will be the first to see a reversal of life expectancy since records began. If this is true, then similar falls in SWB should follow soon after. The data are now available to begin testing these predictions using the methods built in this work.

In the meantime, the simple preliminary studies used in this work suggested a boundary is always operating within the technological constraints of the era, but there is still room for incremental social progress. Before the apparent peak, the boundary was rising by about three months per year. It could be this effect that authors like Veenhoven are tapping into when citing proof for a minor linear gain across time, mistaking background progress with a more causal impact from wealth alone. Moreover, some of Veenhoven's work in this respect relies on his calculation of Happy Life Expectancy, where the variation in both metrics can amplify the 'fuzziness' of their respective boundaries by up to six years. Whatever the underlying mechanism, the fact remains that minor gains are made against comparatively huge ecological costs in the developed world. By contrast, the reverse is true for the developing world – huge gains can be made in health and happiness with comparatively lower impact on the ecology. This resonates with earlier descriptions of the utility function, its transformation to time and Pareto efficiency.

The global inequity in health and happiness can be likened to an overflowing cup in the developed world, its set-point creating the rim beyond nothing much more than internal equity could ever improve its carrying capacity at the population level.

This creates a diminishing return, the problem being that the overflow is not being captured and shared, especially across developing countries where the impact of small amounts would be large and enduring. The diminishing return for SWB previously shown by so many other authors was again replicated in this study using a completely different method in the form of the frontier. Again, it argues that redistribution of resources to serve the more primary needs of the developing world could still preserve the higher levels enjoyed by the developed world.

Whether it also allows for gains in the developed world itself then hinged on whether a bell-shaped, not linear, curve was making further resource consumption more antagonistic to human health beyond some unknown threshold of input. This was merely hinted at by the Bermuda Triangle - a consistent failure of any country in any given year to reach the possible boundary that manifested in a small triangular gap of lost years at the upper corners of the curves. Even the most long-lived countries like Norway, Hong Kong, Japan and Liechtenstein never fully reached the apparent ceiling in any given year. If a bell-curve could be fitted, it meant there were more complex metabolic limits to growth operating not just in terms of the broader ecology but also within the human organism itself.

This was first explored in this study by applying the frontier methods to calories. This was a logical first step because the caloric study served multiple purposes. It introduced and tested the frontier method for a basic physiological need supported by a century of known data against which the frontier results could be directly compared. Given the known links between calories and health on one hand as well as calories and carbon emissions on the other, the basic logic underlying the health co-benefits of climate change mitigation could be more intuitively understood - the value of moderating consumption on behalf of both people and the planet.

Two main findings from past research were presented in the first instance – one a study of half a million men and women within the United States that demonstrated the bell-curve between death rates and food consumption and the other that suggested the optimum outcome would be achieved at around 3000 calories per person per day. As expected, both were confirmed by the frontier curve across countries, demonstrating the method bypassed problems of ecological fallacy and minimised the effects of major omitted variables. The bell curve emerged in every year sampled from 1962-2005 and the interpolated optimum averaged 3030 calories. In spite of the gradual and significant gain of three months per year of life expectancy, the optimum value of caloric intake remained stable. It was consistently confirmed using various combinations of test-retest stability, split-sample reliability and even predictive validity, where the curve in 1962 successfully predicted the curve in 2005 at the level of r^2=0.82.

The fact that countries at the frontier changed across time also meant that the frontier curve could not be attributed to the cultural characteristics of one or two special nations. As would be expected from previous data from the World Bank, the shape of the bell-curve became more pronounced as more countries reached and then breached the peak of consumption (another metabolic set-point), all beginning to slide down the right-hand side of the bell curve – from Norway to Japan

This began to explain how one or two input metrics, when simultaneously pursued beyond threshold, could manifest in the mysterious Bermuda Triangle. If other factors operated in the same way, then the linear pursuit of growth in material consumption could create a cluster of effects that began pulling countries away from the maximum boundaries of human life expectancy. This cluster is sometimes summarised under the name of ‘affluenza’ (see deGraaf, Wann & Naylor, 2005; Hamilton & Denniss, 2005) with reference to the health gradient identified by the WHO Global Burden of Disease. So the next step in the study was to see how the frontier method worked with other factors, starting with human disease.

If the frontier was an appropriate method for other needs, it would first have to create a very different kind of curve for problems that are inherently antagonistic to human society. Rather than finding a bell-curve, it should reverse the findings, creating a linear curve that extrapolates to the fuzzy boundary at an input of zero rather than a moderated threshold. Traditionally, the development literature supporting the Millennium Development Goals has focused on problems like war, malnutrition, malaria, infant mortality and HIV death rates. Using data on death rates from WHO (2002), the frontier behaved exactly as predicted - each of these metrics, when extrapolated to zero, maximised life expectancy to the fuzzy boundary of around 84 years old. From the Global Burden of Disease Study and the economic health gradient, it was already known that one of the biggest sources of premature death and living disease burden afflicting wealthier nations was obesity manifesting in cancer, diabetes and heart disease. Once again, each metric behaved as it should have, all reversing the curves and again converging on the fuzzy boundary at zero cancer, diabetes, war, etc. The same occurred for tobacco and alcohol consumption.

Extrapolation to the zero intercept on life expectancy also began to support the idea that Maslow's original hierarchy could be tested across metrics. But given that the original study on caloric intake failed to match known survival times of about 65 days, the results were treated cautiously. Later tests found ways of stabilising the intercept, but it was already known from the caloric study that extrapolation became progressively less reliable as it strayed from the existing and observable data range, another major worry remaining that the birth and death registrations used to calculate LE vary with development, again affecting extrapolation.

Notwithstanding, what was found was fascinating. Applying the frontier to a much broader set of candidate needs from the World Bank Millennium Development Goals (2005), United Nations Human Development Index (2007) and New Economics Foundation Happy Planet Index (2005), it was found that Maslow's hierarchy was plausibly approximated. Using the zero intercept as a rough guide of survival times under conditions of deprivation, it was found that primary needs like food and water were more immediately important than higher needs like safety, social support, respect and education. This also supported Alderfer's distinction between primary and secondary needs, tending towards the idea that secondary needs are tapping factors of development, where theorists like Sen and Nussbaum focus on freedom and capabilities like education.

Although recent UN studies suggest 21 years' life expectancy might be a minimum below which no society can survive, the present study used an alternative approach to estimate a similar cut-off. It argued that allometric regression across species, relying on the known correlation between body mass and lifespan, could estimate a rough lifespan for humans in the absence of development. Across almost 600 species, the interpolated human result was 26 years. This meant any extrapolated deprivation intercept below this level would probably reflect a primary need, whereas all the deprivation points above this value should begin to capture the influence of social development outside of basic human metabolism. Once again tenuous but especially interesting given that gender equity in education came out as a primary need. By contrast, education itself was a secondary need, which meant gender equity was fundamentally more important on its own.

Most of the concerns of the developed world, such as freedom of the press, emerged as comparative quibbles when contrasted to the issues confronted by the developing world, where life expectancies have been as low as 36 years over the past few decades. To further contextualise, the world's first democracy only achieved life expectancies of 28 years, several years lower than the Upper Palaeolithic period of 33 years (Caspari & Lee, 2004; Hillard-Kaplan et al., 2000). It was not until the past 500 years that human life expectancy ranged much higher than 40 years (Galor, 2005). Other issues of concern to the developed world, such as economic growth turn out to be antagonistic to human needs if sustained across many years, only offering positive benefits when moderated to 1.7%, and even then achieving minor gains about equal to freedom of the press itself.

When it came to placing some of the most inequitable metrics on the emerging hierarchy, a major statistical obstacle emerged. To capture extremely high levels of input among the developed nations on key issues like GDP, Ecological Footprint and Carbon Emissions needed a natural logarithmic transformation to fit the same inclusive curve. The problem was that the transformation always inflated the zero intercept, making their results impossible to place on the same hierarchy. Many different alternatives were tested but the solution was fairly simple in the end – simply relaxing the original criterion that the same curve shape should be applied and again allowing the data to speak for itself using robust regression across different curve shapes. Transformations were avoided, curve shapes were strengthened but it did sometimes require judgment on behalf of the researcher as to which curve to select among equally significant shapes. The simplest curve that minimised error was always chosen. This was later tested for calories using other techniques and was generally confirmed as a reasonable and stable approach.

Notwithstanding these issues, the results were still clear in the growing attempt to build a plausible hierarchy of human needs. All of the results suggested that there is some kind of ‘sweet pot’ wherein the health co-benefits of climate change mitigation could move societies towards a healthier outcome – even if the threat of climate change was moot.

There was only one way of testing the hierarchy that emerged using a different method and this was based on econometric studies of elasticities. A recent global study across 73 nations (Hertwich & Peters, 2009) found that 72% of GHGs were due to household consumption, the rest given over to government and private investment. In this study, food and shelter both accounted for about 20% each, transport mobility about 17% but these, along with manufactured goods and services rapidly started rising among advanced nations. What was fascinating, however, was the way in which expenditure versus carbon elasticities diverged. Whereas carbon efficiencies were all over the place, expenditure elasticities, as expected, followed Maslow’s hierarchy as well as the emergent rankings found in this study.

Recall that elasticities are measured in a way that completely bypass life expectancy by measuring how little the amount spent varies in spite of changes in incomes or prices. So the smaller elasticities suggest that people and nations, no matter how much their external conditions might change, will still pursue the same general levels of consumption. The higher the elasticities, the more they move towards discretionary spending based on personal preferences rather than metabolic needs. In other words, elasticity is a proxy of need strength. What was found in this study was that the frontier method converged with the same results. What emerged was a hierarchical ranking with food and clothing as more basic and inelastic essentials compared with products and services at the higher and more elastic levels of consumption.

Following on from this, one of the most important studies in this work replicated the caloric intake study using carbon emissions alone. This was a more detailed study that sampled the frontier in every available year from 1960-2007 to measure the stability of the optimum. It tested the same optima using robust regression and more than a thousand simulations of each curve and data point. But even when using more advanced statistical processes, the same results emerged. Every year displayed a bell curve where the interpolated optimum was stable within a tight band averaging only 6.6 tonnes per capita, a far more moderated level than those pursued by countries like Australia and the United States.

It was especially important to demonstrate the bell curve in this study because it offered the first empirical test of the Contraction and Convergence target based on human outcomes. Because the curve had been stable over the past half century, it also meant it would be just as relevant leading up to 2050, allowing some predictions based on the Meinshausen model of climate change and carbon budgets of only 0.33 tonnes per capita from 2050 onwards. The implications, taking into account growth in population, offered a slim chance of redemption as long as the international community moved to restrict carbon emissions immediately. Although the impact of climate change itself would continue to affect death rates, the more direct effect of pulling back carbon emissions would cause no *global loss* in life expectancy, especially given that any effect would be softened by the background gains of three months per year trending since 1960. Moreover, there is some evidence emerging from this work that even this level of 6.6 tonnes might be an over-estimate, making the implications a little more optimistic again.

4.1.10 Methodological Constraints

Rigorous scientific logic, when applied to social systems, is hard to achieve because it has to rely on results that cannot, without statistical ingenuity, experimentally control for major problems of logical inference. These are briefly revisited below and then discussed in the context of the results (Table 4-1).

Table 4-1 Common issues in scientific reasoning as they might affect this study

Exception Fallacy	Mistakenly attributing exceptional characteristic of an individual, whether good or bad, to their broader group (as in racism)
Ecological Fallacy	Attributing the ecological characteristics of a group to an individual member or subset of that group (again as in racism)
Spurious Correlation	Attributing causality between two characteristics that rise and fall together when there is a hidden characteristic affecting both
Simpson's Paradox	An extreme version of ecological fallacy where shifting between a subset and larger group reverses results (as in diabetes)
Ecological Range Restriction	Attributing the characteristics of a smaller subset to a larger possible group (as in generalising from OECD data to all nations)
Time Range Restriction	Attributing the characteristics at one time to all times (as in generalising from results in one decade to expectations in the future)
Unequal Data Densities	Fitting a curve that is exaggerated by individuals collecting around a tighter range (increasing the probability of outliers)
Statistical Average Bias	Thinking that trends based on the average reflect the best possible outcomes available (as in thinking the average global life expectancy of only 66 years is the optimum)

Range restriction was a problem confronted by Cantril and Easterlin and later overcome by the work of Veenhoven. It creates many more problems than it should. Even this year, the OECD produced a range-restricted study showing Australia was the happiest country in its dataset but this was interpreted by the public media as being confirmation of wealth being the main driver, completely forgetting that the OECD study covers only a subsample of the world's nations and many other countries are much more efficiently happier and healthier for reasons other than wealth. This is why the current study always maximised the sample size as the primary concern, not only across countries but also across time periods.

Context is everything, from sensory neuropsychology to scientific method. Even Simpson's Paradox as an extreme form of Ecological Fallacy becomes less paradoxical when range restriction is accounted for in comparing individual studies (especially when funding for studies is more available in wealthier nations and so results are more likely to be reported). It was argued that even if studies on diabetes were to be expanded across impoverished nations where funding is less available, the results would likely reflect the cross-national economic gradient.

The next point is a little simpler - that fallacies of Exception or Ecology, whilst always casting a shadow over range-restricted studies, can be completely eliminated, by falsification, when results actually match across countries, within countries and across time. This project turned these fallacies on their heads by arguing that if the same results triangulate under each condition they can be eliminated as fallacies by falsification. For example, this can be seen in the degree to which recommended caloric intake in advanced economies matched optimal life expectancies across countries and across time, whether by reference to the past half-century of data from the UN and WHO or by inference from anthropological studies in the current era versus paleoanthropological studies from pre-history. Further evidence tends to emerge using allometric regression, another level of evidence that is usually overlooked in social science – despite being one newly available disciplinary equivalent of the animal analogue in medical physiology.

Even when these issues are successfully bypassed, the problem of spurious correlation remains intact. Just because the same value of caloric intake tends to increase life expectancies across and within nations, does not mean some other factor is not the hidden variable linked to both, such as unstable food distribution due to war - both influencing death rates.

Here, another problem interacts. The statistical bias towards analysing the mean intrinsically embraces a whole bunch of possible influences where the error above and below the mean captures the combined inputs of malnutrition alongside war, disease and extreme inequity at the lower ranges of national wealth versus over-eating and sedentary lifestyles, alcohol and tobacco consumption at the higher ranges of national wealth. This does not even include the depth and consistency of healthcare investments affecting maternal and infant mortality, immunization, malaria and HIV. In this work, the gross effects of omitted variables are partially eliminated by shifting the analysis from the average to the frontier.

In the final analysis, the work returned to caloric intake as a test case for the methods in an attempt to address some other serious concerns. The first concern was the influence of outliers at the frontier, especially given that a single unusual country could completely change the extrapolated intercepts upon which the hierarchical ranking relied. By contrast, the interpolated optima, used to identify the actual target for each input variable, was always much more robust and consistent. For the more vulnerable intercept, the effect of outliers that were stubbornly retained in each analysis was partly minimised by splitting and recombining subsamples that displayed high split-sample reliability.

But even further splits (unreported) could not avoid the problem of data density raised by an anonymous reviewer for the first paper (Read, et al., 2013). Although most countries collected around the optimal value, as would be predicted for a human need, this raised the possibility that data density around the optimum could increase the risk of outliers. By contrast, the lower density at the extreme ends in either direction persistently dwindles down to only one country, which then minimises the risk of outliers but lowers confidence in the validity of the extrapolation. If just one of these more extreme countries turned out to be an outlier itself, the curve would be distorted for the extrapolated intercept. This is why continuous splits could never overcome the problem of divergent data density across the input range but merely carved up the same curve with all its inherent problems.

As it turned out, the only way to overcome the problem was to retest the curve with data density more or less equalised across the range of input. As in all of the previous analyses, a solution was sought that would apply a general rule outside of the researcher's own judgment so the datasets could continue to speak for themselves. The way it was done was to apply the maximum accepted level of α-trimming to the z-transformed metric of normally distributed efficiency. Whilst retaining respectable sample sizes, the cut-off of 25% eliminated the most extreme outliers for both variables (in this case calories and life expectancy), whether because of measurement error or unusual advantages. It meant the remaining sample of raw data represented the ability of the majority (75%) of nations to maximise efficiency under normal conditions.

This had the unintended but welcome effect of also increasing, sometimes doubling the sample size at the frontier. Moreover it significantly decreased the standard error for the split-sample reliability, the interpolated optima and the extrapolated intercepts, all of which then became more stable and predictive across time. The final result confirmed the bell curve but inflated the target from 3030 calories to 3244 calories. This suggested that data density was not distorting the basic curve but that the majority of advanced countries, as expected, are relying on more consumption than needed, whether due to overconsumption, structural inefficiencies, inequities, wastage or all four.

Food wastage was a major problem in this study as it likely distorts the curve. Among poorer countries, inefficiencies in production and storage cannot be escaped as the infrastructure is unavailable to protect produce from vermin, mould and bacteria. Wealthier countries have better production efficiencies but wastage emerges down the line at the consumer level based on choices for out-of-season produce, more stringent policies on food safety and rejection of ‘imperfect’ food stuffs by supermarkets and household consumers themselves. At the global level, existing inequities already distort the market because it is cheaper for wealthy countries to import food than to buy local produce. If they have an open trade system with minimal tariff barriers, it also encourages supply manipulation by market dumping or even making it cheaper for farmers to destroy their local produce. These are all market distortions that have unintended and wasteful consequences. One of the exceptions among wealthy countries is Japan, where waste is minimised because food is more highly taxed.

The fact that up to one third of all global food production is wasted because of all these different mechanisms make it all the more surprising that the more moderated bell-curve still asserts itself across time and as countries become wealthier. It is this trend that has the biggest implications for sustainability.

One third of emissions come from the global food system (Bellarby et al., 2008), animal products make up a third of the average developed diet, which then accounts for about 15% of disease burden. By contrast, human and animal studies show that caloric restriction prolongs life and pure vegan diets again reduce the carbon footprint by 91%. Although imperfect in terms of extrapolation, pure frontier regression does begin to build a framework supporting a moderation of metabolic consumption that moves towards global sustainability and improves national health.

The extrapolated intercepts, whether based on zero calories (-61 LE) or zero LE (841 calories), were significantly correlated even though the former still became less stable as it moved away from the observable data range. This suggested using the zero intercept to rank human needs is cautiously supported, but could be further improved on behalf of most countries if all metrics were rechecked using α-trimming. The results tend to suggest that data density and the risk of outliers is not nearly as worrisome as might be expected, especially for the interpolated optima, although their possibility should be kept in mind and tested whenever possible. Inflated optima also provide a buffer for adaptation in the short-term, were policies pursued based on this work. Regardless, the same broad trend towards moderation continues to emerge, is stable across time and different frontier countries, and is further supported by other studies across many different disciplines.

Which brings the argument to the next major challenge to the bell shaped curve. Infancy and old age are the two primary peaks of mortality. In undeveloped countries and cultures, infant mortality can account for up to half the overall mortality, which then underestimates life expectancy itself. It has the effect of increasingly underestimating the adult life expectancy as it slides down the left-hand slope of the consumption curve. This would then naturally create falling extrapolations to negative values, (which remain nonsensical against the expected survival time of 65 days for food, as an example) and again evokes the spectre of Ecological Fallacy. The solution used here was taken from standard practice in studies of national life expectancy. Rather than taking life expectancy at birth, it returned to the original mortality league tables and retested the *remaining* life expectancies at ages 1 and 5 years. What emerged was just as expected.

At age 1, the extrapolated intercept was almost halved from -60 to -34 years, suggesting around 25 years (60-34+1) of lost life expectancy due to *infant* mortality alone. At age 5, it again changed from -34 to -21 years, suggesting about 8 years (34-28+5) lost due to *child* mortality. The study went a little further and replicated the curve across the entire life course. In every case, the bell shaped curve reasserted itself, creating optimal population targets of 2900 calories at age 1, 2950 at age 5, 3000 at age 30, 3125 at age 65 and 3000 for supercentenarians. (Recall that the life expectancies refer to the remaining population and so it's not surprising that the bell curve still predicts similar optima, even though children and the elderly need much less caloric intake than adults.) These results were replicated for 22 age cohorts in 2000 and six age cohorts in 1990. When splitting by gender at age 1 in 1990, it even began to correctly distinguish the greater caloric needs of men at 3000 calories versus women at 2800 calories. This difference could never be replicated for the remainder of the studies because they all focused on life expectancy at birth.

A quick summary is that the problems of outliers, data density and infant mortality did not so much challenge the broad trends uncovered in this work as point to better ways of measuring them. Had these issues been understood from the outset, the project would have restricted the analyses to life expectancies at age 1 and split each analysis by gender. The issue of data density is not as great as it might seem but it would still serve to retest the final results using α-trimming, if only to gain a better appreciation of what the majority of countries under normal conditions are capable of achieving within the constraints of sustainability.

Note the latest recommendations have actually reduced the daily recommended intake, from the original UN estimate of 3000 calories (Bissio, 1997, pp. 15-17) to an even more moderated range based on age and gender from 2100-2700 calories across France, Australia (NSW, 2012) and the United States (DHHS & USDA, 1989). In other areas, caloric restriction has only recently become a salient factor in longevity, fitness and health, and is also demonstrated in non-human primates where Alpha females die earlier than expected despite their privileged access to food (Colman et al., 2009). It turns out that ‘middle class’ monkeys live longest.

The final challenge to this work was more theoretical as it came up against the issue of causality. Almost all of the curves depicted in this work assumed causality in one form or another, either directly or indirectly through a cascade of intermediary effects. Whilst a broad and picturesque landscape was painted using stylised curves, there can be no escaping the problem that without causality affecting life expectancy on one hand and carbon emissions on the other, any movement towards the apparent sustainability targets would be a waste of time and effort on behalf of the world’s nations.

This argument would appear to be handing resistant interest groups a key to unravelling the science but it should be remembered that causality is a two-edged sword. The same kinds of tests would have to be applied across every metric. If causality could not be proven for something as basic as caloric intake, then it would be exceedingly unlikely to operate for extreme wealth, in which case the Precautionary Principle still puts a premium on acting to mitigate risk, especially if the externalities of pursuing the sustainability targets are likely to be benign. What's more, if causality does not exist, as some might argue, then pursuing these targets would have no negative effect on people anyway. So those who want to preserve business as usual would, by their own arguments, fail. Ultimately causality is completely unprovable in any science (see Hume, 1739), but it can still be inferred by looking at changes across time and ensuring any change in an independent variable like calories tends to precede changes in the dependent variable, here life expectancy. Austin Hill (1965) applied the philosophical works of Hume and Popper to notions of causality in human epidemiology, nominating the following characteristics as necessary conditions: strength, consistency, specificity, temporality, gradient, plausibility, coherence, evidence and analogy. Many of these echo previous discussions on validity and reliability and their handling in this work is briefly addressed for each criterion in Table 4-2 overleaf.

So far, causality has not been tested in this work but the first step would be to examine dose-response changes within countries and across time as they move towards or away from the interpolated targets, preferably with additional reference to instrumental variables. But this is much more complicated than it sounds (as was found when it was attempted in preliminary studies). Because the various metrics are ranked by their inherent survival time, such a test would have to account for divergent lag-times, so concurrent validity would have to be adjusted for each metric, which presumes accuracy in the first place.

Table 4-2 Foundational requirements for epidemiological causality applied to needs

Strength	Correlation captures the numeric gradient that underlies the significance of more blunt statistical methods based on divergent group comparisons (e.g. odds ratios, ANOVA). In this work, frontier curves were all strong.
Consistency	Consistency means the same correlation can be observed by different people in different places and times. The methods here were purposefully simple enough for many different observers to replicate using split-sampling and time series.
Specificity	Specificity is where an effect is limited to certain people in certain specific situations This was shown in this work, wherever possible, by reference to historical accidents.
Temporality	The direction of causality can be inferred when a change in input temporally precedes a change in output and not vice versa. In this context, partial deprivation of a need should precede a reduction in life expectancy. This is impossible to test in the case of slow effect times, described following this table.
Gradient	A biological gradient, or dose-response relationship, was shown for all candidate needs; in fact, was a defining characteristic of being included in the hierarchy
Plausibility	Based entirely on past research and theory, plausibility is similar to face validity – the degree to which causality makes sense. In the case of needs like food and water the likelihood of death under deprivation is eminently plausible.
Coherence	Coherence demands any causal relationship should not conflict with what is already known. Although bidirectional pathways are likely to exist for some needs, triangulation from a multidisciplinary literature supports the broad findings.
Evidence	Experimental evidence is unethical in the context of this work as was discussed in detail. An ABAB design in a laboratory or other controlled setting is impossible.
Analogy	Analogy is reasoning from similar phenomena. In this study, the bell curve was proposed for higher needs by analogy to lower needs. Metabolic homeostasis was used as a model for seeking planetary and socioeconomic balance.

To illustrate, the results so far suggest that halving caloric intake might impact life expectancy in the same year, but halving education could take another four decades to manifest any effect. This is perhaps why Sen only found that economic growth was antagonistic to life expectancy when he looked at decadal rather than concurrent trends. To add further complexity, the lag-time was also influenced by the position the individual country started off in the first place. If the country started off *below target* and lost another 500 calories, the β-slope would predict a short lag-time for an effect on life expectancy through the direct impact of malnutrition. By contrast, countries starting *above target* that gain another 500 calories would have a much longer lag-time through more indirect routes via obesity.

The analysis becomes even more complex as some countries longitudinally cross the target, where different β-slopes start interacting to affect the lag-times themselves. This kind of approach is likely to be used in further studies as further work is pursued beyond this preliminary work. Preliminary results, not reported here, are at least promising but the complexity could never have been captured without first looking at the stylised curves. On top of this, the emergent ranking, whilst tenuous, at least points to a number of key variables that must be tested in a multivariate framework.

Econometric methods have led the way in identifying and handling many of these issues by continuously refining statistical methods and including new regression techniques using time series and instrumental variables to eliminate omitted variables and infer causality. In this project, causality is not yet addressed using instrumental variables across social data and this would be a natural next step in the work, along with measuring temporality. Although the cross-sectional data across time demonstrates universality and stability, further within-country data across time are necessary to assess causality. The Australian Unity dataset would be a perfect candidate, along with HILDA and SOEP datasets, among others, although further work is also needed to replicate their results among developing and impoverished nations, along with some key countries like Vietnam, Costa Rica and Vanuatu.

A lot of data are available from the extant literature but should also be explored in much more detail wherever gaps emerge to start making these intra-country efforts more universally contextualised and placed in their proper place as critical to issues of sustainability and measuring social progress ‘beyond’ GDP. One of the biggest gaps in this literature is the degree to which human needs are either preserved or perverted within comparatively sustainable and unsustainable countries. It should also explore changing needs across the lifecourse and how national policies adapt to their own changing age and gender-based demographics.

One final potential criticism of the entire work hinges on its use of life expectancy as the universal output. Aristotle insists that “not everything that is last claims to be an end (telos, the goal), but only that which is best” (Phys. 194 p 32-33). Ironically, that which is last is ultimately death, which, due respect to Aristotle, is hardly that ‘which is best’. In this work, delaying death on behalf of whole populations would seem to be a reasonable goal, but raises some uncomfortable issues itself.

Longevity seems to be a universal goal for both populations and individuals. But when it comes to the species, increasing longevity could start creating difficulties in a climate-constrained future. At present, the average life expectancy is 66 years. However, imagine a hypothetical world where all countries reached the current fuzzy boundary of 84 years. It would immediately increase the world’s living population by roughly 25%, mostly among the aged. This would put acute demands on younger generations via the dependency ratio, probably result in lower fertility rates, and again limit their ability to satisfy their own needs at their own stage of the human lifecourse.

This raises some peculiar issues of relevance to both international and intergenerational equity that deserve to be explored in further detail as they raise the possibility of paradoxical and unintended consequences. One example would be a continuous distortion of the dependency ratio that leads to economic collapse in the long run. Having noted this, however, satisfying human needs at each stage of the lifecourse should maximise health-adjusted life years, such that older people will be healthier, more fully functioning and more economically self-sufficient in their later years. Reasonable self-sufficiency would be possible and then puts less pressure on younger generations so they can redistribute income to satisfy their own needs and the needs of their children.

Moreover, the world would, according to this work, be a happier place, and probably more inter-generationally supportive and cohesive, as a secondary outcome of satisfying human needs which support social and family cohesion. Notwithstanding methodological weaknesses, the ultimate stability of the curves over time, plus their validation by within-country studies, tend to obviate the demand for more sophisticated analyses - but only for now.

As stated, the results all converge on the idea that human and planetary needs could be balanced in a way that preserves development across nations and time, but only if rapid, more human-centred, changes are made to concepts of prosperity in the short term. This puts the obligation firmly in the hands of government to match policy to human needs, without which individual efforts to curb carbon emissions are not supported and possibly even self-defeating when government is at odds with the concerns of households, families and their children. The same goes for economic growth and the way it manifests in the workplace and economy. Social progress must pursue and support human integrity that is informed across disciplines and levels of social aggregation from the individual all the way up to the governments of nations, without which people are forced to live in ways that are antagonistic to their needs, hopes and more enlightened aspirations.

Despite a few decades focused on happiness, theorists are revisiting concepts of existential meaning and virtue (Baumeister, 2012; Mackay, 2013). Baumeister (2012) recently published work in which the relationships between happiness and meaning were disentangled, finding both factors feed one another but that living a meaningful life was the only pathway towards adaptive self-actualisation. Happiness was more affective (as per Cummins, 2013) whereas meaning was more resilient to misfortune and grounded in making a social contribution that both sacrifices and expresses the self – in other words deriving life satisfaction, and possibly even joy, by giving back to the community. This hardly overturns work on the importance of measuring human happiness but again suggests global ‘life satisfaction’ is more reflective of SWB, perhaps protective of the set-point because of greater resilience. The problem, again, is that none of this serves government policy focused on economic growth.

As for the battle between Easterlin and Veenhoven, a key study by Diener, Khaneman and associates (2009) separated cognitive and affective elements of SWB and concluded whilst “the well-being of nations can indeed change over time, and that certain forms of well-being are more likely to change in association with changes in income …, other factors in societies besides income must be considered, such as social trust … and Easterlin was correct in his claim that rising incomes do not invariably increase subjective well-being” (p 16).

Australian social researcher Hugh Mackay (2013) goes much further and says the ‘happiness movement’ has become ‘a collective neurosis’ that stunts authentic wholeness and feeds into the growth mentality. It privileges one emotion – happiness - as the goal across the whole spectrum of human experience, promoting hollow notions of a perfect emotional utopia founded on materialism. Despite rising prosperity, Mackay said the consumption of antidepressants in the 1990's tripled and psychologists are seeing children wounded by the social push for self-esteem. He says the best way to 'land your kids in therapy is tell them they're special'. By promoting what he calls 'Brand Me', children will not be resilient enough to cope with all the other competing 'brands', much less the pressures of climate change, globalisation and social change. Mackay cites Carl Rogers as understanding the self not as an individualistic unit but as a part of society. He further says, perhaps resonant of Diamond (2005), that civilisations fail almost exclusively because of selfishness but altruism is just as much a part of the human condition as competition.

Mackay (2013) returns to the Golden Rule of the secular humanists that a meaningful life is a life lived for others, where self-esteem is replaced with self-control and self-respect. Embracing almost every religion and secular philosophy, Mackay summarises the Golden Rule as treating others as you would like to be treated. To paraphrase, he says the application of the Golden Rule is achieved by four key tools - to listen attentively, to respect equally, to apologise sincerely and to forgive generously. The ultimate reason, he says, "is not about survival of the fittest but survival of the species." Without respect, extending to the natural world, he concludes: "even if we happen to survive, we become our inglorious worst" (Mackay, 2013, p 197).

4.1.11 Summary, Policy Implications and Conclusions

The studies outlined in the project support the argument that human ‘socio-metabolic’ limits, even disregarding ecological limits, constrains the value of economic growth in its current form, whether applied to health, height or happiness, all basic human outputs that are essentially bounded in every era even despite prevailing ideology and data over the past century that argues more is better. Whereas human outputs are bounded to a set-point, human inputs are unbounded and their pursuit is probably damaging human health and happiness, much less the existing impact on the planetary ecology and, by extension, its impact on future health and happiness.

The concept of human needs, rather than values, is more resonant with the original definition of sustainability and even offers a more optimistic view of the future. Evidence for Set-Point Theory resonates with Max-Neef’s threshold theory. Maslow’s Hierarchy, when combined with Alderfer’s distinction between primary and secondary needs then matches the emergent data. All are variable enough to accommodate hard-wired and heritable primary needs with more elastic and adaptive secondary needs, both requiring enough freedom to maximise human outcomes - after Sen’s Capability Theory.

This is a form of Synthesis (Eckersley, 2005) that attempts to balance simplicity (Occam’s razor) with Complexity Theory (Kaufman, 1995) and the Evolutionary Health Principle (Boyden, 1994). Each theory is needed for the preservation of human needs, cultural diversity, freedom and dignity, whilst balancing universality and adaptability across time. Without synthesis, intradisciplinary reductionism creates more confusion and debate – a luxury that is probably not available when it comes to climate change.

The hierarchy of human needs should transcend cultural values at the social level whilst still allowing the freedom and dignity of people to pursue their own values at the individual level – as long as they do not impact upon their own or other people's basic needs, including people living in the future. In retaining the strongest elements of each theory, the argument emerges that society and its elected government has a duty to build capabilities for self-actualisation that never suppress the needs of self or others. Impacting on needs of the self becomes a psychological problem whereas impacting on those of others becomes, to varying degrees, morally bereft. Even the concept of dynamic flux can be retained within this framework as different needs must be reasonably elastic to ensure adaptability within different socioeconomic and cultural milieus.

The key point, however, is that dynamic flux can never outrank or over-ride the basic hierarchy of primary needs and this, along with freedom, ensures movement towards equity within and cross nations. At the global level, as population growth collides with climate change, the only way to engage multilateral cooperation aimed at preserving the biosphere on behalf of future generations will be to champion international equity on behalf of present generations. This is not to argue, as is traditional, that equity must be expressed in terms of the dollar. Wealth itself is part of the problem and little more than a symbolic metric for the transfer of energy. It's not so much the absolute value of the symbol that is important as how, why and what is transformed and transferred between the planet and its people. There is no doubt there are limits to absolute energy consumption when drawn from non-renewable resources. What this study shows is that there are probably also metabolic limits to human consumption as well.

Originally, the work set out to find out why so many special nations have achieved high human outcomes despite meagre resources, and whether they might provide a model for the rest of the world to follow. In this endeavour, it ended up asking many more questions. Even as this work sought to build a framework that might uncover the secrets of Vanuatu, Costa Rica, Malta, Vietnam, Bhutan and many others, it gradually evolved into an exploration of far more complex issues, laying the foundations for future research. One issue that received scant attention was whether the findings are unusually influenced by the predominance of small island nations in this special category. To fill this gap, Figure 4.2 briefly shows the main results for LE and CE when all of the smaller nations are first eliminated from the sample. Any country with a population below 1 million effectively removed 26 countries, including Vanuatu, Bhutan and Malta, leaving 151 countries.

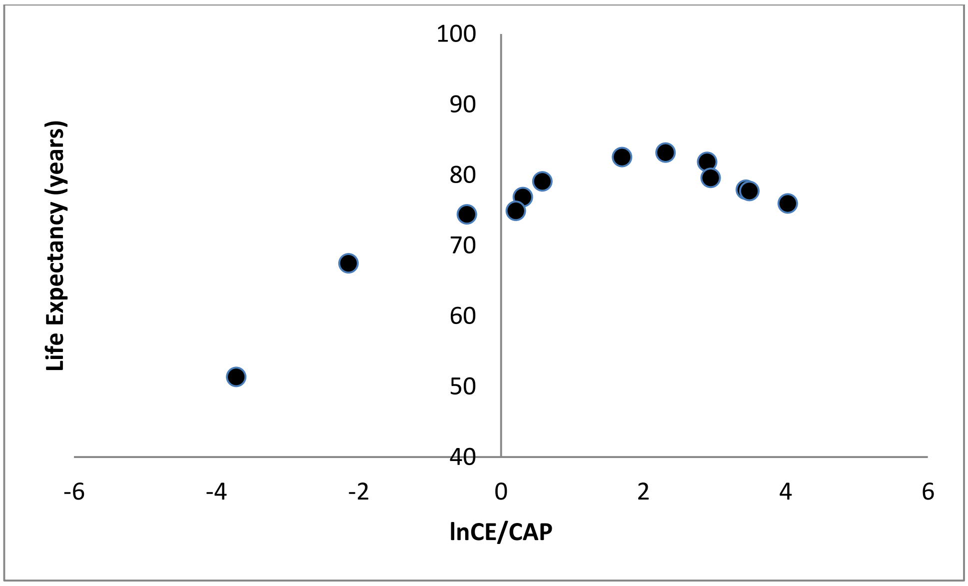


Figure 4-2 Not just small island nations – the same curve emerges for populations above one million people.

As can be seen, the same curve emerges yet again, with LE maximised, as expected, at 6.6 tonnes per capita of CE (ln1.8=6.6). A stated earlier, even if the smaller budget is applied as early as 2050, the frontier curve in this study might still offer a more optimistic outcome with no average global loss in LE, even when using the highest CE in 2005 (8.9 CE/cap).

To fill another gap in the analyses, a very brief description of policy implications is offered before finishing, comparing Rwanda, Vanuatu, Japan, Australia and the United States. Whilst further work is needed, the implications of the current work for selected individual countries is informed by Table 4.3.

Much more work is yet to be done on validating the intercepts, optima and causality for these and many other indices. But as long as they are demonstrated to be time-invariant, it means equivalent indices can be usefully compared to develop case profiles for different nations, fruitfully used in modelling where some counter-intuitive metrics emerge as more or less important than previously thought (e.g. income share of the richest and carbon emissions respectively).

To illustrate, Table 4.3 compares five countries on a representative selection of indices that were explored in the current work. Rwanda was chosen to represent low development, Costa Rica to represent low development but especially high life expectancy and life satisfaction, Norway and Japan for their comparatively high sustainability among developed nations, Australia and the United States because they consistently begin to fall short of human outputs even as their reliance on carbon emissions increases.

Table 4-3 Reading zero intercept and optimum for policy across selected nations.

Subindices	Zero Intrcpt	Optimum	Rwanda	Costa Rica	Japan	Norway	Australia	USA
Life Expectancy	0	83	51	79	83	81	82	79
Primary Needs								
Water Quality	-24	100%	65	97	100	100	100	99
Calories (2002)	-12	3000 kcal	2086	2872	2775	3500	3090	3766
Income share richest 10% ('02)	5	<30%	24.2%	34.6%	21.7%	21.8%	25.4%	30.5%
Feeling Safe	15	100%	80	44	73	81	63	75
Safe from Assault	15	100%	94	84	99	97	96	98
Social Support	22	100%	56	90	89	93	94	91
Gender Equity	23	0.25	0.638	0.501	0.273	0.234	0.296	0.400
Secondary Needs								
Life Satisfaction	32	7.8	4.2	8.5	6.8	8.1	7.9	7.9
Education Years	32	11 years	10.6	8.3	11.5	12.6	12.0	12.4
Respected	34	100%	77	90	60	90	89	89
Feeling Free	37	80%	77	87	70	93	91	83
Gini Coefficient	57	33	46.7	49.7	24.9	25.8	35.2	40.8
GDP (2009)	59	34603	458	6564	38455	94759	47370	46350
Income share poorest 10% ('02	61	>3.5%	4.2%	1.7%	4.8%	4.1%	2%	1.8%
GNI (PPP 2010)	66	37729	1190	10870	34692	58809	38692	47094
Carbon Emissions	68	6.6	0.1	1.8	10	8.6	18	19
Press Freedom	69	0=100%	64.7	8	3.3	0	3.1	4.0
Recent Inflation	76	1.7%	8.5	11.3	0.0	1.7	3	2.8
Antagonists								
Malaria	78	0/100k	6510	42	0	0	0	0
Infant Mortality	79	0/100k	72	10	3	3	5	7
Tobacco	79	0%	5.5	N/A	31	26	20	17.5
Adol. Fert. Rate	80	0/100k	36.7	67	4.7	8.6	14.9	35.9
HIV AIDS	80	0/100k	2.8	0.4	N/A	0.1	0.2	0.6
War Fatal. (Civ)	80	0/100k	280	0	0	0	0	0
Homicide	80	0/100k	4.2	8.3	0.5	0.6	1.2	5.2
Malnutrition	81	0%	45%	<5%	<5%	<5%	<5%	<5%

Table 4.3 can be read downwards from primary to secondary needs (based on the intercept) as well as across to see which nations are failing to reach the optimum. Working down the list, the first red flag emerges for Rwanda in terms of water. The low intercept means the B slope is steeper than all following metrics so this means water is a priority for Rwandan policy. The next is calories but this is more nuanced as the curve is not linear; it is more like a dose-response curve. Three countries need to increase caloric intake and three needs to decrease it. Because the slope is steeper leading up to the optimum, the most impoverished nation, again Rwanda, would theoretically gain more in human outputs by increasing daily average calories than Norway and the United States might gain from reducing calories. Japan, which is known to tax foods more heavily than other countries could provide a model for Norway and the United States. An interesting policy mechanism would be to channel those taxes to foreign aid whilst maintaining health spending. This would also have to make sure that healthier foodstuffs were tax-free especially in the presence of high income inequity. The problem of caloric intake is actually not quite as impossible for sustainability as might be thought – as stated there is enough food produced to eliminate malnutrition worldwide. But it would require nations discouraging consumption of meat, imperfect foodstuffs at market, carbon-intensive transport and wastage; such a mechanism could be applied in Australia by adjusting the GST.

Two equity metrics emerge as important in primary needs and they are income equity and gender equity (gender equity in education was also important but this is not included here). Only one country achieves the gender equity target and that is Norway, Japan a close second. The red flag is Costa Rica. Despite its high life expectancy, Costa Rica could still make improvements by embracing much stronger gender and income equity. This would need changes to the taxation regime as well as gender policy and enforcement. It also seems that, among those social metrics included here, Costa Rica has an issue with crime and safety. The importance of equity and good and consistent governance cannot be overstated. This work shows that the ratio of the poorest to richest 10% must be moderated to maximise LE, much more than is evolving in the United States (see Stiglitz, 2014). Further, incentivisation through good governance and meritocratic equity is forcefully shown to build national development in the historical context (Acemoglu & Robinson, 2012).

Another important finding is that interconnected metrics like GNI, GDP, inflation and carbon emissions are all less important to national longevity than primary needs like food, water, safety and equity, as predicted by Maslow. Life satisfaction, education, respect, freedom and equity are also more important than these economic outputs. This means these social needs have steeper slopes, at least heading towards the optimum, and policy designed to enhance them would have a faster and stronger impact on life expectancy than pursuit of further economic growth among already advanced nations. Several countries would make gains, assuming causality, if they pursued less education (Australia, USA, Norway), greater respect and freedom (Japan) and greater equity (USA, Costa Rica, Rwanda). Three countries need to increase their income share to the poorest 10% and these include Costa Rica, Australia and the United States.

As for the economic metrics, it’s not surprising that growth is being pursued more vigorously in Rwanda and Costa Rica, as it should be, but perhaps Australia and the United States could attenuate growth if it’s mainly based on productivity per person in terms of greater work hours rather than more effective work hours that support work-life balance and redistribute jobs. Aiming at work-life balance, with proper policy, could enhance social needs and life satisfaction, as well as more inclusive employment, areas that have a stronger slope and possibly a stronger impact in terms of life expectancy.

One of the most important policy aspects of this work is that carbon emissions can be reduced in economies that seek to enhance human outputs. Even a resource intensive country like Australia, which relies on non-renewable resources for its existing comparative advantage, cannot deny that there are other models of advanced knowledge economies, for example Japan, that can operate successfully in a carbon-constrained model.

A warning is warranted, though. Whilst no *global* loss in life expectancy would be caused by redistribution of carbon budgets, Japan, even though it already sits at the optimum could, paradoxically, lose a few years of LE under a 6.6 budget, at least if causality operates. As stated, 88 countries achieved the frontier over the past half-century but only those like Japan that achieve the optimum across both technical and productive efficiency would lose under a C&C target of 6.6 tonnes if causality operates. Costa Rica retained its position for 41 years, followed by Vietnam, Cuba and Malta. By contrast, Australia reaches the frontier across 18 years but always emits more than the predicted optimum. Because it loses LE and LS as a consequence, Australia could potentially gain by pulling back to the C&C target.

Outside of primary and secondary needs, there is a third classification in this table that covers linear antagonists to human life expectancy. In all cases except malnutrition, which has the strongest slope, there would be no net reliance on further carbon emissions were they to be reduced. Homicide and civil war are known to increase with higher carbon emissions and also produce higher carbon emissions in the efforts of rebuilding both property and lives. Note that tobacco consumption, as per the WHO economic gradient, does increase among wealthier, more carbon intensive nations whereas infant mortality and malaria could be reduced with more spending on health services and infrastructure. Health spending would attract a small carbon cost that would be more than compensated for by eliminating the health costs of tobacco consumption within country as well as the carbon costs of tobacco consumption within and across countries.

4.1.12 One Final Story - Vanuatu

In 1605, the devout Portuguese Captain Pedro Fernández de Quirós set sail in search of a legendary continent in the hope of establishing a utopian society that would balance the needs of people in harmony with the beauty of nature. With the blessing of Pope Clement and the Spanish King Philip, he launched three ships with 160 men in search of Terra Australis. He seems to have failed. Having landed on what he took to be the Australian continent, he named his newly discovered island the Southern Land of the Holy Spirit, *Australia del Espiritu Santo*. That land was Vanuatu.

By all accounts, Captain de Quiros was a noble failure.

But had Captain de Quiros known that exactly 400 years later, Vanuatu would be named as one of the world's happiest and most balanced 'utopias', he might have rested easily, especially given that Australia itself became one of the least balanced societies under the threat of climate change.

Vanuatu, a volcanic archipelago of 82 rainforest islands, was inhabited by people for 4000 years before successive waves of Portuguese, Spanish, British and

French colonised the islands. To the English it became the New Hebrides. It was not until independence was declared in 1980 that it became known as Vanua meaning 'homeland' plus tu meaning 'to stand'. Today it is home to a quarter of a million people living in a clutch of island municipalities led by elected councils and local chieftains. The native people (Ni-Vanuatu) speak English or the creole Bislama. Education is not compulsory, leaving about a quarter of the population illiterate and an equal portion of children either unenrolled or not completing primary school.

Latest data from the Vanuatu National Statistical Office (2010) puts the median age at 21 years, with an age profile split across 40% children, 20% youth, 40% adults and elderly. Village fisheries provide most of the food (90%) along with small village gardens. Around 76% live in rural areas and 45% are engaged wholly in a barter economy rather than being salaried (33%). Latest estimates from the International Monetary Fund (2012) put GDP per capita at around \$5,000 but inequality is growing as development projects begin to serve the financial interests of a smaller minority. More distant rural communities are living mostly outside economic development and basic government services.

Although most of Vanuatu's land (91%) is too steep, unstable or lacking fresh water, the small amount of land available for food is increasingly given over to beef cattle, copra, kava and cacao. Slash and burn tactics in the rainforests are being used to access rare timbers for foreign markets. Growing investment from China in terms of tourism, scholarships and machinery is used to establish more fishing for export and palm oil investment that displace communities and their own resources. Tourism remains a strong source of income (especially following release of the syndicated reality television show Survivor) and there have always been strong financial services relying on Vanuatu's traditional status as a tax haven (now changed since 2008).

Figure 4-3 Vanuatu's divergence from optima compared to some key countries on gender.

As unique as this island paradise might appear in terms of sustainability, life expectancy and 'happiness', there is still room for improvement across key gender issues. When women were asked in 2012 what their greatest challenges were, they beautifully resonated with the concerns of women the world over:

"The main complaint regarding husbands was their lack of support and assistance with household duties, their kava abuse, overworking, unfaithfulness, and over-controlling treatment. Lack of sufficient finances was the second most frequent response to the question, followed by gossip, violence, and other uncooperative women." (Malvatumauri National Council of Chiefs, 2012, p 89)

Development has its advantages, especially in terms of gender equity, and this, among other advantages, should increase. But despite being one of the world's most sustainable nations according to the NEF-HPI, Vanuatu, like so many others, can still do much more for its people - not by pursuing the Western development model wholesale. Women in Vanuatu say that their own childhoods were much more fun than those of their children as they watch them grow in a less traditional and more urbanised and developed society. In fact, people of the West could learn much from Vanuatu and other countries like Malta, Vietnam and even Costa Rica with its high crime rates. The message of moderation cuts both ways.

This work suggests balance between people and planet is not only possible, but could move towards greater human wellbeing. Given a rapidly closing window of opportunity, all nations must make changes very quickly, under strong leadership, to the way we value our children and measure our lives. The extremes of childhood innocence and adult self-actualisation must be supported to maximise human survival and wellbeing, both now and in the future. A rapid and fundamental shift from notions of material to psychosocial prosperity, grounded in stable, time-invariant and universally shared human needs, will help preserve humanity, the planet and its children.

Hopefully, the frontier method will offer much more in the future by allowing different countries to be assessed based on their proximity to target needs and the way in which this manifests in health, height and happiness. More equitable distribution of the world's resources could simultaneously reduce carbon emissions whilst enhancing life expectancies for both developing and developed countries in the long-run, affecting the world's children now living and not just distant generations long into the future.

Even in the absence of climate change, social change is needed across the developed world. Moreover, if other existing countries are already providing observable examples of sustainable, high-quality living, and if their characteristics are learnt adaptations rather than constrained by comparative advantage, then they could offer the rest of the world some insight into pathways towards maximising human outcomes.

Like Captain Pedro Fernández de Quirós, almost every person cited in this work was united by their search for a new and better world. Science is and always will be built on noble failure, setting out with a bold and beautiful vision with nothing more than a crumpled blessing, a leaky vessel, some star charts, brass astrolabes and half-finished maps of the human soul. With any luck, the best we can hope for is to get it 'almost right'. The rest of the voyage belongs to others.

If nothing else, this work has been steadily moving towards an argument for generational equity to be placed within the broader framework of measurement across nations. So far, the UNHDI has made explicit the need for international and gender equity but its next voyage should be charted towards the health and wellbeing of all age groups, especially children, under the banner of sustainability and its direct impact on future human needs. Based on earlier modelling, climate scientists had every reason to be alarmed if trends continued into the future. They had a moral obligation to communicate their findings as quickly as possible and the message to the world was loud and clear: change course or sink!

This scared many and prompted others to question the science rather than give in to helpless defeatism. Yet since the 1990s, the scientific community has been more circumspect about methods and predictions which simultaneously strengthen arguments for anthropogenic climate change but moderates the long-term impacts at slightly more manageable levels than originally predicted. This subtlety has not yet reached the political and public spaces, where the issue remains divided into black and white camps. The Hadley Centre in the UK says we do not yet know how well the ocean and further atmospheric pollutants might or might not counter-act the worst predictions of earlier climate change models (Stott, 2012; cited by Johnston, 2012). Even the 92-year old James Lovelock, the original author of Gaia Theory, said the world's climate had been a little steadier than was originally suggested.

Yet even Lovelock still, along with many others from divergent disciplines, warns us that the trends remain and we must inevitably pursue a more balanced relationship with our natural world sooner rather than later. The latest science gives us little time for action. Species extinction is accelerating faster than ever and some elements of the climate and the global economy are moving faster, not slower, than originally predicted. Nobody really knows how the voyage will end, so we need to keep a weather eye open for the rise and fall of the tides.

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Appendices

Appendix 1.

Age Groups: 1990 frontier countries by calories per capita against LE

Age	Birth		Age 1		Age 5		Age 30		Age 65		100+	
	CC	LE	CC	LE	CC	LE	CC	LE	CC	LE	CC	LE
Belgium											3533	2
Belize			2590	75.5	2590	72.1	2590	48.3	2590	18.4	2590	2.6
Brunei											2785	2.9
Burundi												
Cambodia	1809	59	1809	63.5	1809	61.7	1809	39.4			1809	1.7
Chad	1697	48.9	1697	54.5	1697	55.9	1697	35.4	1697	11.6	1697	1.7
Congo	1858	60.1			1858	61.8	1858	39.4	1858	12.8	1858	1.7
Costa Rica	2736	75.6	2736	75.9								
Djibouti	1779	52.4	1779	58.2	1779	58	1779	36.8	1779	11.8	1779	1.7
France	3512	77.4	3512	77	3512	73.1	3512	48.9	3512	18.4	3512	2.1
Ghana									1812	12.3		
Greece	3536	77	3536	76.7								
Haiti	1783	54.6	1783	60	1783	59.2	1783	37.6	1783	12	1783	1.7
Hungary	3709	69.4	3709	69.4	3709	65.6	3709	41.5	3709	13.9	3709	1.8
Iceland	3056	78	3056	77.5	3056	73.5	3056	49.3				
Ireland	3637	74.6	3637	74.3	3637	70.4			3637	15.1	3637	1.8
Italy	3591	76.9	3591	76.6	3591	72.7	3591	48.4	3591	17	3591	1.9
Japan	2823	79.1	2823	78.5	2823	74.6	2823	50.2	2823	18.5		
Kuwait	2238	73.1	2238	73.1	2238	69.3	2238	45.4			2238	2.3
Mexico											3074	2.3
Namibia											2075	1.7
Nicaragua							2234	44.4	2234	16.8	2234	1.9
Paraguay			2433	74.5	2433	71.1	2433	47				
Panama	2310	73.2	2310	74.1	2310	70.7	2310	47				
Peru	1933	66.6	1933	69.7	1933	67.1	1933	44.2	1933	15.3		
Sri Lanka									2229	15.4	2229	1.9
Switzerland							3346	49				
Thailand	2149	68.8										
USA	3472	2.2										
Vietnam											2149	1.8

Appendix 2.

Publication webpage for the first paper published from this work (see http://link.springer.com/article/10.1007%2Fs10668-012-9432-y)

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Towards a contraction and convergence target based on population life expectancies since 1960

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Abstract This paper explores a finding that emerged in the early phases of a multidisciplinary project applying population health and psychology to issues of social progress and sustainability. Across 180 countries and half a century of data, the levels of carbon emissions per capita that maximise life expectancy fall within a tight band averaging only 6.6 tonnes—considerably less than wealthier countries emit per person. Various tests fail to break down the curves and, although the authors remain cautious, the stability since 1960 offers implications for the carbon budget leading up to 2050. This is the first time these curves have been contextualised against established climate science, with timely implications for international negotiations on sustainability and development.

Keywords Contraction · Convergence · Population · Life expectancy

Since going to press, COP18 suggests the 2 °C limit has been surpassed and the world is heading towards a 4–6 °C increase in global temperatures, making agreement on the C&C target described in this paper, or lower, more urgent than ever before (see Peters et al. 2012).

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1 Introduction

As yet, there is no target for carbon emissions (CE) empirically established for human development. Respected economists have made educated guesses ranging 2–6 tonnes per capita (Stern 2008; Ekins et al. 2009; Hansen 2009; Schmidt-Bleek 2009; Garnaut 2011), but the issue spans climate science, public health, economic development and human ethics under the umbrella of global warming (e.g. Stern 2006; Frumkin et al. 2008). Copenhagen achieved multilateral agreement on a limit of ≤2 °C warming, beyond which it was agreed there would be unacceptable impacts on biosocial systems (McGray 2010). This then creates an upper ceiling of total allowable emissions based on constraining the atmospheric concentrations of carbon dioxide (Hare and Meinshausen 2006). Leading up to 2050, the strongest modelling was developed by Meinshausen et al. (2009), whose seminal work demonstrated a 25 % risk of exceeding 2 °C with a total cumulative emissions budget of a trillion tonnes (1,000 Gigatonnes, Gt) from 2000 to 2050. Using the same model, risk is reduced on the smaller budget of 750 Gt suggested by Hansen et al. (2008). The problem confronting both is that the world had already used up 234 Gt from 2000 to 2006 (Meinshausen et al. 2009).

As of 2011, global emissions peaked at a record high, prompting the International Energy Agency's Chief Economist Fatih Birol to warn 'the door to a 2 °C trajectory is about to close' (International Energy Agency 2012, p. 1). Given current growth (see International Energy Agency 2012), close to half the entire Hansen budget will have been used up by mid-next year (2013), leaving much smaller rations for the next four decades. Delayed international action then makes the rate of change in the future much steeper and harder to adapt to for both advanced and developing economies.

This raises an ethical dilemma in terms of both international and intergenerational equity because in order to satisfy the one it must undermine the other. This is because we are close to reaching the precipice of exceeding the 2 °C limit without allowing the bulk of the world's developing nations to reach parity with a minority of wealthier, carbon-intensive economies. Moreover, because global emissions (International Energy Agency 2010) and population (United Nations Population Division 2011) are both steadily growing, the yearly amount of allowable emissions compound the ethical problems yet to be confronted.

One principle that tries to balance the dilemma is contraction and convergence (C&C). Although the implementation rate was a stumbling block at Copenhagen and Durban (Meyer and O'Connell 2010), C&C begins to provide a fair platform for multilateral negotiations. This principle (see Global Commons Institute (GCI) 1996) first assumes that global CE will negatively impact human and planetary health in the longer term and so must be 'contracted' if we care about the likely impact on younger generations (e.g. Sherwood and Huber 2010). If it were not a normal public good, this would not present a problem, but because CE is tied to economic development (York et al. 2003; Rosa et al. 2004), it means any pursuit of global contraction could result in recession or depression amongst advanced economies. This was suggested when the global financial crisis (GFC) reduced world emissions (see Jotzo et al. 2012). Although there is resistance to the idea of contraction, whether by a Pigovian tax or a trading scheme (Garnaut 2011), climate science suggests we have no choice. The alternative could be resource and energy wars and further destruction of ecologies subserving human survival (e.g. Parry et al. 2004; Thomas et al. 2004; Malcolm et al. 2006). The second element of C&C is 'convergence', where every nation must be granted an equal portion of emissions per capita under a constrained global budget (Global Commons Institute (GCI) 1996). This applies the same ethical principle of