TOWARDS A CONTRACTION & CONVERGENCE TARGET BASED ON POPULATION LIFE EXPECTANCIES SINCE 1960

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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, Meyer & Schmidt-Bleek, 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, McMichael & Hess, 2008). Copenhagen achieved multilateral agreement on a limit of $\leq 2^{\circ}\text{C}$ 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 & Meinshausen, 2006). Leading up to 2050, the strongest modelling was developed by Meinshausen and colleagues (2009), whose 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 reduced on the smaller budget of 750Gt suggested by Hansen and colleagues (2008). The problem confronting both is that the world had already used up 234Gt from 2000-2006 (Meinshausen *et alia*, 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). Given current growth (see IEA, 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 (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 alia*, 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 alia*, 2004; Thomas *et alia*, 2004; Malcolm *et alia*, 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 conservative budget of 750Gt would mean around 450Gt will be subtracted from the cumulative budget by mid-next year, 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 alia*, 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 paper explores what these C&C targets might mean for human LE, hoping there might be a more optimistic outcome. Before describing the methods, we outline evidence suggesting economic growth might not offer positive, monotonic and linear returns on human welfare in the first place. In fact, there may be reasons why developing nations should not expect linear gains in human welfare from carbonised growth beyond a certain limit. If stable, this limit might offer a more optimistic C&C target up to 2050.

Human Health and Happiness

In the mid-1970s, two stylised curves were identified across countries that suggested national wealth can only achieve so much in terms of human outcomes. Preston found LE and GDP per capita both rise until they reach a certain point, after which no amount of wealth seems to make much difference (Preston, 1975). A year earlier, Easterlin (1974) found the same curve emerged for human wellbeing. These curves offer cross-validation by virtue of their different methods - wellbeing is based on survey data of how people subjectively feel about their life circumstances in different countries (see Diener & Suh, 2000) and LE is an objective average based on the relevant year's reported death rates weighted by population and age (CSDH, 2008). Both have problems but their cross-validation partly obviates the need to explore them here. They suggest no matter what the outcome metric, wealth reaches a threshold beyond which it has little or no impact on health and wellbeing across countries. Note the same occurs within countries and across years. Easterlin (2005) demonstrated wellbeing 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 similar trend occurs for LE, with minor gains accumulating each year despite changes in national and global wealth (World Bank Report, 1993).

The literature has not yet reached consensus on the meaning of these curves but 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 alia*, 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 Brundtlandt definition of sustainability (Brundtlandt 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.

Development and Sustainability

Stepping backwards, we revisit the United Nations Human Development Index (UNHDI), a composite of LE, GDP per capita and education that weights each metric as if equally valued by all people (see Haq, 1995). 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. It was Veenhoven (1996), a wellbeing researcher, who pointed out that the UNHDI mixes outputs such as LE with metrics that are usually viewed as inputs. Veenhoven suggested a universally valued output could multiply LE by subjective wellbeing to create the Happy Life Year (HLY), similar in logic to the Disability-Adjusted Life Year (Murray & Lopez, 1996). HLY is now used by the New Economics Foundation as the numerator for the Happy Planet Index (NEF-HPI) when dividing it by Ecological Footprint (EF) as the denominator (Marks *et alia*, 2006). The NEF-HPI then becomes an efficiency metric that bypasses GDP altogether, avoiding issues of parity, utility, income, inflation, consumption, production, non-market activities, bartering, volunteerism and household production of labour (e.g. Robinson, 1962; Folbre, 2008).

The HPI recently nominated Costa Rica as the world's most sustainable country because it achieves a 'long and happy life' despite lower ecological impact than wealthier countries (Abdallah *et alia*, 2009). This raises the question of whether the rest of the world could pursue parity. The problem is that most are small island nations that have geographic advantages in terms of tourism, so unless there are also cultural patterns of sustainable living that the rest of the world might follow, this endeavour plunges the issue back into the realm of economics, trade and comparative advantage. There is also another problem with the NEF-HPI that tends to push it back into economic territory.

Wealth beyond threshold is thought to have little, if any, effect on wellbeing because people rate their wellbeing relative to the resources enjoyed by others in their cultural milieu. This means any increase in an already wealthy country hinges on consuming more than another comparatively wealthy person. As the baseline wealth of the country rises, so do expectations – so there is ultimately no net gain in subjective wellbeing beyond threshold in the longer term, even though ecological impact continues to rise. The pursuit of happiness, if relative (first suggested by Duesenberry, 1949), then becomes a 'zero sum game' that drives the Hedonic Treadmill (Brickman & Campbell, 1971). The end result is that the NEF-HPI, by using subjective wellbeing as a multiple of the output, might be just as unsustainable as the UNHDI.

Even in earlier surveys by Cantril (1965), people in poor countries said they would be happier if only they had a *goat* whereas people in wealthy countries wanted a *boat*. Their desires were culturally relative even though their actual satisfaction tends to be short-lived before settling down to what has been described as a genetic, or homeostatic, set-point for human wellbeing (Gullone & Cummins, 2002). Moreover, subjective wellbeing is measured on an ordinal Likert scale with no true zero point, so is statistically shaky when multiplied by LE and then compared to wealth or ecological impact. By

contrast, the current paper uses LE as a universal human output because it is a ratio scale with a true zero point that also offers:

1. A harmonised formula that equally applies across time and countries (HMD, 2011)
2. A universally valued outcome that transcends cultures and disciplines (CSDH, 2008)
3. A proxy of human survival that resonates with the definition of needs (Brundtlandt, 1987)
4. A long heritage of comparable data going back to 18th Century France (HMD, 2011)
5. A wealth of literature that links longevity to paleo-anthropological data (Steckel, 1983)
6. A wealth of laboratory data from medicine, public health and psychology

These advantages allow tests of one key metric that, unlike wealth or wellbeing, is less affected by subjective cultural relativism and much more founded in basic human survival. This means it 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.

Comparability across Time

We argue the NEF-HPI would be more sustainable if it dropped subjective wellbeing because it is polluted by economic and cultural influences that change across time and contexts. On a practical level, wellbeing also constricts the sample size across time and countries because it relies on more recent data from Gallup (2006) and the World Values Survey. By the time it stretches back to 1960, sample size is reduced from 200 to 25 countries capturing the OECD – an unrepresentative group that ignores poorer countries and masks the broader curve (Abdallah *et alia*, 2009). A similar problem emerges for the denominator of the NEF-HPI. Although EF is one of the most validated accounting measures when tested against objective measures like satellite imagery (Sutton, 2003; Sutton *et alia*, 2009), it is more complicated to compute than our preferred metric of CE and so remains less represented across time and countries (Wackernagel & Rees, 1996). In our defence, the NEF-HPI often uses CE as a proxy for EF, which is justifiable given that EF partly relies on CE data itself. Whilst the current paper would prefer EF, stability across time and countries requires we revert to CE to bypass GDP (as per the HPI) whilst directly linking to accepted carbon budgets.

Using Proxy Variables

This leaves us with two national indicator variables that have no mechanistic basis for being causally linked:

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 alia*, 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. Although we use regression techniques, we do not attempt to model a functional form that controls for omitted variables. Rather, the statistical rationale of this paper is more mercenary 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 the environmental Kuznet's curve (see Stern, 2004) and would deserve just as much caution were it not for the fact that this paper 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 such as war, infection and extreme inequity but this was not the original reason for its use. It was in analysing the datasets of the NEF-HPI that the authors noticed its efficiency metric, without further adjustments, made some of the most 'miserable' (and inequitable) countries appear more sustainable. To handle the first problem, the NEF-HPI added a pair of constants to the numerator and denominator, which shifted the target upwards towards more acceptable human outcomes, first represented by Vanuatu (Marks *et alia*, 2006) and then Costa Rica (Abdallah *et alia*, 2009). Yet this still glossed over the need for an empirical target in terms of human outcomes, forcing the NEF to develop a 'Traffic Light' system colour-coding all the key metrics and allowing readers to make their own value judgements about the competing interests of wellbeing, longevity and ecological impact. Once again, this resonates with another problem confronting the UNHDI, which keeps shifting its own definitions for development based on arbitrary statistical manoeuvres, especially as many more countries shift from the 'developed' to the newly created 'highly developed' categories.

Pure Frontier Regression

When looking at the NEF-HPI, the authors of the current paper 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 based on pure frontier regression which we expect will ultimately offer much richer information than the composite efficiency metric of the HPI.

Traditionally, 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 so much as the best possible benchmark at the upper extremes of the curve, sometimes called the 'ceiling'. In a much removed context, frontier regression was first raised by Farrell (1957) and was later applied by Aigner & Chu (1968) using a Cobb-Douglas production function looking at profit maximisation among firms. This identified the maximum boundary of the key output variable achievable for every level of input (Sieford & Thrall, 1990; see also Coelli *et alia*, 2005). In these early approaches, the aim was to explain how factors of production could be more efficiently exploited to maximise performance in terms of profit. For this reason, their focus was on capturing and explaining the error variance below the ceiling, stimulating 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 - the key dependent variable in explanatory models. Many more complex forms later emerged such as Data Envelopment Analysis, with some methods being applied to issues of income (Sen, 1981), health expenditure (Evans *et alia*,

2000), life expectancy (Dietz, Rosa & York, 2009) and the Millennium Development Goals (Jayasuriya & Wodon (2003).

Where the current paper diverges is that no explanatory model is needed to empirically estimate a carbon threshold. Because maximising LE is one of few human outcomes that is universally valued across cultures (CSDH, 2008), it 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 $y_j = \ln(\text{CE}/\text{Cap})$ for Year j , $x_j = (\text{Year}-2000)$ and ω_j = a non-negative error for Year j

The optimal LE can then be interpolated from the curve formulae for every year from 1960-2007. To test horizontal stability, the paper borrows from psychometrics, using split-half reliability. It then tests the variance across time to see whether there is a stable threshold of CE that matches optimal LE. Regardless of causality, the results empirically prove, by appealing to falsification, that greater CE is not needed to improve human outcomes. This is slightly more optimistic than economic studies might assert under carbon budgets leading up to 2050.

METHODS

Data Sources & Cleaning

The World Bank provides data from 1960-2007 for 205 countries. Life expectancy at birth (LE) is the number of years a newborn infant would live if prevailing patterns of mortality at the time of birth were to stay the same, based on death rates at each age in each year weighted by population cohorts to derive the average age at death for the whole population (based on male and female life expectancies at birth from the United Nations Population Division, 2009). 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. Data is rounded to the third decimal place.

Procedures

For each year, LE and CE per capita are aligned by country and then ranked by LE from highest to lowest. The pure frontier formula is applied for each year to extract the upper boundary of LE. This captures the highest observable 'output' (LE) at every level of observable 'input' (CE/cap) and generates a much smaller sample that is outside the control of the researcher. The strongest curve is fitted to minimise error in every available year from 1960-2007. Using GNU R, F tests are reported for 1000 simulations of cubic versus quadratic curves, with confidence intervals for the interpolated optima. The stability of the value of CE per capita (CE/cap) that interpolates optimal LE can then be

ascertained stretching back to 1960. Additionally, the curve formula for 1960 can be used to predict the actual values in 2007 as a test of predictive validity. As a preliminary test of internal validity, these years are also randomly split into two subsamples before the frontier procedure is applied, allowing the quadratic formula from one split sample within that year to predict the other, the correlation being the usual test of split-half reliability as borrowed from psychometrics.

RESULTS

As would be expected, average LE is higher in 2007 than 1960 but the association with CE/cap follows the same trend in both years (see Figure 1). By converting input to the natural logarithm ($\ln$) of the CE/cap term, the curve is more easily viewed. For 2007, LE increases from Zimbabwe up to a threshold that declines from Costa Rica and Japan, achieving the highest LE (83 years), down to Qatar (N=185). The same pattern is evident in the data sampled in 1960 rising from Afghanistan to Switzerland and Norway (74 years) and then down to Kuwait and Luxembourg (N=155). Note the optimum shifts from Norway to Japan, suggesting it is not an artefact of unchanging advantages enjoyed by a single country. The optimum LE for 2007 is 77 years on 19 tonnes compared to 68 years on 12 tonnes for 1960. Because the curve generated from the average of the full dataset fails to match the observed optima for LE, it demonstrates distortions in the curve. These are now eliminated using the frontier.

INSERT FIGURE ONE

Figure 1. The relationship between LE and $\ln$ CE/Cap using raw data (above) and the frontier (below).

For both 1960 and 2007, the frontier renders the curves depicted in the lower portion of Figure 1, capturing 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 to Japan's observed maximum of 83 on 10 tonnes. Predictive validity is tested using the frontier formula in 1960 to predict the observed results in 2007, $r^2=0.95$ ($p<0.05$). Split-half reliability was $r^2=0.96$ ($p<0.05$) for 1960 and $r^2=0.92$ ($p<0.05$) for 2007. 1000 GNU simulations of cubic versus quadratic curves supports the third order quadratic formula across every year (as did robust regression). Table 1 shows each of the yearly frontier curves is significant ($p>0.001$). This provides F tests based on the third order curve formula, the corresponding p values and the 95% Confidence Intervals of the interpolated optima.

Table 1. Testing quadratic curve fitting of the frontier plus stability across time

	Frontier Curve Function				r^2	F Value	P Value	LE _{max}	CE _{max}	Confidence Intervals	
	B Zero	B 1	B 2	B 3						0.025	0.975
1960	67.09	11.92	-4.89	-1.74	0.97	218.87	0.00	72.62	6.93	5.27	10.38
1961	68.02	11.63	-6.24	-2.66	0.94	103.90	0.00	72.21	4.54	3.63	6.11
1962	68.75	11.20	-5.83	-1.92	0.95	120.18	0.00	73.08	5.13	4.01	6.77
1963	68.98	8.95	-5.84	-1.00	0.93	90.33	0.00	72.06	4.53	3.23	6.13
1964	67.42	12.23	-4.75	-2.20	0.92	74.37	0.00	73.04	6.61	5.04	8.59
1965	67.70	12.48	-4.77	-2.07	0.92	83.00	0.00	73.60	6.99	5.24	9.12
1966	68.61	10.35	-4.91	-1.56	0.92	54.12	0.00	72.96	5.90	4.32	8.37
1967	69.36	9.72	-4.95	-1.49	0.93	63.65	0.00	73.24	5.45	4.08	7.20
1968	68.52	11.78	-5.29	-2.02	0.91	48.69	0.00	73.53	5.91	4.31	8.40

1969	69.80	8.44	-5.08	-0.89	0.89	35.02	0.00	72.92	5.02	3.07	7.65
1970	68.14	12.08	-4.66	-1.80	0.95	120.88	0.00	73.93	7.29	5.84	9.34
1971	69.94	8.23	-4.77	-0.80	0.97	210.75	0.00	73.09	5.35	4.22	6.65
1972	69.21	9.61	-3.81	-1.43	0.93	90.75	0.00	73.74	7.10	5.44	8.94
1973	69.24	9.88	-4.12	-1.24	0.96	138.68	0.00	73.91	7.30	5.81	9.02
1974	70.96	7.83	-4.81	-0.47	0.98	229.87	0.00	73.94	5.44	4.15	7.22
1975	70.30	11.13	-4.95	-1.63	0.97	220.57	0.00	75.20	6.38	5.37	7.58
1976	69.18	12.12	-4.54	-1.93	0.95	117.81	0.00	75.02	7.27	5.70	10.19
1977	70.20	10.40	-5.30	-0.91	0.97	275.96	0.00	74.67	6.48	5.26	8.14
1978	69.84	11.32	-4.91	-1.18	0.97	250.33	0.00	75.20	7.52	6.17	9.78
1979	69.68	12.43	-4.70	-1.73	0.97	225.04	0.00	75.80	7.73	6.20	10.03
1980	69.54	13.54	-4.92	-2.32	0.95	115.07	0.00	76.06	7.18	5.59	9.41
1981	72.26	10.36	-5.75	-1.28	0.93	54.84	0.00	76.26	5.31	3.23	7.74
1982	72.93	10.54	-6.02	-1.45	0.93	57.43	0.00	76.86	5.00	3.49	7.06
1983	71.72	12.18	-5.84	-2.20	0.93	71.09	0.00	76.64	5.45	3.99	8.06
1984	72.32	12.68	-6.03	-2.40	0.94	76.37	0.00	77.44	5.40	4.12	7.17
1985	71.87	14.75	-5.54	-3.19	0.94	82.98	0.00	78.50	6.18	4.78	8.58
1986	72.55	11.63	-5.30	-2.03	0.94	80.16	0.00	77.44	5.79	4.26	7.98
1987	72.59	9.55	-5.00	-0.81	0.97	156.50	0.00	76.61	6.30	4.84	8.78
1988	73.32	10.34	-4.61	-1.96	0.96	119.46	0.00	77.65	5.71	4.63	7.54
1989	73.69	10.29	-4.79	-1.81	0.95	69.51	0.00	77.95	5.66	4.23	7.90
1990	75.39	3.08	-2.11	0.21	0.89	28.36	0.00	76.61	6.78	0.26	34.40
1991	75.38	8.38	-3.35	-2.16	0.96	56.11	0.00	78.87	5.40	4.39	6.48
1992	74.84	5.23	-2.84	-0.36	0.91	36.58	0.00	77.02	6.29	2.78	28.23
1993	73.78	5.72	-2.64	-0.40	0.89	34.07	0.00	76.50	7.97	3.97	33.80
1994	74.96	7.37	-3.56	-0.81	0.95	65.24	0.00	78.16	6.46	4.37	12.30
1995	73.71	11.14	-4.28	-1.66	0.98	245.46	0.00	79.07	7.33	6.29	9.07
1996	73.56	13.81	-4.57	-2.56	0.97	153.81	0.00	80.43	7.44	6.27	8.90
1997	74.89	11.25	-4.70	-1.56	0.92	48.39	0.00	80.11	6.98	5.06	10.73
1998	74.15	13.19	-4.76	-2.10	0.92	53.31	0.00	80.65	7.53	5.44	11.92
1999	73.54	14.92	-4.80	-2.68	0.93	65.95	0.00	81.13	7.78	5.89	12.19
2000	72.94	15.84	-4.76	-2.69	0.93	76.00	0.00	81.39	8.51	6.63	12.29
2001	73.90	14.87	-4.78	-2.71	0.96	131.25	0.00	81.44	7.71	6.47	9.95
2002	74.84	13.82	-5.50	-2.15	0.98	236.99	0.00	81.29	6.94	5.98	8.68
2003	75.86	11.43	-6.00	-0.74	0.98	241.62	0.00	80.79	6.69	5.24	9.81
2004	74.28	14.36	-4.99	-2.00	0.95	102.76	0.00	81.71	8.40	6.23	12.60
2005	74.99	12.90	-4.80	-1.40	0.96	110.57	0.00	81.72	8.91	6.63	12.93
2006	75.12	13.71	-5.16	-1.73	0.96	143.89	0.00	82.02	8.15	6.20	11.56
2007	75.21	13.87	-5.03	-1.93	0.96	146.95	0.00	82.21	8.06	6.56	10.43
Mean	71.77	11.14	-4.82	-1.66	0.94			76.80	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

As can be traced from Table 1, the mean of the predicted optima across all years is 6.6 CE/cap. Whereas LE steadily increases across time at a rate of 2.5 months per year ($r^2=0.99$, $p<0.005$), the CE that maximise LE does not significantly change. Figure 2 now contextualises the optimal LE plus Confidence Intervals against the highest CE/cap in each year. 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.

INSERT FIGURE TWO

Figure 2. CE/cap that optimises LE is lower across 48 years than maximum CE/cap

From 1960 until 2007, 88 countries achieve the frontier. Costa Rica retains its position at lower levels of CE for 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.

DISCUSSION

This paper presents a stable albeit stylised 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 and renewable energy sources. 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, some studies are beginning to confirm this trend (Bloomberg & Aggarwala, 2008) whereas others hint that such an effect might emerge from over-consumption at higher levels of CE (Edwards and 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 alia*, 2007; Stevenson & Wolfers, 2009). This idea is not new; it has a theoretical heritage spanning human development (Sen, 1999), the economic health gradient (Lopez *et alia*, 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 alia*, 2012; Thornton *et alia*, 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. This and other curves should be more fully explored using frontier regression.

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 DEA. Moreover, preliminary work testing the curve within nations across

time already suggests the effects of carbonised growth are inconsistent when applied to LE, although this is ameliorated when time-lags of up to a decade are controlled for. Another work in progress uses an adapted form of α -trimmed sampling to simultaneously equalise sample sizes across development whilst eliminating the effects of outliers and time lags.

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 10 billion in 2100 (conservatively, 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 paper suggests a moderate C&C target might be a first step towards balancing the competing demands of both international and intergenerational equity.

Footnote: 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.

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